Development and Application of a Farm Assessment Index (FAI)

-Towards a Holistic Comparison of Organic and Chemical Farming

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DEVELOPMENT & APPLICATION OF A FARM ASSESSMENT INDEX (FAI):
Towards A Holistic Comparison of Organic and Chemical Farming

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PREFACE

It was in an internal meeting in ASHA (Alliance for Sustainable & Holistic Agriculture) in 2011 that a small thought was first articulated – that we need a HDI equivalent (Human Development Index) in agricultural sciences, and what it (HDI) managed to do to expose GDP (Gross Domestic Product) as a narrow but much-used indicator of growth and development in our world today. For several working in the domain of ecological agriculture, the narrow focus mainly on yields in the mainstream agricultural development paradigm was disturbing and they wanted an assessment tool that was more holistic, that had the potential to capture overall performance of a particular agricultural paradigm on numerous fronts, beyond yields. This, it was felt, would be useful to farmers and policy makers too, to make decisions that are rooted in sustainability.

ASHA representatives reached out to Organic Farming Association of India (OFAI), and also some scientists like (late) Dr Om Prakash Rupela to collaborate with us in this. They also began reaching out to several organisations working with farmers in different states, in promoting organic farming. Some states and locations were shortlisted where we could take up the comparison of organic farms with chemical farms, using a composite index that looks at social and environmental impacts too. Sitting in Dharamitra's campus in Wardha in 2012, an initial intense workshop was undertaken, about the scope and methodology of such a research endeavour. It was decided that a one-season or one-year study will not do. That it has to be over several seasons. There was no access to any funds at this point of time but the team decided to plod on with the idea taking shape slowly.

After visiting several places, the collaboration of Chetana Vikas and Dharamitra in Maharashtra, Tribal Health Initiative in Tamil Nadu, Chetna Organic project of Forum For Integrated Development in Odisha and Savayava Krushikara Sangha in Karnataka was enlisted for taking up field based research in four states. The contribution of these organisation to obtaining high quality field data, by extending the time of their senior staff voluntarily, to oversee the work of field enumerators regularly, is sincerely acknowledged. Field enumerators were local staff and their work is gratefully acknowledged.

The cooperation extended by all the farmers who participated in the study, in both the organic farm samples as well as the conventional ones, is noteworthy and sincere thanks are extended to them. Data collection began, using a survey-based methodology, with the questionnaires administered at three different points of an agricultural season, after an orientation to the field enumerators from all the 4 states and after a piloting of the questionnaires evolved.

It was in 2013 that IIT-Bombay's CTARA came into the picture and this was a great boost to the whole effort. Prof Om Damani of CTARA and his doctoral student Siva Muthuprakash were instrumental in bringing in the theoretical framework to the development of the composite index and a more thorough sorting of indicators to be used. The methodology also shifted to inclusion of a farm diary to be maintained for each farmer by the field enumerators and not just a 3-time survey with questionnaires. It was a unique collaboration between a PhD student supported by an able guide and a set of civil society organisations, that started unfolding thereafter. Dr Srijit Mishra who was with IGIDR in Mumbai and later with NCDS in Bhubaneswar added to the methodological rigor required for a study like this. Within the collaborating organisations were scientific brains of Ashok Bang of Chetna Vikas and Dr Tarak Kate of Dharamitra, who are both ecological agriculture science experts. The insights and inputs of Kapil Shah of Jatan (Baroda) throughout the research project were very useful and valuable. While Siva Muthuprakash focused on the states of Tamil Nadu and Maharashtra for the purposes of his PhD, ASHA and OFAI focused on Odisha and Karnataka, to continue with the original 4-state effort. The "composite index" was also formally renamed as "Farm Assessment Index" or FAI.

While Dr OP Rupela passed away succumbing to cancer in 2015, his contribution to this study is enormous and significant, starting from discussions on indicators to be included, to framing of questions in the Questionnaire. The study also benefited from the inputs of Dr N Devakumar, who was with the Regional Institute of Organic Farming in University of Agricultural Sciences, Bangalore.

In the entire effort, the support of Swissaid is notable. Starting from the initial pilot phase in 2012-13, they supported the study through their partner organisations like Indian Social Action Forum, Centre for Sustainable Agriculture, Forum For Integrated Development and Sahaja Samrudha. Joint review workshops on an annual basis and payment of honorarium to field enumerators was done with this support. Association for India's Development (AID) also pitched in with a small grant at the beginning of this effort. Based on a proposal put in by IIT-B, NABARD extended its support to the research project for two seasons in the state of Maharashtra. This also enabled soil sample analyses to be taken up.

This research report is long over-due, after having completed its formal processes of wrapping up in 2017 and with Siva Muthuprakash submitting his PhD thesis in April 2018. A major part of this work was carried out and submitted by the first author for his partial fulfilment of the degree of Doctor of Philosophy to CTARA, IIT Bombay, under the supervision of Prof. Om Damani, IIT Bombay, Mumbai. We advise any citation to this report should accompany the reference to the PhD thesis as per the details below

"Siva Muthuprakash (2018), Development and Field Application of the Farm Assessment Index (FAI) for Evaluation of Farming Systems, PhD Thesis, Centre for Technology Alternative for Rural Areas, IIT Bombay, Mumbai."

Siva also developed an alternative, more user-friendly online tool for any stakeholder including farmers, to feed in data on their farming system along chosen parameters, obtain a Farm Assessment Index value and monitor progress or compare with other systems themselves. This demonstrated clearly that a simpler version of FAI is possible to evolve, for mass application.

It is hoped that the Farm Assessment Index developed here, on a stock-and-flow based framework, will indeed be adopted by the Indian National Agricultural Research System (NARS) so that research results are appraised holistically before they are disseminated and deployed on a large scale. The collaborators of this study are enthused by some recent announcements to this effect by the Indian Council for Agricultural Research (ICAR) and sincerely encourage policy makers to use more comprehensive indices like FAI in their decision-making so that agricultural development is not lopsided, or short-sighted.

- All Collaborators of this Research Project

November, 2018

Abstract

Traditionally, crop yield has been the main focus of agricultural policies and technological interventions. While there have been continuous efforts to improve farming practices towards food and farm sustainability, it is necessary to develop a metric to assess farming system in a holistic manner. Also, to design and promote appropriate agricultural interventions, a set of indicators covering long-term environmental impacts on agro-ecosystem, and socio-economic sustainability of farmers is needed. In order to address this need, we develop a *Stock* and *Flow* based framework for a systemic identification of both short and long-term indicators across the socio-economic and ecological dimension. In this framework, stock variables inside the system capture the stability and resilience of the system, and the variables from biophysical flows across the system-environment boundary capture both the desirable outcomes and undesirable impacts. The framework also aids in the selection of appropriate proxy indicators for hard to measure primary indicators by tracing their forward and backward linkages rather than avoiding complex indicators altogether.

This stock and flow based framework is used to identify a holistic set of indicators for comparing farming system. These indicators are classified under three widely accepted dimensions: economic, social and ecological dimension. A methodology is designed to estimate these indicators and the estimated values are normalized using the min-max method with standard reference. The indicators under each dimension are aggregated using progressive weighted mean to give three dimensional indices. These dimensional indices are further aggregated to give a single holistic index called Farm Assessment Index (FAI).

The methodology was applied to evaluate farming practices of a set of 100 organic and 100 chemical farmers, across Maharashtra, Tamil Nadu, Odisha and Karnataka. The major crops including cotton, soybean, wheat, bengal gram, turmeric and paddy cultivated during the year 2013 – 2016 totalling to 764 plots are studied. While there have been variations in yield and income trends, FAI score of most organic farms is better than the corresponding chemical farms. Even in the cases where the gross income from chemical farms is relatively higher, the economic index is higher for organic farms due to their higher benefit-cost ratio, lower risk, as well as better resource use efficiency. Similarly, in case of the social and environmental index, organic farms have scored higher than chemical farms due to the impacts caused by excessive fertilizer and pesticide usage in chemical farms. The variance of FAI among chemical farms was significantly higher than that of organic farms. Further, among the chemical farms, less intensive crops like wheat and gram have significantly higher index score than that of input-intensive cotton cultivation.

The results from FAI application demonstrates that the focus on yield or income as the sole indicator for policy decisions will not lead to sustainable farming systems. Policy makers need to shift towards holistic measures emphasising human health, livelihood of farmers and sustenance of agro-ecology. The case studies prove the FAI to be a valuable tool for a holistic assessment of farm practices that can aid in designing of appropriate farm policies. Further, the comparative studies have shown that the organic farming practices needs to be encouraged for improving the long-term socio-economic viability of the farmers and ecological sustainability of agriculture.

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List of Abbreviations

ADI	Agricultural Development Index
ADI*	Average Daily Intake
AEMBAC	Agri-Environmental Measures for Biodiversity and Conservation
AESIS	Agro-Environmental Sustainability Information System
AHP	Analytical Hierarchical Process
AICRPs	All India Coordinated Research Projects
AP	Andhra Pradesh
APEDA	Agricultural and Processed Food Products Export Development Authority
ASHA	Alliance for Sustainable and Holistic Agriculture
BAP	Budget Allocation Process
BCR	Benefit-Cost Ratio
BHC	Hexachlorocyclohexane
BOD	Benefit of Doubt
BT	*Bacillus thuringiensis*
CA	Conjoint Analysis
CBA	Cost-Benefit Analysis
CG	Chhattisgarh
CIAS	Composite Indicator of Agricultural Sustainability
COSA	Committee on Sustainability Assessment
CR	Change in Rank
DARE	Department of Agricultural Research and Extension
DDD	Dichlorodiphenyldichloroethane
DDE	Dichlorodiphenyldichloroethylene
DDT	Dichlorodiphenyltrichloroethane
DEA	Data Envelopment Analysis
DMNL	Dimensionless
DPSIR	Driving force-Pressure-State-Impact-Response
DSI	Dairyman-Sustainability-Index
DSR	Driving force-State-Response
eDPSIR	enhanced-Driving force-Pressure-State-Impact-Response
EIA	Environmental Impact Assessment
EMR	Environmental Minimum Requirements
EPA	Environmental Protection Agency
EU	European Union

FAI	Farm Assessment Index
FAO	Food and Agriculture Organization
F_{avg}	Fertilizer consumption rate for an average production
FCA	Full Cost Accounting
FESLM	Framework for Evaluation of Sustainable Land Management
FIQ	Fertilizer Impact Quotient
FIQ-K	Fertilizer Impact Quotient of Potassium
FIQ-N	Fertilizer Impact Quotient of Nitrogen
FIQ-P	Fertilizer Impact Quotient of Phosphorous
FYM	Farm Yard Manure
GDP	Gross Domestic Product
GHG	Green House Gases
GJ	Gujarat
GM	Genetically modified
HCH	Hexachlorocyclohexane
HDI	Human Development Index
HP	Himachal Pradesh
HR	Haryana
ICAR	Indian Council of Agricultural Research
KA	Karnataka
KL	Kerala
MAUT	Multi-Attribute Utility Theory
MAVT	Multi-Attribute Value Theory
MEFA	Material and Energy Flow Analysis
MESMIS	(Spanish acronym for) Assessing the Sustainability of Natural Resource Management Systems
MFA	Material Flow Analysis
MH	Maharashtra
MOTIFS	Monitoring Tool for Integrated Farm Sustainability
MP	Madhya Pradesh
MRL	Maximum Residual Limit
MT	Metric Tonne
NAAS	National Academy for Agricultural Sciences
NABARD	National Bank for Agriculture and Rural Development
NCR	National Capital Territory
NGO	Non-Governmental organization

NHM	National Horticulture Mission
NICRA	National Initiative on Climate Resilient Agriculture
NOX	Nitrogen Oxide emissions
NPK	Nitrogen Phosphorous Potassium
NRM	National Resource Management
NSSO	National Sample Survey Office
OAT	One At a Time
OECD	Organisation for Economic Co-operation and Development
PB	Punjab
PCA	Principle component analysis
PCB	Polychlorinated biphenyls
PCI	Principles, Criteria and Indicators
PIQ	Pesticide Impact Quotient
RISE	Response-Inducing Sustainability Evaluation
RJ	Rajasthan
S	First order sensitivity
SAFA	Sustainability Assessment of Food and Agriculture systems
SAFE	Sustainability Assessment of Farming and the Environment
SFD	Stock and Flow Diagram
SLCA	Social Life Cycle Assessment
SOC	Soil Organic Carbon
SOM	Soil Organic Matter
SSP	Sustainability Solution Space
ST	Total effect sensitivity
TDI	Tolerable Daily Intake
TL	Telangana
TN	Tamil Nadu
UCM	Unobserved component model
UK	United Kingdom
UN	United Nations
UNDP	United Nations Development Programme
UP	Uttar Pradesh
US	United States
UT	Union Territory
UTK	Uttarakhand
WB	West Bengal

Chapter 1 Introduction

Increasing population and food demand have always kept the agricultural production under pressure. The existing agricultural policies and interventions focus only on increasing crop yield and overall production, overlooking the long-term undesirable outcomes. For example, Green Revolution has helped India in achieving self-sufficiency in food grains, but in the last decade, it was realized that the input-intensive farming has caused serious environmental and health impacts (National Academy of Agricultural Science [NAAS] India, 2011; Planning Commission of India, 2002). NAAS, India (2011) has emphasized the need for developing and deploying sustainable agriculture with efficient management of natural resources including soil, water, and biodiversity. While there have been continuous efforts to develop new farm technologies and improve farming practices, it is necessary to develop a metric to assess their performance in a holistic manner. The development of Farm Assessment Index (FAI) and its field application to compare farming practice is of great relevance and value.

In this chapter, we begin with an introduction to the state of Indian agriculture and its transition over several decades. Then we describe the motivation behind the development of Farm Assessment Index (FAI) followed by a brief description of various assessment tools to contextualize the aim and objectives of this work. A scheme of the overall design of this research work and the structure of the thesis is given in the last two sections of this chapter.

1.1. State of agriculture in India

Agriculture may not be the backbone of Indian Economy but it is so far the livelihood of about half of the population of India. We use the data from various NSSO (National Sample Survey Office) surveys and agricultural censuses to describe the state of agriculture sector over the decades.

India has the largest agrarian population in the world with almost 50% of its population dependent on agriculture for their livelihood. Since 1981 the economic contribution of agriculture to the national GDP has shrunk from about 35% to 14%. Although the share of working population employed in agriculture has decreased over the decades, the actual population employed in the sector has increased significantly (Figure 1.1).

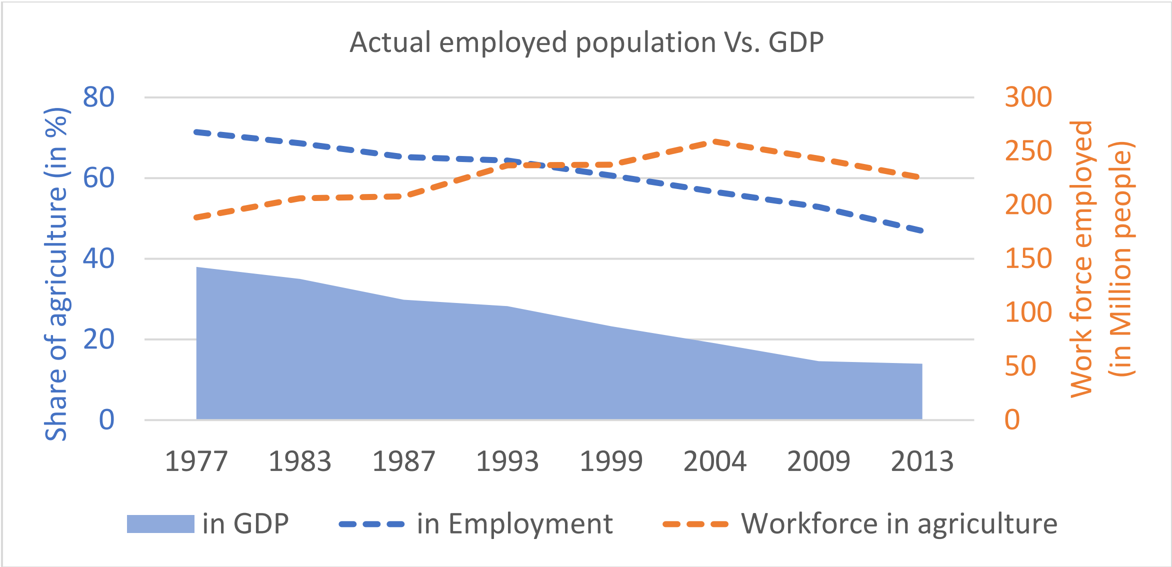


Figure 1.1 Agricultural GDP and workforce employed (Data sources: Labour Bureau, 2014; NSS 55th Round, 2000; Planning Commision, 2011; Population Census, 2011; Statistical year book, 2010)

The decreasing space of agriculture in the national economy with a huge population dependent on it, has created a huge disparity in per capita income. Figure 1.2 shows that the per capita income of the workforce in the non-agriculture sector has increased from about ₹6123 in 1977 to ₹19371 in 2013, a contrast to the agricultural workforce which has increased meagrely from ₹1502 to ₹3553. The increasing population of agricultural labourers than that of cultivators (Subramanian, 2015) and decreasing size of the landholdings (GOI, 2015) are the two major reasons for low per capita income in the agricultural sector.

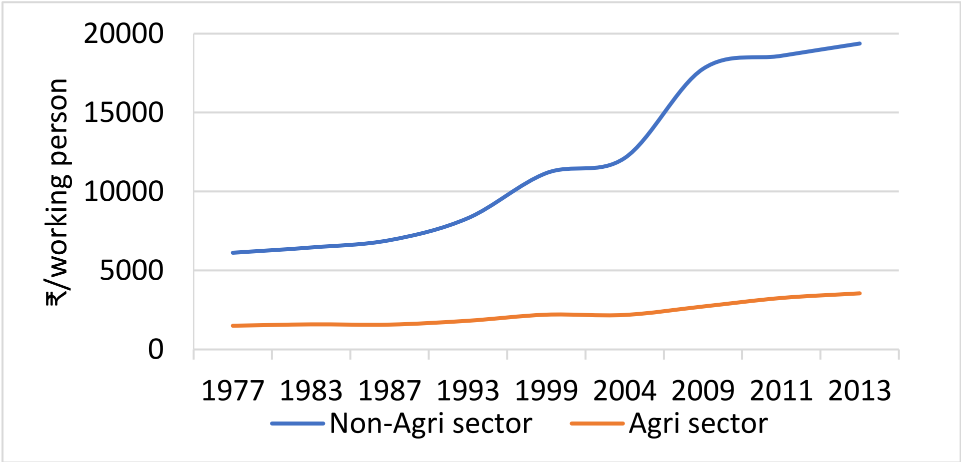


Figure 1.2 Income per capita of Agri and Non-Agri sector (Ratio of GDP to corresponding worker population) (Data sources: (GOI, 2010; Labour Bureau, 2014; NSS 55th Round, 2000; Planning Commission, 2014, 2011; Population Census, 2011)

As shown in Figure 1.3, top 15% farmers own more than half of the country's cultivated area during the year 2011. Almost half of the farmer population has less than 0.5 ha of land (Agricultural census, 2012). Further, the monthly expenses of marginal farmers (with landholding less than one hectare) were higher than the monthly income from their own farms (Figure 1.4).

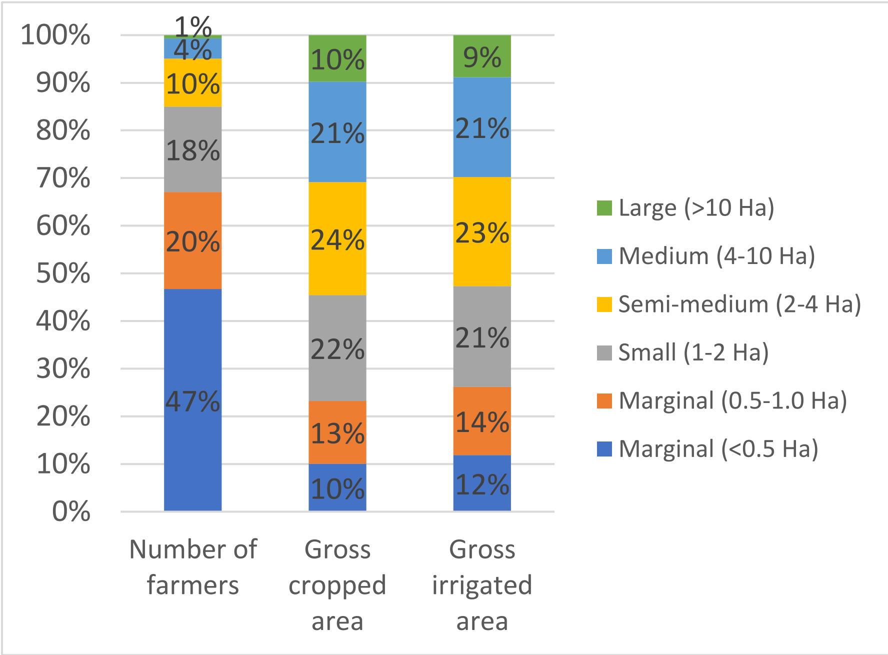


Figure 1.3 Proportion of population under various landholdings groups and the distribution of gross cropped and irrigated area among the groups (Data source: ICAR, 2012)

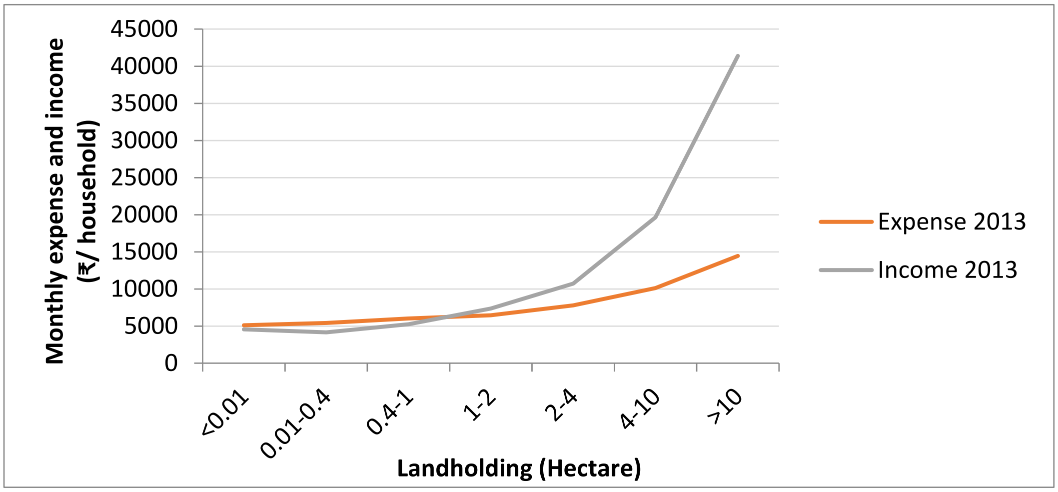


Figure 1.4 Monthly income and expenditure for various landholdings (Data Source: NSS 70th Round, 2013)

Irrigation is considered as one of the key elements in agricultural development and the area covered under irrigation has increased from about 30% in the early 1990s to about 48% in 2015-16. The coverage of irrigation facility has spread across all the landholding groups proportionally (Figure 1.3). However, the majority of irrigation has come from the extraction of groundwater using tubewell constituting about 50% of the current source of irrigation (Agricultural census, 2012).

Farmers across all the groups have moved towards paddy and wheat cultivation, with the expansion of irrigation. This shift towards mono-culturing of paddy and wheat has not just negated the crop-diversity, but has also compromised the nutritional security of rural population. Wheat and paddy cultivation has expanded tremendously since 1950s especially in irrigated areas with green revolution technologies (Figure 1.5). During the same period, non-food crops like cotton, and fodder, have also seen a double fold increase. In contrast to this, the area under pulses cultivation has barely increased and the cultivation of cereals like millets, has dropped by over 30%. Similarly, productivity and production of wheat, paddy, oilseeds and fibre have seen a multifold increase but the growth rate of pulses has been relatively slow. Although there has been a surplus production of cereals, India has been heavily dependent on the imports for vegetable oil (>50%) and pulse (>20%) consumption.

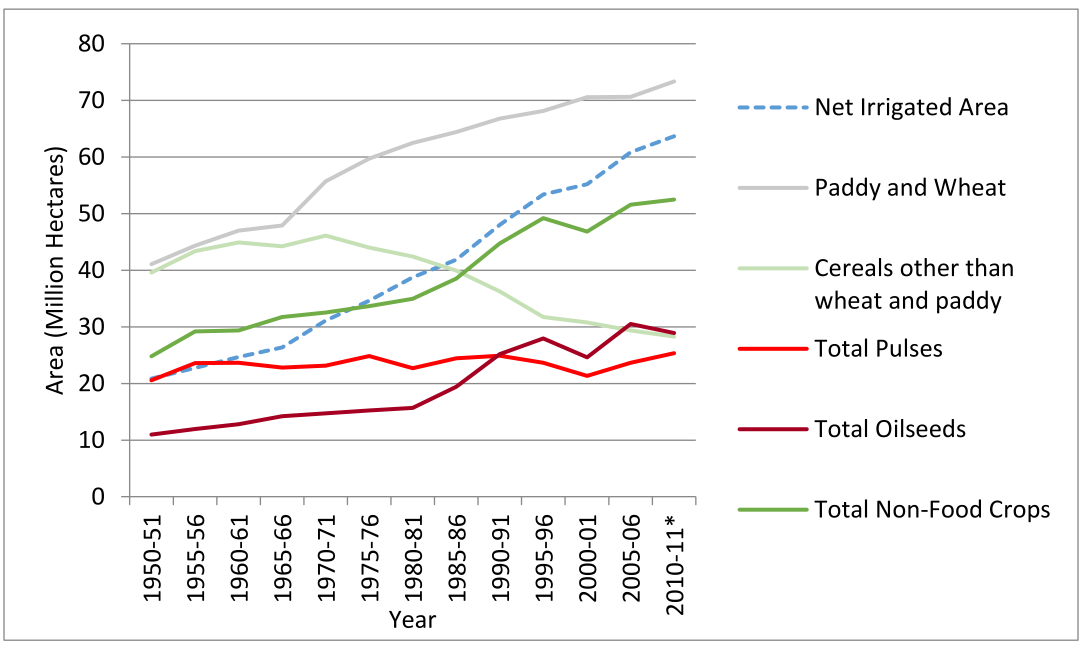


Figure 1.5 Area under different crops over the decades in India (Data source: GOI, 2014)

Though technologies like high yielding varieties, synthetic fertilizers etc., have helped to turn the country as a net agricultural export nation, various set of socio-economic and ecological challenges have emerged in the past decades. The agricultural census over the last two decades shows that the fertilizer input per unit area has almost doubled since 1996-97 till 2011-12 (Figure 1.6). Though the average yield per unit area of the cereals has increased by a third, the yield per unit fertilizer consumed has decreased by about 30% (Figure 1.7).

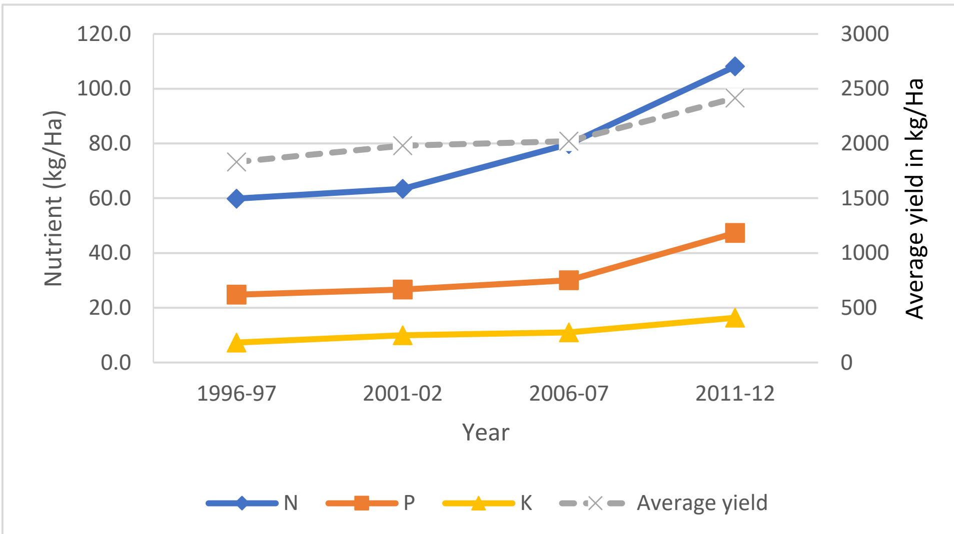


Figure 1.6 Rate of fertilizer application and average yield per hectare in cereal production (Data source: Agriculture Census, 2012)

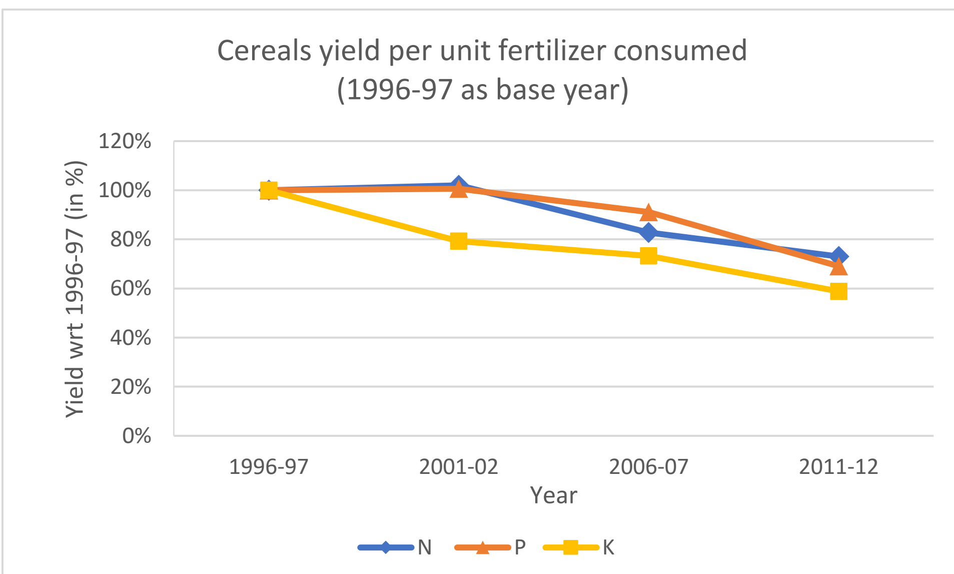


Figure 1.7 Yield per unit fertilizer consumed (1996-97 base year) in India
(Source: (Agriculture census, 2012; IndiaStat, 2017)

The input surveys show that the marginal farmer have a slightly higher rate of nutrient application, while the larger farmers have a higher rate of pesticide application (Figure 1.8). It also shows that the application of farmyard manure (FYM) has declined steadily and the application of pesticide has been on the rise (Figure 1.9). Similarly, the bovine livestock which contributes a major proportion of farmyard manure has increased by a meager 4% since 1992 till 2012.

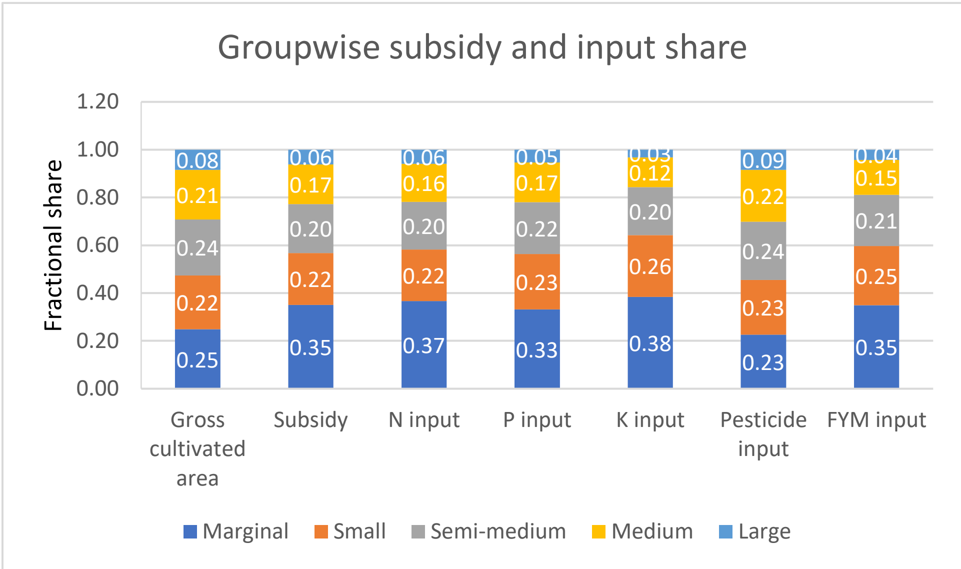


Figure 1.8 Distribution of cultivated area, subsidy, nutrients and pesticides across various landholding groups (Data source: Agriculture Census, 2012)

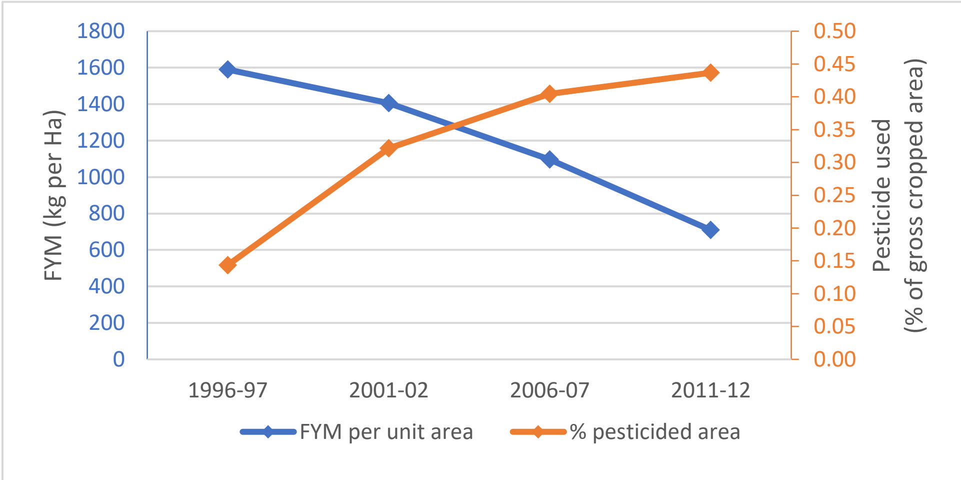


Figure 1.9 FYM and pesticide usage over the last two decades in India (Data source: Agriculture Census, 2012)

One of the major policy challenges for the decision makers is the monetary subsidy given to synthetic fertilizers. The expenditure on fertilizers subsidies has drastically increased since the last decade while the public investments in the agriculture and allied sectors have remained stagnant (Figure 1.10). The expenditure on fertilizer subsidy increased exponentially during the period 2005-06 to 2009-10. The major cause for this increase is mainly attributed to the increase in international prices of fertilizers (94%) and only 6% attributable to increase in consumption (GOI, 2017). Though the expenditure on the public investments and subsidies were similar till 2005-06, the fiscal shock due to Pay Commission let to cutbacks on investments and extension but not in subsidies (Planning Commission, 2007).

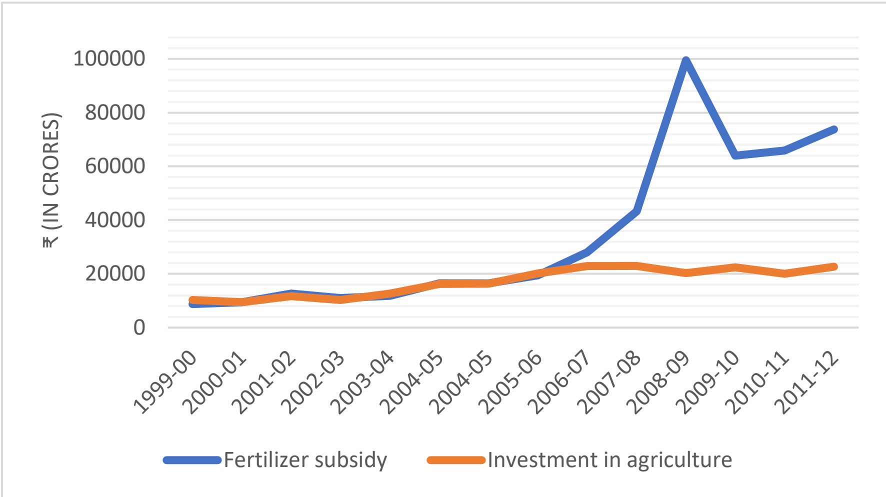


Figure 1.10 Public investment in agricultural and allied activities at (2004-05 Prices) and fertilizer subsidies in India (Data source: GOI, 2013; IndiaStat, 2017)

Although the subsidies help in cutting down the cost of inputs, the cost of cultivation has been ever increasing. Intensive application of synthetic fertilizers has reduced the potency of soil. It has increased the dependence of farm over external inputs and made the farmers, market dependent. With less than 20% of marginal farmers access institutional credits (Ministry of Agriculture, 2013), a large proportion of farmers are vulnerable to debt and exploitation by money lenders. Further, input subsidies have resulted in excessive application of fertilizers causing resource loss and environmental degradation. The average nitrate pollution in groundwater is above 50 mg/litre in eleven states of India while the desirable limit is less than 10 mg/litre (Novotny et al., 2010). Several reports indicate the presence of pesticide occurrence in various sample including air, water, soil, wildlife, birds, fishes and human beings. Average amount of pesticide residue in dietary food of various states is at a very high range and there are several cases where pesticide has caused hundreds of fatal poisoning (Abhilash and Singh, 2009).

The future of agriculture is confronted with widespread land degradation, impaired soil health, water contamination, contamination of food, GHG emissions etc. It is necessary to develop, evaluate and implement farming technologies with a long-term perspective and in a holistic manner covering socio-economic and ecological dimensions.

1.2. Motivation

Crop production and crop yield have been the sole focus of most of the existing agricultural policies and interventions. Agricultural policies are failing to support the biophysical sustainability of agriculture and financial remunerativeness for farmers in the longer run. World Trade Organization mandated policies to maintain Indian farm prices to be more aligned with international prices which coupled with a low domestic demand, have sharply affected the profitability of farming (Planning Commission, 2007). India has more than 80% of its farmers, which means, about 500 million people depend on farming for their livelihood with less than 2-hectare land holding (GOI, 2013). Remunerativeness of agriculture for such a population plays a very crucial role in the socio-economic viability of Indian agriculture. A farming practice can be remunerative when it is affordable and gives substantial income for their basic survival including food, shelter, health, and education, and provides financial stability to undertake farming for next cropping season. Since the last two decades, volatile commodity prices and increasing cost of cultivation has put the livelihood of marginal and small-scale farmers under threat. It has led to a huge distress among the farmer community and created an agrarian crisis (Reddy and Mishra, 2010). Further, the farming practice needs to be ecologically sustainable and maintain the stability and resilience of the agroecosystem. The Planning Commission has stressed upon a shift from production based research to the generation of technologies with a holistic farm system approach and their on-farm assessment (Planning Commission, 2007).

There has been an increasing stress on resource management and soil health in the planning commission document from Tenth Five Year Plan, but the Vision 2020 and Vision 2030 documents from Indian Council of Agricultural Research have focused mainly on improving the crop yield especially by genetic alterations (ICAR, 2011). This overemphasis on yield as a single indicator of agricultural production has resulted in several undesirable side effects in the long run.

A paradigm shift in our approach is needed for the long-term sustainability of agro-ecology and livelihood of the farmers. It is essential to assess farming practices in a holistic manner and we need assessment tools and methods to promote sustainable farming practices. The major objective of this work is to design a methodology for assessing agricultural system with respect to socio-economic and ecological sustainability.

1.3. Sustainability assessment tools

There has been an increasing attention towards the assessment of agricultural sustainability because of growing threats to human health, ecosystem, and livelihood of farmers. Assessment plays an important role in effective designing and strengthening of public policies and programs. The methodology for the assessment depends on the availability of financial resources, time and other constraints and may involve surveys, interviews, field measurements, modelling and simulation, etc. (Speelman et al., 2007). The key features of a sustainability assessment are to integrate the planning, monitoring and decision support tools, and provide useful guidance for the transition towards sustainability (Kates et al., 2012; Ness et al., 2007)

A variety of assessment tools have been developed to address the needs of various stakeholders and varying objectives of sustainable agriculture. Simulation models are often considered to be powerful ex-ante and ex-post analysis tools. But these models are dependent on the knowledge of dynamics in agro-ecosystem which is far from complete (Goss, 1993). Further, integrating the model for local conditions makes them very difficult for wider application. In contrast, indicators are the potential alternative tools which can mitigate these gaps. Indicators are usually user-friendly and simpler means to understand the state of the system. They can translate scientific knowledge into manageable units of information that can aid the decision-making process (United Nations, 2001). Several approaches like Environmental Impact Assessment (EIA), Life Cycle Assessment (LCA), Cost-Benefit Analysis (CBA), and Principles, Criteria, and Indicators (PCI), are adopted to identify the indicators of interest and are used in various sustainability studies.

Environment Impact Assessments (EIA) have been well established over past decades and are part of policies and programs. While EIA focus only on ecological dimension, Sustainable Development Assessments (SDA) explicitly consider the interdependency of social, economic and environmental factors of policies (Devuyst, 2000 and Jacobs and Sadler, 1990). The concept of Driving force-State-Response (DSR) or Driving force-Pressure-State-Impact-Response (DPSIR) has been widely used for sustainability assessments (European Commission, 2006; United Nationss, 2001). These techniques root themselves in the causal chain of individual processes but do not consider the interactions among the processes which may lead to insufficiency and redundancy. The enhanced driving force-pressure-state-impact-response (eDPSIR) framework proposed by Niemeijer and de Groot (2008) uses the causal network where multiple causal chains and their interactions are considered.

In contrast to the DPSIR framework which is widely used to evaluate various alternatives of a development project, LCA is used to assess the environmental impacts of a product starting from raw material extraction to its disposal and recycling. It is predominantly used by production industries for designing their business strategies (Cooper and Fava, 2006). While LCA, in general, has been focused on environmental impact, there has been an increasing consideration of social impacts in the LCA methodology in the recent years (Benoît et al., 2010). As the Social Life Cycle Assessment (SLCA), the focus has been varying from social impacts relevant to various stakeholders like workers in production system to end users of the product (Jørgensen et al., 2008). However, SLCA is least applicable to small-scale farms and farmers for comparing and improving their management practices.

The next method, Cost Benefit Analysis (CBA), has been historically used in the evaluation of cost involved against the expected benefits that can be translated in financial terms. It has evolved to Full Cost Accounting (FCA) where the environmental externalities and social impacts are monetized (FAO, 2014). Though this technique is appealing to the end users for its practical application, valuation of social and ecological utility remains a constraint (Bell and Morse, 2008). It is necessary to distinguish between the methods of evaluating objective and non-objective aspects of sustainability. Multi-criteria decision making helps us to avoid ethical and theoretical shortcomings of monetary value based assessment (Prato, 1999).

Principles, Criteria, and Indicators (PCI) has been the most widely used technique for farm assessment. In this technique, a set of principles are identified and organized thematically based on the system and the objective of the study. It is followed by the identification of criteria and selection of a list of indicators using causal relations (Van Cauwenbergh et al., 2007). Several frameworks and case studies have used this method to identify agricultural indicators and assess the sustainability of farms. We discuss these frameworks and case studies in detail in the next chapter. In general, PCI has several advantages of being a simple, flexible and widely adaptable tool, but there is a need to reduce the subjectivity involved in it. Similarly, PCI is good in contextualizing the assessment, but it requires a systems approach to make it complete.

1.4. Indicators and composite index

An indicator is a sign or signal that communicate a complex message in a simplified and useful manner (Jackson et al., 2000). An indicator can be a variable, a parameter, a signal, a statistic, a measurement, a medium, etc., and is a concise denotation for complicated systems with a variety of functions such as reflection, estimation, premonition, and instruction (Rigby et al., 2001). Indicators are often used as a standalone tool to understand, evaluate and monitor the state of a given system. They are practically applicable tool that acts as a bridge to understand complex systems (Monteith, 1996). Indicators facilitate interpretation and judgment of a situation with respect to a norm or an objective (Kerr, 1990). The quality of an indicator depends upon its suitability to the application and the consensus over its scientific value than the quantity of information it represents. Indicators are often used as a diagnostic tool which can be retrospective or prospective (Philippe et al., 2008). In most cases, the absolute value of indicators may not be useful unless reference values are established. These reference values are established with the help of scientific standards or legal norms. In absence of such standards, these reference values are set based upon the consensus among the stakeholders (Wetering and Opschoor, 1994).

A composite index is an aggregate of several base indicators which will help in summarizing the information provided by all the base indicators. It allows us to communicate an overall judgment about the state of the system (Gómez-Limón and Sanchez-Fernandez, 2010). The key criterion of a composite index is the simplicity in calculation and interpretation. Policymakers expect the indicators to be an aggregate index which can be easily communicated and unambiguously interpreted by the wider masses (Hammond et al., 1995). However, due to the loss of information in an aggregated index, the choice between the individual indicators and aggregate index depends on the context of application.

There has been a constant debate on the aggregation of a set of indicators into a single index which would capture the bottom-line and enhance its access to the general public. While the arbitrary nature of weighing might disguise serious failings (Sharpe, 2004), aggregation can be justified if it fits the intended purpose and accepted by peers (Rosen, 1991). Subjectivity is the major debatable area in the design of composite indicators. There is a room for subjectivity in almost all the stages of indicator development starting from boundary selection, definition of an indicator and the choice of variables selected, setting up of reference values, weightage to each indicator and aggregation method (Philippe et al., 2008). However, the subjectivity is accepted as a part of the research process (Munda et al., 1995).

Similarly, while the simplification of indicators might not conform to scientific validation in all the cases (OECD, 1993), careful elaboration will ensure that the loss of information due to simplification does not alter the solution to a given question (Ott, 1978). Typically there is a trade-off between the information captured by the selected indicator with the ease of monitoring (Rigby et al., 2001). For example, Human Development Index (HDI) is an aggregate of three main indicators representing education, health, and income, and has been globally accepted and used for monitoring the developmental progress of nations. Similarly, a composite index aggregating a holistic and concise set of farm indicators is desirable.

Andreoli and Tellarini (2000) have described that building a composite indicator for agricultural system will be the first step in bringing the concept of sustainability to agricultural policies. It is essential to identify an appropriate set of indicators and aggregate them into a holistic index to compare different farming system. With this background and motivation, we define the aim and objectives of our work.

1.5. Aim and objectives

The aim of this study is to design a composite index for a holistic evaluation of agricultural systems and apply the methodology for comparing different farming practices through case studies. The specific objectives of this research work are

- To develop a conceptual framework for systematic and transparent identification of indicators.
- To identify and select indicators for comparing various farming practices with respect to socio-economic and ecological dimensions.
- To design a methodology for transformation and aggregation of the indicators to synthesize a composite index.
- To assess and compare organic and chemical farms in four States (Maharashtra, Tamil Nadu, Odisha and Karnataka) using the methodology developed.

1.6. Research design

Figure 1.11 gives the overall scheme of the work with various components of the study. The study started with developing a conceptual framework followed by the identification and selection of indicators. After the selection of indicators, the methodology for construction of the index is designed. In parallel, field visits and selection of farmers, questionnaire designing and testing, and data collection were initiated. The process of indicator estimation, normalization of indicators, weighing and aggregation of indicators was started after the first round of data collection. Finally, the estimation of index, data analysis, interpretation of the index with respect to various parameters and validation of the framework were done.

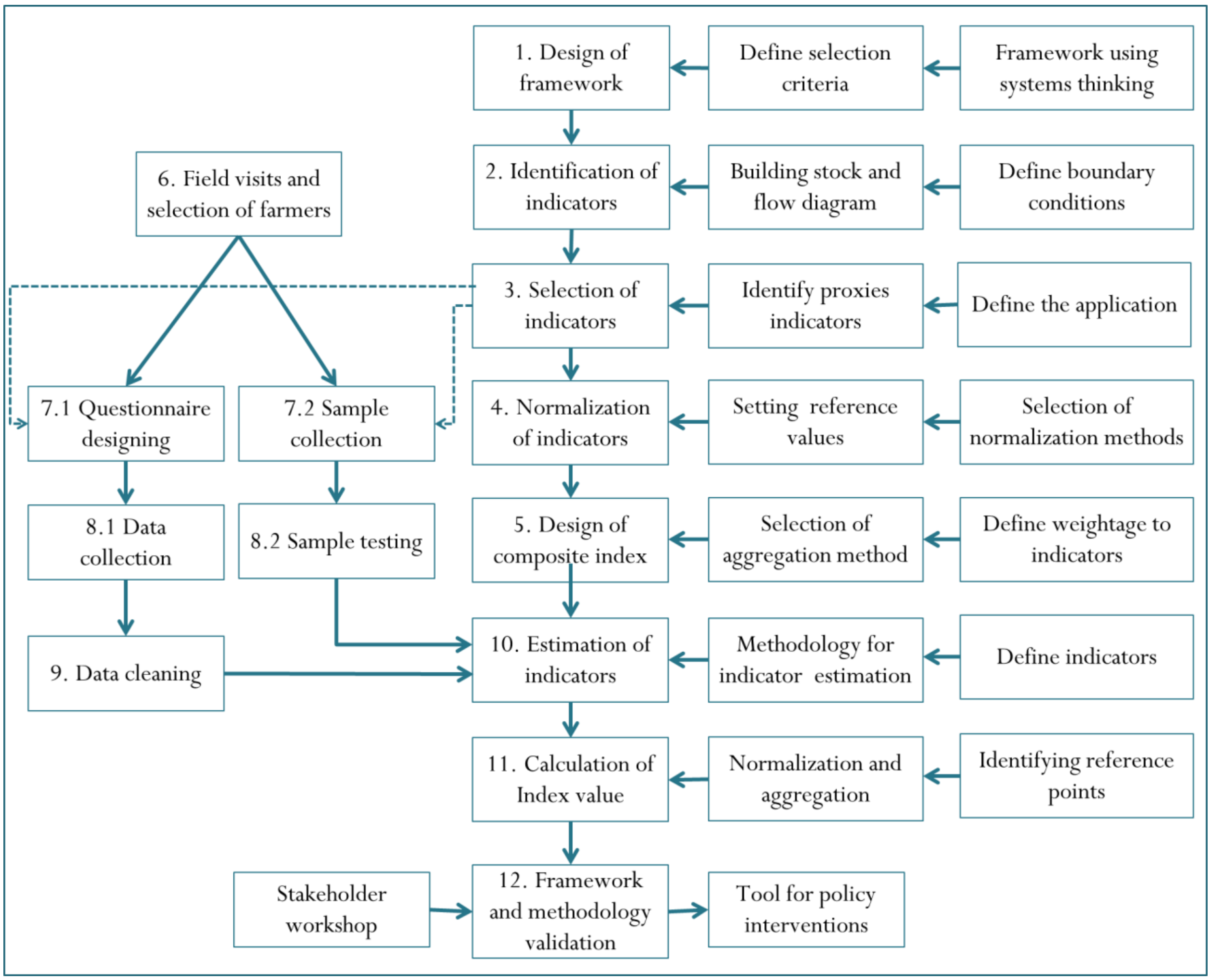


Figure 1.11 Overall research design

1.7. Structure of the thesis

The thesis is divided into seven chapters. This first chapter sets the background for our work with a brief note on the state of agriculture in India, motivation behind the work, an introduction about the area of work, aim and objectives, and the overall research design. The second chapter covers the literature review on the existing indicator frameworks, their methods, application and policy recommendations, and the problem definition. In the third chapter, we describe the newly developed stock and flow based framework. In the fourth chapter, we describe the concept of composite index and discuss various steps and methods to derive the composite index. The fifth chapter discusses the application of the stock and flow based framework to identify and select the indicators for comparing farming systems followed by the design of the Farm Assessment Index (FAI). In the sixth chapter, we describe the field application of FAI in four different states to compare organic and chemical farming systems followed by results and discussion in the seventh chapter. In the last chapter, we conclude with the overall outcomes from the study, future work, and recommendations for improving policy interventions.

Chapter 2 Literature Review

2.1 Indicators and frameworks

Indicators are principally the means to characterize the current status of the system which can be subsequently monitored to predict changes in the system. They help in interpreting and communicating complex systems in a simpler manner. An indicator should be simple, quantifiable, sensitive to change, have a wider scope and help identify the trend over the time (Harger and Meyer, 1996). A range of stakeholders like planners, scientists, farmers, politicians, and common people, use indicators for effective communication. Indicators help in simplifying complex realities into manageable and meaningful information which will in turn aids in decision making (Bossel, 1999). In order to make indicators useful to the target audience, they need to be defined at a meaningful level. Indicators should be sensitive to time, multiple perspectives, attitudes, and practices. More desirably, they should be able to forecast any detrimental change in the system rather than waiting for a physical change in the system (Freebairn and King, 2003). Thus indicators are used to design strategies, give warning that could help avert damages in future or simply to communicate ideas and information (Berke and Manta, 1999; Lundin, 2003).

Since the choice of indicators forms the basis of assessment or diagnostic tool, the process of indicator selection needs to be systemic, rigorous and transparent. The process should involve a heavy scrutiny, as it shapes the role of scientific measurement and prediction over the socio-economic and political decisions (Rigby et al., 2001). As the agro-ecosystem is a very complex system involving a huge number of indicators, it is necessary to use a conceptual framework to aid the process of indicator selection (Gómez-Limón and Sanchez-Fernandez, 2010). A conceptual framework is a virtual platform built to guide any research process by adding rigor to the idea or the concept. The role of framework is to facilitate the identification of an exhaustive list of indicators and ensure the selection of indicators which are core, coherent and consistent. Since the trade-off between the completeness of indicator set and the ease of monitoring is unavoidable, it is necessary to make the trade-offs explicit to maintain the transparency and legitimacy of the framework (Kruseman et al., 1996). The credibility of indicators can be increased by building consensus over the selected indicators and raising the ownership of stakeholders on the indicators.

In general, frameworks can be distinguished as either system based or content based framework. System based frameworks consider the system as a whole and aid systemic selection of key attributes as indicators. Content-based frameworks focus on a particular set of components of the system to address the issues related to a specific function or process. Both the types of frameworks have their own set of pros and cons. System based frameworks are inclusive in approach and provide equal importance to all the components and their linkages. But they demand an extensive knowledge of the system. Also, the complexity of the process is time and resource consuming. Often systemic indicators remain qualitative rather than a quantitative parameter and are challenging during their application (Von Wirén-Lehr, 2001). Content-based framework focus on individual processes within the system which helps to emphasise the functions of the components related to objectives. But they often neglect the interactions between the processes and overlook other system functions.

There has been an increasing need for an assessment and diagnostic tool for policymakers to evaluate, monitor and promote sustainable farming techniques. In general, farm indicators are usually perceivable biological or chemical or physical or socio-economic attributes of the system. Farm indicators can be from two different perspectives - farmers and policymakers. In case of farmers, indicators aid decisions in farm management and, in case of policy makers, indicators help in monitoring, guiding and designing of appropriate schemes and programs (Pannell and Glenn, 2000). Indicators are made more valuable at farm level by linking the negative and positive trends in indicators to farming practices (Tzilivakis and Lewis, 2004). Indicators also help in increasing the awareness among farmers about the issues that are being monitored (Pannell and Glenn, 2000). Ready to access background information and personalized advice based on the indicator, will help the farmers improve their farming practices and set benchmark for their farms (Tzilivakis and Lewis, 2004). Farmers consider the indicators as the starting point of their goal to make better management decision in their farm (Meul et al., 2009).

Since the last decade, there has been a burgeon of farm sustainability studies ranging from field level to national level. The scope of these studies has varied from developing a framework for indicator selection, proposing a set of indicators for farm assessment, case studies using the selected indicators, suggestive action plan for the policymakers or farmers, design of computer-based tools for farm assessment etc. In the following sections, we describe in brief about the existing frameworks, their application and outcomes from these studies.

2.2 Indicator selection frameworks

Framework for Evaluation of Sustainable Land Management (FESLM) is one of the earliest structured schemes to guide sustainable land use. This framework is based on five basic pillars that include productivity, security, protection, viability, and acceptability. It involves a stage-wise process which starts with defining the objectives followed by identification of evaluation factors (qualities, attributes, processes and constrains of sustainability) and diagnostic criteria (to identify cause and effects), and finally determining the indicators and their thresholds. (Smyth et al., 1993).

Walker and Reuter (1996) have grouped indicators into condition indicators and trend indicators which can be compared to that of stock and flow concepts. Condition indicators are those which represent the state of the system and trend indicators are those which represent the sudden shifts and historical development.

Bossel (2000) proposed a systems framework where every functional system is hypothesized to have a subsystem within it and an environment around it. At any state of the system, there are six balancing forces (orientors and orientation) between the system and its subsystems and, similarly, six orientors and orientation forces between the system and its environment. These forces maintain the subsystem-system-environment under equilibrium as shown in Figure 2.1. All the phenomena and characteristics of the system can be captured comprehensively by quantifying these interacting forces. Similarly, an ecological accounting is a system based framework in which connections between living organisms and their ecosystem are quantified in a balanced and unambiguous manner without omission and redundancy, at a scale desired by the investigator (Hannon et al., 1991). While in theory, these frameworks appear to give a complete description of the system, in practice, it is too complex to be applied to most systems.

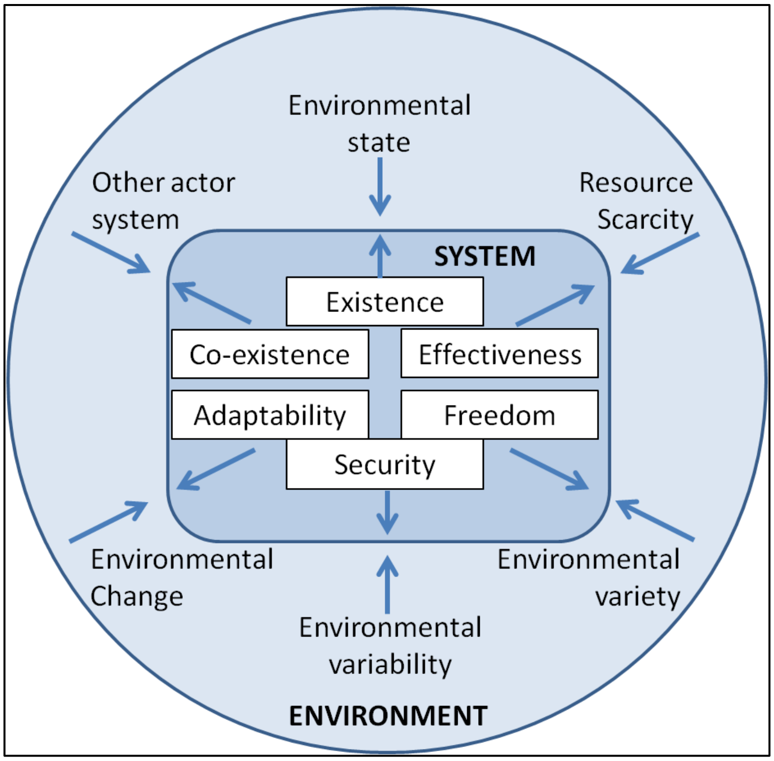


Figure 2.1 Fundamental System-Environment relationship

Pannell and Glenn (2000) have developed a conceptual framework which helps in economic valuation and prioritisation of indicators based on the cost involved in the collection of information and potential value of its utility. An indicator has an economic value, if it changes the decision or if it reduces the uncertainty in a particular decision. The framework is particularly useful to calculate the economic value of information under conditions of uncertainty.

"Response-Inducing Sustainability Evaluation" (RISE) is a farm assessment framework that covers the "driving force" and "state" aspects of natural resources, biodiversity, emissions, local economy, social situation of the farm etc. In contrast to simple causality relation in DSR (Driving force-State-Response) framework, an increase in driving force is considered to decrease the sustainability of the system and an increase in state indicator value is consider as increase in sustainability of the system. The degree of sustainability was determined as state indicator minus driving force indicator (DS = S - D) after normalizing them to a scale of 0 -100. The scores are displayed using sustainability polygons which helps in identifying the weak aspects of the system (Häni et al., 2003).

MESMIS (Spanish acronym for Assessing the Sustainability of Natural Resource Management Systems) framework is one of the frameworks which has been extensively used in case studies. It is based on seven general attributes (productivity, stability, resilience, reliability, adaptability, equity, and self-reliance) of sustainability. The framework is structured as a six-step cyclic process. The steps include characterisation of the system, identification of critical points, selection of specific indicators using diagnostic criteria, measurement and monitoring of the indicators, integration of indicators using multi-criteria analysis and interpretation and recommendations to improve the socio-economic profile of the system. The framework is considered to be a flexible and participatory methodology as it allows site-specific selection of indicators. Further, it is also considered to give a multi-scale approach as the objectives for indicator selection are defined at various impact levels with respect to different stakeholders (López-Ridaura et al., 2005).

Calker et al. (2005) have used a range of stakeholder and expert judgment as a sole basis for selecting indicators of sustainability for dairy farms in the Netherlands. Social sustainability was divided into internal (working condition of farm operators and employees) and external (societal aspects including impacts of farming on well-being of people and animals) social sustainability. While several indicators were selected for external social sustainability and environmental sustainability, only a single indicator was chosen to capture economic and internal social sustainability. A relative ranking was done by an expert group and the major attributes in external social and environmental sustainability were identified. Similarly, several studies have used problem-oriented approach in which the indicators were selected based on the context of the study by the experts and stakeholders (Von Wirén-Lehr, 2001; Wiek and Binder, 2005).

Sustainability assessment of Farming and the Environment (SAFE) framework is a hierarchical framework with principles, criteria, indicators and reference values in a structured way. The SAFE framework has adopted a set of procedures for the selection of indicators which includes pooling of indicators from literature followed by multi-criteria expert evaluation where experts (scientists, civil servants, and farmers) are thematically grouped. Each indicator is validated with respect to eight criteria that includes discriminating power in time and space, analytical soundness, measurability, transparency, policy relevance, transferability and relevance to sustainability issue. Three major pillars namely environment, economic and social pillar were selected and a set of principles are identified under each pillar from which the indicators are identified. A set of 87 indicators were identified for Belgian agricultural systems using 19 principles and 49 sub-themes(Sauvenier et al., 2005b; Van Cauwenbergh et al., 2007).

MEFA (Material and Energy Flow Accounting) is a framework based on material and energy flow which captures the interaction between society and nature by mapping the socio-economic material and energy flows along with their relevant impacts on the ecosystem. Reduction in resource consumption and emission are considered to be the two long-term sustainability characteristics of the system (Haberl et al., 2004). Similarly, biomass flows and material balance of the farm are used to identify the indicators by Andrieu et al. (2007). The impacts of each flow over resources like forage, soil nutrient, financial resources, size of the herd and reserve area, are estimated. The change in characteristics of resources helps in understanding the production strategy of farmers by capturing the interaction between crop and livestock system. This framework is not a predictive tool, rather it aims to support discussions in farmer groups over current farming practices and their alternatives. A case study of fourteen farms has indicated that the productivity of the farms improved with a decline in autonomy (import of external forage) and stability (pressure on natural resource) of the farms.

Wiek and Binder (2005) have described that an assessment tool usually consists of three components that are classified as systemic module, normative module, and procedural module. The systemic module deals with the structure and function of the biophysical system. The normative module deals with the definition of problems and objectives of various stakeholders. The procedural module covers the operational methodology for integrating the systemic and normative elements of the system. The authors have introduced a concept called Sustainability Solution Space (SSP) in which the indicators are represented in an n-dimensional radar chart. This SSP is defined by the maximum and minimum threshold values of each indicator and provides a varying target space for the system under assessment.

Van Calker et al. (2006) used Multi-Attribute Utility Theory (MAUT) to design a sustainability function for Dutch dairy farms. The framework starts with defining an attribute utility function followed by assigning weightage to attributes and then formulating the sustainability function by aggregating the preferences of stakeholders using goal programming approach. Goal programming is multi-objective optimization method used to maximize the agreements and minimize the disagreements among the stakeholders. The application of this methodology indicated that the overall sustainability ranking of farms was not affected with change in weightage allocated to attributes and dimensions.

Material and Energy Flow Analysis (MEFA) is also used in sustainability assessments. It helps in understanding the resource flows in the system and identifying the areas of inefficiencies. Since this tool is dependent on the physical flow, they focus mostly on the environmental impacts (Ness et al., 2007). Such studies have been done in several European countries which have shown that the material use efficiency has been increasing but the waste generated also continues to increase. It stresses the need for physical accounts of resource flow beside the traditional economic accounts (Matthews et al., 2000).

Economic MFA was designed by Eurostat along with a set of guidelines to capture the material flow and balance in an economy at the national level. The methodology categorizes material indicators into input, output and consumption indicators. Input indicators represent the inflow of materials into the economy through production, and output flow captures the material output to the environment in terms of waste and emissions. Consumption indicators are those materials used in the economy. There are hidden material flows like excavation, soil erosion which do not enter the economic system (Eurostat, 2001).

MOTIFS (Monitoring Tool for Integrated Farm Sustainability) developed by Meul et al. (2008), is an indicator based tool for monitoring the farm sustainability including economic, ecological and social aspects of the farm. Economic and ecological indicators were selected based on literature and social indicators were selected based on stakeholder discussion. The major advantage of this tool is its user-friendly design and the visual result by representing the final indicators in a radar chart that captures both weightage of individual indicators and their performance.

A Farmer Development Index has been designed by Qiu et al. (2007), where the indicators are selected based on published case studies and literature. The indicators are classified under three dimensions and, are aggregated using weighted sum and product, for economic, social, and ecological indicators respectively. Similarly, Zahm et al. (2007) designed a self-assessment tool called IDEA (Indicateurs de Durabilité des Exploitations Agricoles for Farm Sustainability Indicators in French), based on 41 sustainability indicators covering all three dimensions of sustainability. In order to compare the farms effectively, indicators were calibrated to give the greatest possible distinction among the farms.

A Committee on Sustainability Assessment (COSA), initiated to evaluate and understand the process of adopting sustainability programs, designed a framework called SMART (Specific objectives, Measurable results, Achievable by participants, Realistic given the resources, Time-bound within the established framework). This framework was used in multi-criteria sustainability assessment of certified and non-certified coffee plantation. The study found that the certified farms had slightly better economic and ecological indicators, and distinctly better social indicators (Giovannucci et al., 2008).

Simoncini (2009) has elaborated the need to shift from multi-functionality approach to agro-ecosystem based approach. A detailed methodology, AEMBAC (Agri-Environmental Measures for Biodiversity and Conservation) has been developed for the integration of scientific results, economic and social values, ecological objectives and opinions of stakeholders. This method depends upon the Environmental Minimum Requirements (EMR) which are essential for the maintenance of agro-ecological structure and process to deliver the environmental goods and services. This method helps in identifying a suitable scheme for a given area, time and critical scale required for the change, and payments to the farmers. The concepts of EMR are also used to define meaningful targets that are based on carrying capacity of the eco-systems, ecological thresholds, and demands and needs of the society. These EMR are usually set based upon sources like scientific literature, laws and regulation, expert knowledge, historical data and comparative analysis. The validity of EMR depends upon the location, time, measuring scale and the objectives of the study (Bastian et al., 2007).

Pacini et al. (2009) have proposed an information system called Agro-Environmental Sustainability Information System (AESIS) to support farm decisions. This framework has been used to evaluate organic, conventional and integrated farm production system in Tuscany. Defining the sustainability issues, identifying alternatives and evaluating the alternatives are the three major components in applying this framework. In order to identify a quantifiable and balanced system, it is necessary to delimitate the system in space and time, and delineate the processes within the system with respect to inputs and outputs. Material, energy and services associated with these processes are captured using stock and flow concepts to integrate the ecological and socioeconomic dimensions.

A methodological framework has been designed by Dantsis et al. (2010) for assessing and comparing the sustainability of plant production systems at a regional level. A set of 21 indicators were identified and aggregated using Multi-Attribute Value Theory (MAVT) to give a unique index. The utility function of an indicator is often non-linear and site-specific depending upon various socio-economic and biophysical factors. It is appropriate for these indicators to have a non-linear function. But, determining such a non-linear site-specific function is very difficult and can be uncertain. So, linear utility functions based on the highest and lowest values from the observed data are used.

A sustainability tool called "INDIGO" originally developed for assessing the sustainability of arable cropping system has been modified to be used for perennial crops in viticulture (Thiollet-Scholtus and Bockstaller, 2014). The INDIGO system is a sustainability assessment framework which focuses on farming practices that are connected with the indicators of interest. This directly feeds in assisting the management decisions of farmers and helps in improving the farming practices (Bockstaller et al., 2008).

Ine et al. (2014) have come up with a set of criteria for an effective development of a sustainability tool. It includes stakeholder participation, continuous communication of objectives, leadership, transparency, and reflection on the tool development process. The difference in objectives among stakeholders and availability of required data have been found to be the major barriers for development and application of sustainability tools. Most of the frameworks are conceptually sound but not operational enough for direct practical application.

2.3 Framework application and case studies

There have been several case studies in which sustainability of farming systems has been evaluated using some of the framework discussed in the previous section. We describe a few of them which help in understanding various approaches and their findings.

Ministry of Agriculture, Fisheries and Forestry, UK employed DSR (Driving force-State-Response) framework to identify a broad set of indicators and selected a set of 35 indicators based data availability and its relevance to rural economy, input usage, resource use, farm management and conservation of agro-ecology (MAFF, 2000). While aggregation of these indicators was designed for a national level data, Tzilivakis and Lewis (2004) have defined farm level indicators equivalent to the national level indicators. In order to make the tool more meaningful, a software was also built to link the trends of indicators with the farm management and to suggest steps to improve farm sustainability.

Rigby et al. (2001) investigated a set of 80 organic and 157 conventional producers in the UK and showed that organic farms are always more sustainable than conventional farms. The study stressed the need to move from abstraction of agricultural sustainability to an operational and application context. Patterns of input usage and other farm management practices are ranked based on their impacts on farm sustainability. This approach relies on the confidence of mapping the farm practices to their impacts with the underlying evidence and assumptions. Freebairn and King (2003) have also emphasized the need to focus on 'soft' system indicators rather than 'hard' system indicators where they refer the interaction between the farm, technology, and farmers as soft system and the biophysical interaction of field with agro-ecology as hard system. Hard indicators help in initiating and prioritizing focus areas, while soft indicators help in integration of indicators with farm management decisions.

Nambiar et al. (2001) developed an index methodology with a broad set of biophysical, chemical, economic and social indicators aggregated with equal weightage, and applied it to two data sets (1990 and 1999) of the three Chinese Coastal zones (East, West, and Middle). They showed that east and middle zones have improved in terms of their sustainability while the west zone has deteriorated. They also showed that the optimal or threshold values of soil indicators can vary depending on the soil type which requires characterization of the properties of ecosystem for a better measure of sustainability. Indicators were selected on the basis of social and policy relevance, analytical soundness and measurability, suitability for different spatial scales, encompassment of ecosystem processes, sensitivity and accessibility to many users.

Praneetvatakul et al. (2001) studied the agricultural sustainability in the Mae Chaem Catchment of northern Thailand at three levels including household, village, and sub-catchment. Three indicators each in economic, social and ecological dimension were selected based on attributes such as production efficiency, resilience and maintenance of ecosystem, satisfaction of basic needs etc. Scoring for each indicator was designed with reference values and the indicators were ranked as sustainable (S), conditionally sustainable (C) or not sustainable (N). The scoring and ranking of indicators helped in identifying the critical factors of sustainability of farms to be the landholding, land tenure and water availability.

Herendeen and Wildermuth (2002) measured the sustainability of beef production system by quantifying the aspects of resource depletion, dependence on other systems and disturbance created to natural cycles. Soil, water, nitrogen, and energy balance were used to estimate the depletion index and the export/import balance is used for estimating the dependence index. While export/import covers the direct energy dependence, the indirect energy dependence was estimated using economic data. Change in soil erosion pattern with respect to grazing practice is taken as disturbance index.

Zhen and Routray (2003) identified an extensive set of indicators for developing countries, based on literature review on agricultural sustainability indicators. Crop and site-specific indicators were selected with the knowledge of local experts and farmers. The field level data and observations in the study have helped in socio-institutional assessment, apart from economic and ecological assessment. A detailed case study of 270 farms in North China Plain has shown that the cropping systems were economically viable but at the cost of human health, and environmental and resource degradation (Zhen et al., 2005).

A methodology was proposed to rapidly calculate environmental indicators to assess the environmental performance of farms in Pampas of Argentina. A Microsoft-Excel based model called Agro-Eco-Index was developed to estimate the values for indicators from the farm data. The results were displayed in a graphical dashboard which provides a colour band for individual indicators depending upon their performance. Though the graphical representation becomes a crude form of results, it is user-friendly and gives out warning signal as the indicators approach the critical level (Viglizzo et al., 2006).

Walter and Stutzel (2009) have evaluated the sustainability of farms in Borken, Germany, by identifying locally relevant issues with the help of literature. Many times, sustainability is defined as the absence of certain issues. In this study, indicators were taken in terms of ‘severity ratio’ which is the ratio of the actual impact level to the critical impact level. The quality of this sustainability measure was assessed with the help of a semi-quantitative survey of stakeholders.

Gómez-Limón and Sanchez-Fernandez (2010) have used regression analysis to identify the relations of farm profile and management, with respect to farm sustainability. Farm sustainability increases with increase in area of the farm, percentage of ownership in operated land, lower age, and proportion of income from farm in farmer's total income. In addition, specialized training and association of farm-owner with cooperatives also contributed towards farm sustainability. In case of farm operation indicators, farm sustainability increases with increase in income from farm produce, rise in agro-environmental payments, reduction in fertilizer inputs, increase in machinery, and decrease in labour input.

Astier et al. (2011) applied a sustainability evaluation framework in over 40 case studies in Latin America. Effect of various alternative management practices on the sustainability of agro-ecosystem was analysed. It was found in all but one case, that some indicators were increasing at the cost of others. This makes it difficult to develop sustainable agro-ecosystems and demands for long-term studies. It showed that the higher yields and income values were obtained at higher production costs. Quantifying biodiversity and agro-diversity was either simplified to the number of species or not considered in the case studies.

Sharma and Shardendu (2011) developed an agricultural sustainability index and applied to evaluate the sustainability of rural eastern India in 2010 in comparison to that of 1950-60. A set of ten indicators were selected for each of social, economic and ecological dimensions and all the thirty indicators were aggregated with equal weightage to give a final index value. The indicators were selected on the basis of local significance, availability of data and availability of threshold or reference values for scoring each variable. The study showed that the economic indicators improved at the cost of ecological and social indicators over the last several decades.

NABARD has designed a district level Agricultural Development Index (ADI) and used it in the state of Maharashtra. The ADI has been developed to measure the development level of agriculture at regional scale considering nine broad areas related directly or indirectly to agriculture. The criteria considered for selecting indicators include relevance, literature review, availability and reliability of data, and measurability. A set of 18 indicators were selected to measure the availability and utilization efficiency of resources in nine areas including land resource, irrigation, human resource, non-credit inputs, credit inputs, infrastructure etc. A high ADI conveys that the region is using its resources efficiently while that with low ADI has not used the resources optimally (NABARD, 2012).

Agricultural sustainability of small-scale farms in Timor Leste was studied by Moore et al. (2013) to understand the perspectives of farmers over the sustainability. A set of 36 indicators classified under four domains namely agronomic, economic, environmental and social, were estimated using a questionnaire with 41 multiple choice and 13 open-ended questions. While the closed-ended questions captured the quantifiable description of farming practices, open-ended questions captured the perception of farmers. The results from the study helped in identifying a variety of problems and needs of the farmers.

Elsaesser et al. (2013) developed a practical tool called Dairyman-Sustainability- Index (DSI) useful for scientists and extension services, to validate and evaluate dairy system. The methodology stresses upon the participation of the stakeholder and the need for region specific reference. They tested it in 127 dairy farms for practical application which helped in identifying the differences among the farms. Brian Ogle (2001) has also described a participatory approach to select indicators for monitoring the rehabilitation of degraded ecosystem. Werf and Petit (2002) has compared various assessment methodologies and proposed a guideline for designing indicators to monitor agricultural impacts on ecosystem. They have preferred impact-based indicators over the cost-effective practice-based indicators, mainly due to their direct link to objectives and outcomes. However, Ghersa et al. (2002) have shown that the linkage between indicators and the management practices is crucial for decision making by the farmers for a sustainable land-use.

2.4 Policy recommendations

Although there have been several case studies and field application of indicator frameworks, most of them focus on the design and validation of the assessment tool, rather than the practical and actionable policy recommendation. Only a few of the studies have commented on the policy recommendations which are briefly reviewed in this section.

The case study in Chase County has shown that range production is relatively less-depleting, independent and non-disrupting than row-cropping and confinement animal feeding (Herendeen and Wildermuth, 2002). A case study of 150 farms showed that overall sustainability index has not changed significantly in Eastern India as the social and economic dimensions have increased and ecological sustainability has decreased since 1950-60 to 2000-2010. Increase in average age of farmers and population density, and decrease in per capita land availability, ecological literacy, agricultural biodiversity and electrical supply were found to be the areas demanding the attention of agricultural policies (Sharma and Shardendu, 2011).

Zhen et al. (2005) have found that the knowledge dissemination in Ningjin County of Shandong Province, China, was narrowed to fertilizer and pesticide inputs, without much focus on water use and conservation, crop diversification and health and environmental impacts of farming practices. They also showed a very weak presence of extension services and the greater dependency of farmers on media, fellow farmers and local dealers for their knowledge input. The sensitivity analysis of indicators has also shown that the crop production is more sensitive to the sales price of farm produce than to the changes in input price.

Speelman et al. (2007) have discussed the vulnerability of a framework when used for field application. In some of the 28 case studies using MESMIS framework, the indicators selected did not correspond to the selected attributes. These case studies showed that a large portion of the indicators covered ecological aspects which can either be due to the preference of the stakeholders or their better understanding of the ecological aspect. However, the case studies have identified that the higher dependency on external input, impacts on local resource, low production, lesser organizational participation of farmers and low biodiversity, are the major factors affecting the sustainability of farms.

Gómez-Limón and Sanchez-Fernandez (2010) have designed nine different indices to provide robust results which help in understanding the advantages and disadvantages of each method employed in the study. The relationships between indices and variables were analysed using regression models which provided numerous insights for potential improvement in agricultural and rural development policies. Capacity building, strengthening of farming skills and aggregation of landholding were the major areas for policy interventions. Further, the results have emphasized the need to formalize the institutional contract to provide financial benefits in return for public goods created by the farmers.

Ceyhan (2010) used a composite index based on 40 indicators, to estimate the sustainability of a set of 93 farms in Samsun province of Turkey. Excessive fertilizer inputs and lack of irrigation were found to be the major barriers to agro-ecological sustainability. Low returns, lack of land ownership and inadequate infrastructure are found to be the major issues in socio-economic sustainability.

Merlín-Uribe et al. (2013) assessed the shifting of flower production from chinampas (a type of Meso-american farming method in the beds of shallow lakes) to plastic greenhouses, using MESMIS framework. A set of 50 farmers per system were interviewed for agro-ecological indicators and a set of 4 farmers per system were interviewed for the socio-economic system. It was observed that the profit margins were better in greenhouse production but the resource efficiency was higher in chinampas. The study remarked that there are several intangible benefits like aesthetic and recreational values, from chinampas for the agro-ecological system. It was also found that there is a large variation in indicator values among the farms. The study showed that a viable compensatory mechanism is required to preserve the ancient system of chinampas and its ecological benefits.

Merante et al. (2015) compared various farming systems based on resource use productivity with respect to pre-determined environmental constraints based on carrying capacity of the ecosystem. It was found that organic farming system did better than conventional farms in many parameters. But neither of them were found to be environmentally sustainable, suggesting that an environmentally sustainable farming system should be defined as the benchmark for farm evaluation.

2.5 Need for a framework

There has been two negating demand over the sustainability assessment tools. At one end, we need an approach which is more site and time specific, and at the other end, we need a broader and widely applicable tool (Ness et al., 2007). It may not be possible to universalize the set of indicators with varying objectives of different stakeholders. Often the indicators originate in response to the local and temporal demands which may not be relevant universally (Viglizzo et al., 2006). Moreover, with change in space, time and stakeholders, it is necessary to contextualize the assessment tools based on the application. In developed nations, the focus of agricultural sustainability is more about diversification of crops and protection from environmental impacts like nutrient runoff and health impacts of pesticides (Bowers, 1995). But in developing countries, agricultural sustainability is meant to increase the land use efficiency and profitability, optimize resource use, improve farm resilience and enhance knowledge usage.

Although there have been a few studies on agricultural sustainability in India, the indicators and weightages considered in the index, are grounded on different objectives and scales of application. For example, ADI (Agriculture Development Index) of NABARD attempts to assess the status of agricultural development at district level by measuring the distribution and utilization efficiency of resources like land, water, credits, human resources etc. But it does not consider agronomic and environmental parameters of the farm sustainability. In addition, these tools help in monitoring the state of the system at a macro level. Although the farm level index developed by Sharma and Shardendu (2011) includes both socio-economic and ecological dimensions, they lack a supportive methodology or framework through which the indicators are selected. This lack of framework often leads to redundancy and gap in system representation, making the methodology less reliable. Besides, most of the existing frameworks do not explain the reason behind the choice and selection of sustainability themes over which the entire indicator selection is dependent (Werf and Petit, 2002).

In order to address these gaps, we develop a stock and flow based framework for a systemic identification and selection of indicators for comparing farming systems with different management practices. Further, we design a single composite indicator by aggregating all the identified indicators to converge to a single measure called Farm Assessment Index (FAI) which will help in a holistic assessment of farming systems at a field level.

Chapter 3 Indicator Identification Using Stock and Flow Based Framework

The concepts of Stock and Flow from System Dynamics are simple and powerful tools which help in differentiating short term and long term characteristics of the system (Chang et al., 2008). Stock describes the characteristics of the system that are accumulated over long-term, and flow describes the transient and dynamic characteristics of the system (Sterman, 2000). System dynamics has been widely applied to various managerial problems. Its application in agro-ecosystem will improve our understanding of the farming system.

An agro-ecosystem is so complex in its structure and non-linear in functioning that it is almost impossible to characterize it in its completeness (Farber et al., 2002; Philippe et al., 2008). Though system dynamics has been used in the context of agriculture, it has been used more on ecological farming where the impacts of conventional farming like health hazard of pesticide usage, water contamination, etc., are not included (Li et al., 2012; Shi and Gill, 2005). Modelling of systems is often used for simulation of future scenarios and evaluation of alternative strategies. However modelling is a very fruitful tool in refining the definition of indicator set of a system (Rossing et al., 2007). In this context, we use, Stock and Flow Diagram (SFD) which is a tool in system dynamics modelling, not for carrying out simulations to predict future scenarios but for identifying an appropriate set of indicators for assessing farming practices. In this work, we design a framework based on systems thinking and stock and flow diagram as discussed in the following section (Siva Muthuprakash and Damani, 2017).

3.1 Stock and flow based framework

In contrast to other frameworks where the indicators are restricted to a set of pre-set attributes like productivity, adaptability, stability etc., we use stock and flow diagrams of the system as the basis of indicator identification. This helps in covering all the essential characteristics of the system. The stock and flow diagram in this framework also helps us to identify appropriate proxy indicator for complex variables in the system which are often avoided in other frameworks. A proxy indicator is a variable that is used when the actual indicator is a non-observable variable or is too complex or intangible (Benoît et al., 2010). Unlike other frameworks where indicator selection is hidden behind the judgment of experts, this framework helps in conceptualizing the system based on stock and flow concepts and provides a structural basis for the indicator identification. The outline of the proposed framework is given in Figure 3.1. Note that, while the indicator selection process is shown as a linear one, in practice, it will often be an iterative one.

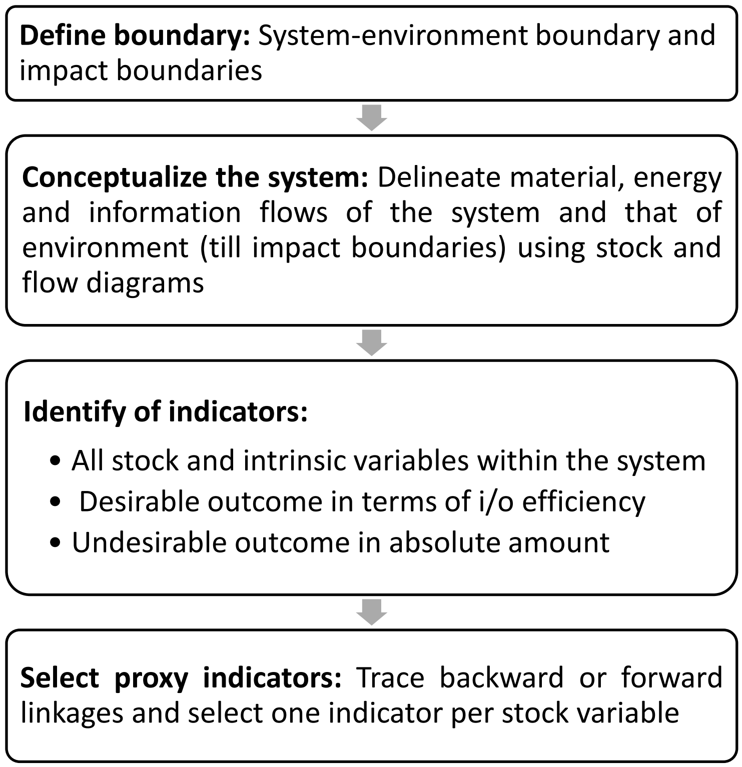


Figure 3.1 Outline of the proposed framework

3.2 System definition

The initial step in the construction of a stock and flow diagram is to define the system and carefully delineate the system-environment boundary. All the physical systems are open and exchange energy, matter, and information with its environment. As shown in Figure 3.2, system behaviour depends not only on attributes within the system but also on elements in environment which would have in turn been affected by the feedbacks of impacts impinged by the system over the environment (Gallop, 2003).

We conceptualize the environment of the system by distinguishing the ecological and the socio-economic dimensions. Any biophysical outflow of the system is associated with its own impacts in social and economic dimensions. In theory, impacts of the system can be traced indefinitely in space and time. However, in practice, it is required to set a boundary for the environment as well.

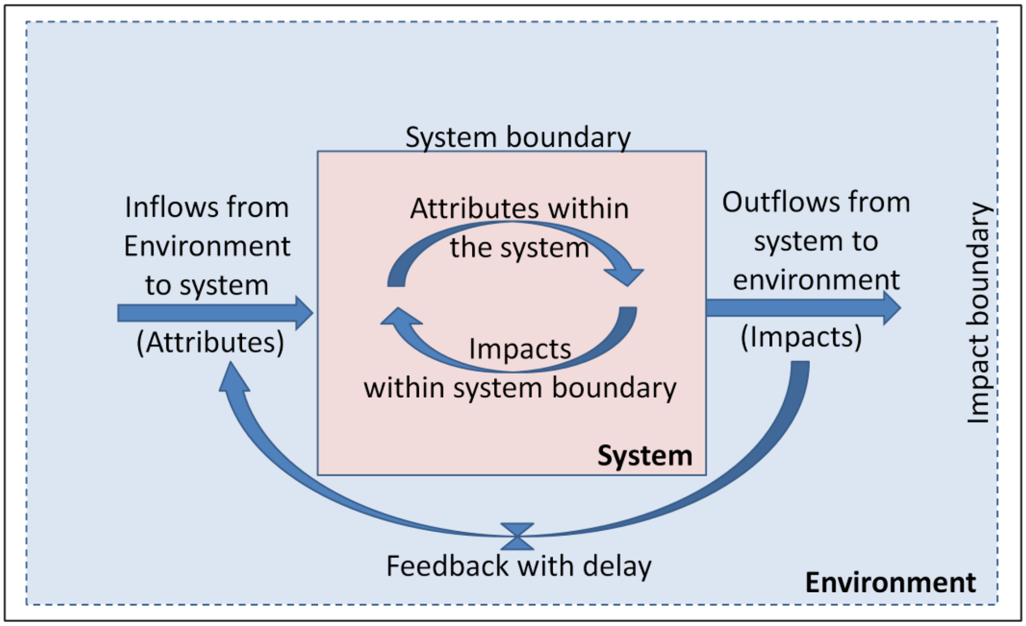


Figure 3.2 Overview of system and its environment

Though it may be ideal to have a uniform boundary across all three dimensions, in reality, we often have imbalanced scenarios across the dimension as the changes along ecological dimension reflect on the socio-economic dimension after a significant delay. For example, as shown in Figure 3.3, the nutrient runoff from a farming field is taken as material outflow from the system to its environment and a part of its downstream linkages in social and economic dimensions. The nutrient runoff causes water contamination, which in turn increases the GHG emission from water bodies. In this case, water contamination leading to drinking water problems are observed after a short delay while GHG emission leading to secondary health impacts are realized after a significant delay. Further, the economic aspect of drinking water contamination or the health impacts appears after even longer delay.

While full-cost accounting can help in filling the gap by assigning economic value for the unpriced cost and benefits (FAO, 2014), it may not be possible to account for all the relevant economic and social impacts like distributional impacts, human health and well-being (Weidema et al., 2005). Therefore, it is necessary to have independent boundaries along different dimensions depending upon the scope and objective of the study which varies with time and space. We use the term 'impact boundary' to represent these dimensional boundaries of the environment.

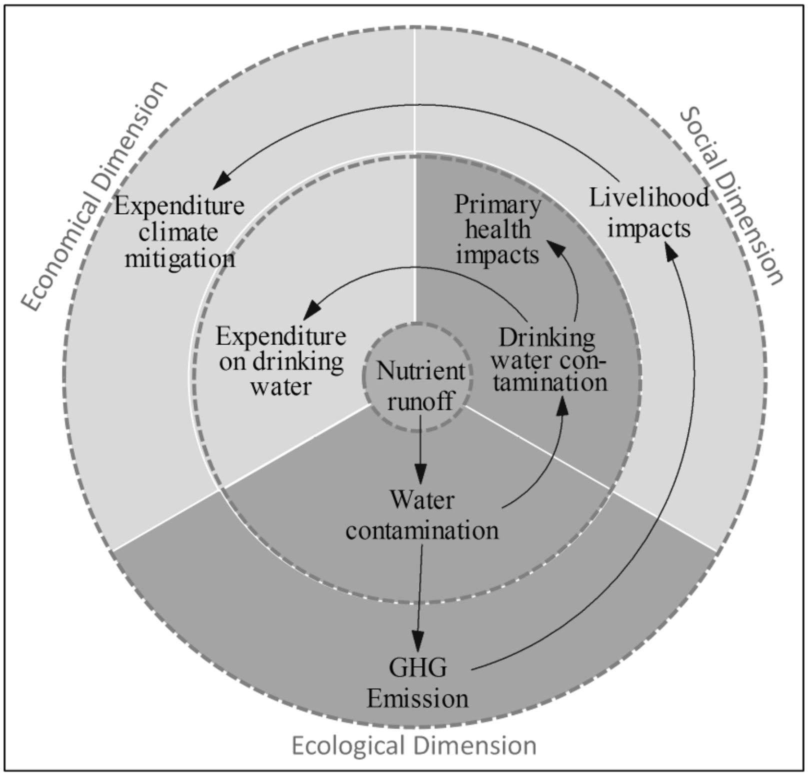


Figure 3.3 Varying boundaries along different dimensions for an outflow variable (Lighter colour annuli represent variables outside the impact boundary)

3.3 Conceptualization of the system

Once the boundaries are defined, the initial step is to conceptualize the system as a black-box (Nathan and Reddy, 2011) and detail the list of the inputs and outputs of the system which will help in identifying the start and end points of interest. Then, all the relevant processes and their feedback loops involving material, energy, and information flows of the system are identified (Wolstenholme, 1983). The temporal period that distinguishes stock variables from flow variables of the system, is set. Then each process is delineated by introducing stocks and flows which might in turn bring focus on yet unconsidered processes involving more variables. Stocks are the variables whose value depends on the past behaviour of the system and they accumulate material or information over time. They represent the inertia of the system and change only as a result of flows. Flow variables cause changes in the system state, and they either flow into or out of the stock.

For example, in Figure 3.4, the nutrient in an arable soil is a stock which is affected by the inflows like nutrient input and natural synthesis, and outflows like nutrient uptake by crops, microbes, etc., and nutrient runoff. Various factors like fertilizer input, biological fixation, irrigation etc. affect the nutrient stock only by affecting the relevant flows. The stock and flow diagram (SFD) with all significant processes and phenomena of the system forms the conceptual model for visualizing various independent and interdependent processes. This helps us in capturing all the essential characteristics of the system and guides us in identification of indicators.

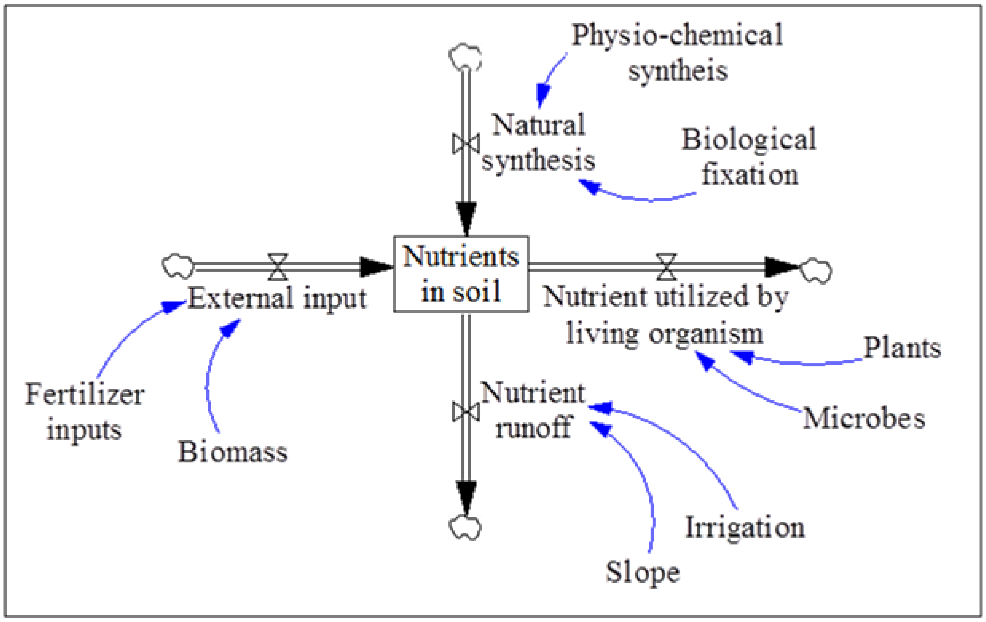


Figure 3.4 Example of stock and flow diagram

3.4 Identification of indicators

Although all the variables in a system can be taken as indicators, it leads to unwarranted redundancy due to interdependency and correlation among the variables. It is necessary to capture the state of the system in totality while avoiding over or under accounting of important system characteristics. Therefore, it is essential to systematize the process of indicator identification.

Basis for identification of indicators

In any production system, short-term desirable outcomes often get the major focus while several desirable and undesirable outcomes that are not perceived to be important in short-term, are neglected. For example, in case of agriculture, conventional indicators like yield and income are flow variables that capture only the immediate outcome of farming and fail to capture the sustainability related attributes like soil quality that has a strong inertia and changes slowly with time.

The production process involves material, energy and information inflows that eventually result in a variety of outputs and outcomes. The inflows to the system are the resources consumed, and the outflow will include the intended outputs along with the unintended outcomes. The unintended outcomes can be either beneficial or harmful, and they can be either within or outside the system. While the intended outputs are visible and measured easily, the unintended outcomes may or may not be apparent in short term, but they impact the sustainability of the system in long run. Since the stock variables describe the state of the system that have accumulated the past impacts, they should be the major focus in the indicator set to account for the long-term sustainability. Therefore, first, the stock variables that are present within the system boundary are taken as indicators.

Following the stock variables, the intrinsic variables of the system are taken as indicators. Intrinsic variables are those variables which represent the characteristic of the system that emerges from the interaction between a set of underlying stocks. The next variables of interest are the input and output flows across the system boundary. Flow variables constitute the biophysical interactions between the system and its surrounding. As discussed earlier in section 3.2, each bio-physical flow variable is associated with its own impact on economic, social and ecological attributes (upstream causality of inflows and downstream causality of outflows) which may be desirable or undesirable. A production system can be considered to perform better if there is either an increase in desirable outcomes or a decrease in undesirable outcomes. In order to evaluate the performance of any system with respect to its desirable outcome, it is appropriate to measure their output efficiency with respect to the inputs (Jahanshahloo et al., 2012). Though this approach is not explicitly conceived in the manner it is proposed in our framework with conceptual reasoning, European Commission (2001), has also recommended the use of stocks followed by efficiency parameters and equity of resources. There has been a long debate on efficiency indicators and the resource depletion in life-cycle thinking (Klinglmair et al., 2014). However, the stock and flow based framework focuses on the production efficiency of only those components which lie within the system boundary.

In case of undesirable outcomes, reducing their impacts to the respective minimum level may not be feasible as it may work against the main objective of the system. For example, it may not be possible to totally curb the GHG emissions from a thermal power plant but it is feasible to minimize it. Therefore, it will be appropriate to have an objective to restrict the harmful outcomes within their safety limits or permissible standards. Thus, the undesirable outcomes are measured in absolute amount of impacts caused. This approach is comparable to the use of biomass flows and balance of the farm by Andrieu et al. (2007), to identify the indicators focusing on the changes to characteristics of resources. In short, the indicators associated with desirable outcomes should be measured in terms of input-output efficiency, whereas the undesirable outcomes need to be measured in terms of absolute values.

Environmental attributes like rainfall, sunlight etc., that originate outside the system boundary but affect crop production, are considered as extraneous variables that constitute the parameters of system. These variables are not taken as indicators and ideally need to be constant while comparing different systems.

Since each flow across the system boundary is associated with numerous processes and their impacts on economic or social or ecological dimension, one representative indicator is selected for each stock variable in all the dimensions in forward linkages of outflows and that of backward linkages of inflows. Thus, the delineation of processes outside the system boundary using SFD in different dimension will help in selection of indicators outside the system boundary. Further, as discussed earlier in section 3.2, impact boundaries are defined independently for each flow variable along various dimension and only the indicators inside the impact boundary are selected.

3.5 Identifying proxy indicators

There are a few scenarios where the selection of indicators is challenging. In case of variables associated with more than one process, appropriate measure needs to be taken to avoid over or under accounting of any characteristics of the process. In such scenarios, stock and flow diagram can facilitate the selection of indicators, where the causal flow and their linkages are traced for a suitable variable. In order to deal with the variables with multiple flows, two strategies can be applied depending upon the case.

One can either trace the variable backward or forward on the causal flow to capture the concerned flow individually, or one can introduce additional indicators as correction factors which will compensate for the errors caused by the other indicator. For example, as we will be discussing later, in a farming system, a variable like water contamination has various inflows from sources other than the system under examination. Therefore, using the backward linkages, the amount of toxicants applied to the system is considered relative to the impact caused, and hence the toxicant applied can be taken as a proxy. A proxy indicator is a substitute variable used when the desired data is unavailable or too complex to measure. It should be representative of the variable of our interest and have a close approximation to the target indicator. In a similar context, various inflows like fertilizers, water, and energy inputs within the system lead to a single desirable outflow of crop harvest. In this case, crop harvest is considered in terms of efficiency with respect to each inflow. This will result in multiplicity of crop harvest factor which may either be acceptable or may need mitigation by appropriate weighing.

In the second case, for indicators which are not measurable directly or whose estimation require complex protocols, an alternative simpler variable can be considered as a proxy variable. For example, in farming systems, field characteristics like pH and salinity can be measured directly, but variables like soil compactness may be too complex to quantify. Therefore, soil porosity can be selected as a proxy indicator using its causal relation.

Thus the stock and flow based framework not only helps in identifying the necessary indicators, it also helps in selecting appropriate alternative measures to capture the required characteristics of the system. In the next chapter, we describe how a set of identified indicators can be aggregated to derive at a composite indicator which can represent the system in a holistic manner.

Chapter 4 Composite Index

A composite index is a useful means to summarize the information provided by several base indicators to assess the performance of any agricultural system. There has been a constant debate on the validity of aggregating a set of indicators from different dimensions, into a single index which would capture the crux of the information that needs to be communicated. The arbitrary nature of weighing might disguise serious failings (Sharpe, 2004), but aggregation can be justified if it fits the intended purpose and is accepted by peers (Rosen, 1991). Typically there is a trade-off between the information captured by the selected indicator with the ease of monitoring (Rigby et al., 2001) which needs to be balanced with respect to objectives and consensus of stakeholders. The main objective behind a composite index (the word composite *index* is used over composite *indicator,* to explicitly indicate the aggregation of indicators from different dimensions) is to improve the access to scientific knowledge for policymakers and public masses. A legitimate and reliable methodology for aggregation of indicators to form a composite index for indicating the state of any farming system is desirable. It helps in ranking of farms which will help in identifying sustainable farm practices (Gómez-Limón and Sanchez-Fernandez, 2010).

The process of transforming a set of indicators into a single composite index involves three distinct steps namely, normalization, weighing, and aggregation. Methods of weighing and aggregation depend mainly on the context of the study and their objectives. In order to ensure the scientific validity of the composite index, it is essential to use appropriate methods at each step of the transformation. In the following sections of this chapter, we discuss various methods applicable for each step. Further, the process of developing a holistic indicator will by itself benefit in identifying the key aspects of the system.

4.1 Normalization of indicators

Normalization of indicators is a prerequisite for aggregation of indicators with varying units in order to express them in relative terms and make them suitable for aggregation. Normalization is a mathematical procedure for converting different scales of measures into a comparable scale. There are several methods of normalization as listed in Table 4.1 with a brief description. Table 4.2 lists the pros and cons of various normalization methodologies.

Table 4.1 Brief description and functions of various normalization methodologies

No	Method	Description	Function
1	Z-Score standardization	This method assumes the mean of sample data to be the desirable point with value as zero and the deviation of sample mean will be considered as undesirable for which extreme samples will be given the value of one.	$$I_{qc}^{t} = \frac{x_{qc}^{t} - x_{qc=\bar{c}}^{t}}{\sigma_{qc=\bar{c}}^{t}}$$ I_{qc}^{t} is the normalised indicator value x_{qc}^{t} is the actual indicator value $x_{qc=\bar{c}}^{t}$ is the average across samples $\sigma_{qc=\bar{c}}^{t}$ is the standard deviation across samples for sample "c" and indicator "q" at time "t"
2	Min-max	This method performs a linear transformation of data with respect to a preset minimum and maximum points of the sample.	$$I_{qc}^{t} = \frac{x_{qc}^{t} - min_c(x_q^t)}{max_c(x_q^t) - min_c(x_q^t)}$$ $max_c(x_q^t)$ *and* $min_c(x_q^t)$ are the maximum and minimum value of x_{qc}^{t}
3	Distance to reference	This method gives the relative position of the sample with respect to a defined reference point.	$I_{qc}^{t} = \frac{x_{qc}^{t}}{x_{qc=\bar{c}}^{t_0}}$ (or) $$I_{qc}^{t} = \frac{x_{qc}^{t} - x_{qc=\bar{c}}^{t_0}}{x_{qc=\bar{c}}^{t_0}}$$ $x_{qc=\bar{c}}^{t_0}$ is the indicator value of the reference sample at the initial time t_0
4	Indicators above and below mean	This is a very simple method where the samples are classified into a category depending on their value that results in a discrete scaling of the indicator.	$$I_{qc}^{t} = \begin{cases} 1 & w > (1+p) \\ 0 \quad if & (1-p) \leq w \leq (1+p) \\ -1 & w < (1+p) \end{cases}$$ Where $w = \frac{x_{qc}^{t}}{x_{qc=\bar{c}}^{t_0}}$
5	Cylindrical indicators	This method is very useful when a parameter needs to be monitored over a regular interval. It measures the	$$I_{qc}^{t} = \frac{x_{qc}^{t} - E_t(x_{qc}^{t})}{E_t(\lvert x_{qc}^{t} - E_t(x_{qc}^{t})\rvert)}$$ $E_t(x_{qc}^{t})$ is the mean over time

		irregularities or deviation of the indicator from the normal pattern over the past intervals.	$E_t(\lvert x_{qc}^t - E_t(x_{qc}^t)\rvert)$ is the mean of absolute values of the difference from the mean
6	Percentage of annual difference	This method eliminates the absolute scaling of the indicator and accounts only for the change in value of indicator over the previous observation.	$$I_{qc}^t = \frac{x_{qc}^t - x_{qc}^{t-1}}{x_{qc}^{t-1}} * 100$$ x_{qc}^t is the indicator value for current year x_{qc}^{t-1} is the indicator value during previous year
7	Categorical scaling	This method is mainly used to convert a qualitative variable to quantitative scale. It assigns discrete scores for the indicator based on relative value but the arbitrary nature of the score as well as their relationship to the qualitative value makes it vulnerable to errors.	Variables are assigned a score depending upon their relative position with respect to each other and that of the benchmark.

Table 4.2 Pros and cons of various normalization methods

No	Method	Pros and Cons
1	Z-Score	• Measures the deviation from mean • Depends on the sample itself • Z-scores will be high for both worst as well as best performing samples
2	Min-max	• Linear and continuous function within the given range • Retains the actual relationship among the sample • Depends on the sample itself
3	Distance to reference	• Continuous and linear function on either side of the reference value • Reference value is independent of the sample which is predefined
4	Indicators above and below mean	• Simple and direct method • Discrete scaling
5	Cylindrical indicators	• Useful for cyclic indicators • Scaling with reference to the previous status
6	Percentage of annual difference	• Measures the percentage change in the indicator value which can be useful for trend analysis
7	Categorical scaling	• Useful for qualitative indicators • Discrete scaling

Andreoli and Tellarini (2000) have discussed the normalization of both qualitative and quantitative parameters using utility functions with external reference values. Discrete utility functions are used for qualitative parameters while continuous utility functions are used for quantitative parameters as shown in Figure 4.1 and Figure 4.2 respectively.

One of the simplest methods to normalize an indicator is to assign a value between 0 and 1 or 0 and 100 for different ranges of each indicator (Nambiar et al., 2001; Praneetvatakul et al., 2001; Sharma and Shardendu, 2011). Several studies have done the normalization of indicators in a two-step process which includes the construction of normalization function by defining its shape followed by the identification of supporting reference points (Sauvenier et al., 2005a; van Asselt et al., 2014). Min-max method of normalization is widely used in indicator studies (Gómez-Limón and Sanchez-Fernandez, 2010; Hajkowicz, 2006; NABARD, 2012; Nathan and Reddy, 2011). Min-max has the advantage of retaining the actual relationship between the samples and has a continuous and linear function. This method is often preferred over the utility function due to dearth of scientific insights in sustainability threshold for indicators (Gómez-Limón and Sanchez-Fernandez, 2010).

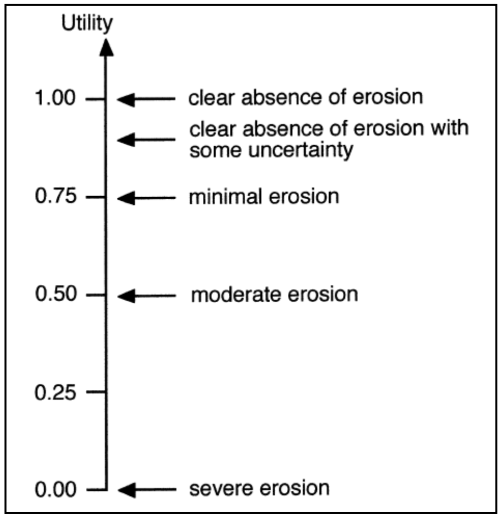


Figure 4.1 Example of a discrete utility function for a qualitative parameter
(Andreoli and Tellarini, 2000)

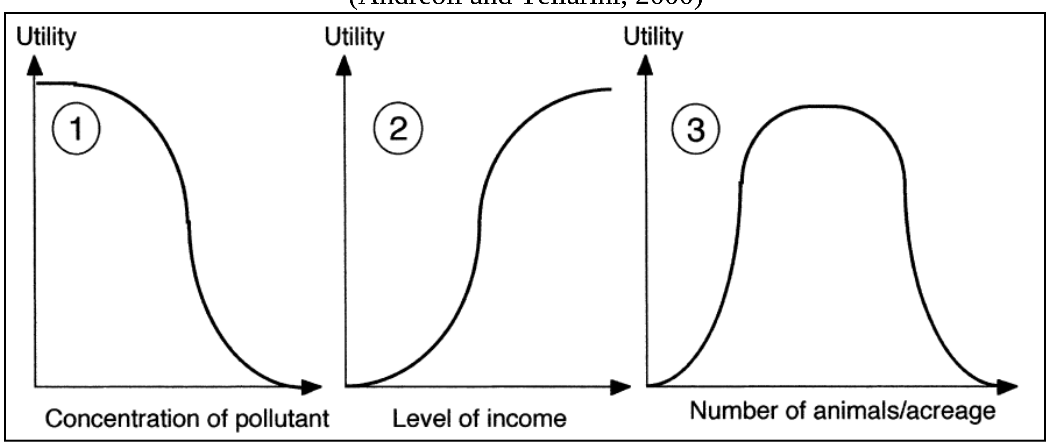


Figure 4.2 Examples of continuous utility functions for quantitative parameters
(Andreoli and Tellarini, 2000)

While the min-max method is a linear function within two reference values at the extreme points, distance to reference has a central threshold value or a range with a similar gradient function on either side. Fuzzy logic can be used to incorporate asymmetric functions in normalization. Membership functions are defined to normalize indicators with required number of reference points as shown in Figure 4.3 (Vecchione, 2010).

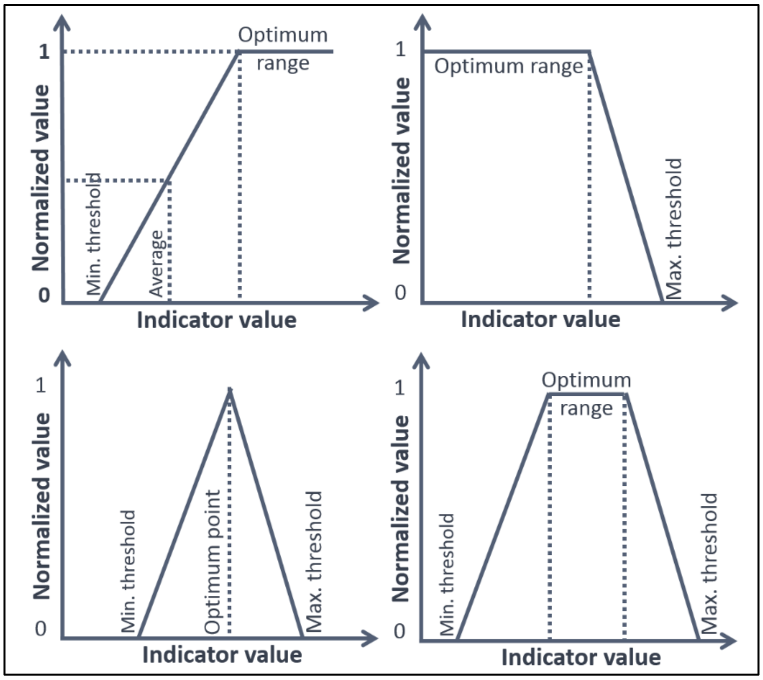


Figure 4.3 Membership function in fuzzy logic normalization with linear function and reference values

Primary indicators in a composite index may have varying ranges of values depending upon their unit. It may be critical to normalize the indicator in such a way that the normalization does not induct weightage to the indicators by itself (Mayer, 2008). So, it is necessary to maintain a reasonably similar range of variability among indicators. Independent of the methodology used for normalization of indicators, it is difficult to convert different scales into a comparable metric in an absolutely meaningful manner. Though normalization makes it possible to compare different dimensions, it implicitly adds a value judgment over the indicators depending upon their scales (Bohringer and Jochem, 2007). However, this can be overcome by compensating in weightage before aggregation.

Reference values

Reference values play a critical role in determining the functional range of the normalization. A system can be assessed using indicators by comparing it with a threshold level or a target, expert appraisal, etc. (Roy and Chan, 2011). Setting up the targets for indicators is very important as they will be the driving force for policy changes and research advancement (Moldan et al., 2012). Indicator estimates may not be useful to understand the status of system unless they are compared against known reference values. The reference values will aid in measuring the relative position of the system with respect to the target scenario. Various factors and assumptions determine the source of references and their usages for each of the indicators. The reference values can be derived from legal norms, policy targets, established standards, scientific evidence, expert opinion etc. In order to make the methodology applicable for comparative studies at a wider scale, it is desirable to have the reference values relevant to a large spatiotemporal scale. However, in order to make a case study meaningful it is often required to use local references though it might be relatively subjective (Viglizzo et al., 2006).

Sauvenier et al. (2005b) have classified the approach in defining the reference values for normalization as shown in Figure 4.4. An indicator can either use an absolute or relative value as the reference point depending upon the availability of data and the complexity of estimation. Indicators with a well-established scientific threshold or recommended range or accepted standards or legal norms, take absolute values as reference point. Indicators, which may not have such standards due to spatial and temporal variability like income (varies across crop, market, weather, etc.) or incommensurability, use sectoral/group/regional/temporal average as reference points. Though the accuracy of relative reference values depends on the source of the data, normalized indicators will remain useful and reliable as they equally affect all the subjects under study.

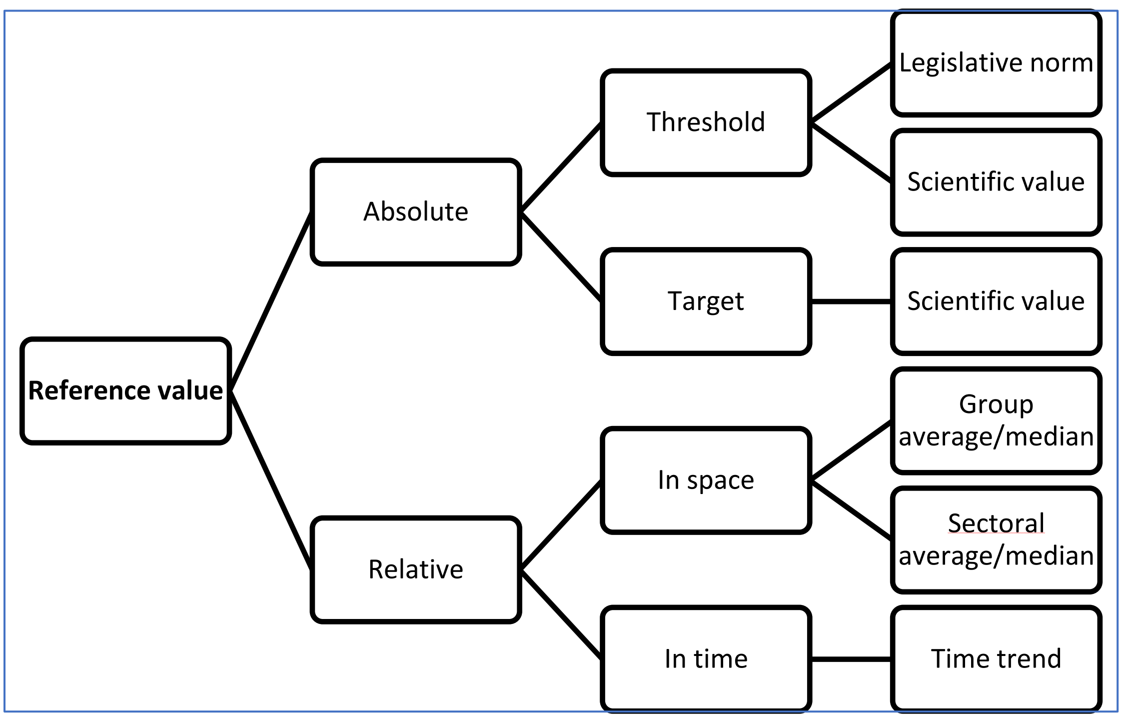


Figure 4.4 Types of reference value system for normalization (Sauvenier et al., 2005a)

These reference values are taken as min-max point to normalize the indicators. For example, Van Asselt et al. (2014) used sustainability limits, non-sustainability limits and mid-sustainability limits to arrive at a gradient in sustainability. The preference order for defining the reference value was legal norms followed by policy target and best practice values. The best practice value has been used as sustainability limit, whereas 1.15 and 1.30 times the best practice value are used for mid-sustainability and non-sustainability limits respectively. Although it is desirable to use the target and threshold limits of indicators as reference points in normalization, often we need to depend on the minimum and maximum values of the parameters.

4.2 Weighing of indicators

Normalized indicators need to be aggregated to arrive at a single composite index that can effectively communicate the information about the system. But, prior to the process of aggregation, the relative importance of indicators needs to be assigned. Trade-offs among various objectives play a crucial role in sustainability evaluation as the criteria selected for most agro-ecological and socio-economic issues are rarely absolute (Kruseman et al., 1996). Weighing of indicators is a very important component as it plays a crucial role in the decision making process. Since weighing of indicators depends upon the objectives and priorities of stakeholders, the process of weighing has always been a point of interest. Further, the level of impact caused by the weightage over the final index will depend on the functional method of the aggregation which will be discussed in the next section.

Selection of weighing method and the process of assigning weightage is often a contentious task as the process can introduce an undue bias among indicators. There are different principles and methods available for the process of weightage allocation. Weighing methods can either be statistical or normative (Gómez-Limón and Sanchez-Fernandez, 2010; OECD, 2008). Statistical methods also referred as endogenous methods, depend on the data of all relevant indicators, usually a large quantity, for a better application. Normative procedures also referred as exogenous methods, depend on participation and consensus built among stakeholders. Statistical method includes principal component analysis, data envelopment analysis, benefit of doubt, unobserved components model etc. Normative or opinion methods include budget allocation process, public opinion, Analytical Hierarchical Process, Conjoint analysis, etc. A brief description of various methods of weighing along with their advantages and disadvantages are given in Table 4.3 and Table 4.4.

Table 4.3 Weighing methods based statistics (OECD, 2008)

S No	Method	Advantages	Disadvantages
1	Principle component analysis (PCA) • Statistically retain the variables with maximum variance • The dynamics of interest is along the dynamics of largest variance.	• Eliminates redundancy • Weight based on variance • Minimize the dimension without losing much of information	• Weightage doesn't have theoretical significance • Indicators should be of same unit
2	Data Envelopment Analysis (DEA) • Construction of a benchmark and measurement of the distance between countries in multi-dimensional framework • Based on linear programming	• Independent of unit of measurement • Measures the efficiency • Endogenous weighing	• Concern that this is more to do with the efficiency than choice of weights • Less discriminatory
3	Benefit of Doubt (BOD) • Application of DEA with exogenous restrictions • Least discrimination of systems	• Maximizes performance ranking position • Incorporate restrictions based on policies	• Multiplicity of solution makes it hard for selecting the weighing • Arbitrary restrictions
4	Unobserved component model (UCM) • Individual indicators are assumed to be dependent on an unobserved variable plus an error term • Regression analysis will help identifying these variables and so the aggregated indicator • Co-relation between indicators improves the ability to distinguish systems	• Statistical and precision weighing approach • Emphasizes the uncertainty associated with ranking • Retains the cardinal differences	• Weighs based on variance of the indicator data • Demands reliable and robust data • Aggregated indicators serve as imperfect proxies

Table 4.4 Weighing methods based on opinions (OECD, 2008)

S No	Method	Advantages	Disadvantages
1	Budget Allocation Process (BAP) • Experts from different stakes and a wide spectrum of knowledge and experience are asked to allocate a budget of 100 points to indicators	• Transparent, straightforward and fast process • Practical in approach • Consensus with various groups	• Expert opinion may be region specific • Cognitive stress to experts • Subjective and easy to manipulate
2	Public Opinion • People are asked to express their degree of concern about issues or indicators through opinion polls	• Bottom-up approach • Help understand the actual preference of the major stakeholder	• General public may not be well informed/aware of the actual situation • Inconsistencies • Chances of biased polls
3	Delphi Technique • A group communication process with an objective of converging opinions and building consensus among stakeholders along with an expert panel	• Participatory method which makes it more acceptable • Relatively quick and direct method	• Depends upon the participating group • Moderator bias • No theoretical basis
4	Analytical Hierarchical Process (AHP) • Pairwise comparison of indicators after classifying them in a hierarchical manner	• Hierarchies help in fixing weights among the groups • Helps in capturing and verifying the perception of the stakeholders	• Difficult to manage as the number of indicators increases • Difficult to manage inconsistencies
5	Conjoint Analysis (CA) • Ranking of different product/system followed by estimation of the preference function using decompositional multivariate analysis.	• Weights represent the trade-offs • Estimates and represents the perceptional value of attributes • Agree with intuitive measure	• Estimation process is complex • Respondents are susceptible to confusion. • Subjective and needs a large sample of respondents
6	Maximum Difference Scaling • Relative preference over a set of paired comparison followed by estimation of the preference function	• Relatively simpler to conjoint analysis which compares all the alternatives simultaneously	

In most of the studies, an equal weightage is given to all indicators to avoid the bias in assigning weightage (Andreoli and Tellarini, 2000; Freudenberg, 2003; NABARD, 2012; Sharma and Shardendu, 2011; UNDP, 2013). Although it is simple to have an equal weightage for the indicators or dimensions, often it may not be representative of the reality. Since it is difficult to have universally agreed relative importance for various indicators (Andreoli and Tellarini, 2000), it is essential to build consensus among the stakeholders based on the objective and utility of assessment. In certain cases, equal importance is given at a higher level of hierarchy like social, economic and ecological dimension while allowing the end user to allocate weights for individual indicators using a weighing tool (van Asselt et al., 2014). Gómez-Limón and Sanchez-Fernandez (2010) have used two methods of weighing, namely, principal component analysis (statistical) and analytical hierarchical process (opinion based), in parallel for the same data set for the assessment of agricultural system. The indices formulated using these different weighing methods had high degree of correlation, though this observation may be case specific.

4.3 Aggregation of indicators

The method of aggregation will have the final impact on composite index. Aggregation of indicators assumes that the indicators in an index are comparable and substitutable with each other. Substitution or compensation refers to the compromise of low performance of one indicator with better performance of another indicator during aggregation. Method of aggregation determines the level of substitutability ranging from total or partial or no compromise among indicators.

A linear summation of the product of normalized indicator value and its weight will imply total substitutability among all the indicators. Aggregation methods with full compensation may not be of practical use as a system with extreme indicators is often worse than moderately functioning system (Nathan and Reddy, 2011). A geometric sum will permit partial compensation and a range of pre-set compensation can be incorporated for different indicators by using multi-criteria methods. Gómez-Limón and Sanchez-Fernandez (2010) have employed three different aggregation techniques to analyse various levels of compensation and their impacts on the index. The weighted sum of indicators was used to allow total compensation followed by the product of weighted indicators to impose partial compensation and finally the multi-criteria function to impose a desired level compensation at each indicator level as given below.

$CIAS_1 = \sum_{k=1}^{k=n} W_k . I_k$ (Total compensation)

$CIAS_2 = \prod_{k=1}^{k=n} I_k^{W_k}$ (Partial compensation)

$CIAS_3 = (1-\lambda).[min_k(W_k.I_k)] + \lambda . \sum_{k=1}^{k=n} W_k . I_k$ (Differential compensation)

where CIAS refers to Composite Indicator of Agricultural Sustainability, W_k is the weight associated with indicator k, I_k is the normalized value of indicator k and λ is the compensation parameter.

In another approach, Nathan and Reddy (2011) have used the displaced ideal method as a non-compromise aggregation method. This method locates the position of each indicator in the corresponding dimension and measures the inverse of Euclidean distance from the ideal point. Since the indicators are normalized, one will be the ideal point while zero will be the least favoured point. The following equation gives an overall index for a given set of indicators accounting their weights (Zeleny, 1976).

$$S_i^{DI} = 1 - \left(\frac{\sum_{j=1}^{m} \left(w_j (1 - x_{ij}) \right)^2}{\sum_{j=1}^{m} (w_j)^2} \right)^{\frac{1}{2}}$$

where, S_i^{DI} is the overall score of the i^{th} alternative having m criteria and weightage w_j for j^{th} criterion. However, the theoretical complexity of this method is considered as a limitation for its larger application and wider communication.

An index is meaningful only when the ordering inferred using the index value remains the same irrespective of any admissible transformation to the scale or unit used for measuring the indicator (Ebert and Welsch, 2004). The method of aggregation plays a key role in retaining the condition of non-variability of ranking with respect to the change in underlying normalization methodology over the measuring unit of indicators. A set of axioms MANUSH (Monotonicity, Anonymity, Normalisation, Uniformity, Shortfall sensitivity, Hiatus sensitivity to level), has been proposed for evaluating robust aggregation methods (Mishra and Nathan, 2018). The nature of measuring scale of each indicator and the desirable properties of the index affect the method of aggregation. Further, the significance or contribution of relative importance or weightage of indicators to the composite index will depend upon the level of compensation allowed during aggregation. Though the level of compensation is defined by the method of aggregation, the assumption of substitutability is often considered to be a limitation in use of composite index. An appropriate method of aggregation depending upon the nature of measuring unit is listed in Table 4.5.

Table 4.5 Aggregation methods based on the nature of indicators (Ebert and Welsch, 2004)

Nature of indicators	**Non-comparability**	**Full comparability**
Interval scale	Dictatorial ordering	Arithmetic mean
Ratio scale	Geometric mean	Any homothetic function

It has been established that arithmetic mean, the commonly used method of aggregation, is meaningful only when all the indicators are ratio scale and fully comparable. However, simple arithmetic mean allowing full compensability of indicators has been used in many studies, where the indicators may not be substitutable (NABARD, 2012; Sharma and Shardendu, 2011). Since the indicators are often ratio scale non-comparable in nature, the use of geometric mean as a method of aggregation has been increasing. For example, the Human Development Index (HDI) has adopted the geometric mean over the arithmetic mean. This change in method has produced lower index value and large changes for those countries with uneven development across various dimensions (United Nations, 2010).

4.4 Validation of the composite index

It is necessary to validate the composite index designed to be accepted by the peers and to be reliably used by the end users. There has been a substantial work on development and use of indicator frameworks, but the validation of framework is not emphasized enough (Roy and Chan, 2011). Only a very limited number of studies have validated their assessment tool. (Meul et al., 2009). Bockstaller and Girardin (2003) have proposed a methodological framework with a three-step validation process which includes 'design validation' (to evaluate the indicators identified) followed by the 'output validation' (to evaluate the informative function of indicators) and 'end use validation' (to confirm its usefulness).

The design validation evaluates the conceptual basis of the framework which often gets shadowed by output validation (Mitchell and Sheehy, 1997). In general, design validation can be done through expert opinion using a Delphi panel, or support from literature, or comparative evaluation of designs using various approaches (Meul et al., 2009).

Output validation evaluates the informative function of indicators for their reliability. This is a common validating approach in modelling which depends on empirical evaluation of its parameters. Visual evaluation, statistical analysis, and judgment of experts are used for output validation (Bockstaller and Girardin, 2003). While design validation ensures the scientific rigor, output validation increases the credibility of the tool for end users. The output validation process has also helped end-users to understand and use the tool in a better way (Meul et al., 2009).

End-user validation is done through a survey on the usefulness of indicators. Several criteria such as level of understanding of indicators, conformity to the objectives of users, ease of usage, reproducibility, weaknesses etc., are studied for end-user validation (Bockstaller and Girardin, 2003). Finally, the credibility of these indicators has to be related to the confidence level of end-users and their willingness to adopt them in practice. So, the validation and adoptability of the indicators necessitate a clear focus on stakeholder participation (Meul et al., 2009).

Cloquell-Ballester et al. (2006) have proposed a three-staged validation framework called 3S framework which includes self-validation, scientist validation, and social validation. Characteristics of each stage have been described along with a process guideline. This framework helps in adding a rigor to the indicators through a well-structured stakeholder participation. The validation begins with a report which contains the complete documentation of the process of indicator selection and the references required. Following the synthesis of the report, criteria are defined for indicator evaluation. The report is subjected to self-validation (by team members) then peer validation (by expertise) and then to public validation (by end users including public and private institutions). Any set of indicators developed is a compromise between the feasibility and the desired goal. It can never be concluded perfect (Pinter et al., 2008). However, objection over the inclusion or exclusion of any particular component of an indicator should not detract the purpose of indicators itself (Rigby et al., 2001).

In the following chapter, we use the stock and flow framework discussed in the previous chapter and the methodologies discussed in this chapter to identify an appropriate set of indicators and design a Farm Assessment Index (FAI) to compare various farming systems.

Chapter 5 Design of Farm Assessment Index

This chapter is divided into two major sections. The first section discusses the application of the stock and flow based framework to identify and select the indicators for comparing farming systems. In the second section, we elaborate the design of the Farm Assessment Index (FAI) which is used in the case studies described in the next chapter.

5.1 Indicators for comparing farming systems

While it is important to follow the principle elements of the framework for a field application, it is also necessary to adapt the indicator selection to suit the local context (Zahm et al., 2007). We apply the stock and flow based framework described in Chapter 3 for identifying a primary set of indicators followed by the selection of proxy indicators based on the context of our field application.

5.1.1 System definition

In order to identify a suitable set of indicators for assessing the farming practices, a stock and flow diagram of the farming system is constructed. In contrast to most of the sustainability assessments that focus on products, we focus on farmer as key enterprise as suggested by SAFA guidelines (FAO, 2013) which emphasize on enterprises to enable more comprehensive and contextual assessment. The biophysical boundary can vary from the level of individual organ to a plant, crop, field, farm, till the watershed or a region (López-Ridaura et al., 2005). Even though a farm is often considered as the smallest enterprise in agriculture, analysing or comparing sustainability of a farm with different types of crops is difficult and scarcely conclusive (Gómez-Limón and Sanchez-Fernandez, 2010). Therefore, we take the field as our system and consider the actual boundary of the field as the system boundary since a majority of the decisions by farmers vary at the field level. The impact boundaries vary among outflow and inflow variables as mentioned in the framework and are discussed in section 3.2.

5.1.2 Construction of stock and flow diagram

The initial step in constructing a stock and flow diagram is to conceptualize the system as a black-box with a detailed list of all inputs and outputs as shown in Figure 5.1. This helps in identifying the start and end points of interest. Since the physical boundary of the field is taken as the system boundary, the input flow starts with materials like seeds, water, nutrients, pesticides, etc., and ends with desirable outputs like harvest of the target product and byproducts, and undesirable outcomes like water contamination, soil health impacts etc.

Figure 5.1 Inputs and Outputs with farming system as a black-box

Following the initial input-output model, flow of each of the inputs and outputs are detailed using the stock and flow diagram. The minimum temporal scale for evaluation of an agricultural system is one cropping season and it is taken as the unit period for a flow. Figure 5.2 gives a simplified stock and flow diagram of a farming system which shows the nutrient and energy inflows, and outflows of the field with two separate components: abiotic and biotic components within the field.

The material flows including nutrient, water, toxicants, and seeds, enter the field to contribute to either abiotic or biotic stock. They flow either to agro-ecological environment in the form of runoff, emissions, ecological services etc. or to the human interface as a farm produce. Though the materials flow through their corresponding stocks in the system, these material stocks affect various intrinsic variables like soil pH, soil compactness etc., which also constitute the characteristics of the system. Since there are numerous interactions among the stocks of abiotic and biotic component within the field, these are not portrayed in Figure 5.2 in order to maintain the readability of the diagram.

For example, Figure 5.3 gives various linkages affecting the 'crops' as a stock. In addition to direct material flow of nutrient and water, other stocks like toxicants etc., affect the inflow and outflow of the 'crops'. Further, certain stocks like 'water available' can be represented in a single stock variable but stocks like soil nutrient may need several stock variables due to the range of nutrients in the soil *viz.*, nitrogen, organic carbon, phosphorous, potassium, magnesium, etc. In similar way, biotic stocks like crop, weeds, beneficial organisms and, pest and diseases are of several species and will have their own individual dynamics. These multitudes of stocks are not depicted individually in Figure 5.2, to avoid the complexity to represent and read.

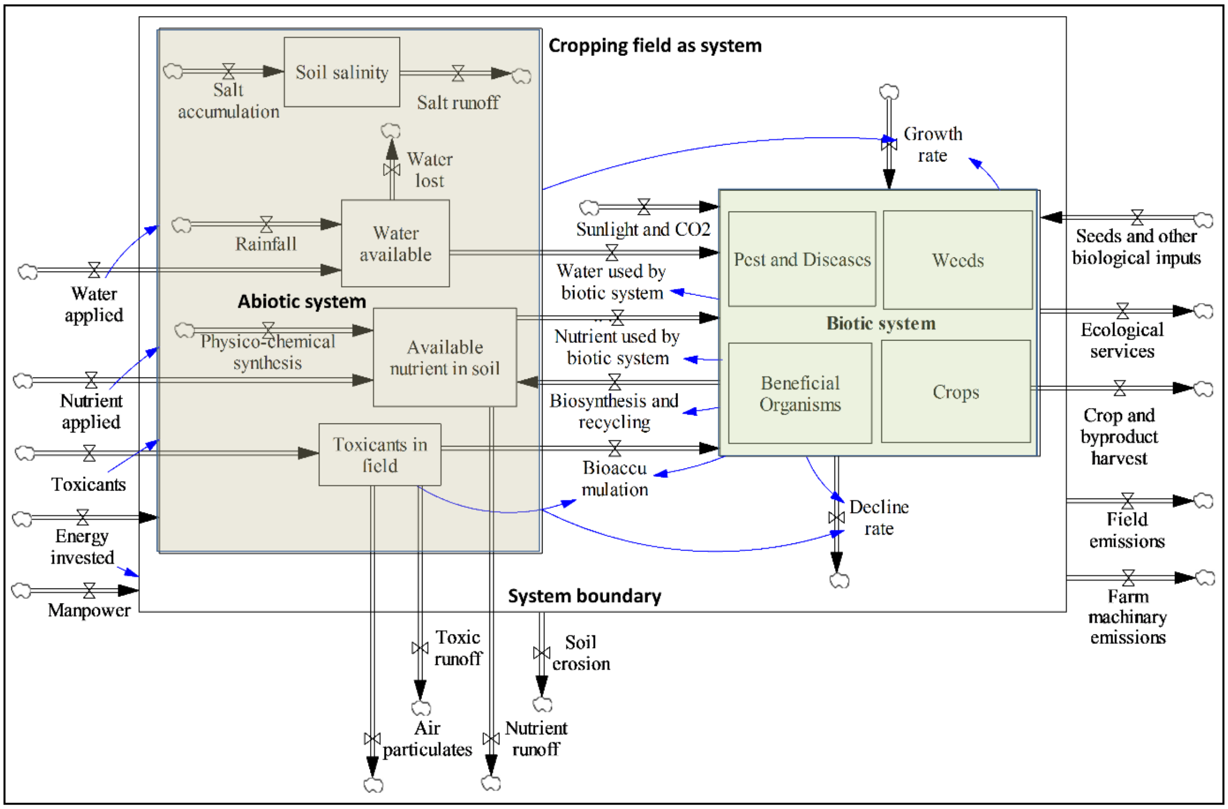


Figure 5.2 A simplified stock and flow diagram for farming system

The energy inflow to the system is usually in mechanical form derived from electricity or fossil fuel or manpower which contributes to work done at the field including land preparation, sowing, irrigation, weeding, harvesting etc. These operations affect both abiotic and biotic components in the field and intend to improve the field condition for crop production. The undesirable impacts from this energy input are captured as the farm machinery emissions as well as the changes in the intrinsic attributes of the system.

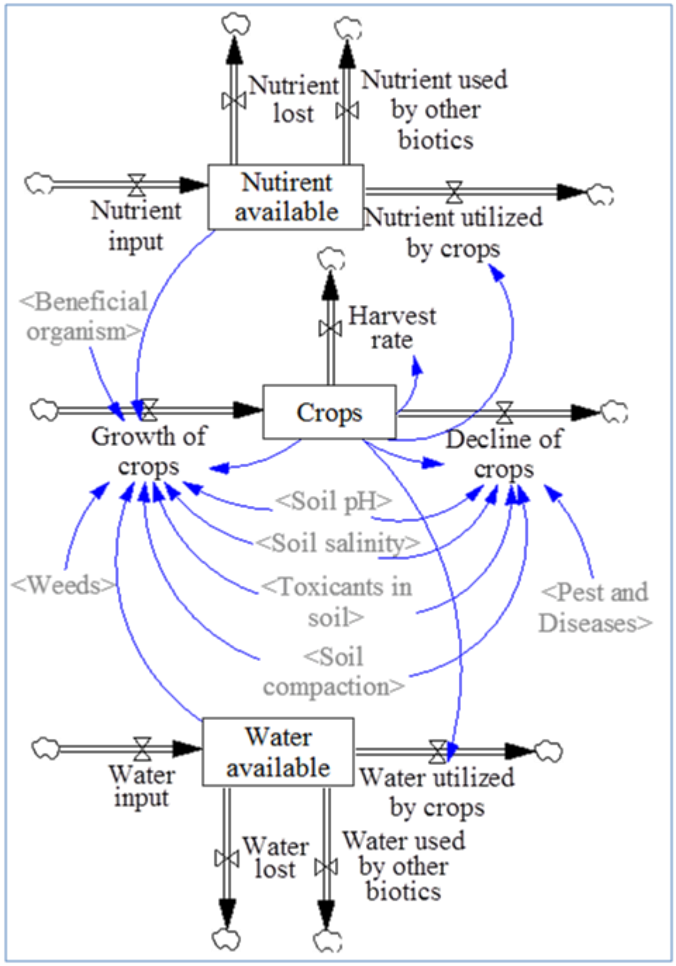


Figure 5.3 An example of interaction among the stock variables within the system

5.1.3 Identification of indicators

As described in section 3.4, initially, all stock variables in the system (representing the biophysical state of the system) and the intrinsic attributes of the system, are taken as indicators (shown in Table 5.1). Next, the flow variables across the system boundary are considered. These flow variables take independent impact boundaries in different dimensions. Therefore, desirable and undesirable outflows, and impacts caused by inflows variables, are covered up to a varying extent of boundary. These impact boundaries are defined by stakeholders such as policymakers, scientists, field officers and farmers, based on the scope of application of selected indicators. In case of desirable outflows, socio-economic aspects like the crop harvested for consumption and the net financial receipt are considered, but the derivative benefits like carbon sequestration by crops are not considered (see Figure 5.4). These desirable outputs are taken in terms of efficiency with respect to each of the anthropogenic inputs as listed in Table 5.2. Further, the framework suggests considering the efficiency of variables like sunlight and mineralization of nutrients but can be avoided as they are extraneous parameters to the system and are often limitless in availability.

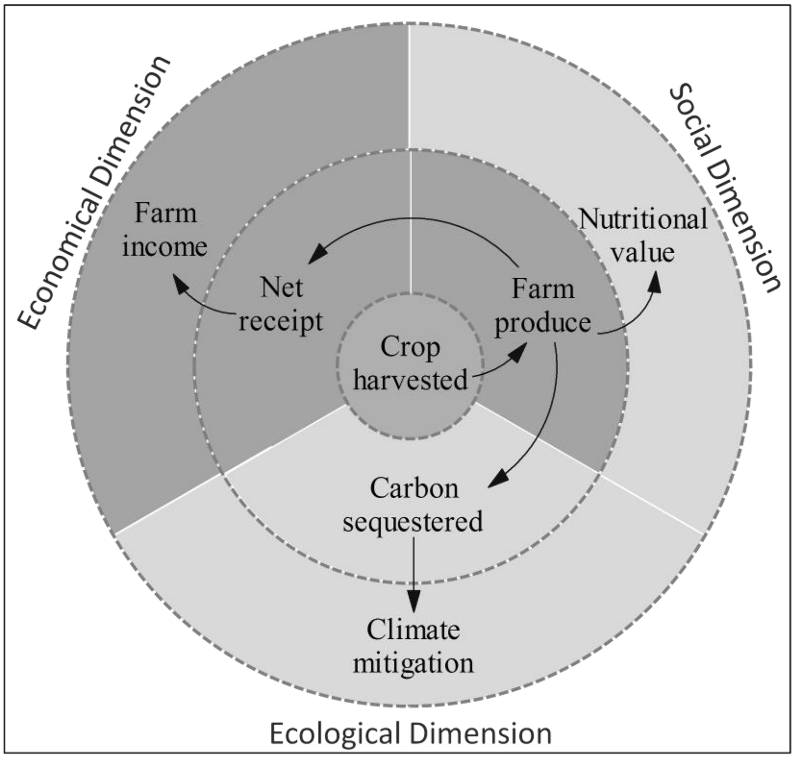


Figure 5.4 Impact boundary (darker annuli) for the desirable outflow from the farm system

In case of undesirable outflows like nutrient runoff, the impact boundary in ecological dimension is taken as the entire agro-ecological environment, including primary impacts like soil contamination, water contaminations etc. All potentially harmful outcomes from outflows to the field, ecosystem, or humans, are taken as undesirable outcomes as shown in Table 5.3. Unlike the desirable outcomes which are measured in terms of efficiency, these indicators are measured in absolute amount. In case of the economic dimension, farmer enterprise is taken as the impact boundary where the riskiness associated with investments on all the material and energy inputs are considered, but the cost of ecological impacts is not considered. Dimensional boundaries of pesticide particulate, nutrient applied, and labour are given in Appendix 1. In case of other outflows like ecological services, soil erosion and inflows like water, toxicants, energy, and seeds applied, only the biophysical aspect is considered.

Table 5.1 Indicators from stocks within the system

S No	Stocks in the system
1	Nutrient in soil
2	Soil contaminants
3	Water available
4	Soil pH
5	Soil salinity
6	Soil compactness
7	Crops population
8	Weeds population
9	Beneficial organisms
10	Pest and diseases

Table 5.2 Indicators from desirable outflow variable

S No	Outflow	Inflow	Ecological dimension	Socio-economic dimension
1	Crop and By-product harvest	Nutrients Water Energy Pesticide and chemicals Seeds	Nutrient use efficiency Water use efficiency Energy use efficiency Harvest per unit pesticide usage Yield per unit seed	Food supply per unit area
2	Farm income	Farm expense		Income per acre, benefit-cost ratio

Table 5.3 Indicators from undesirable outflow variable

<table>
<tr><th>S No</th><th>Outflow</th><th>Ecological dimension</th><th>Socio-economic dimension</th></tr>
<tr><td>1</td><td>Nutrient runoff</td><td>Water contamination and sedimentation</td><td rowspan="7">Health impacts in humans</td></tr>
<tr><td>2</td><td>Heavy metal contaminant runoff (from fertilizers)</td><td>Water contamination, soil contamination and bioaccumulation of heavy metals</td></tr>
<tr><td>3</td><td>Toxic contaminant runoff (from pesticides)</td><td>Water contamination, soil contamination, and bioaccumulation of toxicants</td></tr>
<tr><td>4</td><td>Farm machinery emission</td><td rowspan="2">GHG</td></tr>
<tr><td>5</td><td>Field emission</td></tr>
<tr><td>6</td><td>Toxic particulates in air</td><td>Direct toxic exposure</td></tr>
<tr><td>7</td><td>Toxic residues in harvest</td><td></td></tr>
</table>

Table 5.4 Impacts on environment from the inflows

S No	Inflows	Ecological dimension	Socio-economic dimension
1	Seeds	Impact on biodiversity	Farm knowledge, farm infrastructure like irrigation facility, availability of farm machines, storing and processing units, employment, drudgery etc.
2	Nutrient	GHG emissions during production and transport	
3	Water	GHG emissions from irrigation system	
4	Pesticides and other Toxic inputs	Bioaccumulation, impacts on biodiversity, GHG emissions during production and transport	
5	Manpower/electricity /fossil fuel	GHG emissions in production	
6	Farm expenditure/ investment		Financial resources, self-reliance, and riskiness

Accounting for the social aspects of a system is relatively challenging due to the qualitative nature of social dimension which is often intangible and lacks consensus (von Geibler et al., 2006). These social attributes are context dependent indicators which are difficult to measure, aggregate or compare (Norris, 2006). Our knowledge about interactions among socio-economic and natural system and their functions, is intrinsically incomplete (Gell-Mann, 1995; Oreskes et al., 1994). Measurement of indicators like social progress, animal welfare, soils etc., has always been an arduous task (Harger and Meyer, 1996). While several studies prefer to have quantitative indicators, proxy measures and semi-quantitative indicators are often considered to be the best way to capture the reality. However, the method of choice depends upon the objective and utility of the study (Jørgensen et al., 2008). While material and physical characteristics of the system can be modelled using various techniques, social characteristics like personal values, power etc., require qualitative approaches. The complex and often conflicting nature of qualitative variables demands an active participation of all the stakeholders in order to capture the social aspects of the system (Midgley and Reynolds, 2004). Since the objective of our study is to develop a set of indicators with wider applicability, we have considered only the descriptive characteristics like producer and consumer health, and avoided normative variables like custom, values etc. for social dimension.

In case of impacts caused due to inflows (Table 5.4), the entire ecosystem is taken as the impact boundary for the ecological dimension. GHG emissions and impacts on the biodiversity formed the core of the ecological dimension of the inflows. Riskiness involved in the farm investment forms the economic dimension of the inflow.

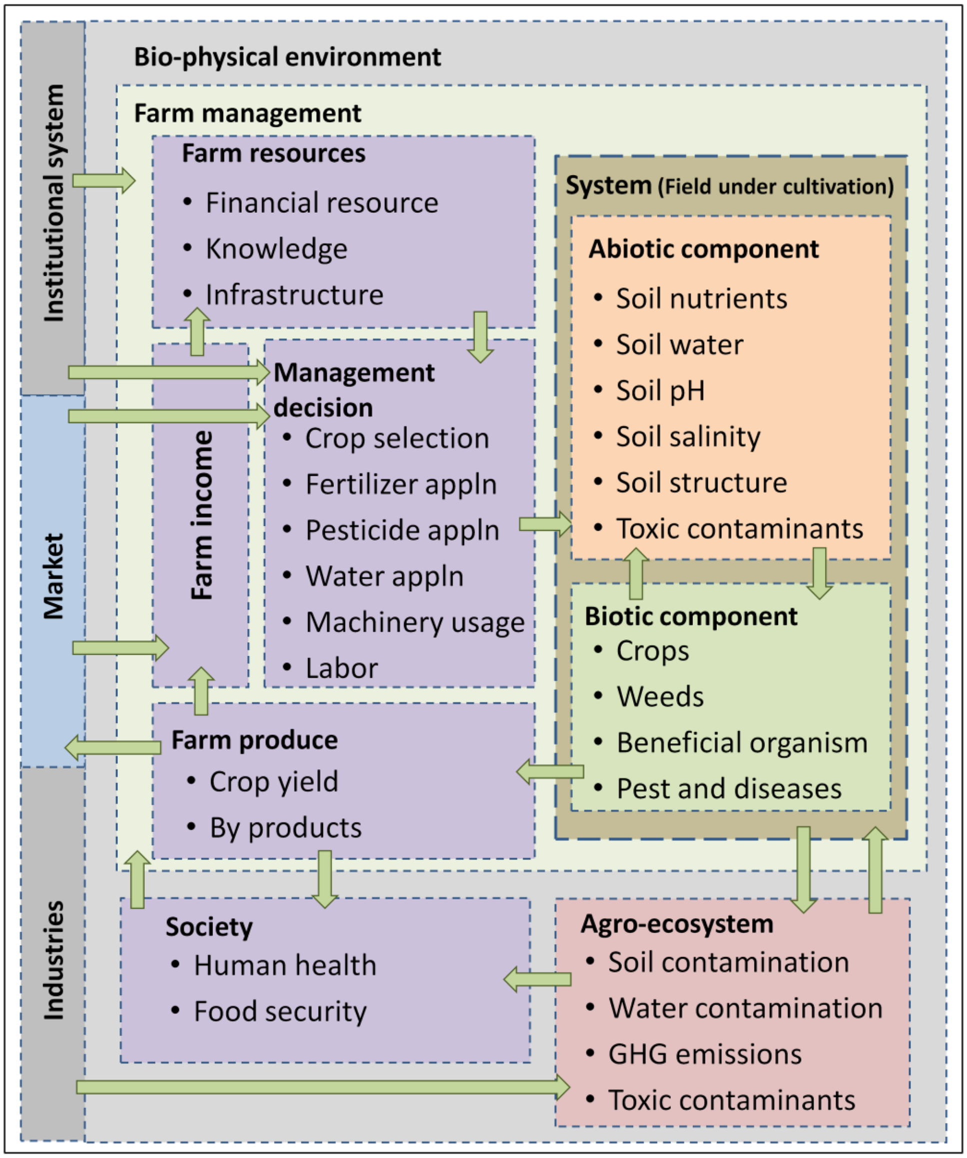


Figure 5.5 Components in farming system and their interactions

In case of social dimension, behavioural response of the farmer to socio-economic environment represents the social aspect of inflows. Since the objective of assessment in field level application is to compare and select better management practices for the farmers, market and policies are considered to be external to the system (Andreoli and Tellarini, 2000; Hengsdijk and Kruseman, 1993; Kruseman et al., 1993; Rossing et al., 1997) As shown in Figure 5.5, factors like resource availability, farm knowledge and infrastructure, institutional access, market demand and prices, affect the decisions on farm in-flows like fertilizer inputs, crop selection, etc. Since these farm characteristics are outside the field (system) boundary, a schematic diagram (Figure 5.5) rather than a detailed stock and flow diagram is used for a simplified representation. The differences in responsiveness between households mainly depend on the resource condition of the farmer and the market. Therefore, we consider the financial resources and riskiness as the key representative indicators for the behavioural response of farmer, as shown in Table 5.4.

In summary, we have identified a comprehensive set of indicators (listed in Table 5.1 – Table 5.4) across the economic, social, and ecological dimensions using the proposed stock and flow framework. It may be ideal to measure all the identified indicators for a comprehensive analysis, however, there is a trade-off between the extent of information captured and the ease of monitoring (Rigby et al., 2001). Therefore, identification of proxy indicators that could capture several indicators with a simpler measure is desirable.

5.1.4 Identifying proxy variables

Since the objective is to come up with a set of indicators adaptable for a wider application, several proxy variables are used to capture a set of thirty-nine primary indicators identified as shown in Table 5.5. Striving for a high scientific standard over indicators involves a high risk of blocking the progress towards the objectives of the study. An extensive description of the indicators may not give the ideal solutions but rather intends to unwind the innate complexity and practical difficulties of indicators (Büchs, 2003). This section describes the basis of proxy indicators selected to capture the indicators that demand complex data collection or high-end analytical examinations, using the stock and flow diagram and published literature.

Indicators from stock variables within the system

Stock variables like soil pH and salinity are easily measurable and are directly taken as indicators. Although soil nutrients including nitrogen, organic carbon, phosphorous, potassium, calcium, iron, sulphur etc. are represented by a single stock variable in our SFD, depending upon the objective of the study, various nutritional elements can be accounted separately. The soil compactness in the SFD represents the soil structure of the field. Soil structure is the physical arrangement of soil particles, which defines the size, shape and the characteristic of soil aggregates. The major role of the soil structure in plant growth is to provide pores and mechanical weakness in the soil for the growth of root system (Gardner et al., 1999) and therefore porosity is taken as a proxy variable for soil structure.

Table 5.5 Primary indicators and the proxy indicators*

S No	Primary indicators	Proxy indicators
1	Soil nutrients	
2	Soil contaminants	FIQ and PIQ
3	Water available	Soil organic matter
4	Soil pH	
5	Soil salinity	
6	Soil compactness	Soil porosity
7	Crops	Biodiversity and species richness
8	Weeds	
9	Beneficial organisms	
10	Pest and diseases	
11	Nutrient use efficiency	
12	Water use efficiency	Soil organic matter
13	Harvest per unit chemical used	PIQ
14	Energy use efficiency	FIQ
15	Seed use efficiency	
16	Benefit-cost ratio	
17	Food supply	Yield per unit area
18	Ecological services	
18	Nutrient contamination in water	Fertilizer impact quotient (FIQ)
19	Sedimentation	
20	Heavy metal contamination	
21	Bioaccumulation (Heavy metals)	
22	Field emission	
23	Health impacts in human	
24	Soil erosion	
25	Water contamination (Toxicants)	Pesticide impact quotient (PIQ)
26	Soil contamination (Toxicants)	
27	Bioaccumulation (Toxicants)	
28	Toxic residue in harvest	
29	Health impacts in humans	
30	GHG Emission during irrigation	Fossil fuel used
31	GHG emission during transport	
32	GHG emissions during production of inputs	FIQ
33	GHG emissions during input application	
34	Financial resources	Paidout cost
35	Riskiness	Total farm expenditure
36	Manpower	Expenditure on labour
37	Farmer knowledge	
38	Social capital	
39	Farm resources	

Biological diversity, consisting of the stock variables like crops, weeds, beneficial organisms, and pests and diseases determines the long-term stability and resilience of the field. Since the estimation of farm biodiversity at various trophic levels is a laborious process, soil microbial diversity and richness can be taken as its proxy. Stephan et al. (2000) have shown that both activity and diversity of cultural soil bacteria is positively correlated and the above-ground biomass increases with increase in plant species richness.

Indicators from desirable outflow

For indicators related to desirable outflows, nutrient use efficiency and benefit-cost ratio are included directly. With respect to water input, the crucial factor determining the production under limited water supply is 'effective use of water' - maximization of captured soil moisture (Blum, 2009). Soil moisture content is mainly affected by soil organic carbon and textural components of the soil (Debnath et al., 2012; Rawls et al., 2003). Since the farming practice generally does not affect the textural components of the soil, soil organic carbon is taken as the proxy indicator for the water input.

Energy use efficiency is defined as the amount of crop produced per unit of energy consumed. Two classes of energy inputs, namely fuel consumed for farm mechanization like usage of tractors, harvester etc., and the energy on agronomic inputs like fertilizers, pesticides etc. need to be taken into account. Several studies have reported varying ranges of energy consumed for each of these components. While there have been variations in the levels of energy consumed, many studies show that the major energy input is through fertilizers/chemical inputs and direct fuel usage (Kızılaslan, 2009; Mendoza, 2005; Safa et al., 2011). Therefore, the amount of nutrient excess and fuel usage in farm machinery are taken as a proxy for energy use efficiency. In case of food supply, yield per unit area is taken as its proxy indicator, as yield is the major factor affecting the food production.

Indicators from undesirable outflows

Stock variables like water contamination, bioaccumulation, health impacts, etc. form the non-point pollution to the environment due to the usage of farm inputs, such as fertilizers and pesticides. Given that these stock variables are influenced by various extraneous factors, it is neither appropriate to attribute all the changes in these variables to farming practices, nor it is feasible to identify the impacts corresponding to farming practices alone. For example, though an open-well may be situated within an organic farm, it might be contaminated due to the sub-surface leaching of contaminants from neighbouring farm.

Pesticide contamination is a universal concern because of the risk of its residues in soil, water and air, degradation of biodiversity. In order to assess the impacts caused by pesticides, several methods such as computer simulation of environment effects, sampling and tracking of changes in biophysical variables, surveying and qualitative research methods and, indexing of the severity of pesticide, can be employed. The latter approach of indexing system connects the test-endpoints to decision-endpoints, making it a favourable tool for policy formulation (Levitan, 1997). A composite indicator designed to measure impacts of pesticides on producers, consumers and eco-system by using the toxicological database of pesticides and the dosage applied (Kovach et al., 1992), is used as a proxy for the ecological and social impacts caused by pesticides. As the efficiency of pesticides significantly varies among different pesticides, yield per unit pesticide may not be feasible without considering the nature of active ingredient. Therefore, Pesticide Impact Quotient (PIQ) is taken as a proxy for the yield per unit pesticide as well.

Similar to pesticide impacts, indicators representing the impacts of fertilizers like sedimentation, heavy metal accumulation etc., are accounted by Fertilizer Impact Quotient (FIQ). It is designed based on the excess nutrient applied to the field. While a negligible amount of pesticide reaches the targeted site of action (Pimentel, 1995), crops utilize a significant amount of fertilizers, that are applied in the field (Ghosh et al., 2015). Therefore, only the excess fertilizer applied needs to be correlated to the amount of impacts caused, for which the nutrient balance is taken as the proxy variable. Only the major imports and exports of nutrients such as fertilizer input and farm produce are considered for the nutrient balance. In order to avoid complexity and maintain the ease of application, several dynamics of nutrients like natural synthesis, depletion, leaching, volatilization etc., were not considered in the calculation of nutrient balance. The contamination risk of nutrients is considered only when there is a positive nutrient balance (Viglizzo et al., 2006). In case of negative nutrient balance, we assume that the nutrient available for runoff is very limited and such farms will get a higher score for FIQ. Similarly when there is an excessive nutrient application, then the excess nutrient in the field is prone to nutrient leaching and so the FIQ will be lesser. Figure 5.6 (on page 69) shows the detailed scheme of FIQ calculation along with an example. The nutrient requirement for the average crop production is calculated using the standard crop specific nutrient consumption data. This fertilizer consumption rate for an average production (F_{avg}) is quadrupled and set as the maximum application limit. Since an efficient farm management can yield fifty percent fertilizer use efficiency, double the F_{avg} is taken as the midpoint reference. This reference point helps us to score a range of farms that have higher efficiency as well low efficiency. Gómez-Limón and Riesgo (2010), have also used nitrogen balance as a proxy indicator for environmental impact of nitrogen fertilizers.

Indicators from the impacts of inflow

Two ecological aspects of energy consumption are depletion of non-renewable resources and pollution due to GHG emissions (Pervanchon et al., 2002). As suggested by Alluvione et al. (2011), only those crop inputs which are modifiable by the management practice and would have a direct or indirect consumption of non-renewable energy, are considered. Maraseni et al. (2009), have shown that emissions from agrochemicals and the fuel usage account for more than 95% of the total emissions caused due to farming practices. Hence, FIQ and fossil fuel used in irrigation and machinery are taken as a proxy for GHG emissions.

Farm riskiness involves various types of risks including production/yield risk, market/price risk, institutional risk, farmer's personal risk etc. (Harwood et al., 1999). As the market and institutions are outside the impact boundary, we consider only the production risk, which includes variability of crop yield due to adverse conditions such as extreme weather, pest attack etc. Since the financial stake involved in the production process includes both the financial investment and manpower by the farmer, total farm expenditure is taken as the proxy indicator.

Financial resources of the farmer depend on various extraneous parameters like secondary source of income, family consumption etc., which necessitates the use of a proxy. A low-cost farming practice will put lesser burden on financial resources of the farmer. Therefore, a farming practice with lesser investment is more favourable and the total farm expenditure is taken as a proxy variable for the financial resources.

Indicators like benefit-cost ratio and farm expenditure account for the economic dimension of manpower. An average of about 40% of the income to farmers' household in India comes from wages and so the employment generated through agricultural labour plays a crucial role in income stability of farmers (NSS 59th Round, 2005). Therefore, manpower involved in the farming practice is taken as an important social factor.

5.2 Farm Assessment Index (FAI)

The main objective of our work is to design a single measure to evaluate farming system in a holistic manner. Towards this goal, we describe the methodology used to estimate and condense all the indicators identified in the previous section into a composite indicator called Farm Assessment Index (FAI).

5.2.1 Indicator estimation

The first step in using the identified indicators is to define the indicators based on the objectives and application. It needs to be defined in spatial-temporal context with the participation of stakeholders (Bockstaller et al., 2008). For example, water use efficiency can be defined in several ways such as yield per unit water consumed by the crop, or yield per unit water applied, or yield per unit water irrigated. A trade-off is made between the level of detailing and feasibility depending upon the end application and utility of the indicator. For example, site-specific policy planning demands more detailed data (Pacini et al., 2009). Depending upon the definition of indicators, an appropriate method to estimate each indicator is selected. Though the indicators might have standardized estimation methods, they can be simplified depending upon the scope of the study, resource availability and data availability (Viglizzo et al., 2006). All estimated indicators are transformed using the normalization and aggregation methods as discussed in the following sections.

In our field application, we estimated 18 indicators covering a set of 26 indicators. Table 5.6 gives the definitions of the indicators that are used in this study along with their unit of measurement and method of estimation. We use direct estimation based on survey data for socio-economic and ecological indicators and use laboratory methods for estimating soil parameters. In defining the socio-economic indicators, we use the term “paidout cost” to represent the actual expenditure of the farmer without imputing any the cost for self-borne labour and inputs (for example, farm yard manure from farmer’s field or kitchen waste). In case of total cost of cultivation and total labour expense, market value of the input and opportunity cost of self-borne labour are calculated and added to the paidout cost and labour expense respectively.

Table 5.6 Indicator definition and units

S No	Indicators	Definition (All variables are calculated on per acre basis)	Unit	Estimation
1	Benefit-cost ratio	Ratio of total value of farm produce to paidout cost of cultivation	Dimensionless (DMNL)	Field survey
2	Income per acre	Total value of the farm produce minus the paidout cost for cultivation	₹/acre	
3	Riskiness	Total cost of cultivation with the cost imputed for self-borne labour and inputs	₹/acre	
4	Nutrient use efficiency	Nutrient balance between total nutrient applied and nutrient consumed by the crop	kg/acre	
5	Financial resources	Paidout cost of cultivation	₹/acre	
6	Self-reliance	Ratio of self-borne cost to total cost of cultivation	Dimensionless	
7	Drudgery	Ratio of gross income to the expenditure on labours including self-borne labours (Gross income per unit labour)	Dimensionless	
8	Crop Yield	Total crop produce including intercrops	kg/acre	
9	Employment	Ratio of expenditure on total labour to the total cost of cultivation	Dimensionless	
10	Fertilizer Impact Quotient (FIQ)	Fertilizer Impact Quotient (FIQ) defined as an estimate of nutrient balance between total nutrient applied and nutrient consumed with respect to the crop yield. It captures the direct and indirect impacts like soil and water contamination, health hazards etc. caused due to fertilizer usage.	Dimensionless	
11	Pesticide Impact Quotient (PIQ)	Pesticide Impact Quotient (PIQ) is an estimate of impact based on the potential toxicity of active ingredients and dosage applied. It captures the direct and indirect impacts like health hazards, soil and water contamination, etc. caused due to pesticide usage.	Dimensionless	Field survey and PIQ tool
12	Soil Organic matter	Amount of organic content in soil	% of soil	Laboratory testing
13	Total Nitrogen	Soil nutrient in soil	PPM of N	
14	Available phosphorous		kg P/Ha	
15	Available potassium		kg K/Ha	
16	Soil pH	pH of the soil	Dimensionless	
17	Soil salinity	Salinity of the soil	DS/cm	
18	Microbial population	Various microbial population in soil	Colony forming unit (CFU) per gm of soil	

While most of the indicators that are estimated from survey data were relatively direct from the data collected, estimation of PIQ and FIQ are relatively complex. PIQ is a measure which is estimated from the amount of pesticide application, nature and concentration of active ingredients, and the maximum recommended dosage. As discussed in section 5.1.4, PIQ is calculated using the toxicological database of pesticides and the dosage applied (Kovach et al., 1992). An online tool designed by Eshenaur et al. (1992-2016), is used to calculate the impact caused by each pesticide with respect to its active ingredients and application dosage. The impact caused by the maximum recommended dosage P_{max} is assumed to be within the safety limit and hence it is set to be the mid-point reference during normalization. Double the P_{max} is considered to be unacceptably hazardous dosage and therefore taken as the upper threshold above which PIQ will be negative/capped as zero.

FIQ is a measure based on nutrient excess in the field calculated using rate of nutrient application, crop yield, average nutrient consumption rate of the crop, and average yield of the crop. Figure 5.6 shows a detailed scheme of FIQ calculation for paddy crop in Tamil Nadu along with an example of data application. The nutrient requirement (F_{avg}) for the average crop production is calculated using the standard crop specific nutrient consumption data. In Figure 5.6, paddy consumes 20 kg of N per tonne of grain production. Its state average yield is 985 kg per acre whose nutrient intake would have been 19.7 kg. Since fifty percent fertilizer use efficiency is considered to be an efficient farm management, double the F_{avg} is taken as the '0.5' reference and double of '0.5'reference value is set as the '0' reference point above which FIQ will be negative/capped as zero. Correspondingly, double of 19.7 kg that is 39.4 kg is set as "0.5" (mid-point reference) reference point and its double 78.8 is set as "0" reference. This means, a field with nutrient excess equivalent to the amount of nutrient consumed by the crop will get a score of "0.5" and a field with nutrient excess of four times the nutrient consumed by the crop will be rated "0". These reference points help us to score a range of farms that have higher efficiency as well as low efficiency. In the example given in Figure 5.6, a plot of 0.4 acre size has harvested 600kg of paddy whose corresponding nutrient intake is calculated as 12 kg. Since the actual nutrient applied was 30.8 kg, an excess of 18.8 kg of N in 0.4 acre. The excess nutrient per acre is calculated as 47 kg of N and fit with the reference points to obtain FIQ as 0.40.

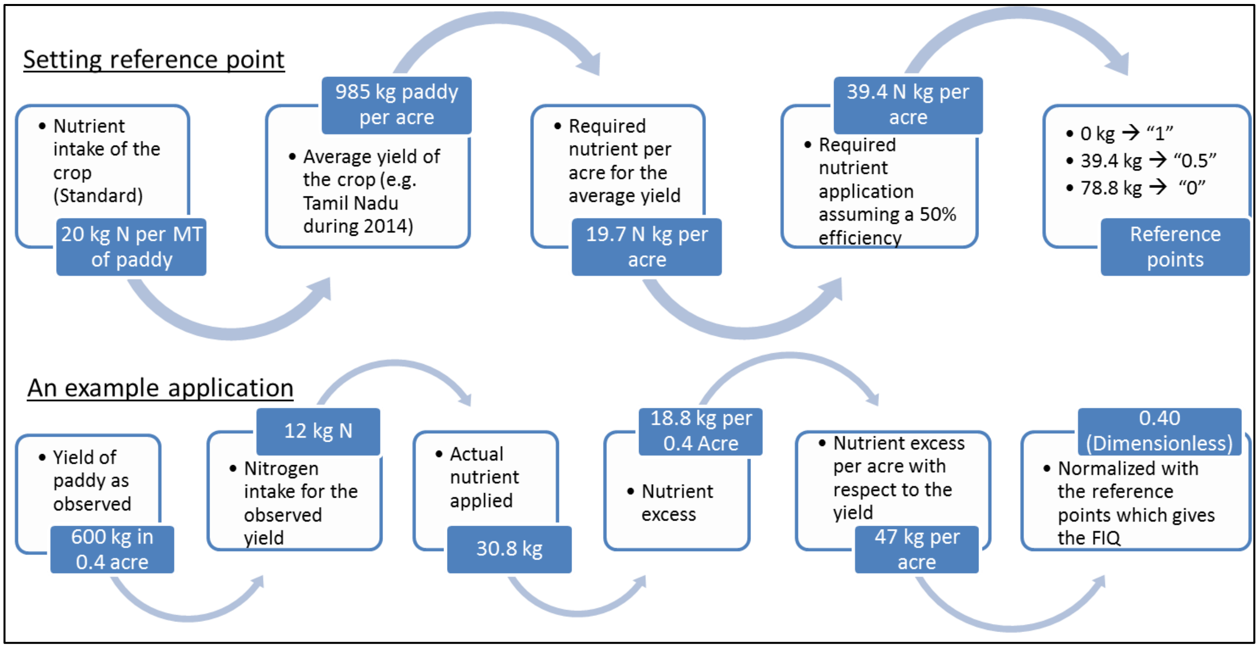


Figure 5.6 Methodology for calculation of Fertilizer Impact Quotient (FIQ)

5.2.2 Normalization

In order to be user-friendly and understandable for non-expert audience, complex methods are better avoided in the design of assessment tools (López-ridaura et al., 2002). After considering a range of mathematical methods, the min-max method with a pre-set reference was selected for normalization of indicators. This method maintains the simplicity of FAI estimation and aids in a wider application. The reference points for normalization are identified for each indicator based on standards, national or state averages and literature.

Data on crop specific and state-specific average is used for setting the reference point of socioeconomic indicators namely cost of cultivation, labour expense, yield etc. In case of PIQ, pesticide specific maximum recommended dosage provided by manufacturers is used to determine their reference points. In case of FIQ, crop specific nutrient consumption per unit yield is used to set their reference points. Unlike other studies where the comparison of the farming system is restricted within the sample under study, normalization of indicators using regional or national average makes the FAI suitable for universal comparison of farming systems across crops and regions. Though the min-max method with pre-defined methods has the advantage of simplicity, the linearity assumed in this method may contradict the often non-linear and site-specific nature of indicators in reality. However, determining the non-linear site-specific function is very difficult and can be uncertain (Dantsis et al., 2010).

Table 5.7 Basis of references points to normalize the indicators used in field application

S No	Indicator	Nature of Reference	Reference point		
			"0"	"0.5"	"1"
1	Net income	Relative	Zero	State and crop-specific average	Double the average
2	Benefit-cost ratio				
3	Yield				
4	Ratio of self-borne expense to total expense				
5	Ratio of labour expenditure to total cost				
6	Farm expenditure		Double the average		Zero
7	Paid-out cost				
8	Labour expense				
9	Fertilizer impact quotient (FIQ) of N		Quadrupled amount of nutrient consumed for average yield	Double the nutrient consumed by the specific crop for the state-specific average yield	Zero
10	FIQ of P				
11	FIQ of K				
12	Pesticide impact quotient	Absolute	Double the maximum recommended dosage	PIQ of maximum recommended dose with respect to active ingredient of the pesticide	Zero
13	Soil organic matter		Half the minimum threshold	Scientifically published threshold	Optimum range
14	Total N				
15	Available P				
16	Available K				
17	Soil pH		Minimum/maximum pH threshold		Optimum Soil pH range
18	Soil salinity		Maximum threshold		Tolerance limit

Table 5.7 gives the nature and basis of reference points for each indicator. In case of indicators where the crop and state-specific average is taken as '0.5' reference point, double its value is taken as reference point '1' or '0' for benefit or impact indicator respectively. In case of PIQ, the PIQ of the maximum recommended dosage of the specific pesticide is set as '0.5' reference point, and double or more than double the maximum recommended dosage is set as '0'.

As discussed earlier in this section, in case of FIQ, the reference point ‘0’ is taken as the quadrupled amount of average consumption of crops as we assumed a 50% benchmark for nutrient use efficiency and took the double of nutrient consumed as ‘0.5’ reference point. In case of soil parameters, reference points were set based on their scientific thresholds.

Since the cost and impact indicators like farm expenditure and pesticide impact, are normalized using negative slope function, the normalized value is in positive scale i.e. lower the farm expenditure, higher will be the value of normalized farm expenditure indicating a better farming system. The actual reference values and standards used in this study for various indicators based on the crop and spatiotemporal factor were compiled from various sources. Table 5.8 gives the reference points for seven socio-economic indicators with respect to two states and five crops.

Table 5.8 Reference values for socio-economic indicators (Directorate of Economics and Statistics, 2016)

Indicators		**Farm expenditure** (₹/acre)	**Paidout cost** (₹/acre)	**Gross income** (₹/acre)	**Net income** (₹/acre)	**BCR** (Dmnl)	**Labour expense** %	**Drudgery** (₹Gross income/ ₹Labour expense)
State	**Crop**							
MH	Cotton	43730	31998	66460	34462	3.04	89	6.83
	Soybean	24772	19741	34545	14804	2.79	68	8.17
	Wheat	28967	22234	40402	18168	2.79	60	9.28
	Gram	21847	16974	34576	17602	3.17	75	8.44
TN	Turmeric	90000	71861	137800	47800	3.06	94*	6.21*
	Paddy	43662	34862	63818	28955	2.92	94	6.21

* Reference values taken from paddy due to unavailability of data

Table 5.9 gives the standard impact scores for various commonly used pesticides along with their maximum recommended dosages. These maximum recommended dosages were taken from commercial products purchased in the market.

Table 5.11 gives the standard nutrient content in various fertilizers and manures used in the fields under study. In case if a reference value specific to a crop or state is unavailable, the average of related references is taken as an alternative. For example, if the maximum recommended dosage of a particular pesticide is not available, the maximum pesticide dose of a closely related pesticide is taken as the reference point. Table 5.12 gives the scientific standards of soil parameters which are set at as their respective reference points.

Table 5.10 gives the average yield of various crops that are cultivated as maincrop or intercrop along with the nutrient consumption of the crop at standard conditions wherever available.

Table 5.9 Reference for PIQ based on maximum recommended dosage (Eshenaur et al., 2016)

S No	Pesticide name	Active ingredient (%)	EIQ per unit pesticide (DMNL)	Max. recommended dose (ml or gm/acre)
1	Acephate	75	41.33	400
2	Carbendazim	50	55.70	300
3	Chloropyrophos	50	28.40	500
4	Cypermethrin	10	7.70	500
5	Flubendiamide	39.35	16.10	20
6	Imidacloprid	17.85	14.00	100
7	Diafenthiuron	50	35.33	160
8	Quinolphos	25	22.80	250
9	λ-Cyhalothrin	5	4.70	400
10	Monocrotophos	36	40.00	500

Table 5.11 gives the standard nutrient content in various fertilizers and manures used in the fields under study. In case if a reference value specific to a crop or state is unavailable, the average of related references is taken as an alternative. For example, if the maximum recommended dosage of a particular pesticide is not available, the maximum pesticide dose of a closely related pesticide is taken as the reference point. Table 5.12 gives the scientific standards of soil parameters which are set at as their respective reference points.

Table 5.10 Reference points for yield and fertilizer impact quotient (GOI, 2013; IndiaStat, 2017; Roy et al., 2006)

S No	Crop name	National/State Average yield (kg per acre)	Nutrient consumption (kg per Metric Tonne produce)		
			Nitrogen	Phosphorous	Potassium
1	Beetroot	800			
2	Bitter gourd	4530			
3	Black gram	408	60.67	9.33	40.00
4	Bottle gourd	7333			
5	Brinjal	7448			
6	Gram	408	60.67	9.33	40.00
7	Chilli	657			
8	Coriander seeds	480			

9	Cotton	193	62.40	14.40	60.40
10	Cowpea	3806			
11	Cucumber	6254			
12	Green gram	408	60.67	9.33	40.00
13	Groundnut	398	58.10	19.60	30.10
14	Ladyfinger	4783			
15	Onion	6393			
16	Paddy	984	20.00	11.00	30.00
17	Palak	3200			
18	Peas	3806			
19	Potato	9105	3.75	0.58	4.36
20	Pumpkin	9325			
21	Radish	5673			
22	Ragi	571	20	11	30
23	Rajgira	140			
24	Ridge gourd	3000			
25	Samai	228	20	11	30
26	Sesame	137			
27	Shimla	2110			
28	Sorgham	345	20.00	11.00	30.00
29	Soybean	542	146.00	25.00	53.00
30	Sugarcane	26795	13.00	5.00	17.50
31	Sweet potato	4043	3.69	1.23	5.07
32	Tapioca	13985			
33	Tomato	8285			
34	Tur	322	70.83	15.00	62.50
35	Turmeric	400	22.10	20.22	19.84
36	Field beans	4094			
37	Wheat	1247	27.83	10.00	47.61
38	Zandu	2968	37.43	24.86	110.00
39	Maize	1021	20.11	9.37	24.74
40	Pearl millet	486	20	11	30

Table 5.11 NPK composition standard of nutrient inputs used in FIQ (Devakumar et al., 2014)

Fertilizer name	**N %**	**P %**	**K %**
Complex	17	17	17
DAP	21	23	0
Potash	0	0	50
Single superphosphate	0	8.8	0
Urea	46	0	0
FYM/Compost/Cow-goat dung	0.5	0.2	0.5
PM	2.14	1.09	1.23

Gomuthram	1.67	0.112	2.544
Green leaves	2.85	0.366	1.668
Green manuring	2.83	0.543	1.736
Jivamrut	1.96	0.173	0.28
VC	1	0.2	0.355
10:26:26	10	26	26
15:15:15	15	15	15
18:18:10	18	18	10
19:19:19	19	19	19
20:20:00	20	20	0

Table 5.12 Reference points for soil parameters (DAC, 2011; Hazelton and Murphy, 2007)

S No	Indicator	"0" reference	"1" reference
1	Soil organic matter (%)	0.43	2.58
2	Total Nitrogen (%)	0.015	0.07
3	Available Phosphorous (kg/Ha)	5	24.6
4	Available Potassium (kg/Ha)	54	280
5	pH	<5 or > 9.5	6.5 – 7.5
6	Salinity (mS/cm)	>15	>4

5.2.3 Weighing and aggregation

Assigning relative weightages for all the indicators in a single level is a challenging task, due to the diversity and number of indicators to be compared. Hierarchical weighing of attributes reduces the splitting biases that are implicitly added to indicators by decision makers for increasing or decreasing their importance. In order to ensure the robustness of weighing, indicators were organized into a hierarchical structure and the relative importance was assigned at each level (Pöyhönen and Hämäläinen, 1998; Weber et al., 1988). Weightage for indicators were assigned using Delphi technique for a wider acceptability of FAI. The Delphi workshop was conducted with various stakeholders of the study and an expert panel. A consensus was built among various stakeholders over the indicator selection and their weightages, as elaborated in section 5.2.4. Though subjectivity in Delphi method can be seen as a demerit, it can also be considered as a social preference factor and more relevant for practical application (Gómez-Limón and Sanchez-Fernandez, 2010).

Aggregation of the normalized indicators is done using simple weighted mean. Progressive aggregation (Sauvenier et al., 2005b), where the weighting and aggregation are done at each hierarchical level individually, is used. The aggregate of indicators at each level has its own meaning and utility. Three separate indices *viz.* economic index, social index, and ecological index are also calculated by aggregating the indicators at dimensional level. The aggregate of indicators across all the dimensions forms the FAI of the farming system.

5.2.4 Validation

Delphi technique was used to validate the indicators selected using the framework. The Delphi workshop was conducted on 17th and 18th June 2016 at Indian Institute of Technology Bombay, Mumbai with various stakeholders. The list of participants during workshop is given in Appendix 2. Two bureaucrats, two scientists, one academician, and one member representing non-governmental organizations formed the expert panel. Other stakeholders including field coordinators, field officers and a farmer representative, also participated in the workshop.

The main objective of workshop was to a build consensus over the set of indicators identified and its classification, and to allocate a weightage for each indicator in the FAI. A brief report on the framework and the indicators selected, was sent to all the participants, a week before the workshop. A detailed presentation about the framework and the proposed indicators was given during the workshop to initiate the discussion. While the framework was accepted by all the participants in full agreement, a suggestion was made to expand the boundary of the system to include the ecological services and was incorporated. With this modification, the indicator set and its hierarchy were agreed upon by all the participants.

In order to assign weightage to all the indicators, a data feed sheet with the hierarchical structure was provided to the panel members. The inputs on weightage from the expert panel were taken anonymously over multiple rounds. Weights were given on the scale of 100% at each level in each round. The average of weight provided by the panellists was disclosed and all the participants were allowed to give their perspective on the weightages given by the panellists. In case of any difference in opinion, panellists were allowed to elaborate and revise their opinions till an agreement was reached. This process was carried out till the last level of each hierarchy. The final weight of each indicator was calculated as the product of the weightage given at each level of the corresponding hierarchy (as shown in Figure 5.7).

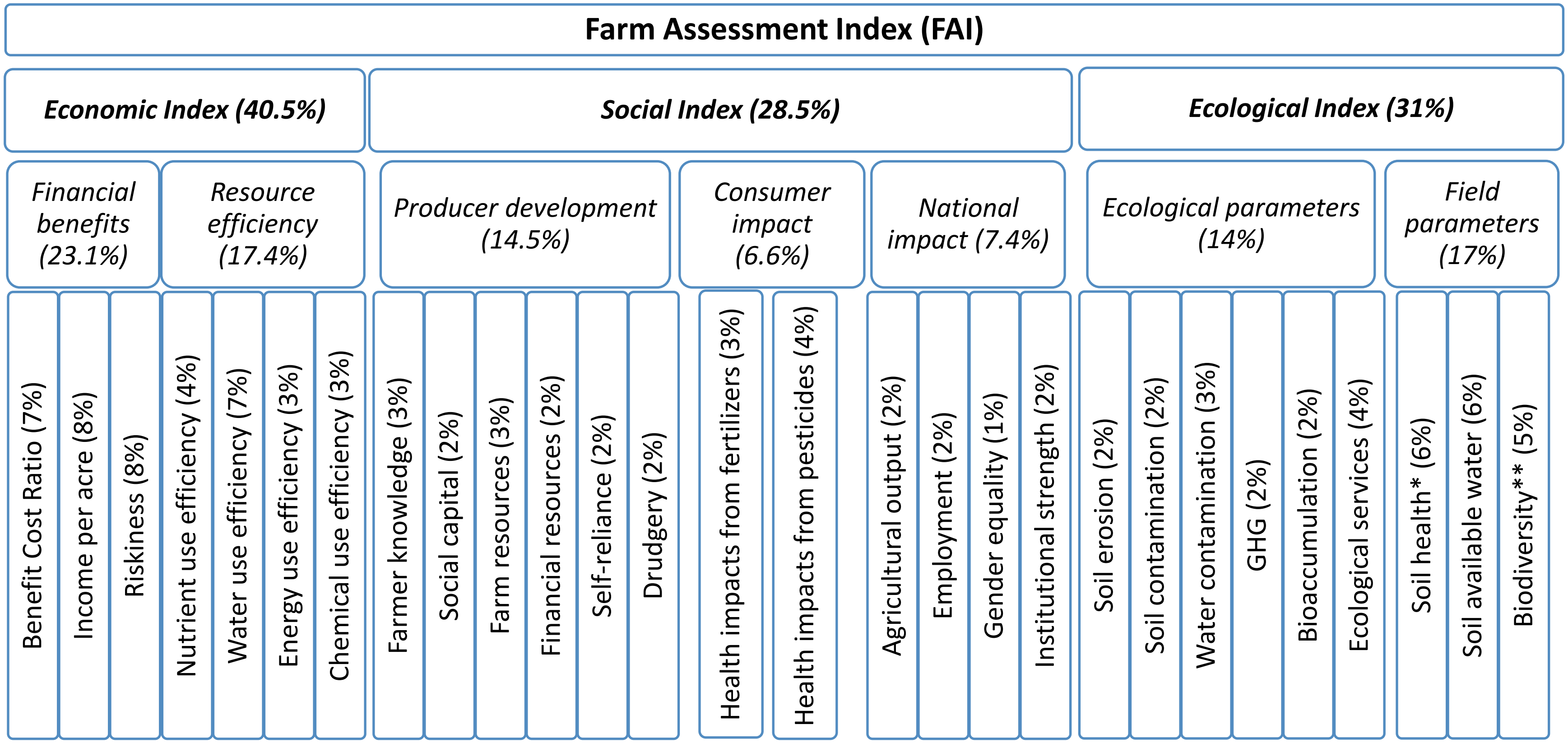


Figure 5.7 List of indicators and their hierarchical classification

**has at least six sub-indicators*

*** has at least two sub-indicators*

5.2.5 Sensitivity analysis

Sensitivity analysis helps in understanding the robustness of a composite indicator with respect to selection of indicators, errors in indicators, changes in scaling methods and influence of individual indicators (Saltelli et al., 2006). In case of composite index, sensitivity analysis is conducted to investigate the contribution of various indicators towards the computation of FAI. Sensitivity analysis usually follows one of the following three approaches. In the first approach, sensitivity analysis is used as a screening technique where the most influential indicators are identified among the many selected. The second approach is to measure the importance of each indicator by quantifying its impact on the dependent variable while keeping the other indicators unchanged. The third approach is of deep exploration where the effect of each independent variable is analysed across the entire variation range of all variables (Iooss and Lemaître, 2015).

In this work, the screening method is more relevant as we intend to identify the indicators which are crucial in determining the ranking of various farming systems that are compared. FAI is a simple weighted sum of indicators, effect of change in an indicator value will affect FAI proportional to its weight. So the second approach may not add much value to our understanding of the relative significance of the indicators. Similarly, the third approach is often used in modelling exercises to simulate the output behaviour over the entire range of each of the inputs. This analysis demands high-end computation and may not be of utility for this field application.

We use OAT (One At a Time) based sensitivity analysis that is often used in screening techniques. It helps to identify the most influential and crucial indicators for the estimation of FAI. Two different approaches namely, change in ranking based method and decomposition of variance were adopted to analyse the field data.

The Change in Rank (CR) method is based on the impact caused by an individual indicator to the overall ranking of sample fields. It is carried out by removing one indicator at a time and comparing the newly computed FAI ranking of samples with the original FAI ranking. A change in ranking indicates the role of a particular indicator in altering the preference of one farming practice over the other. An indicator is considered to be most influential if its removal has caused the maximum change to the FAI ranking of the sample. A change in ranking essentially means that there is a significant variation in that specific indicator across the sample and the range of significance depends on the weightage given to the indicator. If the removal of an indicator did not affect the ranking, the indicator has not varied to a level which might affect the FAI ranking with the given weightage.

In the decomposition of variance method, sensitivity of each indicator is quantified using two measures *viz.* first order sensitivity (S) and total effect sensitivity (ST) based on variance as defined below.

$$S_i = \frac{V_i}{V}$$

$$ST_i = \frac{V - VC_i}{V}$$

where V_i is the variance of i^{th} indicator, V is the variance of FAI and VC_i is the conditional variance which is the variance of FAI after removal of the i^{th} indicator. S is calculated as the fractional contribution of individual indicator variance to the total FAI variance. ST estimates the overall contribution of an indicator to FAI variance including the interaction effects. The values of S and ST provides the relative contribution of individual variance to the overall FAI variance. Higher S and ST values for an indicator imply a greater impact of the indicator on FAI.

Chapter 6 Application of Farm Assessment Index (FAI)

In this chapter, we describe the field application of FAI in four states (Maharashtra, Tamil Nadu, Odisha and Karnataka) for comparing organic and chemical farming systems. The first section gives the background and motivation behind the application of FAI to compare organic and chemical farming systems. The second section discusses the process of sample selection and data collection followed by the challenges faced during the field application in the third section. In the fourth and last section of the chapter, we elaborate the results from the case studies.

6.1 Farming practices

A spectrum of technological choices is available for farming with each technology having its own merits. Farmers adopt various farming practices with different principles and ideas. Based on these farming practices, a range of farming systems like natural farming, organic farming, biodynamic farming, chemical farming etc., are defined. Though these systems of farming have several overlapping principles and practices, they can be broadly classified as organic farming and chemical farming based on the nature of inputs applied. The relative benefits and impacts of both organic and chemical farming have been under constant debate and scrutiny over several decades. In order to holistically compare these two farming methods, a composite index covering the socio-economic and ecological dimension of a farm is needed.

6.1.1 Organic farming

Food and Agriculture Organisation (FAO) defines organic agriculture as a holistic production management system which promotes and enhances agro-ecosystem health, including biodiversity, biological cycles, and soil biological activity. It emphasizes the use of management practices in preference to the use of off-farm inputs, taking into account that regional conditions require locally adapted systems. This is accomplished by using wherever possible, agronomic, biological and mechanical methods, as opposed to using synthetic materials, to fulfill any specific function within the system (FAO, 1999).

In other words, organic farming is a cultivation practice where no synthetic inputs like chemical fertilizers, herbicides, and pesticides are applied to the farm. Organic agricultural practices are based on a harmonious relationship with agro-ecosystem where farming is in sync with natural cycles and least disruption to surrounding ecosystem. Nutrients consumed by the crops are replenished in organic forms such as animal waste, plant waste etc. Similarly, pest and weed management uses natural products like plant extracts and cow urine, or mechanical control methods. Many techniques used in organic farming like inter-cropping, mulching and integration of crops, and livestock are derived from traditional agriculture practices which have sustained the land for many millennia.

6.1.2 Organic farming in India

India has the highest number of organic producers in the world with over 0.6 million certified farmers cultivating about 1.49 million hectares of land under organic system (APEDA, 2016). An estimated 69 million hectares of farmland that is not certified, but is potentially under organic methods without the use of synthetic fertilizers and pesticides (Reddy, 2010). A majority of these organic farms remains uncertified due to various reasons and the cost of certification is found to be the main barrier (Sudheer, 2013). Various crops like cereals & millets, cotton, pulses, sugarcane, oilseeds, medicinal plants, tea, fruits, spices, dry fruits, vegetables, coffee etc. are produced under organic practice. Production of certified organic products has been on rise since the last decade. During the year 2015-16, India produced around 1.35 million MT of certified organic products and exported about 0.26 million MT of products earning about ₹2000 crores. Production of certified organic products is driven mainly by the export market which accounts for almost 80% of the total value of organic market. The Indian organic market is targeting a multi-fold growth to a gross value of about ₹45,000 crores by 2025 (Yes Bank, 2016).

Though there is a huge opportunity and potential for the growth of farmers as well as traders, there are several constraints as well. The major issues faced by organic farmers are non-availability of sufficient organic inputs like seeds, fertilizers and pesticides, local market for organic produce, and inadequate access to certification and guidelines (Pandey and Singh, 2012). Similarly, traders and exporters face problems of credibility in international market and the complexity of certification process. Lack of infrastructures such as residue testing laboratories, warehousing, and cold storages facilities, makes it more difficult for the supply chain in organic market. It is necessary to strengthen institutional support for enhancing capacity building, increasing awareness, easing of certification process, improving regulations, providing market linkages, facilitating export, and incentivizing value addition and product development (Yes Bank, 2016).

6.1.3 Chemical farming

Chemical farming refers to the farming system where synthetic and mined fertilizers are used for crop production, and/or a diverse range of synthetic chemical products like pesticides and herbicides are used for crop protection. It often employs a range of tillage practice, intensive input application, and crop specialization. In contrast to organic farming which has been practiced for centuries, chemical farming has become predominant only in the last six decades. Chemical farming depends on the market for most of its farm inputs, unlike organic farming where the inputs are mostly sourced within the farm or procured locally. The manufacturing of synthetic fertilizers is an energy-intensive process contributing to a significant amount of GHG emissions. Furthermore, the synthetic chemicals used for crop protection like herbicides and pesticides are hazardous to humans as well as agro-ecosystem.

6.1.4 Chemical farming in India

Chemical farming techniques formed the major constituent of the Green Revolution since 1960s in India and transformed the country from a net importer to a net exporter of food. Since the conventional farming portrays the chemical farming system, an elaborate discussion in section 1.1 on the area, production, synthetic fertilizer consumption, cultivable land using pesticides, FYM usage, and farmer’s livelihood, describes the current shape of chemical farming in India. In this section, we focus on various impacts caused due to chemical farming in this section.

Fertilizer consumption and pesticide application have been ever increasing over the past several decades. It has created a multitude of problems for the agro-ecosystem, consumers as well as producers. Inappropriate use of fertilizers and pesticides has deteriorated natural resources including soil fertility, biodiversity, and water quality. The use of synthetic fertilizers without organic supplements have been found to affect several soil parameters like bulk density, soil organic carbon, water retention, microbial biomass and enzyme activities (Bandyopadhyay et al., 2010; Bhattacharyya et al., 2008; Hati et al., 2007; Masto et al., 2008; Nayak et al., 2012; Srinivasarao et al., 2014).

Numerous studies across India that have reported surface and groundwater contamination with nitrate, phosphorous and pesticides in the areas of heavy chemical usage (Dar et al., 2010; Kundu et al., 2009; Raju et al., 2009; Rao, 2006; Sajil Kumar et al., 2014; Sankararamakrishnan et al., 2008; Saxena et al., 2014). Besides the impacts on soil resilience and water, synthetic input production involves a huge amount of energy which is mostly sourced from fossil fuel based natural gas. For example, synthetic production of fertilizer requires over 60MJ per kg of nitrogen and those of insecticides requires over 100MJ per kg (Gellings and Parmenter, 2004; Helsel, 1992). In addition to the GHG emitted during the energy-intensive production process, nitrogen fertilizers increase NOX and methane emissions (Arti et al., 2013; Ghosh et al., 2003; Sharma et al., 2008). In spite of these numerous and ever-growing impacts caused due to fertilizer usage, NAAS has stated that the application of fertilizers is inevitable to meet the nutrient requirements of crops, especially with the increasing production needs. It describes that a nutrient gap of several million MT between the nutrient extraction by the crops and the nutrient applied to the soil has been compensated predominantly with the use of synthetic or mined fertilizers. However, it also stresses the need for a balanced, customized and timely application of nutrients to improve the nutrient use efficiency (Abrol and Johri, 2005).

In addition to the fertilizer application, the gross cropped area treated with pesticides has increased many folds from about 21 million Hectares in 1996 to about 83 million Hectares in 2011. Although Cooper and Dobson (2007), have described a list of primary and secondary benefits of pesticides for humans and environment, most of pesticide usage scenarios neither hold on to the regulations nor appropriately used. In general, the use of pesticides causes disequilibrium in agro-ecosystems. It poses a major threat to the consumer population as these harmful substances enter the food chain through their residues in farm produce.

Environmentally hazardous and persistent chemicals that are banned in developed nation are still under use in most developing countries due to their cheaper cost (Carvalho, 2006). Over 50 pesticides that are banned in other countries are still used in India (Press Trust of India, 2016). Moreover, pesticide resistance developed by pest creates a positive feedback loop where the dosage and frequency of the pesticide application keep increasing with increased resistance (Roush and Tabashnik, 2012). Wilson and Tisdell (2001), have demonstrated the possibility of economic "lock-in" as a major cause for pesticide usage by the farmers, in spite of being aware of hazards of pesticide usage. Further, the lack of appropriate legislation and regulations to control pesticides and absence of capacity building over pesticide usage, are found to be a major concern (Ecobichon, 2001).

There have been numerous reports of pesticide contamination in a range of food products like cereals, pulses, and vegetables (Bakore et al., 2002; Bhanti and Taneja, 2005; Bishnu et al., 2009; Charan et al., 2010; Gurusubramanian et al., 2008; Kumari et al., 2004; Mukherjee, 2003; Rekha et al., 2006; Sinha et al., 2012). These residues in crop produce also led to bioaccumulation in fishes, bovines and humans that show the alarming state of food safety due to pesticide usage (Aulakh et al., 2007, 2006; Kumar et al., 2006; Nag and Raikwar, 2011; Sanghi et al., 2003; Shukla et al., 2002; Singh and Singh, 2008; Subramaniam and Solomon, 2006).

In terms of livelihood of farmers, chemical farming practices have made farming investment intensive, market dependent and risk-prone. Social and ecological resilience are clearly linked with each other and a stable agro-ecology plays an important role in farming based communities (Adger, 2010). Das (2002) has shown that the green revolution has either no impact or negative impact on poverty alleviation in India, when the cost of ecological and health impacts on labourers are considered. According to NSSO (2013), over 41% of agricultural household are still below poverty line and about 5% of them are in extremely poor category. Various reports of acute agrarian distress have been recorded over the past two decades across various states with over 3,00,000 farmers suicide. One of the major reasons for farmer suicides has been found to be indebtedness and crop failure (NCRB, 2015). Over 50% of farmer households are indebted with an average amount of over ₹47,000 amidst an average monthly income of around ₹6,000. As seen in most cases in Table 6.1, chemical farming has always been capital intensive and has made the farmers vulnerable to debt. Further, the dependence of farmers over moneylenders has increased from 15.7% in 1991 to 33.2% in 2013 in which about 68.6% pay greater than 20% interest rate (NSSO, 2016). While financial instability has been a major reason for agrarian crisis, Kumar (2005), has also shown that the absolute number of malnourished population has been rising among farmers and agricultural workers over the decades.

As we discussed the state, prospects and challenges of both organic and chemical farming practices in India, it is very important to adopt and promote appropriate farming techniques for meeting the food demands of growing population without affecting the sustainability of agro-ecology and livelihood of farmers. Many studies across the world have compared organic and chemical farming techniques to evaluate the relative benefits of each technique and make better decisions at the policy level as well as the farm management level.

6.1.5 Comparative studies

De Ponti et al. (2012), have compiled and analysed a meta-dataset of 362 published literature on organic-chemical comparative studies across the world. Their analysis showed that, on an average, the yield in organic system is about 80% of that of the conventional system. However, they observed a huge variation across the crop groups and regions, and attributed the maintenance of nutrient availability as the major challenge leading to the yield gap. NAAS, India has forecasted a negative balance of about 8 million MT of soil NPK in 2020, and estimated a maximum possibility of 25-30% of total nutrient requirement to be met by organic inputs (Abrol and Johri, 2005). In contrast, Yadav et al. (2010) have proposed a strategy in terms of resource management, farmer's livelihood, and policy alternative, to match the nutrient requirements of agriculture using livestock and other sources. Likewise, Ghosh (2004), has also shown that the shift from synthetic fertilizers to organic fertilizers is possible with a very limited financial implication on the farmers.

In India, several studies have compared the yield and income from organic and chemical farms of various crops over different states. In most cases, organic farms were reported to have a better profitability than chemical farms. However, the crop yield was found to have varying results depending upon the crop, period of organic conversion, region, landholding, irrigation etc. We describe a few key findings of these case studies in Table 6.1. Though these studies are on comparison of organic and chemical farming systems in India, they are mostly focused on yield and economic aspects. In this work, we use a holistic set of indicators identified in Chapter 5 to compare organic and chemical farming systems. Further, previous studies were usually local and relevant mainly for the region and the crop under study. For wider applicability, it is important to contextualize the sample under study with respect to regional or national scenario. So, we use Farm Assessment Index (FAI) for a universal comparison of farming systems across crops and regions.

Table 6.1 Comparative studies on organic and chemical farming systems in India

Reference	State	Crops	Parameters	Number of farmers and year	Remarks
(Ramesh et al., 2010)	MH, KA, TN, KL, and UTK.	Various horticultural and field crops	Yield Cost of cultivation Net returns Soil quality	50 + 50 (2008-09)	Organic farms had relatively lesser yield but better profitability and better soil quality.
(Charyulu et al., 2010)	GJ, MH, PB and UP	Various field crops	Yield Cost of cultivation Net returns	15 + 15 per state (2009-10)	Mixed results. In general, organic had lesser yield, low energy input, and higher labour input.
(Forster et al., 2013)	MP	Cotton, wheat, and soybean	Yield and gross margin	Randomized Block Design experiment (2007-10)	Organic had lesser yield during the first year of conversion but relatively similar yield during the second and third year of conversion.
(Patil et al., 2014)	KA	Various horticultural and field crops	Yield Net returns Nitrogen losses	30 + 15 Per village for two villages (2009)	Organic yield has been lesser in most cases but net margin has been higher. Net losses have been lesser in organic farm in case of crop failure. Conventional farms had higher nutrient loss and organic farms had negative nutrient balance or soil nutrient depletion.
(Raj et al., 2004)	AP	Cotton	Input economics and yield	29 + 11 (2004)	No significant difference in yield of organic and chemical farms, but organic farms had better profit due to lesser expenditure, especially in pest management.

(Sudheer, 2013)	AP	Paddy, redgram, and groundnut	Cost of cultivation and net returns	350 + 200 (2010-11)	Organic farms have relatively better net returns.
(Eyhorn et al., 2007)	MP	Cotton	Economic and soil parameters	58 + 112 62 + 108 (2003-04)	Gross margins in organic farms were higher than chemical farms due to their low input cost and premium price. Soil parameter had no significant difference.
(Venugopalan et al., 2010)	MH	Cotton, Green gram, chickpea, and soybean	Yield, quality of farm produce, diversity index and soil parameters	(2001-2005)	Yield and diversity index was slightly higher in organic than chemical farms. No quality difference. Soil organic carbon and zinc were higher in organic farms while pH and exchangeable sodium were higher in chemical farms.
(Panneerselvam et al., 2012, 2010)	UTK, MP, and TN.	Various field crops	Farm production, crop yield, input cost, and income	120 + 120 (2008)	Yield in organic farms was lesser than chemical farms. Profit margin was similar due to lesser input cost.

6.2 Field selection and data collection

6.2.1 Preliminary field work

Initially, six states including Andhra Pradesh, Gujarat, Karnataka, Maharashtra, Odisha and Tamil Nadu, were considered for the comparative study. An NGO working with organic farmers was identified for each of the states as the host institution and a preliminary visit was made for baseline survey. These preliminary visits showed a huge diversity in organic farming practices being followed by the farmers. Although there were hundreds of organic farmers associated with NGOs, various factors like absence of comparable chemical farmers in nearby locality, differences in cropping preferences within the farmer group, led to the discontinuation of Andhra Pradesh and Gujarat from the multi-state study. Similar reasons also led to change of field location in Tamil Nadu.

6.2.2 Selection of farmers

In coordination with Alliance for Sustainable and Holistic Agriculture (ASHA), New Delhi, regional host institutions were identified in each state as given in the Table 6.2. These organisations helped in farmer identification, data collection, and coordination. Purposive sampling was done for selecting the set of farmers.

Table 6.2 Local partners and the location of fields under the study

S No	State	Local partner	Districts of fields under the study
1	Maharashtra	i) Chetana Vikas, Wardha ii) Dharamitra, Wardha	Wardha, Nagpur and Chandrapur
2	Tamil Nadu	Tribal Health Initiative, Sittilingi	Dharmapuri
3	Odisha	Chetana Organic, Bhawanipatna	Kalahandi
4	Karnataka	MYRADA, HD Kote	Mysuru

Efforts were taken to have a sample with maximum number of rainfed small land holding farmers so that it is reflective of the vast majority of Indian farmers. The major criteria for selecting organic farmers in the study were that the farms should have been converted to organic at least 3 years earlier and practice multi-cropping and/or crop rotation. Chemical farmers were selected so as to form the best comparative group for the set of organic farmers. Chemical farms with similar farming conditions (soil, water availability, crop pattern, plot size etc.) and practicing similar management techniques were selected at closest possible locations.

Figure 6.1 shows the field sample locations across four states. The samples in Tamil Nadu, Odisha and Karnataka were located within 2- 4 villages in 10 km range. In case of Maharashtra, sample farms are spread over 100 km in 22 villages around Wardha in Nagpur, Chandrapur and Wardha district, as depicted by a larger green circle.

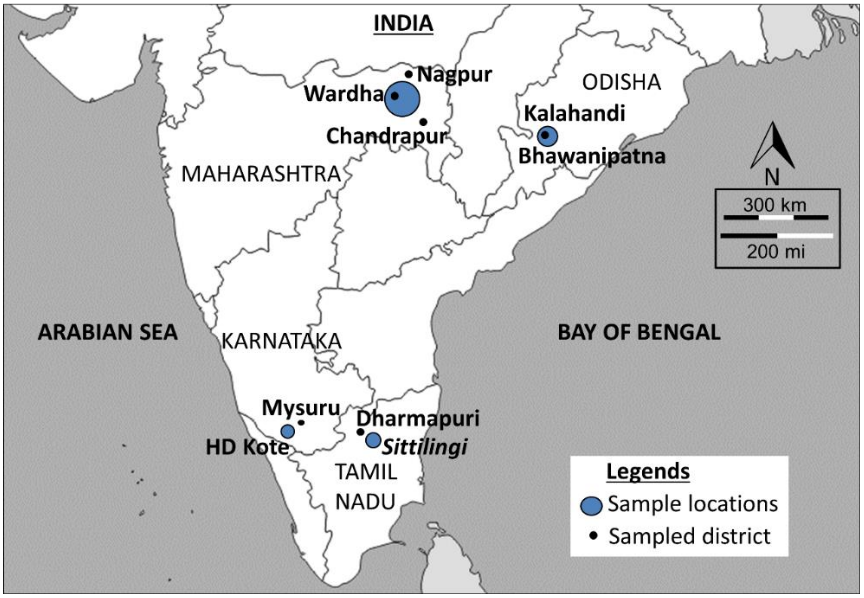


Figure 6.1 Location of fields samples in four different states

6.2.3 Data collection and processing

Questionnaire and surveys

Preliminary field visits were made during the year 2012-13 to understand the suitability of field areas selected for the study. Initially, a pilot survey was conducted using a set of three questionnaires designed to collect data related to farm input and output details. Each questionnaire was administered at three different stages of the season to capture the details at relatively shorter duration of time to avoid recall error. But multiple questionnaires caused redundancy in data collection and complicated the process of data compilation. So, the questionnaires were clubbed into a single questionnaire (Appendix 3) after the pilot studies. The pilot survey helped us in improving the structure and format of the questionnaire. It also helped to ease the data entry process for the surveyor. During the second year of the study, it was found that the data collection for the combined questionnaire took about two hours. The chances of recall error were very high at the end of the season as the data detailing was also higher. So, it was decided to maintain a farm diary to document the farm activities at a regular interval of three days with the help of field researchers.

Farm diary

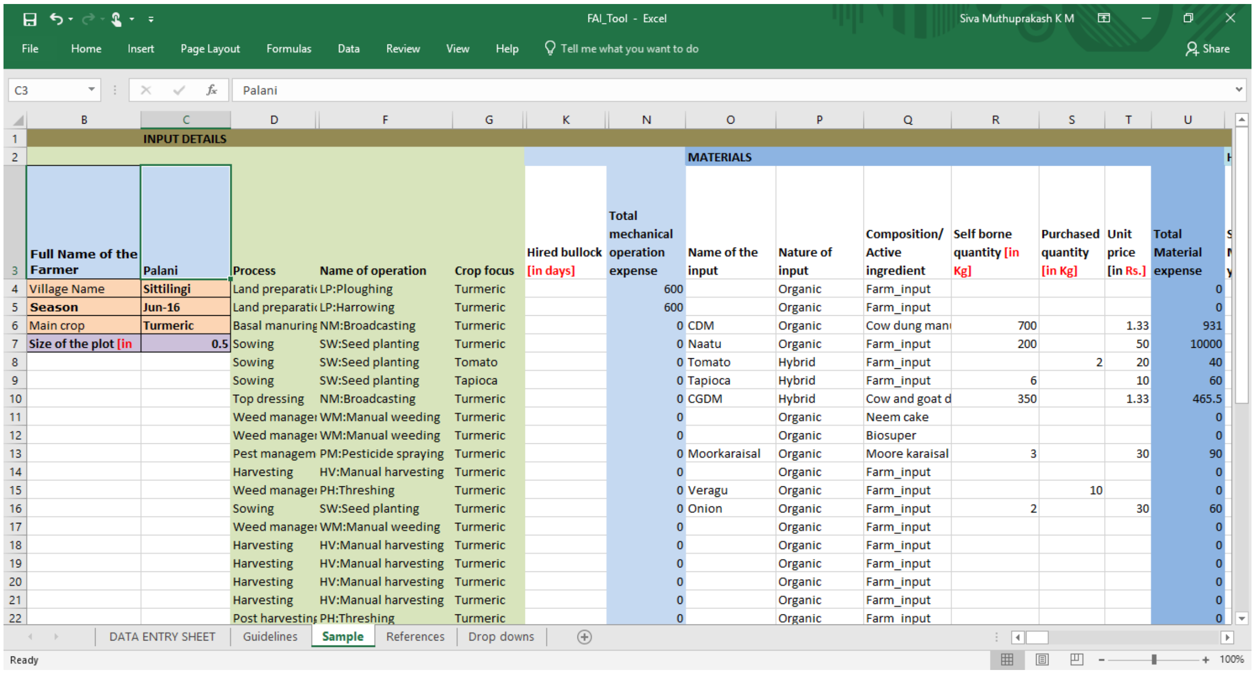
A field officer visited all the farmers once in every three days to collect information regarding the activities in their farm. A separate diary was maintained for each farmer participating in the study in which all the input/outputs, farming cost, labour used and other details were documented. A checklist of various activities involved in farming was created to help the field researcher in documenting all the activities in the farm. Since the checklist was not user-friendly and cumbersome to record data, a data entry form (Appendix 4) was designed to ensure that the field researcher records all the activities in the farm during each visit made to the farm. At the end of the season, the questionnaire was filled with help of the farm diary and the data was recorded in a pre-set format. Further, a data entry template was created to compile the data from each set of farmers under study.

Data entry forms

A data entry template was created in Microsoft Excel to compile the data from all field visit forms. Though the template was created with the objective of data compilation, it was gradually modified into a data analysis and FAI tool.

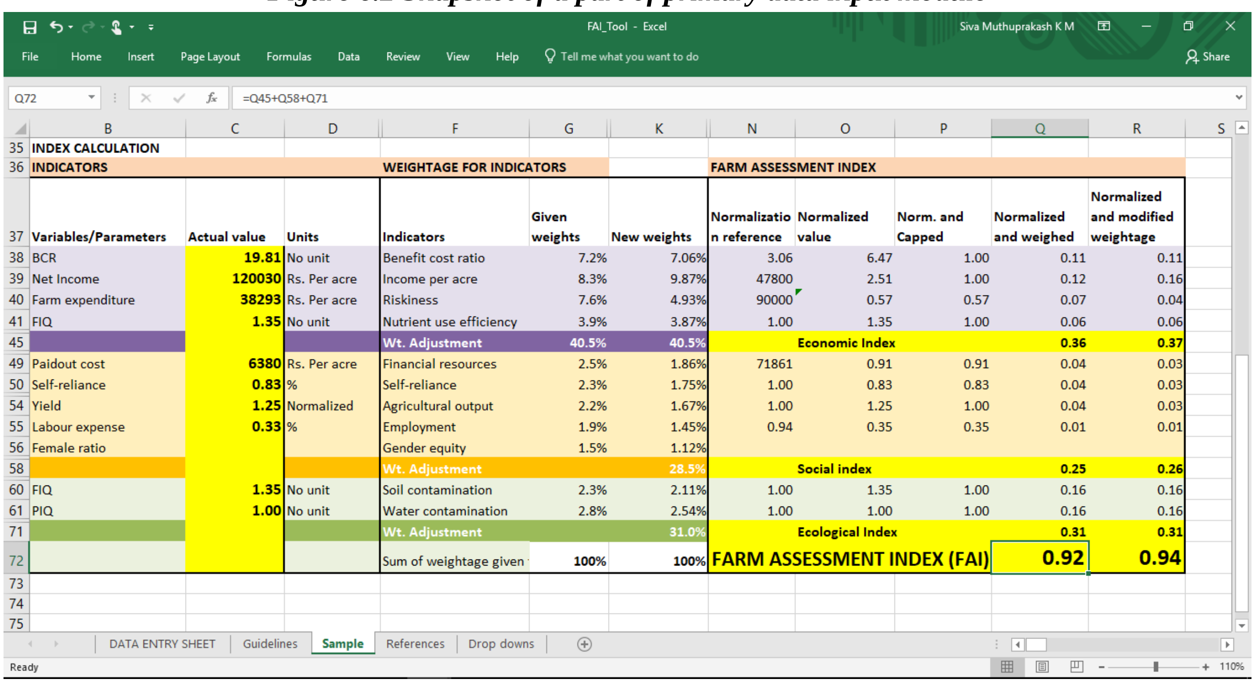
FAI Tool

The tool was designed to estimate all the selected indicators using a comprehensive set of primary data collected through farm dairy approach. Figure 6.2 and Figure 6.3 show the snapshot of a part of input and output module with a sample entry. The tool has five components namely user manual, sample entry, estimator, reference and options. The user manual sheet gives an introduction of the FAI tool and guidelines to use the tool for estimation of individual indicators and composite indices. The sample entry sheet illustrates the use of the tool with an example. Estimator sheet is the main component of the FAI tool where the primary data collected is fed into corresponding fields to estimate all the indicator values (actual and normalized), and composite indices. This sheet also has the option to alter the weightage assigned to indicator for estimating the composite indices.



	B	C	D	F	G	K	N	O	P	Q	R	S	T	U
1		INPUT DETAILS												
2								MATERIALS						
3	Full Name of the Farmer	Palani	Process	Name of operation	Crop focus	Hired bullock [in days]	Total mechanical operation expense	Name of the input	Nature of input	Composition/ Active ingredient	Self borne quantity [in Kg]	Purchased quantity [in Kg]	Unit price [in Rs.]	Total Material expense
4	Village Name	Sittilingi	Land preparati	LP:Ploughing	Turmeric		600		Organic	Farm_input				0
5	Season	Jun-16	Land preparati	LP:Harrowing	Turmeric		600		Organic	Farm_input				0
6	Main crop	Turmeric	Basal manuring	NM:Broadcasting	Turmeric		0	CDM	Organic	Cow dung man	700		1.33	931
7	Size of the plot [in	0.5	Sowing	SW:Seed planting	Turmeric		0	Naatu	Organic	Farm_input	200		50	10000
8			Sowing	SW:Seed planting	Tomato		0	Tomato	Hybrid	Farm_input		2	20	40
9			Sowing	SW:Seed planting	Tapioca		0	Tapioca	Hybrid	Farm_input	6		10	60
10			Top dressing	NM:Broadcasting	Turmeric		0	CGDM	Hybrid	Cow and goat d	350		1.33	465.5
11			Weed managei	WM:Manual weeding	Turmeric		0		Organic	Neem cake				0
12			Weed managei	WM:Manual weeding	Turmeric		0		Organic	Biosuper				0
13			Pest managem	PM:Pesticide spraying	Turmeric		0	Moorkaraisal	Organic	Moore karaisal	3		30	90
14			Harvesting	HV:Manual harvesting	Turmeric		0		Organic	Farm_input				0
15			Weed managei	PH:Threshing	Turmeric		0	Veragu	Organic	Farm_input		10		0
16			Sowing	SW:Seed planting	Turmeric		0	Onion	Organic	Farm_input	2		30	60
17			Weed managei	WM:Manual weeding	Turmeric		0		Organic	Farm_input				0
18			Harvesting	HV:Manual harvesting	Turmeric		0		Organic	Farm_input				0
19			Harvesting	HV:Manual harvesting	Turmeric		0		Organic	Farm_input				0
20			Harvesting	HV:Manual harvesting	Turmeric		0		Organic	Farm_input				0
21			Harvesting	HV:Manual harvesting	Turmeric		0		Organic	Farm_input				0
22			Post harvestin	PH:Threshing	Turmeric		0		Organic	Farm_input				0

Figure 6.2 Snapshot of a part of primary data input module



	B	C	D	F	G	K	N	O	P	Q	R
35	INDEX CALCULATION										
36	INDICATORS			WEIGHTAGE FOR INDICATORS			FARM ASSESSMENT INDEX				
37	Variables/Parameters	Actual value	Units	Indicators	Given weights	New weights	Normalization reference	Normalized value	Norm. and Capped	Normalized and weighed	Normalized and modified weightage
38	BCR	19.81	No unit	Benefit cost ratio	7.2%	7.06%	3.06	6.47	1.00	0.11	0.11
39	Net Income	120030	Rs. Per acre	Income per acre	8.3%	9.87%	47800	2.51	1.00	0.12	0.16
40	Farm expenditure	38293	Rs. Per acre	Riskiness	7.6%	4.93%	90000	0.57	0.57	0.07	0.04
41	FIQ	1.35	No unit	Nutrient use efficiency	3.9%	3.87%	1.00	1.35	1.00	0.06	0.06
45				Wt. Adjustment	40.5%	40.5%	Economic Index			0.36	0.37
49	Paidout cost	6380	Rs. Per acre	Financial resources	2.5%	1.86%	71861	0.91	0.91	0.04	0.03
50	Self-reliance	0.83	%	Self-reliance	2.3%	1.75%	1.00	0.83	0.83	0.04	0.03
54	Yield	1.25	Normalized	Agricultural output	2.2%	1.67%	1.00	1.25	1.00	0.04	0.03
55	Labour expense	0.33	%	Employment	1.9%	1.45%	0.94	0.35	0.35	0.01	0.01
56	Female ratio			Gender equity	1.5%	1.12%					
58				Wt. Adjustment		28.5%	Social index			0.25	0.26
60	FIQ	1.35	No unit	Soil contamination	2.3%	2.11%	1.00	1.35	1.00	0.16	0.16
61	PIQ	1.00	No unit	Water contamination	2.8%	2.54%	1.00	1.00	1.00	0.16	0.16
71				Wt. Adjustment		31.0%	Ecological Index			0.31	0.31
72				Sum of weightage given	100%	100%	FARM ASSESSMENT INDEX (FAI)			0.92	0.94

Figure 6.3 Snapshot of a part of output module with indicator estimates, weightage and indices

Data entry and cleaning

Reference sheet contains all the reference values used for normalization of indicators which can be updated according to spatiotemporal application. Options sheet provides the room to add or modify the drop-down menu of certain parameters and functions used in the estimator sheet. This template has been made available freely available through the website for an open access (https://www.cse.iitb.ac.in/~damani/). While this template gives the Farm Assessment Index (FAI) score for any farm, it can also be used for personal accounting of expenditure and income. Data from field visit forms were entered into FAI tool and verified for the completeness. Data gaps were identified and resolved either by revisiting the farm diaries or clarifications were sought from farmers. Extreme values in the data were also rechecked with the farmers.

6.2.4 Soil sampling and testing

Soil parameters like nutrient content, soil pH, salinity etc. are selected for the FAI and estimation of these soil parameters requires soil sample analysis. Though it is ideal to collect and analyse samples from all the farms in the study, only a representative set of samples were analysed due to limitations in resources and logistics. Sixty soil samples were collected as described below:

- Organic farms: 3 composite replicates of soil from 10 farms to make 30 composite samples
- Chemical farms: 3 composite replicates of soil from 10 farms to make 30 composite samples

Irrespective of the size of the field, soil was collected from ten different spots which constituted three different composite soil samples. First two composite samples were taken from three primary samples collected diagonally across the field. Third samples were taken using four primary samples collected in a rhombus fashion from the middle parts of the field. A core cutter was used to dig up to 15 cm of soil to collect each primary sample. Leaves and root debris were removed and the primary samples were mixed well before taking the composite sample. Approximately 1 kg of the well-mixed sample was packed in a cotton bag or a poly bag and labeled. Similarly, three composite replicates were collected from each of the 10 organic and 10 chemical farmers. In total, 60 samples were transported for testing.

Three rounds of soil sample collection were done in Maharashtra which includes once in soybean plots and twice in cotton plots. The first round of soil samples were collected during the month of April in 2015 in soybean plots. The main reason for the choice of soybean plot for soil sampling was the availability of same crop in comparative organic and chemical farmers. However, there was no significant difference between organic and chemical farms in the soil parameters of soybean plot as it will be discussed in section 7.1. So the following rounds of soil samples were taken from cotton plots. The second round of soil samples was collected from cotton plots during the month of November 2015. The third round of samples was collected in the same cotton plots during the month of April 2016 after the crop harvest.

Soil testing was partly done at IIT Bombay and partly done in a laboratory in Pune. (Maharashtra Rajya Draksha Baigatar Sangh, Pune). Parameters like total Nitrogen, available phosphorus, available potassium, soil organic carbon, pH, and salinity were analysed using the standard protocol provided in soil testing manual of India. Table 6.3 gives the methods used to estimate the soil parameters and their reference for the experimental protocol.

Table 6.3 Methods used for soil parameter estimation

S No	Parameter	Method	Reference
1	Soil Organic Carbon	Walkley and Black method	(DAC, 2011)
2	Total Nitrogen	Kjeldahl method	
3	Available phosphorous	Modified Bray's method	
4	Available potassium	Flame Photometric method	
5	pH	pH meter	
6	Salinity	Electrical conductivity meter	
7	Soil microbial diversity (Actinomycetes, total bacteria, total fungi, nitrogen fixers and phosphate solubilizers)	Enriched or selective media plating techniques	(Caceres, 1982; Gupta et al., 2012; Sivapalan et al., 1993)

6.3 Methodological challenges

Practical application of any assessment methodology involves various challenges. Viglizzo et al. (2006) have summarized several practical constraints in data collection and documented the challenges faced during the field application to improve transparency and reliability of the study. They have also described various limitations in a methodology designed to make them adaptable. In this section, we describe the challenges encountered during the field application of FAI in comparison with various other field studies.

6.3.1 Challenges in the survey

Survey-based field data needs to be handled cautiously as they have the inherent problem of faulty perception and recollection error of the sampled population (Sharma and Shardendu, 2011). A detailed data was collected to estimate indicators like farm expenditure, income, labour involved, self-borne expenditure, paidout expenditure, fertilizer and pesticide impact quotient, etc.

Table 6.4 gives a list of few challenges faced during the data collection and the mechanism by which they were addressed.

Table 6.4 Challenges in farm surveys and measure taken to address the issues

S No	Challenges in data collection	Actions to address the issue
1	Participation of chemical farmers: Since the local NGO works mainly with organic farmers, chemical farmers were reluctant to spend time in sharing their farm information.	Farmers' orientation workshop
2	Technical specifications in farm inputs: Details like active ingredients in pesticides, nutrient composition of fertilizers etc. are required for estimation of a few indicators. But, it is very difficult to acquire such information from farmers.	Detailed information regarding the common practice in pesticide and fertilizer application was collected from the local shopkeeper. Technical specifications of various farm inputs were recorded from their stock.
3	Details on outsourced process/operations: A few farmers outsource their farm operation individually at a fixed rate per acre. For example, one round of weeding process is outsourced for a cost of ₹2000 per acre for cotton. In such cases, details of labour and other inputs may not be available with the farmer.	Labour details are imputed from the average.
4	Quantities of self/farm borne inputs: Farm borne inputs are not measured as they are applied directly to the field.	The quantities are estimated with help of utensils used or the number of livestock they own.
5	Self-labour and its variability: When a farmer works in his/her own farm, the time he/she spends in the field varies from two hours to more than 6 hours.	Independent of the number of hours spent, the number of working days is accounted unless it is for irrigation.
6	Conversion of farming methods (organic to chemical and chemical to organic) by the sample farmers during the course of study led to the drop of several farmers from the sample.	New set of farmers were identified and included in the sample.
7	Since many of the fields are located in remote areas which demand a tiresome travel for the field researchers to meet the farmers individually and collect the data regularly, field researchers often tend to leave the job at any point of the season.	The data collection is taken as a part-time activity of the field officers who are already working with the local NGO.

Similar challenges had been experienced by Merlín-Uribe et al. (2013), especially for data collection regarding economic variables and details of farm practice like agro-chemical inputs especially pesticide dosage. A study on comparing certified and un-certified coffee plantations has observed several methodological challenges starting from identification of sample farms, data collection, variations with local measurement, to that of collecting economic details. It was also observed that there were several challenges in design of questionnaire, selection of respondents, repetition of questions and time consumption. The field experience of COSA (Committee on Sustainability Assessment) has stressed upon capacity building of local organizations to help improve the quality of data and achieve the objective of the study (Giovannucci et al., 2008).

Farmers' orientation workshops

Farmers' orientation workshops (Figure 6.4) were organized separately for organic and chemical farmers in the study. The main objective of farmers' orientation workshop was to increase the participation of farmers in the study. The workshop helped in introducing the study and explaining the objectives, benefits, methodology etc., to all farmers. It also helped us to understand their farm condition, farming practices etc. To incentivize the farmers to attend the orientation workshop, an exposure visit was also organized during the workshop. During the exposure visit, farmers visited a few model farms in agriculture universities or NGOs, which gave them the opportunity to learn new farming methods and practices.

Figure 6.4 Farmer orientation workshop in Tamil Nadu and Odisha

The workshop was also used as a platform to get the opinions from farmers regarding various indicators and their weightage to different dimensions of the FAI. A brief exercise on group model building of farm was done during the workshop. However, as observed by (Speelman et al., 2007) in the process of indicator selection, modelling exercise received a very little input from the stakeholders during the participatory discussion. Since the process of assigning weightage to each indicator is too complicated, only the relative importance of three representative indicators including income for economic dimension, soil fertility and sustainability for ecological dimension, and health for social dimension, were considered. It was interesting to note that the women farmers gave significantly higher weight to health indicators while male farmers gave significantly higher weightage for net income.

6.3.2 Challenges in soil sampling and testing

Sampling and testing of such a large number of soil samples turned out to be a very challenging task. Some of the challenges faced in soil sampling and testing are as follows

- Since the time of harvest varied across individual farmers and across the type of crop under cultivation, it was difficult to collect the samples uniformly during their respective harvest period.
- The process of sample collection was tedious and heavy time consuming as the fields were located in remote areas that were spread over a hundred kilometre in Maharashtra.
- Packing and transporting of sixty kilograms of samples to laboratories situated several hundred kilometres far, subjects the sample to various externalities.
- Heterogeneity of soil properties within the sample plot and subjectivity of soil testing facilities and conditions were the major challenges for soil testing. Significant differences even by two folds were observed for most of the parameters among the soil samples collected from the same plot. Similarly, the results from different labs for the same sample and same parameter varied significantly.
- While soil sampling and testing were the most resource consuming part of the holistic assessment, the results and inferences from it were less conclusive.

6.3.3 Alternative questionnaire

As discussed in the previous section, data collection for the entire set of indicators is a difficult and resource consuming task. While data collection for such a large number of indicators by itself is a tedious job, detailing of each variable to capture them accurately, and timely survey to avoid recollection errors, makes the data collection even more laborious. To overcome this limitation, a questionnaire based on broader questions was designed to estimate all the indicators. Though moving from a quantitative measure to a qualitative one involves several assumptions and simplification, it eases the comparative assessment of farming practices and reduces the data requirement thereby making it suitable for large-scale applications (Rigby et al., 2001).

The sample questionnaire was discussed during the Delphi panel workshop. In this questionnaire methodology, value of each indicator (I_1, I_2,…I_n) is computed using a set of multiple-choice questions (Q_1, Q_2,…Q_m). Each question has a different weightage for different indicators given by a matrix W with 'n' rows and 'm' columns (each i^{th} row representing an indicator and each j^{th} column corresponding to a question). Further, each option in a given j^{th} question can have a different score associated for different indicators given by a matrix S^j with 'n' rows and 'o' columns (each i^{th} row representing an indicator and each k^{th} column corresponds to the score for different choice in a given j^{th} question for i^{th} indicator when the specific option is selected). Finally, we have an input binary matrix R^j which gives the choice selected by the farmer for the j^{th} question. The feedback or answers from the farmer for each question is converted into a binary matrix with 'o' rows corresponding to the options in each question. Then the raw value contributed by j^{th} question to i^{th} indicator is given by v_i^j in equation (1). The final value for each indicator is estimated from the weighted sum of the raw score of the indicator from each question as given in the equation (2) and (3).

$$W = \begin{bmatrix} w_{11} & w_{12} & \dots w_{1m} \\ w_{21} & w_{22} & \dots w_{2m} \\ \vdots & \vdots & \vdots \\ w_{n1} & w_{n1} & \dots w_{nm} \end{bmatrix}$$

$$S^j = \begin{bmatrix} s_{11}^j & s_{12}^j & \dots s_{1c}^j \\ s_{21}^j & s_{22}^j & \dots s_{2c}^j \\ \vdots & \vdots & \vdots \\ s_{n1}^j & s_{n2}^j & \dots s_{nc}^j \end{bmatrix}$$

$$R^j = \begin{bmatrix} b_1^j \\ b_2^j \\ \vdots \\ b_c^j \end{bmatrix}$$

$$v_i^j = s_{i1}^j * b_1^j + s_{i2}^j * b_2^j + \dots + s_{ic}^j * b_c^j \qquad \text{.....(1)}$$

$$I_i = \sum_{j=1}^{m} w_{ij} * v_i^j \qquad \text{.....(2)}$$

$$I_i = \sum_{j=1}^{m} w_{ij} * \left(s_{i1}^{j} * b_1^{j} + s_{i2}^{j} * b_2^{j} + .. + s_{ic}^{j} * b_c^{j}\right) \quad .....(3)$$

For example, we consider a set of three indicators *viz.*, soil health, biodiversity and GHG emission, which are covered using six questions as given in Table 6.6. A weightage is assigned to each of the questions to each indicator as shown in Table 6.5. Each question has five different options marked with specific score for each indicator as shown in Table 6.6. We assume a response by a farmer and represent it in binary as shown in Table 6.7. Then we derive a raw value for each indicator for a corresponding question followed by a weighted value as shown in Table 6.8. The sum of weighted value from each question corresponding to a specific indicator gives the final value of the indicator.

Table 6.5 Weightage (W) assigned to individual questions for each indicator

S No	Indicator	Q1	Q2	Q3	Q4	Q5	Q6	Total
1	Soil health	0	0.25	0.25	0.4	0	0.1	1
2	Biodiversity	0.5	0.2	0.3	0	0	0	1
3	GHG emission	0	0	0.3	0	0.5	0.2	1

Table 6.6 List of questions along with choices and their corresponding scores for different indicator

S No.	Questionnaire and the response choice	Scores for the choices (S^j)		
		Soil health	Biodiversity	GHG Emission
Q1	*How many intercrops are present during the current season?*			
	i. 1-2	0	0.5	0
	ii. 3-5	0	0.75	0
	iii. 5-10	0	1	0
	iv. >10	0	1	0
	v. None	0	0	0
Q2	*How many times legume crop has been cultivated as main crop in last three years?*			
	i. 1	0.25	0.25	0
	ii. 2	0.5	0.5	0
	iii. 3	0.75	0.75	0
	iv. 4	1	1	0
	v. Nil	0	0	0
Q3	*What is the tillage practice carried out in the field for the current season?*			
	i. No tillage	0.3	1	0.5
	ii. Green manuring	0.4	0	0.5
	iii. Mulching	0.3	0	0

	iv. Conservative tillage	0.2	0	0.2
	V. None	0	0	0
Q4	*What is the amount of Farmyard manure/compost/other organic inputs applied in the field during this season?*			
	i. 10-100	0.2	0	0
	ii. 100-500	0.5	0	0
	iii.500-2000	0.75	0	0
	iv. >2000	1	0	0
	v. None	0	0	0
Q5	*What is the amount of chemical fertilizer applied in the field during this season?*			
	i. 10-50	0	0	0.75
	ii. 50-100	0	0	0.5
	iii.100-200	0	0	0.25
	iv. >200	0	0	0
	v. None	0	0	1
Q6	*How many number of batches were the fertilizers applied?*			
	i. 1	0	0	0
	ii. 2	0	0	0.25
	iii. 3	0	0	0.5
	iv. 4	1	0	0.75
	v. Nil	0	0	1

Table 6.7 Response of the farmer to the questionnaire converted into binary form

S No	**Choice (R^j)**	**Q1**	**Q2**	**Q3**	**Q4**	**Q5**	**Q6**
1	i.	0	0	0	0	1	1
2	ii.	0	1	0	0	0	0
3	iii.	1	0	1	0	0	0
4	iv.	0	0	1	1	0	0
5	v.	0	0	0	0	0	0

Table 6.8 Raw value for indicators from different questions and final estimate of indicator

	Raw scores for indicator from each question (v_i^j)			**Weight to each question (w_{ij})**			**Weighted score for indicator from each question ($w_{ij} * v_i^j$)**		
	I_1	**I_2**	**I_3**	**I_1**	**I_2**	**I_3**	**I_1**	**I_2**	**I_3**
Q1	0	1	0	0	0.5	0	0	0.50	0
Q2	0.5	0.5	0	0.25	0.2	0	0.125	0.10	0
Q3	0.5	0	0.2	0.25	0.3	0.3	0.125	0.00	0.06
Q4	1	0	0	0.4	0	0	0.4	0.00	0
Q5	0	0	0.75	0	0	0.5	0	0.00	0.385
Q6	0	0	0	0.1	0	0.2	0	0.00	0
Total weight/ Final indicator value (I_i)				1	1	1	**0.65**	**0.60**	**0.44**

In this way, all the indicators are estimated based on the answers provided by the farmers for a set of multiple choice questions. The main advantage of the methodology is that it will enable us to estimate all the indicators and avoid elaborate data collection which is often erroneous and resource consuming. The execution of the survey is simpler and quick as it includes multiple choice questions. This method also provides room for a suggestive action plan for farmers as soon as the survey is conducted. Moreover, as the social and cultural phenomena demand a qualitative approach due to their subjective characteristics (Denzin and Lincoln, 2008; Myers, 1997), this alternative qualitative approach will enable us to capture the socio-cultural indicators in a better way.

However, the disadvantage of this methodology is the subjectivity in the questionnaire and scores given for the options as well as weightage assigned to each question. Though the execution of survey is simple, designing a robust and reliable questionnaire along with indicator estimation score demands an elaborate discussion and consensus building. In order to process the survey results to estimate indicators, a web-based computational tool is being designed as a part of a different project. The field application of this questionnaire with a participatory validation of the questionnaire will make the tool robust and reliable. This platform will aid in making the indicators identified as a functional tool for comparing and monitoring the sustainability of farming practices.

Chapter 7 Results and Discussion

In this section, we describe the results from the field samples from all the four states under the study. Though the data collection was done for three years (June 2013 – May 2016) in all the states, the first-year data had several gaps in all the states except Tamil Nadu. In order to avoid misinterpretation of farms, the first-year data from Maharashtra, Odisha and Karnataka were not included in the data analysis. First, we discuss the comparison of organic and chemical farms with respect to individual indicators, followed by the description on various composite indices, then its statistical comparison using meta-analysis, and finally the sensitivity analysis of FAI with respect to each indicator. Data from 100 organic and 100 chemical farmers covering a total of 764 plot data were collected and analysed. Table 7.1 gives the details on the number of plots in each crop during different year in different states.

Table 7.1 Number of plots under major crops

State	**Year**	**2013-14**		**2014-15**		**2015-16**	
	Crop	**Organic**	**Chemical**	**Organic**	**Chemical**	**Organic**	**Chemical**
Tamil Nadu	Turmeric	19	27	30	26	28	27
	Paddy	18	21	25	18	21	19
Maharashtra	Cotton			19	21	14	19
	Soybean			19	19	22	21
	Wheat			14	8	11	14
	Gram			8	7	11	13
Odisha	Cotton			30	30	30	30
	Paddy			22	27	18	28
Karnataka	Cotton			8	6	7	9
	Sub-Total	85		337		342	
	Total	**764**					

7.1 Trends in indicators

Although FAI helps us in summarising the overall ranking of farming system, trends of individual indicators are also important. Radar chart is one of the commonly used tools to compare multiple parameters like indicators of various farming systems. A radar chart is a powerful visual tool to communicate the relative trends of multiple parameters in a comparative study. This chart requires a uniform scale of measure across all the parameters under study. We use the normalized indicators to present the crop wise and year wise results with respect to the organic and chemical farming systems. It is important to note that cost indicators like risk, paidout cost etc., are normalized with a negative function and so higher the score, the better they are. The mean of normalized indicator values and their corresponding indicator means are given in this section. Further, several observations and inferences from the patterns of individual indicators as also discussed.

7.1.1 Tamil Nadu

Turmeric

Figure 7.1 shows the trends of various indicators in turmeric cultivation over three years in Sittilingi, Tamil Nadu. Table 7.2 gives the corresponding normalized indicator values and Table 7.3 gives the actual value of each indicator with its unit.

- In general, most indicators had better values in case of organic farms over all three years. Although chemical farms had a slightly better yield during the first year of the study, organic farms have produced higher yield during the second and third year. This change in the trend can be attributed to increased input application by organic farmers during the second and third year of the study.
- In spite of lesser yield and higher paidout cost in organic farm during the first year, net income and BCR were better in organic farms than that of chemical farms. This is mainly due to the premium price fetched by the organic produce.

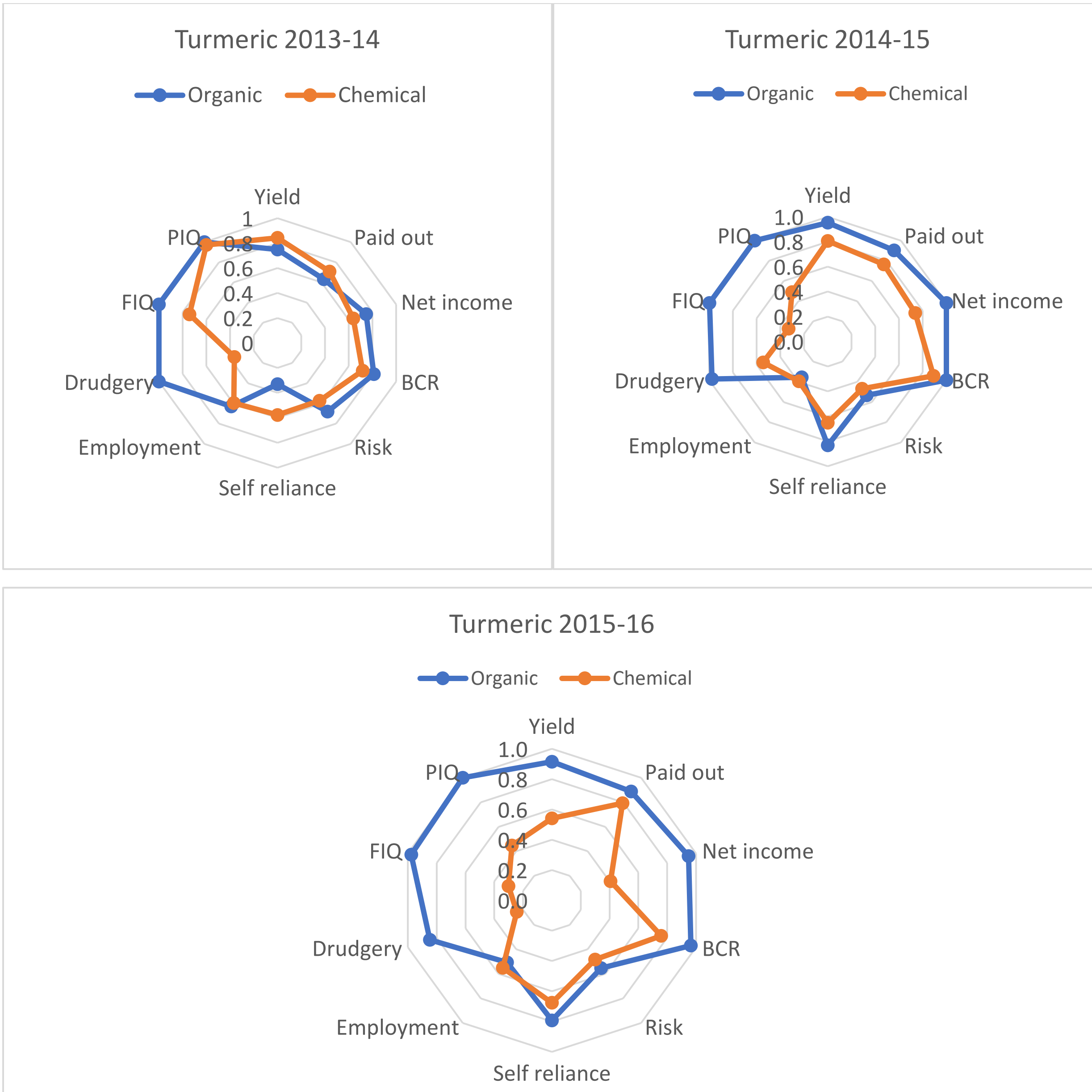


Figure 7.1 Radar charts for individual indicators of turmeric cultivation in Sittilingi, Tamil Nadu

Table 7.2 Normalized indicator values of turmeric cultivation in Sittilingi, Tamil Nadu

Year	**2013-14**		**2014-15**		**2015-16**	
Indicator	**Organic**	**Chemical**	**Organic**	**Chemical**	**Organic**	**Chemical**
Norm. yield	0.75	0.84	0.95	0.81	0.92	0.54
Financial resource	0.63	0.71	0.90	0.77	0.89	0.79
Net income	0.75	0.64	1.00	0.74	0.95	0.41
BCR	0.81	0.72	1.00	0.89	0.96	0.76
Risk	0.50	0.50	0.53	0.47	0.55	0.48

Self-reliance	0.41	0.54	0.83	0.65	0.79	0.68
Employment	0.63	0.59	0.35	0.39	0.51	0.55
Drudgery	0.50	0.36	0.98	0.55	0.85	0.24
FIQ N	1.00	0.79	0.99	0.32	0.97	0.23
FIQ P	1.00	0.85	1.00	0.36	0.99	0.29
FIQ K	1.00	0.59	1.00	0.31	0.98	0.39
FIQ-Overall	1.00	0.74	1.00	0.33	0.98	0.30
PIQ	1.00	0.97	1.00	0.49	1.00	0.45

Table 7.3 Actual indicator values of turmeric cultivation in Sittilingi, Tamil Nadu

Indicator	**Year**	**2013-14**		**2014-15**		**2015-16**	
	Unit	**Organic**	**Chemical**	**Organic**	**Chemical**	**Organic**	**Chemical**
Yield	kg/acre	649	675	1004	738	823	405
Financial resource	₹/acre	26583	20928	6953	16866	8043	14923
Net income	₹/acre	51963	34281	119793	42392	100594	19989
BCR	DMNL	3.10	2.20	19.80	4.23	18.69	2.55
Risk	₹/acre	45281	45330	42117	47946	40225	46514
Self-reliance	₹/acre	18698	24402	35164	31079	32182	31591
Employment	Percentage	59	56	33	37	48	52
Drudgery	DMNL	3.13	2.26	9.20	3.47	5.91	1.51
FIQ N	DMNL	-19.56	3.60	-10.11	30.40	-3.36	33.96
FIQ P	DMNL	-22.58	-2.58	-10.46	26.89	-5.66	29.04
FIQ K	DMNL	-16.88	11.87	-12.21	29.05	-6.33	27.03
PIQ	DMNL	0.00	0.65	0.00	7.14	0.00	7.34

- Risk, drudgery, FIQ, and PIQ remained better in organic farms over all three years because organic farming involved lesser total farm expenditure, higher income per unit labour expense, no excess nutrient and zero synthetic pesticide usage, respectively.
- Self-reliance was lesser in organic farms during the first year but increased significantly during the second and third year as there was a significant increase in home-borne farmyard manure application. This led to a decrease in the proportion of labour expenditure in the total farm expenditure making the chemical farm score better from an employment perspective.
- The negative FIQ in Table 7.3 shows that there is a negative farm-gate nutrient balance in the respective nutrient where the nutrient removed from the farm through farm produce is higher than that of nutrient applied by the farmer. However, the farm-gate nutrient balance does not include the natural synthesis in the farm. Since FIQ is a proxy indicator to measure

the potential run-off from the field, the negative nutrient balance implies that lesser nutrient is available for run-off and so FIQ gets a positive score on normalization.

- Further, a decrease in FIQ of chemical farming during the second and third year indicates the increase in fertilizer usage without a corresponding increase in farm produce. This can also be attributed for increase in cost of cultivation and decrease in net income for chemical farms over the years.
- Similarly, PIQ of chemical farms has also decreased due to increased use of pesticides during the second and third year of the study.

Paddy

Figure 7.2 shows the trends of various indicators in paddy cultivation over three years in Sittilingi, Tamil Nadu. Table 7.4 gives the corresponding normalized indicators values and Table 7.5 gives the actual value of each indicator with its unit.

- In contrast to turmeric, organic farms had better yield than chemical farms during the first year of the study but the chemical farms had better yield during the second and third year of the study. This is attributed to the significant increase in potassium input in chemical farms.
- Although the yield from chemical farm is higher than that of organic farms for the second and third year, their net income has remained lesser than that of organic farms. This is mainly due to the higher paidout cost of cultivation.
- In general, paidout cost, net income, BCR, self-reliance, and employment has been better in case of organic farm over all three years of the study except for a marginally higher net income in chemical farm during the third year of the study. This higher net income in chemical farms is mainly due to a significant increase in yield during the third year.
- Risk in both organic and chemical farms was significantly affected in the third year of the study due to increase in wage rates from ₹300 and ₹150 to ₹350 and ₹200 for men and women respectively. This increased the total cost of cultivation significantly.
- Drudgery has been very poor in both organic and chemical farms as the net receipt from the farm produce is relatively less compared to the labour involved in production process.

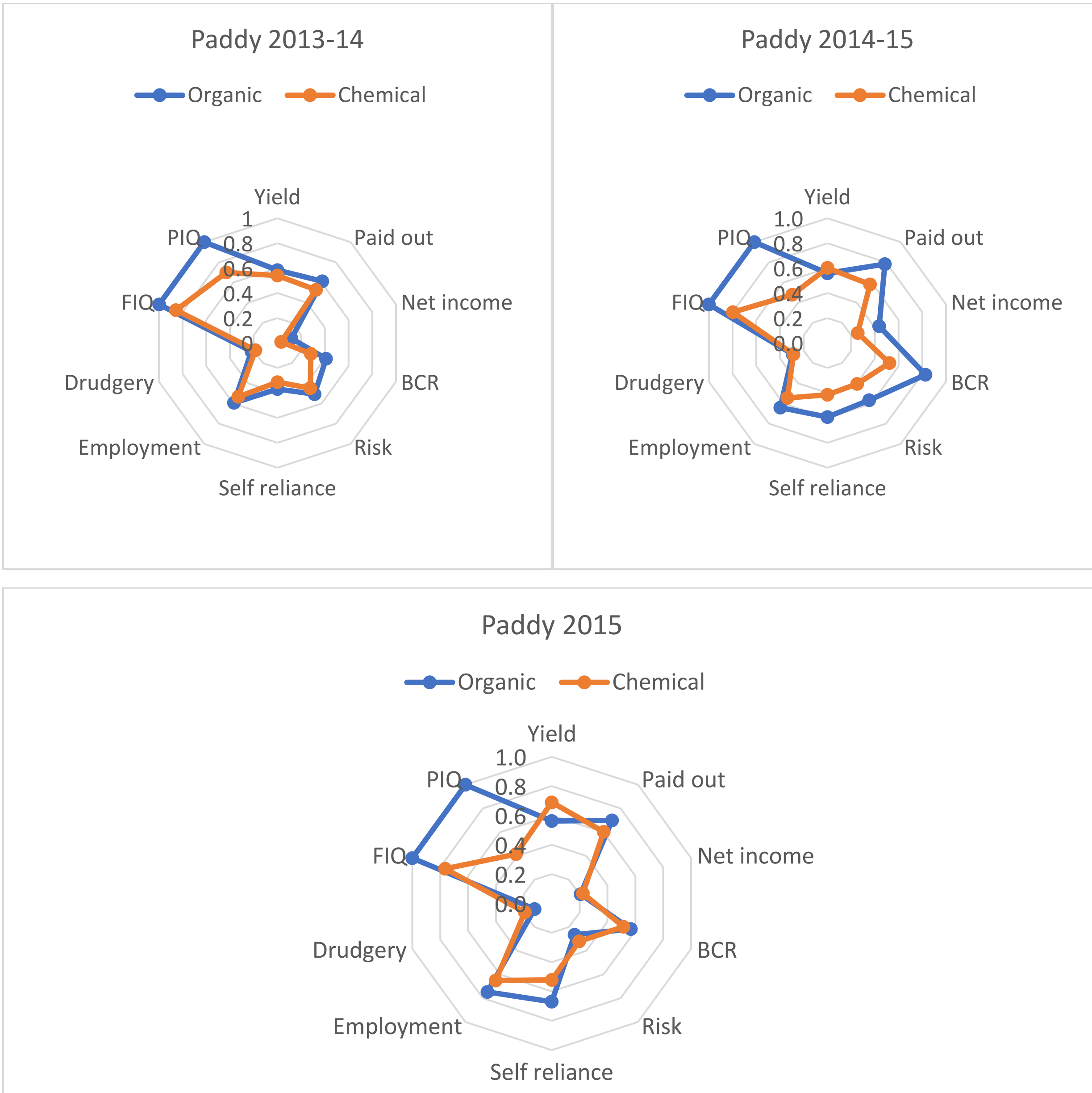


Figure 7.2 Radar charts for individual indicators of paddy cultivation in Sittilingi, Tamil Nadu

- In contrast to turmeric, the increase in synthetic fertilizer application in chemical farms has not decreased the FIQ as the yield has also increased significantly over the years.
- PIQ of chemical farms has been decreasing over the years indicating an increase in the pesticide usage.

Table 7.4 Normalized indicator values of paddy cultivation in sittilingi, Tamil Nadu

Indicator	2013-14		2014-15		2015-16	
	Organic	Chemical	Organic	Chemical	Organic	Chemical
Norm. yield	0.58	0.54	0.56	0.60	0.56	0.69
Financial resource	0.61	0.53	0.78	0.58	0.70	0.60
Net income	0.12	0.03	0.44	0.26	0.21	0.22
BCR	0.41	0.28	0.83	0.52	0.57	0.52
Risk	0.51	0.45	0.57	0.40	0.26	0.32
Self-reliance	0.37	0.31	0.59	0.41	0.67	0.52
Employment	0.59	0.53	0.64	0.54	0.75	0.65
Drudgery	0.22	0.18	0.29	0.29	0.12	0.19
FIQ N	1.00	0.68	1.00	0.77	1.00	0.71
FIQ P	1.00	0.89	1.00	0.66	1.00	0.60
FIQ K	1.00	1.00	1.00	0.97	1.00	0.99
FIQ-Overall	1.00	0.00	1.00	0.80	1.00	0.77
PIQ	1.00	0.70	1.00	0.48	1.00	0.41

Table 7.5 Actual indicator values of paddy cultivation in Sittilingi, Tamil Nadu

Indicator	Unit	2013-14		2014-15		2015-16	
		Organic	Chemical	Organic	Chemical	Organic	Chemical
Yield	kg/acre	1327	1207	1366	1534	1351	1677
Financial resource	₹/acre	13529	16478	7573	14664	10470	13845
Net income	₹/acre	2395	-2784	12618	6555	6015	5871
BCR	DMNL	1.20	0.82	3.06	1.54	1.85	1.51
Risk	₹/acre	21515	24130	18888	25996	33554	31316
Self-reliance	₹/acre	7986	7652	11315	11332	23084	17471
Employment	Percentage	56	50	60	51	70	61
Drudgery	DMNL	1.36	1.14	1.82	1.78	0.76	1.19
FIQ N	DMNL	-19.74	31.97	-20.93	21.59	-17.93	27.16
FIQ P	DMNL	-12.62	0.86	-10.40	17.22	-10.10	19.55
FIQ K	DMNL	-34.77	-20.22	-35.46	-17.20	-35.34	-24.32
PIQ	DMNL	0.00	3.94	0.00	4.72	0.00	6.12

7.1.2 Maharashtra

Cotton

Figure 7.3 shows the trend of various indicators in cotton cultivation over two years in villages around Wardha, Maharashtra. Table 7.6 gives the corresponding normalized indicators values and Table 7.7 gives the actual value of each indicator with their unit.

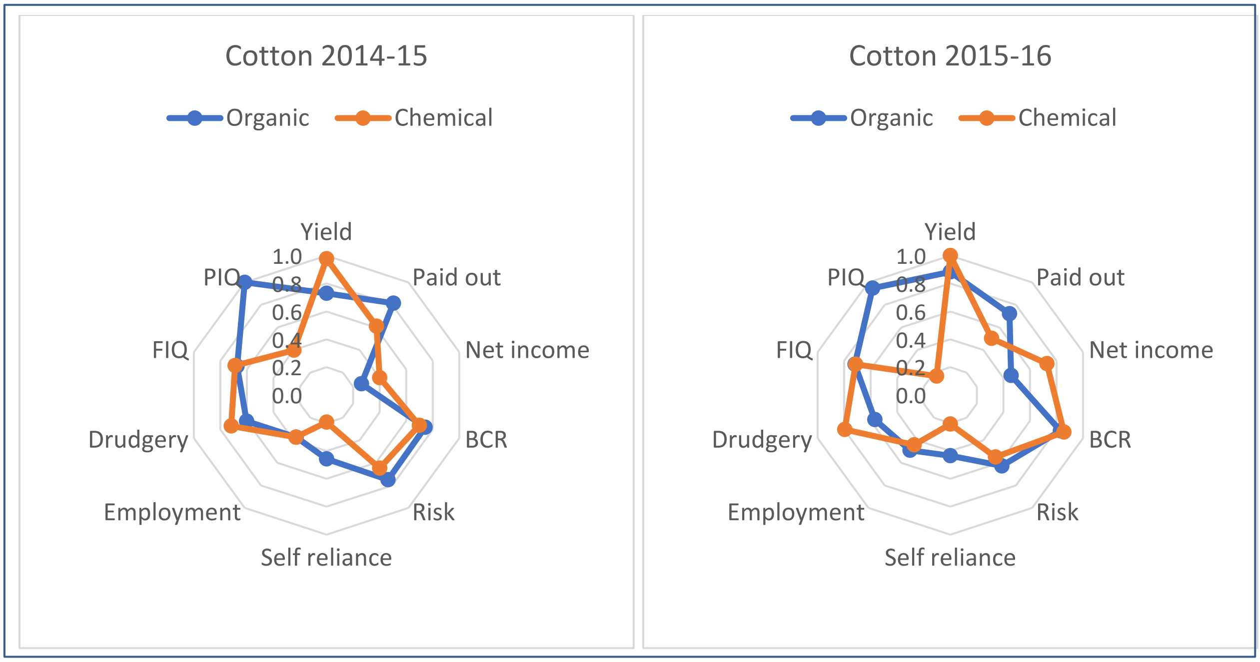


Figure 7.3 Radar charts for individual indicators of cotton cultivation in Wardha, Maharashtra

- Yield and net income have been significantly higher for chemical farms in both the years. The main reason for the huge yield gap is the use of BT seeds by chemical farmers.
- The net income has increased during the second year for both organic and chemical farms in spite of higher paidout expenditure. This higher income is due to the increase in crop yield.
- Paidout cost, BCR, and risk have been better in organic farms as the chemical farms are input and capital intensive. Further, the majority of these inputs are from the market and hence the self-reliance of chemical farms is significantly lesser than that of organic farms.
- While employment was similar in both organic and chemical farms, drudgery in chemical farms was better than that of organic farm. This difference is due to higher farm produce in chemical farms and its corresponding increase in income per unit labour expense.

- While FIQ has remained same over both the years, PIQ has dropped down during the second year due to increase in pesticide use during the second year. It can be noted that the FIQ of organic farms has scored lesser than any other crop. This is mainly due to the relatively lesser consumption of phosphorous by cotton and it corresponding excess phosphorous has affected the FIQ in organic farms as well.

Table 7.6 Normalized indicator values of cotton cultivation in Wardha, Maharashtra

Indicator	**2014-15**		**2015-16**	
	Organic	**Chemical**	**Organic**	**Chemical**
Norm. yield	0.73	0.98	0.88	1.00
Financial resource	0.81	0.61	0.72	0.50
Net income	0.26	0.40	0.46	0.73
BCR	0.74	0.70	0.83	0.86
Risk	0.75	0.65	0.63	0.55
Self-reliance	0.46	0.19	0.43	0.21
Employment	0.37	0.37	0.49	0.44
Drudgery	0.60	0.72	0.57	0.80
FIQ N	0.81	0.80	0.85	0.93
FIQ P	0.47	0.28	0.50	0.24
FIQ K	0.74	0.99	0.80	0.97
FIQ-Overall	0.67	0.69	0.72	0.71
PIQ	1.00	0.40	0.95	0.17

Table 7.7 Actual indicator values of cotton cultivation in Wardha, Maharashtra

Indicator	**Unit**	**2014-15**		**2015-16**	
		Organic	**Chemical**	**Organic**	**Chemical**
Yield	kg/acre	240	548	370	717
Financial resource	₹/acre	5967	12477	8973	15900
Net income	₹/acre	9515	13667	16051	25452
BCR	DMNL	2.92	2.15	3.47	2.77
Risk	₹/acre	10932	15444	16337	19757
Self-reliance	₹/acre	4974	2967	12085	12801
Employment	Percentage	33	33	44	39
Drudgery	DMNL	4.47	5.66	4.00	5.62
FIQ N	DMNL	-3.56	-3.35	-8.77	-15.73
FIQ P	DMNL	5.39	10.35	5.92	12.47
FIQ K	DMNL	-0.23	-23.11	-4.57	-24.37
PIQ	DMNL	0.00	67.21	2.22	95.87

Soybean

- Figure 7.4 shows the trend of various indicators in soybean cultivation over two years in villages around Wardha, Maharashtra. In contrast to other crops, yield in soybean was relatively less in comparison to state average for both organic and chemical farms.
- Net income, BCR, and risk were similar in both organic and chemical farms during the first year. But, organic farms had better net income and BCR during the second year due to increase in the income from intercrops.
- While self-reliance and employment were better in case of organic farms, drudgery was better in case of chemical farms.
- Both organic and chemical farms had very good FIQ during both the years as the nutrient input has been minimal in both organic and chemical farms. However, pesticide application has resulted in poorer PIQ for chemical farms.

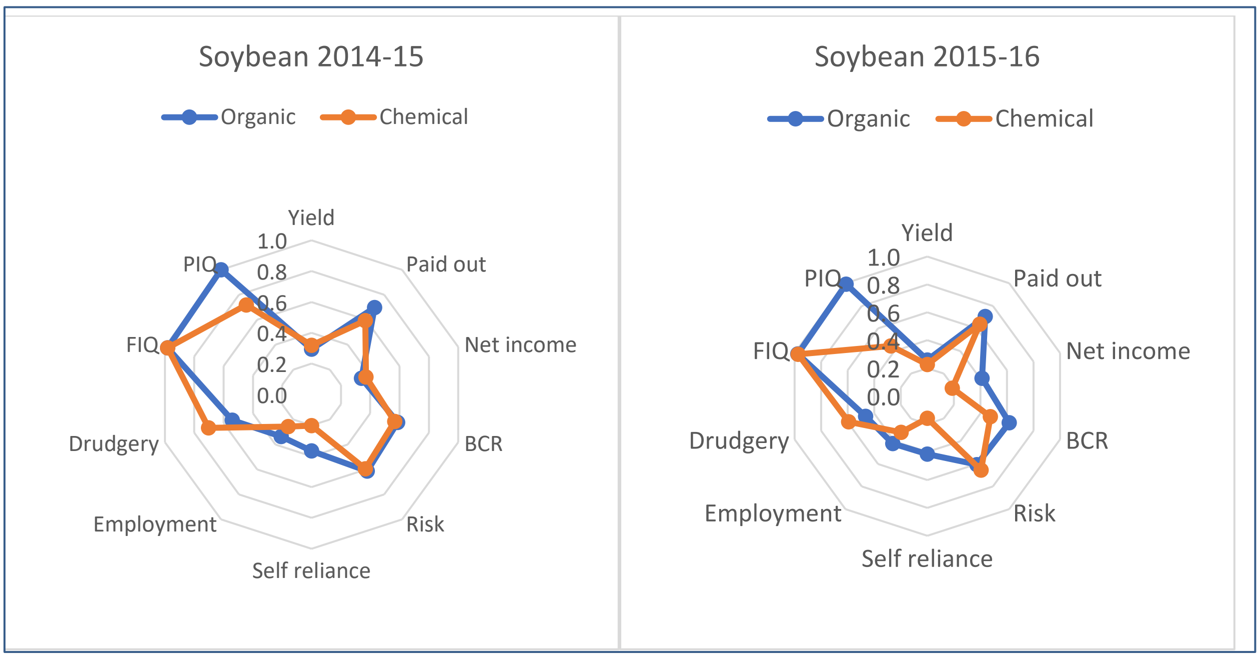


Figure 7.4 Radar charts for individual indicators of soybean cultivation in Maharashtra

Table 7.8 gives the corresponding normalized indicators values and Table 7.9 gives the actual value of each indicator with their unit.

- In contrast to other crops, yield in soybean was relatively less in comparison to the state average for both organic and chemical farms.

- Net income, BCR, and risk were similar in both organic and chemical farms during the first year. But, organic farms had better net income and BCR during the second year due to increase in the income from intercrops.

Table 7.8 Normalized indicator values of soybean cultivation in Wardha, Maharashtra

Indicator	**2014-15**		**2015-16**	
	Organic	**Chemical**	**Organic**	**Chemical**
Norm. yield	0.29	0.32	0.26	0.23
Financial resource	0.70	0.59	0.71	0.64
Net income	0.34	0.37	0.41	0.19
BCR	0.59	0.57	0.62	0.48
Risk	0.61	0.59	0.61	0.65
Self-reliance	0.36	0.20	0.41	0.16
Employment	0.34	0.26	0.42	0.32
Drudgery	0.54	0.70	0.46	0.59
FIQ N	1.00	1.00	1.00	1.00
FIQ P	0.97	0.94	0.96	0.94
FIQ K	0.98	1.00	0.97	0.99
FIQ-Overall	0.98	0.98	0.98	0.97
PIQ	1.00	0.72	0.99	0.45

Table 7.9 Actual indicator values of soybean cultivation in Wardha, Maharashtra

Indicator	**Unit**	**2014-15**		**2015-16**	
		Organic	**Chemical**	**Organic**	**Chemical**
Yield	kg/acre	323	332	158	234
Financial resource	₹/acre	6002	8065	5803	7141
Net income	₹/acre	4711	4307	6417	2002
BCR	DMNL	2.20	1.68	2.14	1.33
Risk	₹/acre	9580	10047	9773	8572
Self-reliance	₹/acre	3578	1982	8006	3903
Employment	Percentage	23	17	29	22
Drudgery	DMNL	5.32	8.72	3.91	4.84
FIQ N	DMNL	-39.62	-38.53	-20.43	-29.31
FIQ P	DMNL	-4.85	0.20	-0.67	1.17
FIQ K	DMNL	-11.24	-14.21	-4.32	-7.87
PIQ	DMNL	0.00	11.16	0.28	29.56

- While self-reliance and employment were better in case of organic farms, drudgery was better in case of chemical farms.

- Both organic and chemical farms had very good FIQ during both the years as the nutrient input has been minimal in both organic and chemical farms. However, pesticide application has resulted in poorer PIQ for chemical farms.

Wheat

Figure 7.5 shows the trend of various indicators in wheat cultivation over two years in Wardha region of Maharashtra. Table 7.10 gives the corresponding normalized indicators values and Table 7.11 gives the actual value of each indicator with their unit.

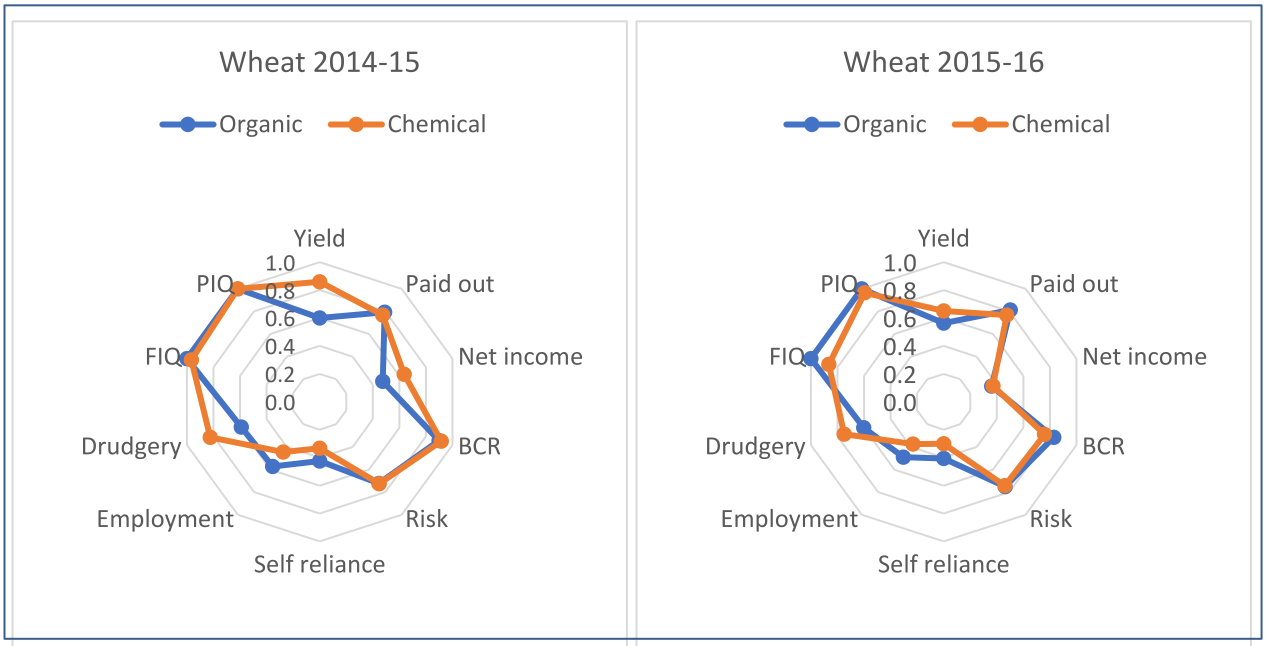


Figure 7.5 Radar charts for individual indicators of Wheat cultivation in Maharashtra

- Yield and net income have been significantly higher for chemical farms during both the years.
- While paidout cost and BCR were marginally better in organic farms, risk was almost similar in both organic and chemical farms during both the years.
- Similar to any other crop, self-reliance and employment were better in organic farms and drudgery were better for chemical farms during both the years.
- In contrast to other crops, PIQ has been good for chemical farms for both the year indicating a significantly lesser usage of pesticides in wheat cultivation.

- While the FIQ of chemical farm was almost similar to organic farms during the first year, the decrease in FIQ of chemical farm during the second year is mainly due to decrease in yield rather than increase in fertilizer application.

Table 7.10 Normalized indicator values of wheat cultivation in Wardha, Maharashtra

Indicator	**2014-15**		**2015-16**	
	Organic	**Chemical**	**Organic**	**Chemical**
Norm. yield	0.60	0.86	0.56	0.65
Financial resource	0.79	0.77	0.81	0.77
Net income	0.47	0.64	0.36	0.37
BCR	0.90	0.92	0.83	0.76
Risk	0.72	0.73	0.75	0.74
Self-reliance	0.43	0.33	0.41	0.30
Employment	0.57	0.44	0.49	0.38
Drudgery	0.59	0.83	0.60	0.75
FIQ N	1.00	0.98	1.00	0.71
FIQ P	1.00	0.92	1.00	0.88
FIQ K	1.00	1.00	1.00	1.00
FIQ-Overall	1.00	0.97	1.00	0.87
PIQ	1.00	1.00	1.00	0.97

Table 7.11 Actual indicator values of wheat cultivation in Wardha, Maharashtra

Indicator	**Unit**	**2014-15**		**2015-16**	
		Organic	**Chemical**	**Organic**	**Chemical**
Yield	kg/acre	664	1036	634	802
Financial resource	₹/acre	4634	5183	4180	5188
Net income	₹/acre	9446	12013	6553	6996
BCR	DMNL	3.74	3.41	4.15	2.56
Risk	₹/acre	8038	7953	7227	7431
Self-reliance	₹/acre	3404	2771	2509	2825
Employment	Percentage	34	27	30	23
Drudgery	DMNL	6.22	9.32	5.97	7.68
FIQ N	DMNL	-19.99	-13.27	-17.34	14.65
FIQ P	DMNL	-7.36	-5.50	-6.31	1.13
FIQ K	DMNL	-35.19	-54.36	-30.14	-33.72
PIQ	DMNL	0.00	0.00	0.00	1.46

Bengal gram

Figure 7.6 shows the trend of various indicators in Bengal gram cultivation over two years in Wardha region of Maharashtra. Table 7.12 gives the corresponding normalized indicators values and Table 7.13 gives the actual value of each indicator with their unit.

- Yield and income have been better in chemical farms during both the year of the study. However, the yields of both organic and chemical farms were lesser during the second year than the first year.
- The paidout cost of organic farms is significantly lesser than that of chemical forms but the net income has been higher for chemical farms which is mainly due to higher crop yields in chemical farms.
- BCR and risk were marginally better in organic farms during both the years of the study and the self-reliance was significantly poorer in case of chemical farms.
- While employment was similar in both organic and chemical farms during both the years, drudgery was better in chemical farms during the second year of the study.
- Similar to wheat cultivation, FIQ of chemical farms were better and similar to that of organic farms but PIQ was significantly poorer in chemical farms during both the years of the study.

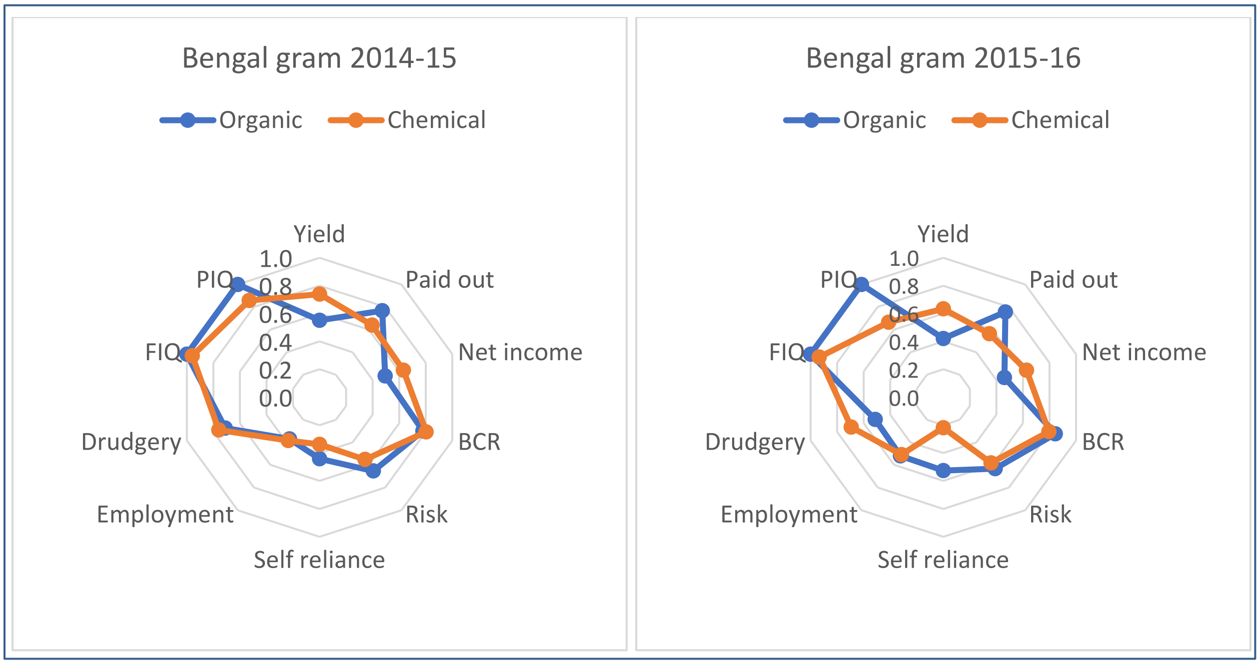


Figure 7.6 Radar charts for individual indicators of Bengal gram cultivation in Maharashtra

Table 7.12 Normalized indicator values of bengal gram cultivation in Wardha, Maharashtra

Indicator	**2014-15**		**2015-16**	
	Organic	**Chemical**	**Organic**	**Chemical**
Norm. yield	0.55	0.74	0.42	0.63
Financial resource	0.77	0.64	0.76	0.56
Net income	0.50	0.63	0.46	0.63
BCR	0.78	0.80	0.84	0.80
Risk	0.65	0.55	0.63	0.58
Self-reliance	0.44	0.34	0.53	0.22
Employment	0.37	0.38	0.52	0.51
Drudgery	0.71	0.76	0.51	0.69
FIQ N	1.00	1.00	1.00	0.99
FIQ P	1.00	0.88	1.00	0.82
FIQ K	1.00	1.00	1.00	0.99
FIQ-Overall	1.00	0.96	1.00	0.93
PIQ	1.00	0.86	1.00	0.67

Table 7.13 Actual indicator values of bengal gram cultivation in Wardha, Maharashtra

Indicator	**Unit**	**2014-15**		**2015-16**	
		Organic	**Chemical**	**Organic**	**Chemical**
Yield	kg/acre	356	543	271	428
Financial resource	₹/acre	3980	6113	4130	7410
Net income	₹/acre	9033	13499	8070	12024
BCR	DMNL	4.07	3.34	6.78	3.41
Risk	₹/acre	7569	9792	8021	9141
Self-reliance	₹/acre	3588	3679	5472	3702
Employment	Percentage	28	29	39	38
Drudgery	DMNL	6.00	7.85	4.33	6.22
FIQ N	DMNL	-22.06	-30.31	-16.19	-22.04
FIQ P	DMNL	-3.41	-1.61	-2.37	0.24
FIQ K	DMNL	-14.69	-20.52	-10.55	-15.81
PIQ	DMNL	0.00	4.49	0.00	22.74

7.1.3 Odisha

Cotton

Figure 7.7 gives the trends in individual indicators for cotton. *Table 7.14* gives the values of actual indicators for cotton cultivation and *Table 7.15* gives the normalized values for the same.

Similar to the farms in Wardha, Maharashtra, the chemical farms have significantly higher yield in both the years. Following are a few observations from the field data of two years.

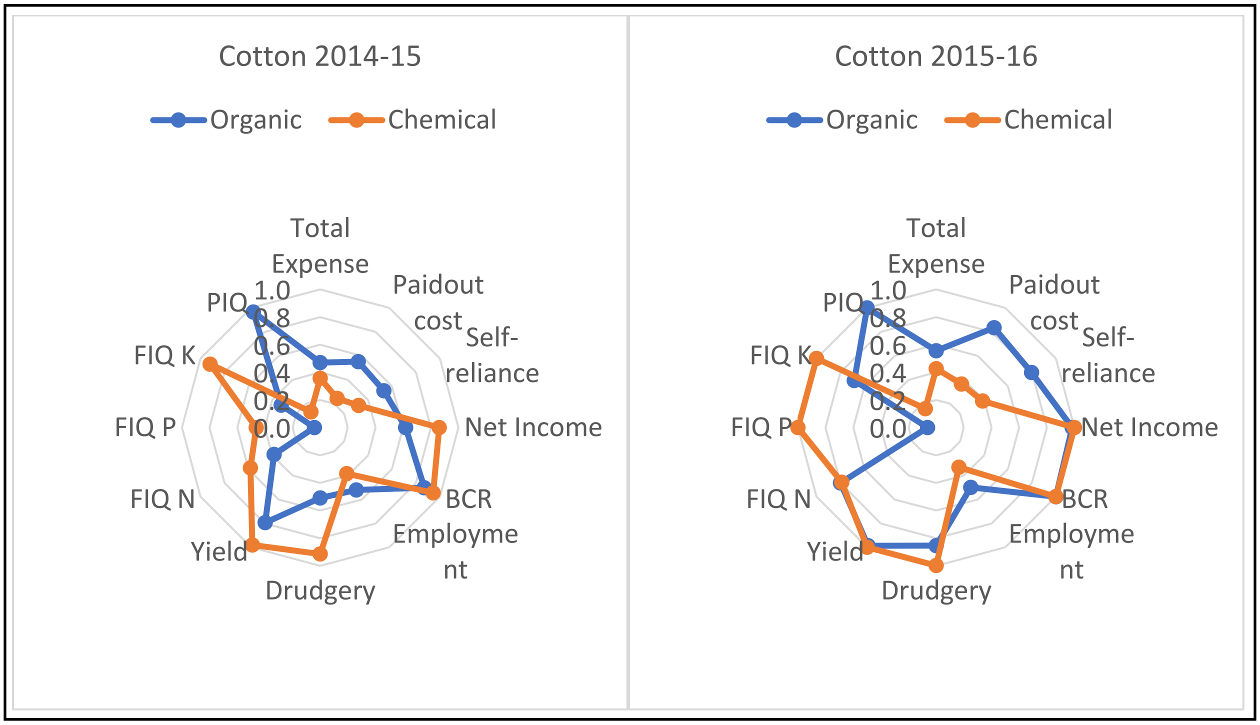


Figure 7.7 Radar charts for individual indicators of Cotton field in Bhawanipatna, Odisha

- In general, ratio of female labour in overall labour is higher for cotton cultivation as the cotton harvest accounts for a majority of labour and women labour is preferred for cotton plucking. While ratio of women labour is higher in organic farms during the first year, a drastic increase in cotton yield in chemical farm lead to a higher ratio in chemical farm during the second year. However, the ratio of male self-labour to total self labour is significantly higher in organic farms during both years.
- While both total farm expenditure and paid out cost are lower in organic farms, net income was higher in case of chemical farms. However, benefit-cost ratio is higher for chemical farms during the first year and higher for organic farms in second year.
- Organic farms are found to have higher self-reliance but labour intensive and lower returns on the labour expense for both the years. Similarly, chemical farms are found to have higher expenditure on both machinery and input materials during both the years.

- Interestingly, chemical farms have better fertilizer impact quotient than organic farms. Poor yield in organic farms with a high manure inputs has impacted the FIQ values of organic farms. However, pesticide impact quotient is worse off in chemical farms.

Table 7.14 Actual indicators for cotton cultivation in Odisha

Indicator	**Unit**	2014-15		2015-16	
		Organic	**Chemical**	**Organic**	**Chemical**
Total female/total HR	Dimensionless	0.58	0.55	0.58	0.72
Male self/Total self labour	Dimensionless	0.56	0.48	0.42	0.28
Total farm expenditure	INR/acre	14789	17962	12401	16024
Paid out cost	INR/acre	6904	12277	2529	9793
Self borne in %	Dimensionless	7885	5685	9872	6230
Net income	INR/acre	5812	21205	17329	25035
Benefit Cost Ratio	Dimensionless	2.06	2.95	8.48	3.61
Labour expense %	Dimensionless	0.61	0.45	0.59	0.39
Drudgery	Rupees receipt/ Rupees on labour	1.41	4.49	2.77	5.79
Subsidy in materials	INR/acre	0	2317	0	1584
Yield	Kg/acre	234	668	417	784
N excess	Kg/acre	20.3	13.0	3.8	-6.7
P excess	Kg/acre	16.7	5.3	12.8	-11.7
K excess	Kg/acre	22.9	-28.5	9.3	-43.3
Machinery cost	INR/acre	2108	4309	2039	3408
Material cost	INR/acre	3640	5785	3048	6386
Labour expenditure	INR/acre	9041	7868	7313	6230

Table 7.15 Normalized indicators for cotton cultivation in Odisha

Indicator	2014-15		2015-16	
	Organic	**Chemical**	**Organic**	**Chemical**
Total farm expenditure	0.47	0.36	0.56	0.43
Paid out cost	0.55	0.25	0.84	0.36
Self borne in %	0.53	0.32	0.80	0.39
Net income	0.62	0.86	0.98	1.00
Benefit Cost Ratio	0.87	0.94	1.00	1.00
Labour expense %	0.52	0.38	0.50	0.33
Drudgery	0.51	0.91	0.85	1.00
Yield	0.79	0.98	0.99	1.00
N excess/N FIQ	0.39	0.58	0.80	0.79
P excess/P FIQ	0.04	0.46	0.06	1.00
K excess/K FIQ	0.33	0.92	0.68	1.00
PIQ	0.97	0.13	1.00	0.16
Economic Index	0.48	0.57	0.64	0.67
Social Index	0.62	0.48	0.80	0.56
Ecological Index	0.31	0.20	0.39	0.28
FAI	0.47	0.43	0.61	0.52

Paddy

Figure 7.8 shows the trends in individual indicators for the paddy field studies in Bhawanipatna. Table 7.16 gives the values of actual indicators for paddy cultivation and Table 7.17 gives the normalized values for the same. In contrast to cotton farms, the organic farms has significantly higher yield in both the years. Following are a few observations from the field data of two years.

- While ratio of female labour in overall labour expense is higher for organic farms, ratio of male self-labour to total self labour is slightly higher in chemical farms during both years.

- Organic farms are strongly place with lesser total farm expenditure and paid out cost as well as significantly higher net income, self-reliance and BCR during both the years. This can be attributed to a very high yield in organic paddy farms compared to chemical farms.
- Though organic farms are found to have labour intensive, they have also got better returns on the labour expense during the first year. Similar to cotton farms, chemical paddy farms are found to have higher expenditure on both machinery and input materials during both the years.
- In case of FIQ, organic farms were significantly better in Nitrogen FIQ during both the years. However, FIQ of phosphorus and potassium are slightly higher in chemical farms.

Table 7.16 Actual indicators for paddy cultivation in Odisha

Indicator	**Unit**	2014-15		2015-16	
		Organic	**Chemical**	**Organic**	**Chemical**
Total female/total HR	Dimensionless	0.49	0.36	0.49	0.48
Male self/Total self labour	Dimensionless	0.60	0.66	0.51	0.52
Total farm expenditure	INR/acre	8475	9924	6252	7292
Paid out cost	INR/acre	3399	6493	2089	4638
Self borne in %	Dimensionless	5075	3431	4162	2653
Net income	INR/acre	11854	2848	12681	6289
Benefit Cost Ratio	Dimensionless	5.27	1.72	7.17	2.56
Labour expense %	Dimensionless	0.50	0.43	0.50	0.36
Drudgery	Rupees receipt/ Rupees on labour	3.88	2.62	4.31	5.63
Subsidy in materials	INR/acre	0	968	0	1320
Yield	Kg/acre	1235	671	1049	670
N excess	Kg/acre	3.5	12.2	-4.8	23.9
P excess	Kg/acre	4.2	4.2	-1.3	-7.6
K excess	Kg/acre	-4.4	-16.7	-12.7	-20.0
Machinery cost	INR/acre	2170	3388	1464	1971
Material cost	INR/acre	2077	2408	1561	2663
Labour expenditure	INR/acre	4228	4128	3227	2657

Table 7.17 Normalized indicators for paddy cultivation in Odisha

Indicator	2014-15		2015-16	
	Organic	**Chemical**	**Organic**	**Chemical**
Total farm expenditure	0.75	0.71	0.82	0.78
Paid out cost	0.81	0.64	0.88	0.74
Self borne in %	0.60	0.34	0.66	0.36
Net income	0.60	0.18	0.47	0.32
Benefit Cost Ratio	0.99	0.66	0.97	0.91
Labour expense %	0.38	0.32	0.37	0.27
Drudgery	0.94	0.71	0.90	0.96
Yield	0.51	0.31	0.36	0.30
N excess/N FIQ	0.92	0.84	0.96	0.74
P excess/P FIQ	0.89	0.89	0.95	1.00
K excess/K FIQ	0.95	0.98	0.98	1.00
PIQ	1.00	0.86	1.00	1.00
Economic Index	0.64	0.45	0.62	0.56
Social Index	0.77	0.62	0.77	0.69
Ecological Index	0.50	0.46	0.51	0.49
FAI	0.63	0.50	0.63	0.58

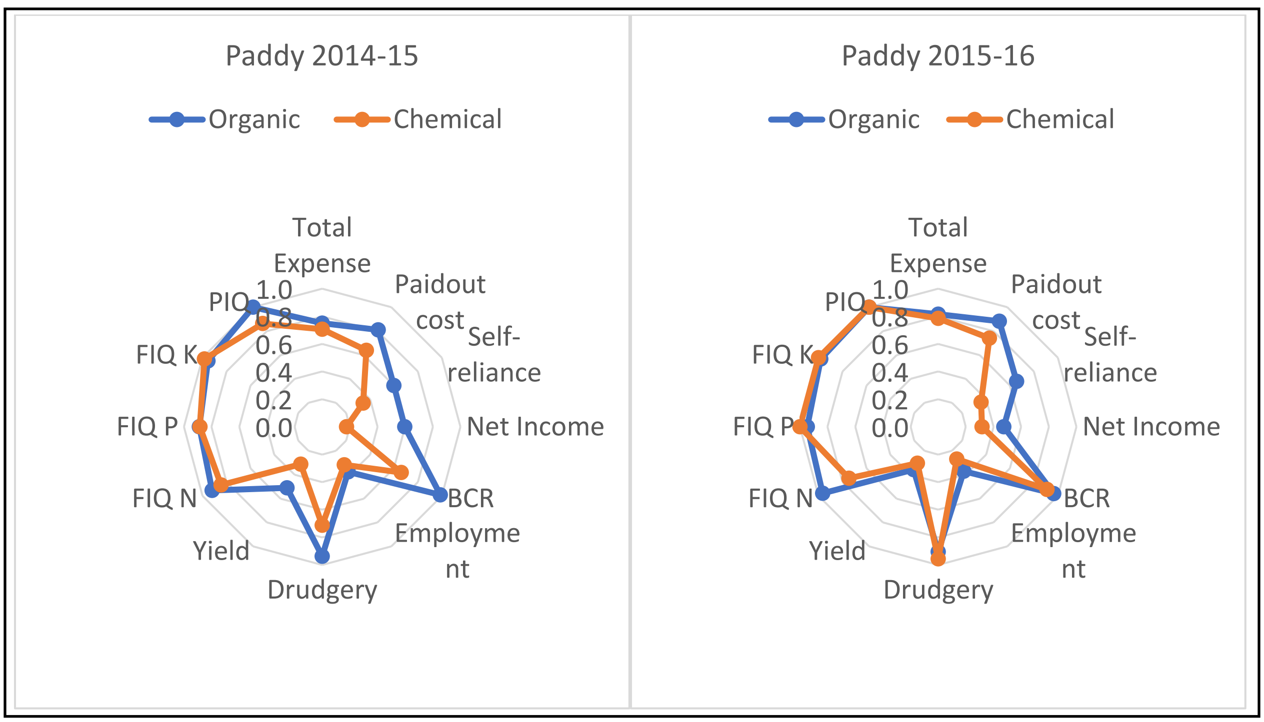


Figure 7.8 Radar charts for individual indicators of Paddy field in Bhawanipatna, Odisha

7.1.4 Karnataka

Cotton

Table 7.18 gives the values of actual indicators for cotton cultivation and Table 7.19 gives the normalized values for the same. Figure 7.9 shows the trends in individual indicators of cotton fields studied in Karnataka. Similar to the farms in Odisha sample, chemical farms has significantly higher yield in both the years. Following are a few observations from the field data of two years.

- In contrast to Odisha, ratio of female labour to overall labour is similar in organic and chemical farms and the ratio of male self-labour to total self labour is higher in chemical farms during both the years.
- While the paidout cost in organic farms are lesser in organic farm during both the years, total farm expenditure was lesser during the first year but higher in organic farm than chemical farms. Similarly, mixed trends are found in net income and BCR where the organic farms are higher during the first year but lesser than chemical farms during the second year.
- However, organic farms are found to have higher self-reliance during both the years. Similar to other crops, proportion of labour expenditure in overall farm expense is higher in organic farms during both the years but returns per labour invested during first year was higher for organic farms.
- While each of the machinery, input materials and labour expenditure are lesser for organic farms during first year, both machinery and labour cost are higher in organic farms during the second year.
- Organic farms have better fertilizer impact quotient than chemical farms during both the years in all three nutrients except for phosphorous during the second year. Pesticide impact quotient is certainly worse off in chemical farms.
- While economic index shows a mixed trend, organic farms has scored significantly higher in both social and ecological index as well as overall Farm Assessment Index during both the years.

Table 7.18 Actual indicators for cotton cultivation in Karnataka

Indicator	Unit	2014-15		2015-16	
		Organic	Chemical	Organic	Chemical
Total female/total HR	Dimensionless	0.80	0.79	0.83	0.83
Male self/Total self labour	Dimensionless	0.55	0.58	0.40	#DIV/0!
Total farm expenditure	INR/acre	11514	17131	18079	15329
Paid out cost	INR/acre	5130	8912	8464	9595
Self borne in %	Dimensionless	6384	8219	9615	5734
Net income	INR/acre	18527	16534	21263	29500
Benefit Cost Ratio	Dimensionless	4.69	2.89	3.87	4.08
Labour expense %	Dimensionless	0.28	0.27	0.46	0.41
Drudgery	Rupees receipt/ Rupees on labour	7.68	5.76	4.36	6.44
Subsidy in materials	INR/acre	0	677	0	505
Yield	Kg/acre	475.00	497.00	529.00	717.00
N excess	Kg/acre	-0.42	12.26	3.01	3.33
P excess	Kg/acre	11.92	25.25	18.43	24.55
K excess	Kg/acre	5.24	14.63	0.47	5.76
Machinery cost	INR/acre	4777	6752	5227	3866
Material cost	INR/acre	3483	5884	4741	5143
Labour expenditure	INR/acre	3254	4495	8111	6319

Table 7.19 Normalized indicators for cotton cultivation in Karnataka

Indicator	2014-15		2015-16	
	Organic	Chemical	Organic	Chemical
Total farm expenditure	0.66	0.50	0.47	0.55
Paid out cost	0.81	0.67	0.69	0.65
Self borne in %	0.54	0.47	0.52	0.37
Net income	0.95	0.76	0.79	0.99
Benefit Cost Ratio	1.00	0.91	0.89	1.00
Labour expense %	0.28	0.26	0.45	0.40
Drudgery	1.00	0.93	0.70	0.93
Yield	1.00	1.00	1.00	1.00
N excess/N FIQ	0.84	0.58	0.70	0.67

P excess/P FIQ	0.13	0.00	0.12	0.17
K excess/K FIQ	0.70	0.53	0.81	0.62
PIQ	1.00	0.36	1.00	0.62
Economic Index	0.66	0.54	0.56	0.64
Social Index	0.77	0.56	0.73	0.63
Ecological Index	0.40	0.19	0.40	0.29
FAI	0.61	0.44	0.56	0.53

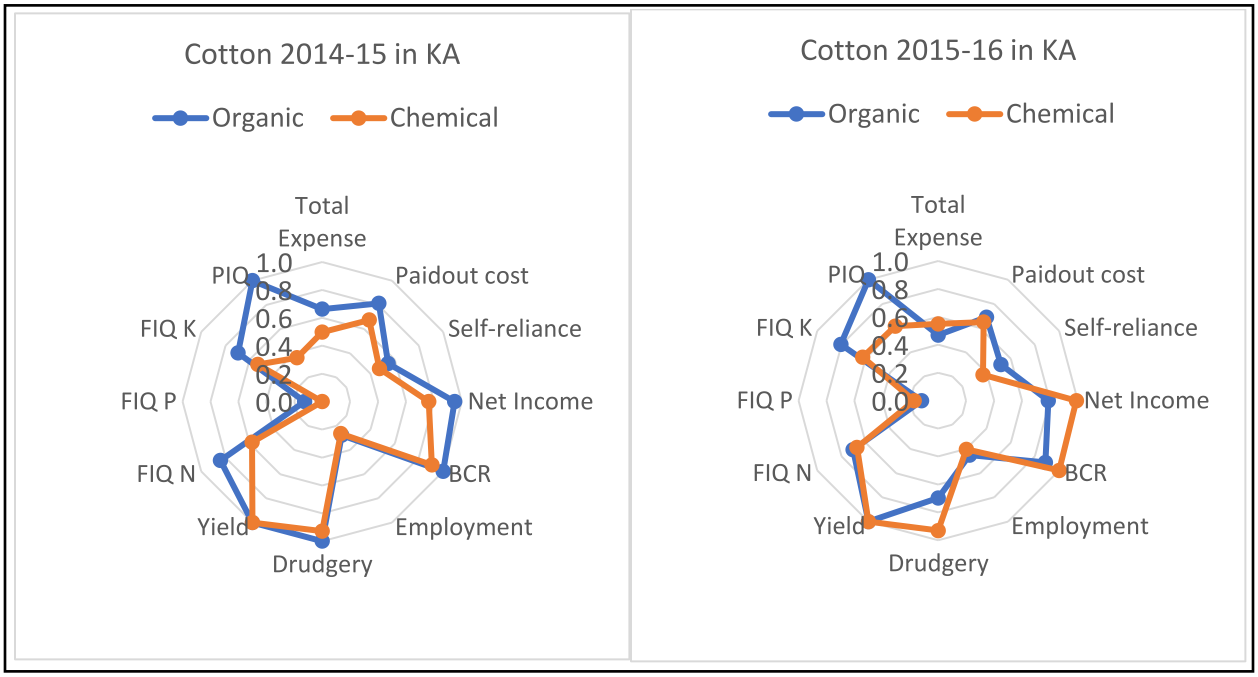


Figure 7.9 Radar charts for individual indicators of Cotton field in HD Kote, Karnataka

Soil parameters

Figure 7.10 shows the physio-chemical properties of soil in organic and chemical farms of soybean and cotton plots that were sampled during three different seasons.

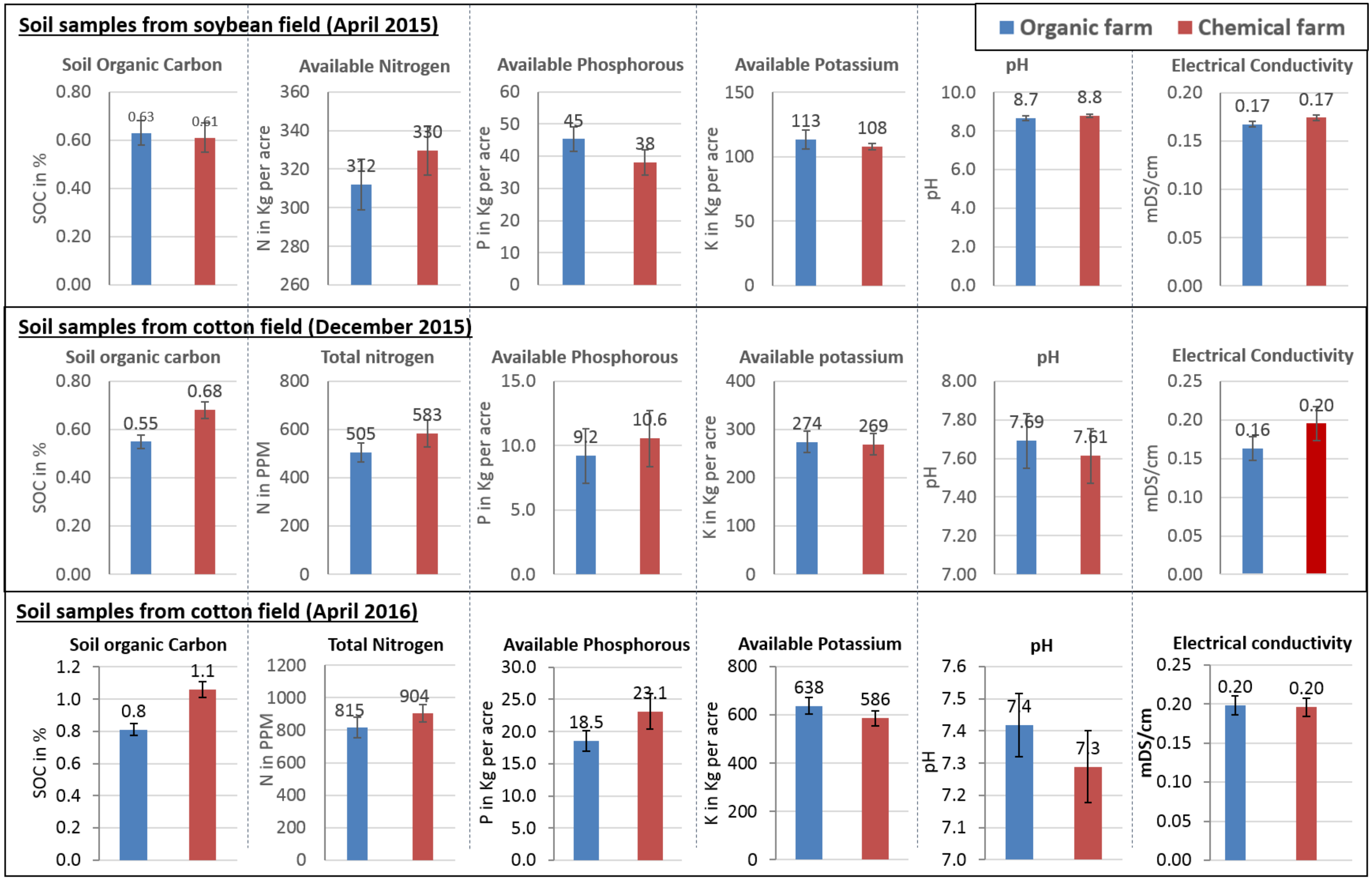


Figure 7.10 Soil parameters of three rounds of soil samples from Wardha, Maharashtra

SOC was marginally higher in organic farms of soybean plots but the difference was significantly higher in chemical farms for cotton plot during both the rounds. Available nitrogen in soybean plots and total nitrogen in cotton plots were significantly higher in chemical farms. Available phosphorous was marginally higher in organic farms than chemical farms for soybean but it was lesser in organic cotton plots. Available potassium was found to be slightly higher in organic farms for both soybean and cotton plots. Soil pH was found to be marginally lower in organic farms of soybean and marginally higher in organic farms of cotton plots. Though the conductivity of all the farms was within the normal range, the conductivity of organic farms was significantly lesser than that of chemical farms. Figure 7.11 depicts the biological parameters of soil samples collected during the month of April 2016. Organic farms had a relatively higher population across all the microbial content but not significantly higher in comparison to chemical farms, except for the fungal population where the organic farms had significantly higher population than chemical farms.

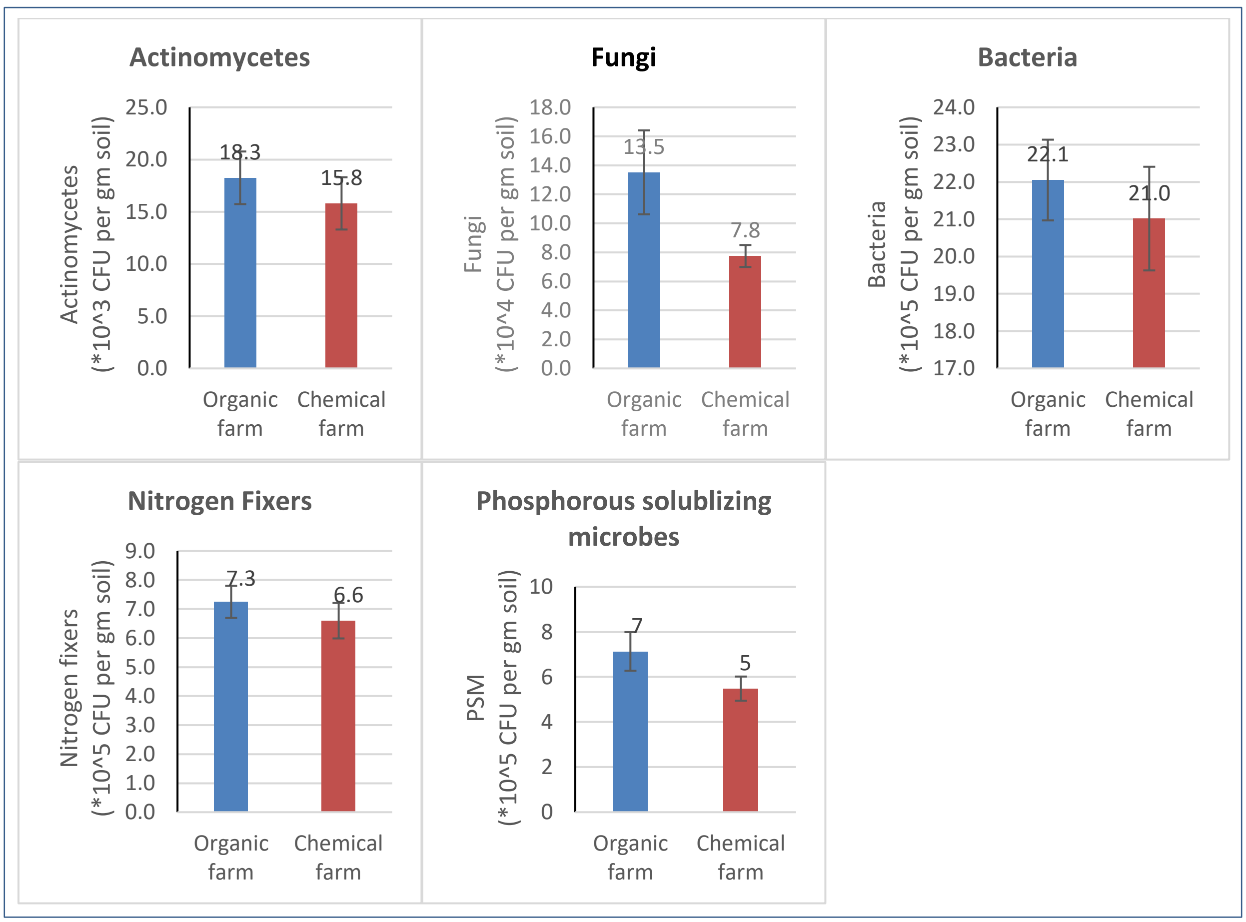


Figure 7.11 Biological parameters of cotton plot (December 2015 samples)

7.2 Composite indices

As discussed in section 5.2.4, the weightages were assigned for all the identified indicators during the expert panel workshop. The weightage at the highest hierarchy of the dimension was rounded off to 40%, 30% and 30% for economic, social and ecological dimension respectively. The weightage for individual indicators is calculated based on the rounded-off weightage. Due to lack of data for a few indicators, the weightages were redistributed among the indicators within the hierarchies. Table 7.20 gives the redistributed weightages based on data availability and proxy indicators capturing larger set of original indicators. FAI is calculated by aggregating all the available indicators and the dimensional indices are calculated using those available within the respective dimension.

Table 7.20 Redistributed weightage based on data availability and proxy indicators

Indicator	**Original indicators covered**	**Weightage in %**	
		Cotton	**Soybean/wheat/gram**
Net income	Farm income	9.88	12.29
Benefit-cost ratio	Benefit-cost ratio	8.52	10.59
Farm expenditure	Riskiness	9.04	11.24
Paid-out cost	Financial resource of farmer.	4.26	4.26
Ratio of self-borne expense to total expense	Self-reliance	3.93	3.93
Ratio of labour expenditure to total cost	Employment	3.28	3.28
Labour expense	Drudgery	3.44	3.44
Yield	Agricultural output	3.77	3.77
Fertilizer impact quotient of N	Soil contamination, GHG, water contamination, bioaccumulation, health impacts, nutrient use efficiency	5.68	8.46
FIQ of P		5. 68	8.46
FIQ of K		5. 68	8.46
Pesticide impact quotient	Soil contamination, GHG, water contamination, bioaccumulation, and health impacts	14.48	21.67
Soil organic matter	Soil water available and efficiency	19.00	
Total N	Soil nutrient in soil chemical properties	0.36	
Available P		0.36	
Available K		0.36	
Soil pH	Soil pH	1.07	
Soil salinity	Electrical conductivity	1.07	
TOTAL		100	100

Farm Assessment Index (FAI)

In this section, we describe and discuss the dimension indices and Farm Assessment Index of all the main crops from each state individually. The indices were estimated for three cropping years in case of Tamil Nadu and for two cropping years in case of other three states. The composite indices were calculated for each of the plots cultivated by the selected farmers and categorised based on the maincrop of the plot. The crop-wise mean of organic and chemical farms were compared for each year using the bar charts.

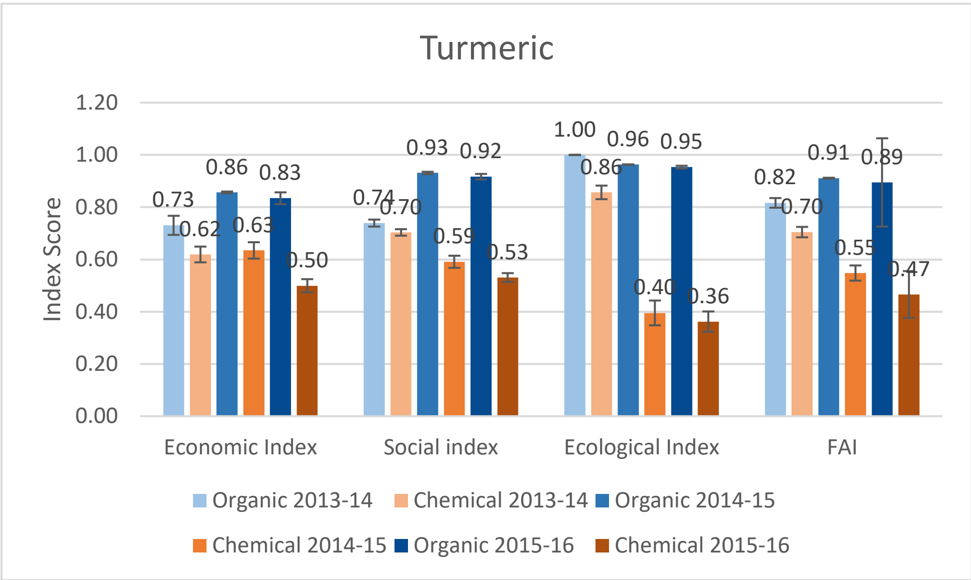


Figure 7.12 Dimensional Indices and FAI of Turmeric plots studied in Tamil Nadu

Figure 7.12 and Figure 7.13 show the dimensional indices and FAI of turmeric and paddy farm samples from Tamil Nadu. The economic index of turmeric is significantly higher for organic farms in spite of relatively similar farm expense and yield. This is mainly due to the higher sales value per unit organic produce compared to that of chemical produce. The economic index of organic paddy has scored better mainly due to the lesser paidout cost. Similarly, in case of social index, organic farms of both turmeric and paddy have scored significantly higher than that of chemical farms. In case of chemical turmeric farms, the yield during the second and third year have decreased while the nutrient input remained similar. This resulted in nutrient excess thereby potentially increasing the fertilizer impacts on social index. Furthermore, pesticide usage has also affected the social index of chemical farms for both turmeric and paddy cultivation. The ecological index has not been calculated for Tamil Nadu as the soil parameters which form a significant component of ecological index, were not measured.

In case of FAI, organic farms were significantly higher than that of chemical farms for both turmeric and paddy farms over all three years in farm samples from Tamil Nadu. Premium price fetched by organic turmeric and heavy pesticide used in chemical paddy were the major factors affecting the FAI in Tamil Nadu.

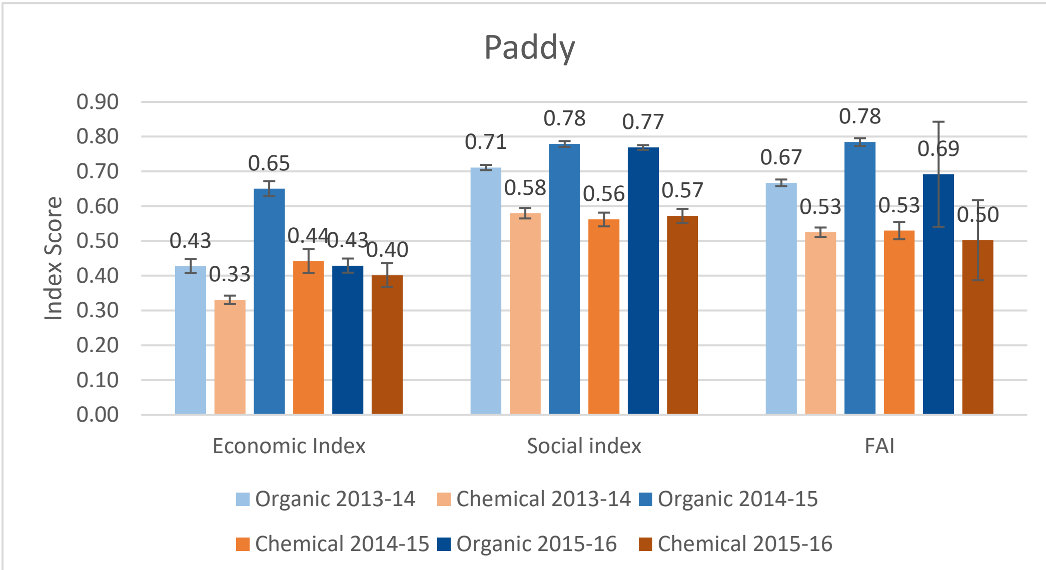


Figure 7.13 Dimensional Indices and FAI of Paddy plots studied in Tamil Nadu

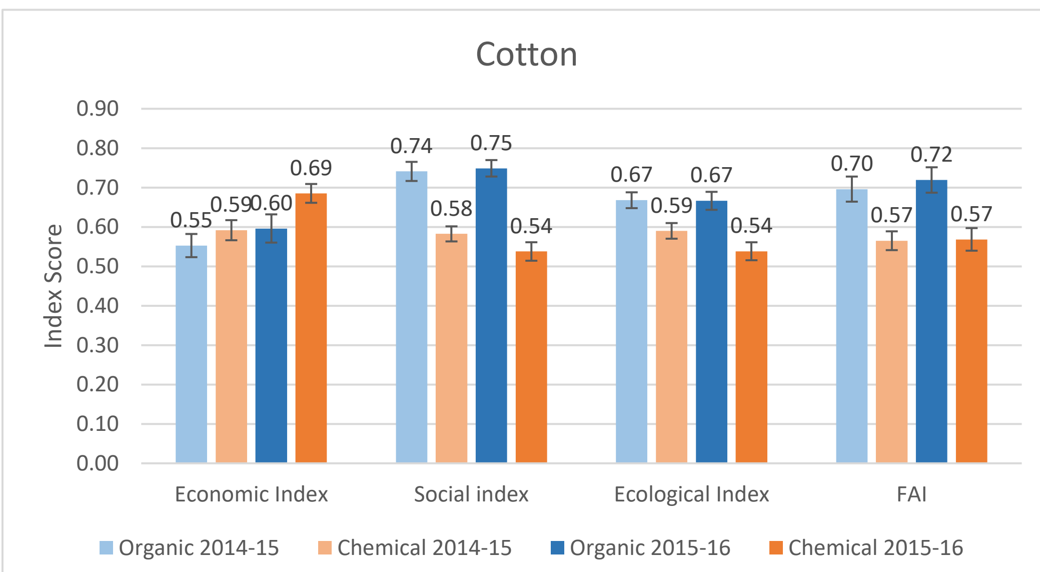


Figure 7.14 Dimensional Indices and FAI of Cotton plots studied in Maharashtra

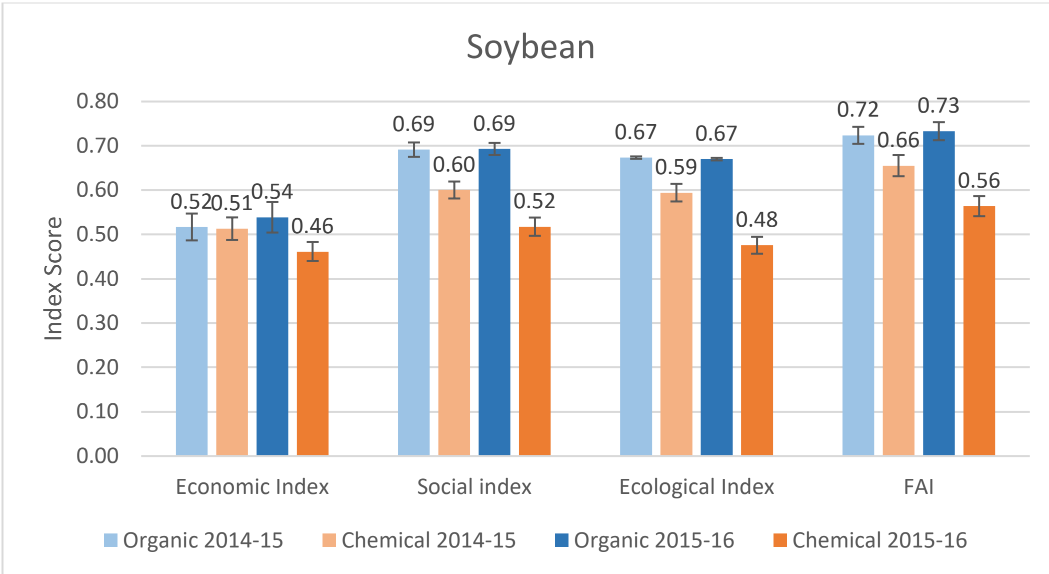


Figure 7.15 Dimensional Indices and FAI of Soybean plots studied in Maharashtra

Figure 7.14 - Figure 7.17 give the dimensional indices and FAI of four major crops from Maharashtra. The economic index of chemical farms in most of the crops across the years have been higher than that of organic farms for the sample farms in Maharashtra. In spite of higher yield and income in chemical farms, the economic indices of chemical farms across the crops were not significantly higher than that of organic farms. This is mainly because of high farm expenditures in chemical farms. The chemical farms in wheat and Bengal gram had a slightly higher economic index during the first year due to relatively lesser difference in overall farm expenditure between organic and chemical farms.

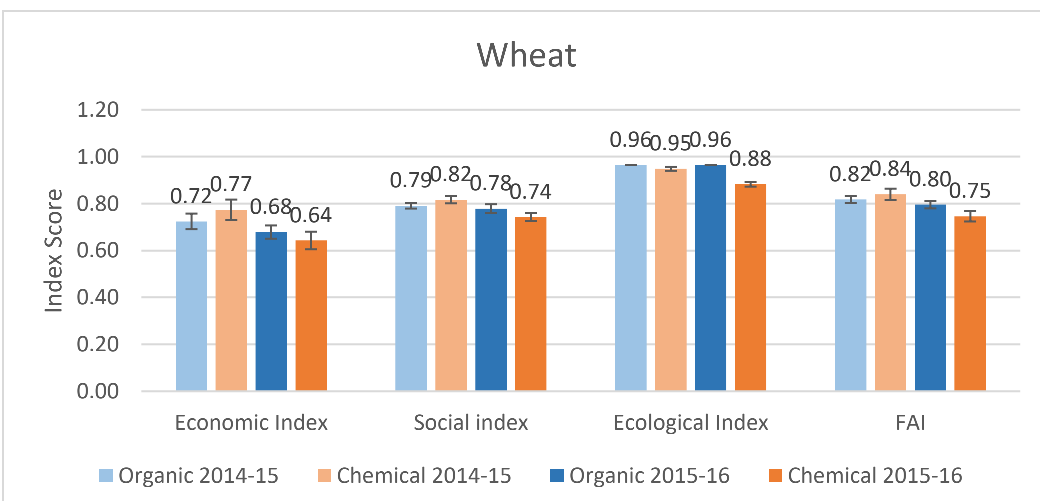


Figure 7.16 Dimensional Indices and FAI of Wheat plots studied in Maharashtra

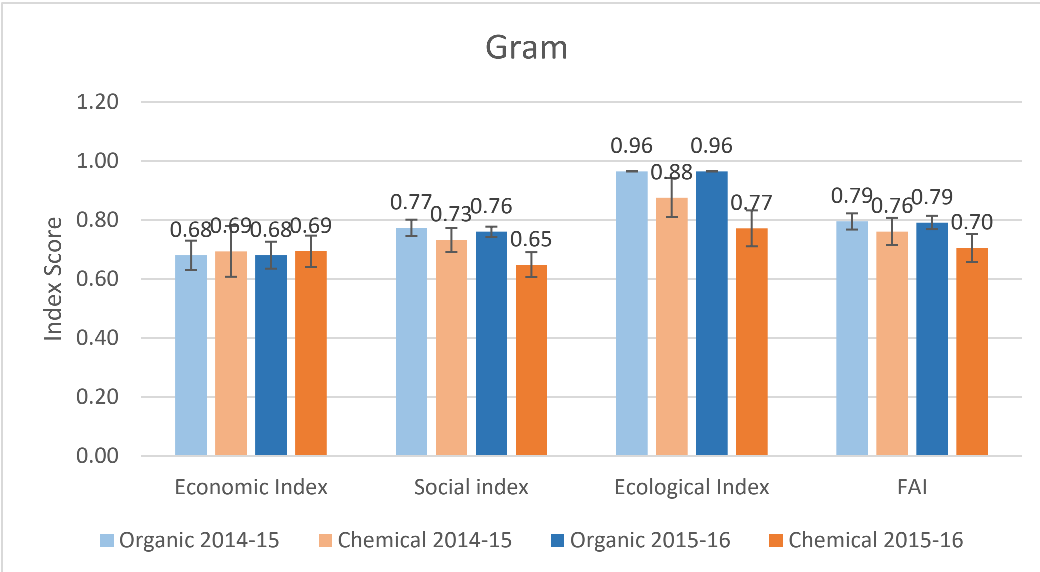


Figure 7.17 Dimensional Indices and FAI of Gram plots studied in Maharashtra

The social indices of organic farms are much higher than that of chemical farms, especially in the cases of cotton and soybean. This is mainly because of lesser paidout cost in organic farms and the impact of pesticide usage in chemical farms. Social index of wheat and gram has remained similar due to relatively lesser usage of fertilizers and pesticides. Since the soil parameters were estimated only for the cotton and soybean, ecological index was calculated only for cotton and soybean farms. The ecological index was relatively higher in organic farms for soybean and cotton cultivation. Though there was no significant difference in the soil parameters between organic and chemical farms, score of chemical farms were affected by fertilizer and pesticide usage. Both dimensional indices as well as Farm Assessment Index are significantly higher for organic farms during both the years.

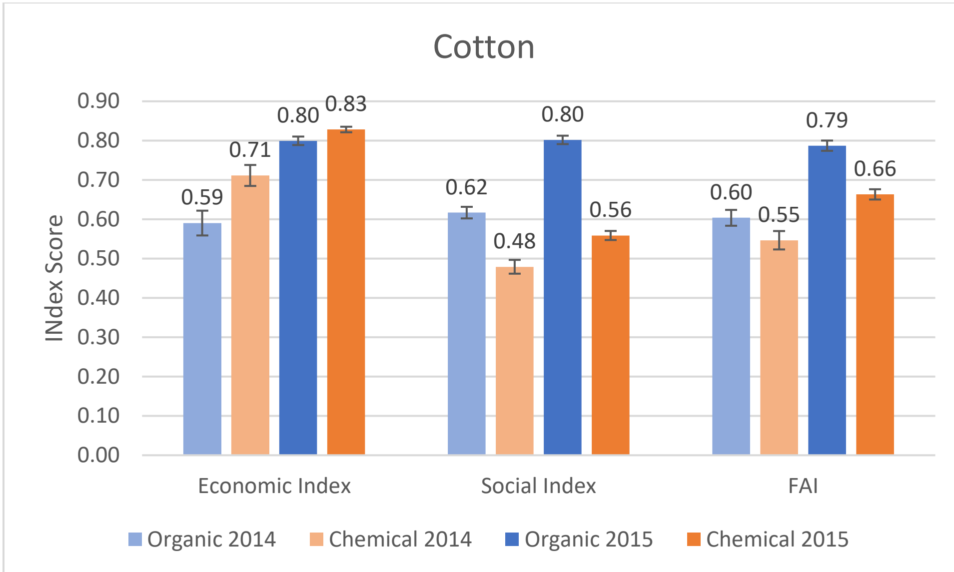


Figure 7.18 Dimensional Indices and FAI of Cotton plots studied in Odisha

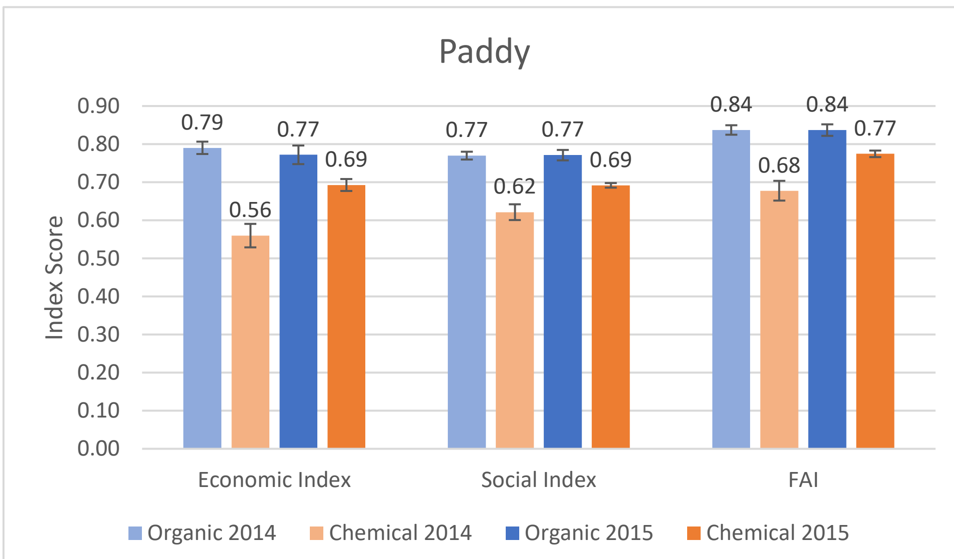


Figure 7.19 Dimensional Indices and FAI of Paddy plots studied in Odisha

Figure 7.18 and Figure 7.19 gives the dimensional indices and FAI of cotton and paddy cultivation in Odisha. Similar to Maharashtra, chemical farms of cotton had significantly higher economic index than that of organic farms. Higher economic index in chemical farms is due to higher yield as well as relatively lesser cost of cultivation. In case of paddy, organic farms had a significantly higher economic index than chemical farms due to better yield and low cost of cultivation. The social index of chemical farms was significantly less than that of organic farms due to a very high usage of pesticides for cotton and very low self-reliance. FAI of the organic farms was significantly higher than chemical plots in both cotton and paddy farms from Odisha.

Figure 7.20 gives the dimensional indices and FAI of cotton farm samples from Odisha. In contrast to Maharashtra and Odisha, organic farms had significantly higher economic index during first of the study. But the economic index of organic farms got reduced significantly during the second year of the study. Similar to almost all the other social index and FAI, organic farms of cotton had significantly higher scores than chemical farms. An overall observation of the FAI scores shows that less input intensive crops like wheat and gram have significantly higher index scores than that of input intensive cotton cultivation under chemical farming.

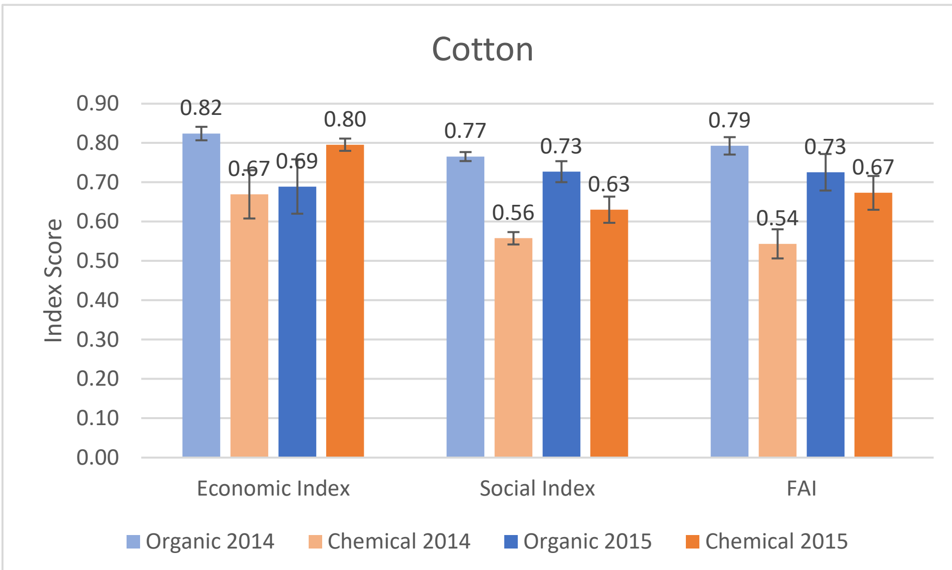


Figure 7.20 Dimensional Indices and FAI of Cotton plots studied in Karnataka

7.3 Meta-Analysis

Statistical methods are needed for effective assessment and interpretation of alternative farming approaches (Bianconi et al., 2013). Table 7.21 gives the crop-wise mean score of the indices for each crop along with the comparative statistics between organic and chemical farms. In the case of Maharashtra, FAI scores of organic plots were relatively higher than that of chemical farming, but in most cases, they were not statistically different (p-values >0.05). Since the p-values are relatively higher for individual years, combining the results over the years using meta-analysis will help in aggregating the statistical evidence and increase the confidence level of the results (Borenstein et al., 2009).

Table 7.21 Mean scores of FAI and dimensional indices of organic and chemical plots with comparative statistics *(O: Organic plot; C: Chemical plot; M: Combined p-value)*

Crop	Year	Statistic function	FAI			Economic index			Social index			Ecological index		
Maharashtra			***O***	***C***	***M***	***O***	***C***	***M***	***O***	***C***	***M***	***O***	***C***	***M***
Cotton	2014-15	Mean Score	0.64	0.59	***0.037***	0.56	0.60	***0.069***	0.70	0.55	***< 0.001***	0.69	0.61	***< 0.001***
		P- value	0.089			0.323			< 0.001			0.009		
	2015-16	Mean score	0.66	0.60		0.60	0.69		0.71	0.51		0.69	0.56	
		P- value	0.067			0.040			< 0.001			< 0.001		
Soybean	2014-15	Mean score	0.61	0.56	***< 0.001***	0.52	0.52	***0.233***	0.65	0.57	***< 0.001***	0.70	0.62	***< 0.001***
		P- value	0.079			0.932			0.009			< 0.001		
	2015-16	Mean score	0.62	0.48		0.55	0.47		0.66	0.49		0.69	0.49	
		P- value	< 0.001			0.066			< 0.001			< 0.001		
Tamil Nadu			***O***	***C***	***M***	***O***	***C***	***M***	***O***	***C***	***M***			
Turmeric	2013-14	Mean score	0.82	0.70	***< 0.001***	0.72	0.61	***< 0.001***	0.73	0.69	***< 0.001***			
		P- value	< 0.001			0.022			0.059					
	2014-15	Mean score	0.91	0.55		0.86	0.64		0.87	0.55				
		P- value	< 0.001			< 0.001			< 0.001					
	2015-16	Mean score	0.90	0.47		0.83	0.50		0.86	0.50				
		P- value	< 0.001			< 0.001			< 0.001					
Paddy	2013-14	Mean score	0.67	0.53	***< 0.001***	0.43	0.33	***< 0.001***	0.66	0.54	***< 0.001***			
		P- value	< 0.001			< 0.001			< 0.001					
	2014-15	Mean score	0.79	0.53		0.65	0.44		0.73	0.52				
		P- value	< 0.001			< 0.001			< 0.001					
	2015-16	Mean score	0.69	0.50		0.43	0.40		0.72	0.53				
		P- value	< 0.001			0.488			< 0.001					
Odisha			***O***	***C***	***M***	***O***	***C***	***M***	***O***	***C***	***M***			
Cotton	2014-15	Mean Score	0.6	0.55	***0.004***	0.59	0.71	***0.143***	0.62	0.48	***<0.001***			
		P- value	0.07			0.005			<0.001					
	2015-16	Mean score	0.79	0.66		0.8	0.83		0.8	0.56				
		P- value	<0.001			0.03			<0.001					
Soybean	2014-15	Mean score	0.84	0.68	***0.027***	0.79	0.56	***0.043***	0.77	0.62	***0.001***			
		P- value	<0.001			<0.001			<0.001					
	2015-16	Mean score	0.84	0.77		0.77	0.69		0.77	0.69				
		P- value	0.006			<0.001			<0.001					
Karnataka			***O***	***C***	***M***	***O***	***C***	***M***	***O***	***C***	***M***			
Cotton	2013-14	Mean score	0.79	0.54	***0.11***	0.82	0.67	***0.844***	0.77	0.66	***0.004***			
		P- value	0.017			<0.001			<0.001					
	2014-15	Mean score	0.73	0.67		0.69	0.8		0.73	0.63				
		P- value	0.424			0.112			0.047					

Meta-analytic thinking contextualises the current results with past findings and aid the planning of future research (Cumming, 2013). The combined p-values estimated using Fisher's method, indicate that the FAI scores of organic plots are significantly higher in both cotton and soybean at 95% confidence level with the combined p-value of 0.037 and <0.001 respectively. In contrast to FAI, the economic index of chemical farm for both cotton and soybean was not statistically different from that of organic farms (combined p-value >0.05).

In case of Tamil Nadu, FAI of organic plots were significantly higher than that of chemical plots for both turmeric and paddy for each of the three years at 95% confidence level (p-value <0.001). Similar to FAI, the crop-wise mean scores of dimensional indices were also significantly higher at 95% confidence level for the organic farms except for economic index of paddy in the year 2015-16. The meta-analysis gave the combined p-values as less than 0.001 for all the indices indicating organic farms were doing significantly better than chemical farms when compared holistically.

Similar to Maharashtra, meta-analysis helped to improve the statistical evidence that FAI of organic cotton farms to be significantly higher than chemical farms. In contrast, the economic index of chemical farms in cotton were not statistically different from organic farms even after combining the data for two years. In case of paddy, the combined p-values reiterated that the organic farms had significantly higher FAI and dimensional index scores than chemical farms.

In case of Karnataka, there was no significant difference between organic and chemical farms in both FAI and economic index, even after the meta-analysis of two years. This can be attributed to the limited sample size during both the years.

Significance testing with p-values as used conventionally prompts dichotomous thinking that focuses on making a choice between alternatives. In order to move beyond the dichotomous question “is there an effect?” toward the estimation question of “How much effect”, we estimate the *effect size* (ES) of the mean difference between organic plots and chemical plots for various indices. ES is a measure of magnitude (“size”) along with the direction (“effect”) of any estimation statistics (Cumming, 2013). ES gives a cognitive advantage in understanding and communicating the results among researchers and readers. Point and interval estimates of ES are recommended for a better interpretation and discussion of results (APA, 2010).

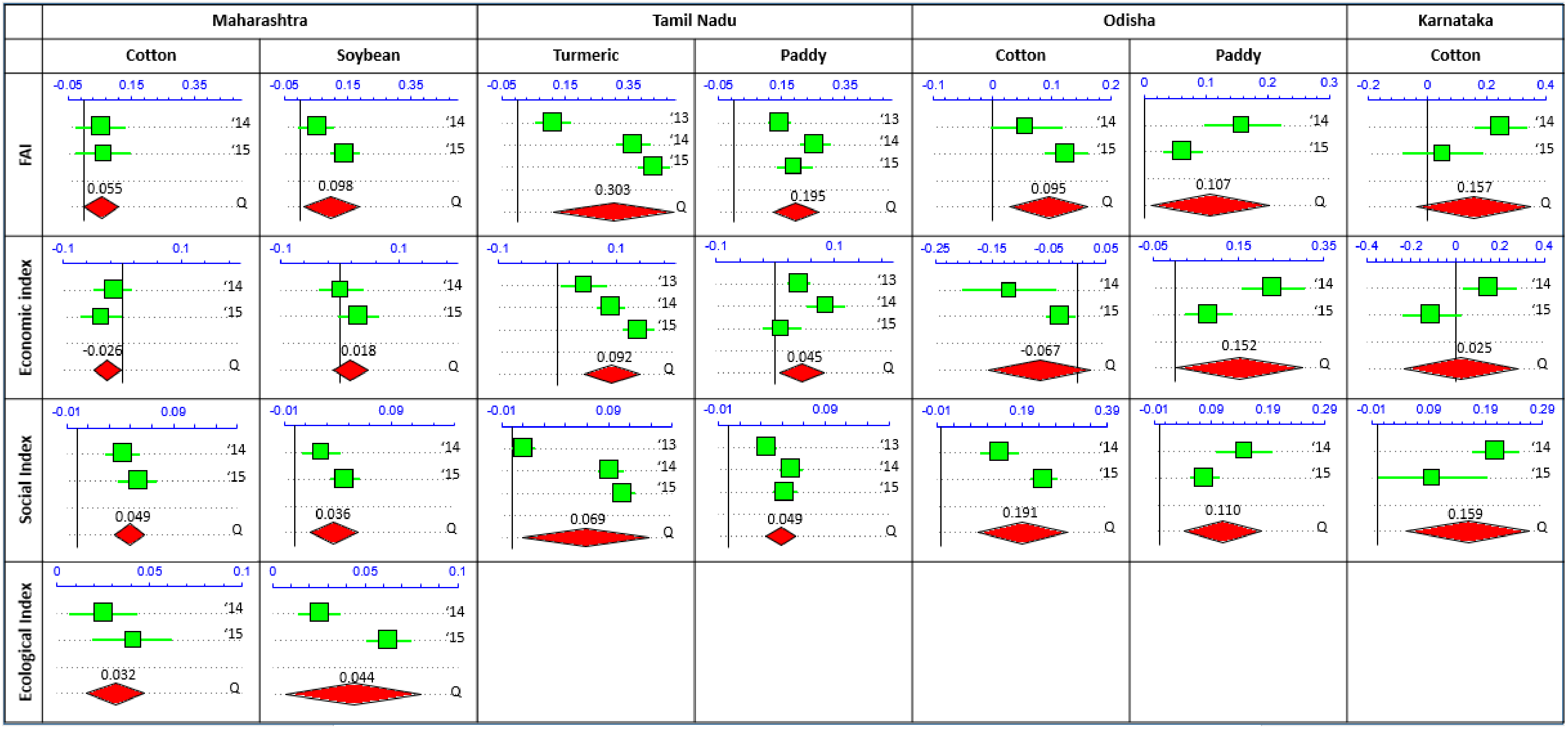


Figure 7.21 Forest plot of FAI and dimensional indices of various crops from four Indian states

Note: The unit of scales are the corresponding index scores and the measuring axis varies for each index. The green squares represent the effect size (ES) of the mean difference between chemical and organic plots with 95% confidence interval (CI) as indicated by the green bars on either side of the square. Red diamonds give the combined ES (Q) of the mean difference over the entire study period using the random effects model. A positive ES indicate that organic farms have scored higher than chemical farms during the respective year. A positive Q value indicate that organic farms have scored higher than chemical farms when compared over the years.

Figure 7.21 gives the *forest plots* of mean difference among chemical and organic plots for various indices. It gives the ES of mean difference with 95% confidence interval (CI), for each crop and each year individually as well as the combined effect size (Q) over the years, using the random effect method (Cumming, 2013). Aggregation of ES from similar studies helps to improve the statistical power and increases the likelihood of detecting the differences among groups (Ellis, 2010). The positive ES in most cases indicates that the scores of various indices for organic plots are higher than chemical plots. Though the point estimate of ES of FAI for cotton cultivation is positive for both years in Maharashtra and Odisha, CIs show that there are chances of zero mean difference during each year. However, pooling of results from both years gives a positive Q value with 95% confidence. In case of Karnataka, FAI of cotton farms had a positive effect size but the confidence interval was very large due to limited number of samples.

The major advantage of the forest plot over the p-values is the indication of the magnitude of the mean difference between the organic and chemical plots (Q = 0.03 to 0.3). The combined effect size (Q) of results over the years show that organic plots have scored significantly higher in all the indices across all the crops in all the states except for the economic indices of cotton in all the three states and soybean in Maharashtra.

7.4 Sensitivity analysis

Table 7.22 to Table 7.27 provide the results from sensitivity analysis using the change in rank method (CR) and decomposition of variance method for different categories over two years. An indicator with higher CR and higher S (first-order sensitivity) and ST (total effect sensitivity) values indicates a greater impact of the indicator over FAI. The tables are colour coded for a quick inference. Red implies maximum impact followed by yellow gradient and green for the least impact indicator. The results from decomposition of variance method (S and ST) were found to be consistent with that of change in ranking (CR) method in most cases.

In general, the sensitivity analysis shows that the crucial indicators influencing FAI score in most cases are PIQ, FIQ, net income and riskiness. In case of Tamil Nadu, FIQ is found to have the highest influence on the index for both the years. Net income and riskiness are found to be the second and third most influencing indicators for the year 2014-15 (Table 7.22). However, PIQ and riskiness are found to be the second and third most influencing indicators during the year 2015-16 in Tamil Nadu. In Maharashtra, net income is found to have the highest influence on the index followed by PIQ and FIQ during both the years (Table 7.22). In Odisha and Karnataka, the highest influencing factor were found to be PIQ, FIQ, net income and riskiness (Table 7.23).

Further crop-wise sensitivity analysis as given in Table 7.24 indicates that riskiness, FIQ, yield and PIQ are the top influencing factors in turmeric cultivation for the year 2014-15, and in the year 2015-16 it is riskiness, FIQ, PIQ and net income. In the case of paddy, PIQ, riskiness, net income and FIQ are found to be the top four influencing factors respectively. PIQ emerges to be the most influencing factor in cotton cultivation as well, followed by FIQ, net income and BCR indicators respectively (Table 7.25). Similarly, in soybean cultivation, PIQ is found to be the most influencing indicator followed by net income, BCR and riskiness. FIQ did not have much impact in case of soybean due to less fertiliser application, but in the case of paddy, the lesser influence of FIQ is due to a corresponding increase in yield. Net income and FIQ were the most influencing indictors in wheat cultivation during 2014-15 and 2015-16 respectively (Table 7.26). Similarly, net income and PIQ were the most influencing indicators in Bengal gram cultivation during 2014-15 and 2015-16 respectively (Table 7.26). In case of Odisha, the PIQ, the FIQ and the net income were found to be the most influencing indicators during both the years for cotton. Net income and FIQ were found to be the most crucial indicators in paddy field samples from Odisha (Table 7.27). It is notable that the PIQ has not made any significant difference among the sample farmers in wheat cultivation from Maharashtra and the paddy cultivation in Odisha.

Table 7.22 Sensitivity analysis of indicators for Tamil Nadu and Maharashtra across various crops

State	Tamil Nadu						Maharashtra					
Year	2014-15			2015-16			2014-15			2015-16		
Indicator	**CR**	**S**	**ST**	**CR**	**S**	**ST**	**CR**	**S**	**ST**	**CR**	**S**	**ST**
Total expenditure	3.31	0.01	0.08	3.92	0.01	0.06	2.75	0.01	0.02	3.12	0.01	0.07
Self-borne	1.03	0.00	0.05	0.74	0.00	0.02	1.84	0.00	0.04	2.18	0.00	0.05
Paidout cost	0.85	0.00	0.04	0.63	0.00	0.03	1.18	0.00	0.03	1.66	0.00	0.05
Net Income	2.87	0.05	0.21	2.19	0.05	0.28	7.36	0.08	0.28	8.51	0.08	0.17
BCR	1.58	0.02	0.14	2.11	0.02	0.14	3.79	0.05	0.27	4.18	0.05	0.22
Employment	0.77	0.00	-0.01	0.55	0.00	-0.01	1.13	0.00	0.02	1.12	0.00	0.02
Drudgery	0.85	0.00	0.06	0.59	0.00	0.08	1.97	0.01	0.06	2.03	0.00	0.03
Yield	1.19	0.00	0.03	0.93	0.00	0.04	2.37	0.01	0.02	2.77	0.01	0.01
PIQ	3.54	0.12	0.48	6.38	0.14	0.46	10.56	0.23	0.35	17.52	0.39	0.52
Total FIQ	6.53	0.21	0.51	8.82	0.19	0.48	7.77	0.18	0.36	7.68	0.11	0.21

Table 7.23 Sensitivity analysis of indicators for Odisha and Karnataka across various crops

State	Odisha						Karnataka					
Year	2014-15			2015-16			2014-15			2015-16		
Indicator	**CR**	**S**	**ST**	**CR**	**S**	**ST**	**CR**	**S**	**ST**	**CR**	**S**	**ST**
Total expenditure	3.32	0.02	0.17	5.53	0.05	0.24	0.43	0.01	0.13	0.38	0.02	0.11
Self-borne	1.01	0.00	0.03	2.68	0.01	0.07	0.00	0.00	0.01	0.00	0.00	0.00
Paidout cost	1.38	0.00	0.09	1.43	0.01	0.14	0.00	0.00	0.03	0.13	0.00	0.03
Net Income	8.04	0.09	0.02	11.98	0.22	-0.40	0.14	0.02	0.20	0.75	0.04	0.02
BCR	3.34	0.02	0.11	1.17	0.01	0.03	0.00	0.01	0.10	0.38	0.01	0.06
Employment	0.57	0.00	0.00	1.23	0.00	0.02	0.14	0.00	0.01	0.00	0.00	0.02
Drudgery	1.38	0.00	0.04	1.04	0.00	0.01	0.00	0.00	0.02	0.25	0.00	0.00
Yield	1.89	0.01	-0.04	4.11	0.02	-0.10	0.00	0.00	0.00	0.00	0.00	0.00
PIQ	16.68	0.37	0.34	28.81	0.95	0.49	1.43	0.27	0.51	1.63	0.28	0.37
Total FIQ	16.46	0.34	0.38	16.43	0.45	-0.23	1.71	0.21	0.47	2.38	0.40	0.64

Table 7.24 Sensitivity analysis of indicators within turmeric and paddy cultivation in Sittilingi, Tamil Nadu

Crop	**Turmeric**						**Paddy**					
Year	**2014-15**			**2015-16**			**2014-15**			**2015-16**		
Indicator	**CR**	**S**	**ST**	**CR**	**S**	**ST**	**CR**	**S**	**ST**	**CR**	**S**	**ST**
Riskiness	4.07	0.00	0.05	3.35	0.00	0.04	0.98	0.01	0.14	3.10	0.03	0.05
Self-reliance	0.93	0.00	0.03	0.69	0.00	0.02	0.23	0.00	0.05	0.30	0.00	0.03
Paidout cost	0.71	0.00	0.03	0.40	0.00	0.02	0.14	0.00	0.06	0.45	0.00	0.05
Net Income	0.75	0.02	0.17	0.76	0.03	0.28	0.93	0.03	0.22	2.05	0.02	0.09
BCR	0.39	0.01	0.07	0.65	0.01	0.12	0.56	0.03	0.27	1.50	0.02	0.14
Employment	0.82	0.00	-0.01	0.36	0.00	-0.01	0.23	0.00	0.02	0.35	0.00	0.01
Drudgery	0.54	0.00	0.07	0.51	0.00	0.09	0.28	0.00	0.01	0.55	0.00	0.00
Yield	1.04	0.00	0.03	0.58	0.00	0.06	0.28	0.00	0.01	1.00	0.00	-0.03
PIQ	1.07	0.11	0.48	2.04	0.10	0.43	2.47	0.18	0.54	5.90	0.37	0.66
Total FIQ	1.39	0.23	0.70	2.87	0.19	0.62	0.51	0.07	0.37	1.70	0.11	0.44

Table 7.25 Sensitivity analysis of indicators within cotton and soybean cultivation in Wardha, Maharashtra

Crop	**Cotton**						**Soybean**					
Year	**2014-15**			**2015-16**			**2014-15**			**2015-16**		
Indicator	**CR**	**S**	**ST**	**CR**	**S**	**ST**	**CR**	**S**	**ST**	**CR**	**S**	**ST**
Riskiness	0.90	0.01	0.06	0.55	0.01	0.11	1.16	0.01	-0.01	1.26	0.01	-0.02
Self-reliance	0.60	0.00	0.03	0.79	0.00	0.03	0.58	0.01	0.06	0.70	0.00	0.05
Paidout cost	0.50	0.00	0.04	0.48	0.00	0.05	0.53	0.00	0.03	0.42	0.00	0.02
Net Income	1.85	0.05	0.11	1.88	0.06	0.04	3.00	0.13	0.43	1.95	0.10	0.38
BCR	1.55	0.04	0.21	0.91	0.02	0.12	1.79	0.09	0.41	1.95	0.07	0.29
Employment	0.15	0.00	0.01	0.24	0.00	0.02	0.63	0.00	0.00	0.23	0.00	0.03
Drudgery	0.70	0.00	0.04	0.48	0.00	0.00	0.95	0.01	0.13	0.47	0.00	0.03
Yield	0.55	0.00	0.01	0.06	0.00	-0.01	0.47	0.00	0.08	0.23	0.00	0.04
PIQ	5.10	0.31	0.28	5.76	0.49	0.49	3.84	0.25	0.34	6.88	0.39	0.56
Total FIQ	4.60	0.27	0.52	3.09	0.19	0.38	0.63	0.01	0.01	0.88	0.01	0.03

Table 7.26 Sensitivity analysis of indicators within wheat and Bengal gram cultivation in Wardha, Maharashtra

Crop	Wheat						Bengal gram					
Year	2014-15			2015-16			2014-15			2015-16		
Indicator	**CR**	**S**	**ST**	**CR**	**S**	**ST**	**CR**	**S**	**ST**	**CR**	**S**	**ST**
Riskiness	1.00	0.02	0.08	0.48	0.01	0.00	0.53	0.03	-0.10	1.08	0.01	0.12
Self-reliance	0.64	0.02	-0.06	1.04	0.01	0.12	0.27	0.01	0.06	0.67	0.01	0.07
Paidout cost	0.18	0.00	0.01	0.48	0.00	0.06	0.13	0.00	0.01	0.42	0.00	0.08
Net Income	2.91	0.35	0.72	1.20	0.15	0.49	2.27	0.24	0.49	2.92	0.08	0.23
BCR	0.45	0.08	0.38	0.80	0.09	0.47	0.40	0.09	0.42	0.25	0.04	0.29
Employment	0.64	0.01	-0.03	0.72	0.00	0.04	0.40	0.00	0.01	0.42	0.00	-0.03
Drudgery	0.82	0.03	0.15	0.48	0.01	0.03	0.13	0.01	0.09	0.83	0.00	0.07
Yield	1.00	0.03	0.15	0.40	0.01	0.10	0.67	0.01	0.11	0.83	0.00	0.01
PIQ	0.00	0.00	0.00	0.72	0.03	-0.01	1.47	0.32	0.01	2.67	0.31	0.49
Total FIQ	0.45	0.02	0.06	1.52	0.10	0.30	0.00	0.02	0.16	0.42	0.04	0.20

Table 7.27 Sensitivity analysis of indicators within cotton and paddy cultivation in Odisha

Crop	Cotton						Paddy					
Year	2014-15			2015-16			2014-15			2015-16		
Indicator	**CR**	**S**	**ST**	**CR**	**S**	**ST**	**CR**	**S**	**ST**	**CR**	**S**	**ST**
Riskiness	1.97	0.02	0.06	1.53	0.02	0.17	1.43	0.01	0.09	1.13	0.02	0.05
Self-reliance	0.63	0.00	0.04	0.97	0.01	0.10	0.57	0.00	0.05	1.22	0.01	0.12
Paidout cost	1.10	0.01	0.07	0.90	0.01	0.15	0.49	0.00	0.07	0.48	0.00	0.08
Net Income	5.07	0.13	0.28	0.17	0.01	0.03	3.47	0.08	0.36	2.87	0.18	0.58
BCR	1.53	0.02	0.13	0.00	0.00	0.00	1.06	0.05	0.30	0.57	0.06	0.31
Employment	0.43	0.00	0.01	0.33	0.00	0.04	0.16	0.00	0.02	0.48	0.00	0.05
Drudgery	1.23	0.01	0.02	0.37	0.00	-0.01	0.33	0.00	0.07	0.26	0.01	0.06
Yield	0.77	0.00	0.02	0.00	0.00	0.01	0.65	0.00	0.05	0.48	0.01	0.10
PIQ	13.10	0.70	-0.08	20.20	1.10	0.53	1.10	0.18	0.40	0.00	0.00	0.00
Total FIQ	10.73	0.48	0.07	7.33	0.55	-0.71	2.61	0.07	0.20	1.83	0.06	0.31

Chapter 8 Conclusion and Recommendations

8.1 Conclusion

In this work, we have designed a stock and flow based framework to identify a holistic set of indicators for evaluation of any farming system. In contrast to the existing frameworks for indicator identification that are based on pre-set attributes, this framework has been designed for a systemic identification of indicators. It aides in identifying and selecting indicators that cover both short and long-term characteristics of the system across socio-economic and ecological dimensions. It also helps us to capture the stability and resilience of the system. This framework improves the transparency and reliability of the process of identification and selection of indicators. In addition, the framework aids in the selection of appropriate proxy indicators for hard to measure primary indicators by tracing their forward and backward linkages.

A comprehensive set of indicators was identified using the framework and validated at a stakeholder workshop. These indicators were transformed using min-max normalization followed by hierarchical weighing and progressive aggregation using weighted mean to form the Farm Assessment Index (FAI), which can be used as a single holistic measure for any farming system. In addition, three dimensional indices *viz.* economic index, social index, and ecological index, were also calculated. These indices help in relative rating of farming systems and practices, and identification of appropriate policy interventions. While these composite indicators are powerful tool for communicating the masses and policy discourse, the inherent assumption of substitutability among indicators and compromise on the individual characteristic narratives are their limitations to be acknowledged.

We applied the FAI to compare the organic and chemical farming systems of 200 farmers from the states of Maharashtra, Tamil Nadu, Odisha and Karnataka. The results from FAI application indicate that the focus on yield or income as the sole indicator will not lead to sustainable farming practices. Agricultural policies need to shift towards more holistic interventions with an emphasis on human health, livelihood of farmers and sustenance of agro-ecology.

In case of Maharashtra and Odisha, field data shows that in spite of variations in trends of individual indicators like yield, cost of cultivation, income etc., organic farms have significantly higher FAI than that of chemical farms. Popular economic indicators like yield and income are predominantly higher in case of chemical farms, but the inclusion of other indicators like riskiness and resource use efficiency makes the economic index of organic and chemical farms relatively similar. Organic farms have scored better in both social and environmental indices. Pesticide and fertilizer impact quotients have been the critical factor affecting both social and ecological indices of chemical farms. Further, social index score has also been affected due to higher paidout expenditure in chemical farms.

In the case of Tamil Nadu, the FAI of organic farms were significantly higher than that of chemical farms for both turmeric and paddy farms over three years. The gap between the FAI of organic and chemical farms is larger in Tamil Nadu than in Maharashtra. This is due to low net income and poorer PIQ in chemical farms. The economic index of turmeric is significantly higher for organic farms due to premium pricing for organic produce. In case of Karnataka, the sample size was too less to have any statistical inference for the indicators and composite indices.

The variance in FAI among the farmers within the chemical group was significantly higher than that of organic farms both in Maharashtra and Tamil Nadu. Also, less input intensive crops like wheat and gram have significantly higher index scores than that of input intensive cotton cultivation under chemical farming. Thus, the designed FAI will be a useful tool for assessment of farming practices as well as selection of crops, thereby aiding the design of farm policies. Field application of FAI has shown that organic farming practices have scored better in most cases and need to be encouraged for a long-term social viability of farming and ecological sustainability of agriculture.

Future work

There are two scales of application in assessment studies. A site-specific data will provide an accurate and more reliable assessment, and generic data like regional or national statistics will provide an approximate estimation (Manhart and Grießhamme, 2006). While we have applied indicators to compare farming system at field level, the same set of indicators can be defined for regional level data and used for a state level comparison of farming systems. Further, it is necessary for indicators to evolve from just a measurement tool to a management decision support system.

Feedback, analysis, and reflection of practical application of indicators are essential for such a transition to decision support tool (Kaplan and Norton, 1999).

In this study, we have taken the farming field as the system boundary and considered the social aspect of producers and consumers, in contrast to a wider boundary for ecological aspects. Expanding the boundary for socio-economic aspects of flow variables to institutions, market etc., will help in macro level agricultural sustainability evaluation. Additionally, as discussed in the previous section, FAI can be used to evaluate effectiveness of new technologies and assess the impacts of any policy interventions and schemes to its beneficiaries.

Although the field application of FAI helped to rate farming practices, the data collection for the entire set of indicators was very challenging and resource consuming. At present, FAI was computed with a limited number of indicators depending upon the availability of data and feasibility of indicator estimation. While this intensive field study is required for a comprehensive scientific evaluation, it is also desirable to have a more rapid and simpler methodology for a wider application of the index. Further, the methodology can be integrated with a feedback system which will support and improve the decision making of farmers in farm management.

8.2 Recommendations

In this section, we discuss the scope of FAI by describing a few general recommendations for the application of the methodology designed and a set of site-specific recommendation based on the case studies. While there have been continuous efforts to improve farming practices towards food and agricultural sustainability, a metric to assess their performance in a holistic manner has been the need of the hour. So the first and foremost, we suggest government agencies like ***Niti Aayog, ICAR, and NABARD to facilitate wider discussions on the need for deploying a holistic index with relevant stakeholders such as DARE (Department of Agricultural Research and Extension, Ministry of Agriculture and Farmers' Welfare), State universities etc.*** The Farm Assessment Index (FAI) developed in this work has a great potential in assessing farm management practices across various dimensions. As an outcome of this work, we discuss the usefulness of the FAI in the context of agricultural research and extension as follows.

Agricultural Research

The current appraisal system adopted in the agricultural research system has a narrow focus that does not assess the performance of farm systems comprehensively by neglecting socio-economic and ecological dimensions. This results in a whole set of approaches which ignore sustainable farming and livelihood of farmers. Institutes like ***ICAR and NABARD should adopt FAI kind of composite index based evaluation in the projects and programs they support, such as AICRPs (All India Coordinated Research Projects), NHM (National Horticulture Mission), NICRA (National Initiative on Climate Resilient Agriculture), NRM (National Resource Management) program,*** etc. The use of proposed FAI will provide a multi-dimensional assessment at the field level and hence will aid in identifying both the potential and shortcomings of any farming technology or program implemented. In addition, agencies like NABARD should institute tools like FAI for ***assessing the farming practices that are refinanced for medium and long-term investments in agriculture sector.*** This will provide a better understanding of overall outcomes and impacts of such investments, and their sustainability.

Agricultural Extension

Some state governments as well as the central government have identified areas with acute agrarian distress and have listed out 'suicide-prone districts' in PM Rehabilitation Programme. ***Ministry of Agriculture should encourage the extension agencies to take up monitoring of the situation using FAI as a way of looking at the situation holistically*** and to monitor the interventions that have been brought in. Intra-intervention comparisons are also possible. Appropriate sampling should be taken up for monitoring and evaluation of various interventions as well as assessment of current situation of farming system at any given point of time.

Recommendations based on the case study

The following recommendations are based upon field application of FAI in 100 organic and 100 chemical farmers across four states in India.

- Since FAI score of organic farms is found to be significantly higher than that of chemical farms for all the crops, government agencies need to ***strengthen their support for organic farming practices to improve the multi-dimensional sustainability of farms***.
- The economic index of chemical farms is affected mainly due to lesser resource use efficiency and higher riskiness. Since the importance of resource conservation and climate resilient agriculture is increasing, the government should ***encourage organic farming to reduce the risk involved in their credit loans and to increase the resource use efficiency in NRM programmes***.

- Pesticide usage has been found to be a critical factor affecting ecological and social indices. In most of the chemical farms, pesticide application has been over double the level of maximum recommended dosage. Agricultural department needs to initiate programmes to ***sensitize farmers***, ***farmers' clubs and farmer producer organizations, about the direct and indirect impacts caused by pesticides and their appropriate usage.*** The indiscriminate use of pesticides is often due to inadequate guidance given by the shopkeepers. The government ***should design policies for stricter regulation and monitoring of pesticide sales and usage.***
- While FIQ-N and FIQ-K are relatively better, FIQ-P is observed to affect the indices of both organic and chemical cotton farms. This is mainly due to a mismatch between phosphorous consumption and its application rate. Programmes to ***sensitize farmers about the benefits of balanced, crop-specific, and timely nutrient application, needs to be improved***.
- Though the soil biological activity was found to be higher in the organic farms, soil nutrients were relatively lesser, indicating the need to increase the organic nutrient inputs. *C**redit incentives to small-scale enterprises producing organic manures need to be increased and livestock maintenance by farmers needs to be promoted for increasing the access to organic manures***.
- In case of Maharashtra, more than one-third of the total expenditure is spent on machinery or bullocks for ploughing, tilling etc., for both organic and chemical farmers. In order to reduce this burden on farmers, ***schemes on machinery hiring and support through farmers groups for farm operations should be increased in this region***.
- Since the FAI is comparable across the crops, significantly higher FAI of organic farms in crops other than cotton indicates that the ***schemes promoting organic farming can prioritize food crops over cash crops like cotton.***

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Appendix 1

Dimensional boundaries for various inflow and outflows

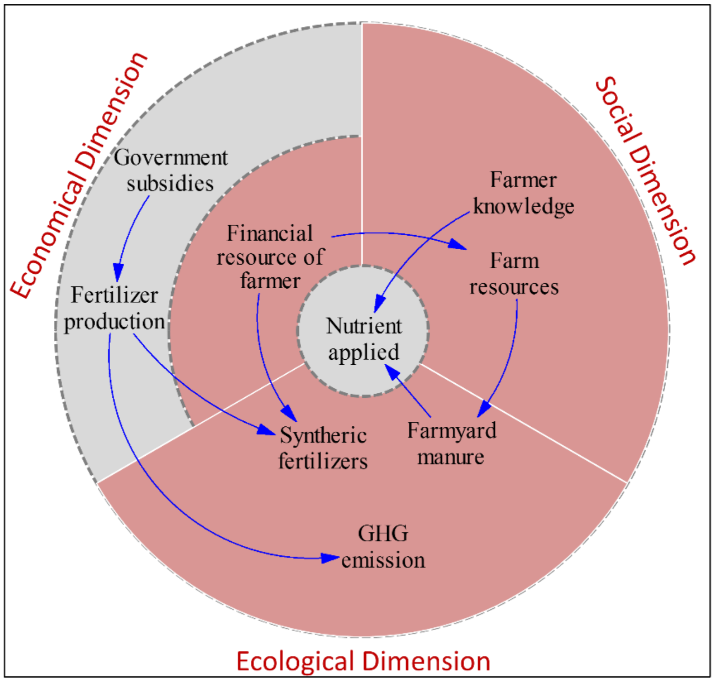

Figure A.1 Dimensional boundaries for nutrient applied

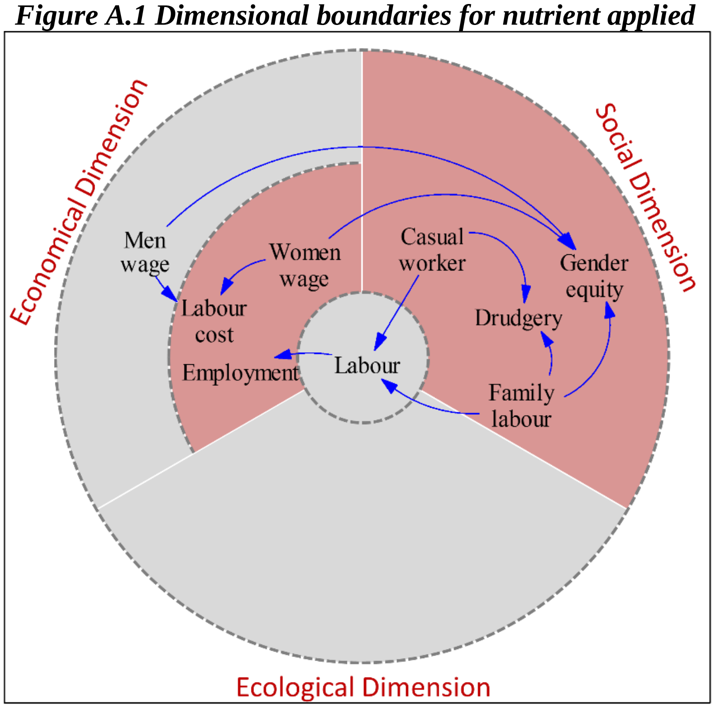

Figure A.2 Dimensional boundaries for labour used

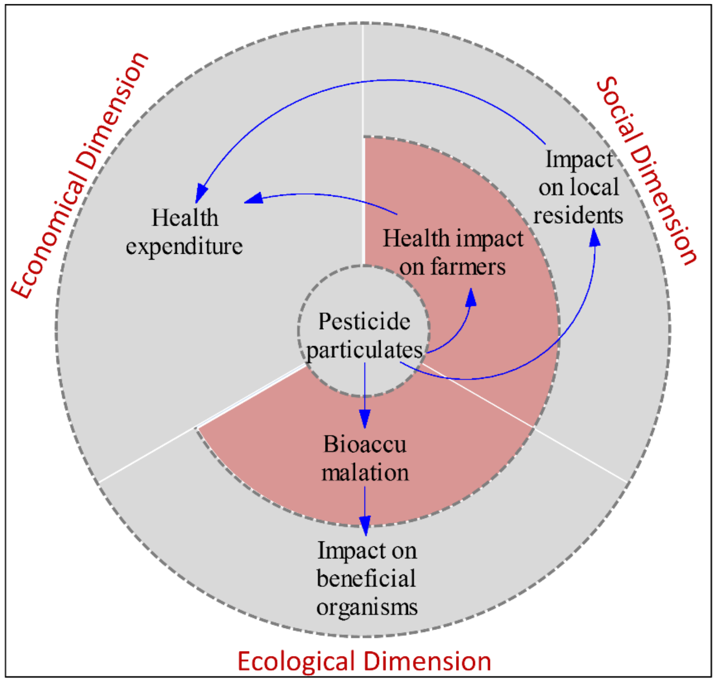

Figure A.1 Dimensional boundaries for pesticide particulates

Appendix 2

Participants in Delphi workshop

Expert panel

S No	Name and affiliation
1	Dr. Sudhir Goel, Ex. Agricultural Secretary, Govt. of Maharashtra
2	Prof. Surya Narayanan, IGIDR, Mumbai
3	Dr. Satyasai, Deputy General Manager, NABARD, Mumbai
4	Dr. Devakumar, Professor, UAS, Bengaluru
5	Mr. Ashok Bang, Chetana Vikas, Wardha
6	Mr. Kapil Shah, Jatan Trust, Vadodara

Other participants

S No	Name and affiliation
7	Prof. Srijit Mishra, IGIDR, Mumbai
8	Ms. Kavitha Kuruganti, ASHA, New Delhi
9	Ms. Kavita Gandhi, SwissAid, New Delhi
10	Mr. Ananthasayanan, ReStore, Chennai
11	Ms. Shamika Mone, OFAI, Mumbai
12	Mr. Manjunath, Tribal Health Initiative, Dharmapuri, TN
13	Mr. Chinnathurai, Tribal Health Initiative, Dharmapuri, TN
14	Mr. Jay Vaidya, Research Intern, Washington University, St. Luis, USA

Appendix 3

Quantitative Questionnaire

COMPOSITE INDEX FOR SUSTAINABLE PRODUCTIVITY STUDY

Date of Survey............. **Name of the interviewer...................................**
Name of the farmer.. **Farmer code..**
Year and Season..

1. BASIC DETAILS

1.1. State		1.2. District		1.3 Taluka		1.4. Village	
1.5. Full Name of the cultivator/ decision maker					1.6. Sex: Male □ / Female : □	1.7. Age in Years:	
1.8. Name of the Respondent & Relationship with cultivator							
1.9. Total Number of people in Family written as (Adults) + (Children) number:			1.10. No. of people who work on Agriculture (Shown as Adults + Children)				
1.11. Complete postal address				1.12. Phone/Mobile/email			
1.13. Principal Occupation				1.14. Subsidiary Occupation			
1.15. Farmer's Education	A. Illiterate □ B. Primary □ C. Secondary □ D. Graduate □ E. Post-graduate □						

2. LANDHOLDING DETAILS

	Plot 1	**Plot 2**	**Plot 3**
2.0. Plot name as referred to by the household			
2.1. Plot size, in acres			
2.2. Irrigated area in acres			
2.3. Source of irrigation (open well, tubewell, tank, farm pond, etc.)			
2.4. Rainfed area in acres			
2.5. Land extent under ecological farming, in acres			
2.6. If certified organic, indicate by Yes or No.			
2.7. Soil type (Sandy, Sandy Loam, Loamy, Red, Black, Other)			
2.8 Main crop			

3. LAND PREPARATION PROCESSES

Wage Rate for Men: ₹………/day **Wage Rate for Women:** ₹………/day **Bullock hire:** ₹………/Day **Tractor hire cost:** ₹………/hour

		Plot 1	**Plot 2**	**Plot 3**
Process 1 name				
Man power, Number × days				
Women power (Number × days)				
Machine/livestock (mention which)				
Hours	Hours			
Diesel consumed	Number of bulls			

Process 2, 3…

4. BASAL MANURE APPLICATION

Wage Rate for Men: ₹………/day **Wage Rate for Women:** ₹………/day **Bullock hire:** ₹………/Day **Tractor hire cost:** ₹………/hour

	Plot 1	**Plot 2**	**Plot 3**
Fertilizer/manure 1 name			
Source (home made/market/govt)			
Total Quantity with unit			
Unit description in kilos			
Cost per unit			
Man power (Number × days)			
Women power (Number × days)			
Machinery (diesel and hours)			

Fertilizer/manure 2, 3…

5. SOWING, RESOWING, TRANSPLANTING etc. (All three activities combined)

Wage Rate for Men: ₹………/day **Wage Rate for Women:** ₹………/day **Bullock hire:** ₹………/Day **Tractor hire cost:** ₹………/hour

Plot 1	**Main crop**	**Inter crop 1**	**Inter crop 2**	**Inter crop 3**	**Inter crop 4**
Name of crop					
Seed variety name					
Seed type (Bt/Hybrid/Improved/Traditional)					
Source (Home/Govt/Pvt/Fellow farmers)					
Seed rate (number of kgs/acre)					
Seed cost per unit					
Man power (Number × days)					
Women power (Number × days)					

Bullock power (number of pairs X days)					
Machinery (diesel and hours)					

Plot 2, 3…

6. TOP DRESSING/PLANT GROWTH PROMOTERS

Wage Rate for Men: ₹………/day **Wage Rate for Women:** ₹........./day **Bullock hire:** ₹........./Day **Tractor hire cost:** ₹………/hour

	Plot 1	**Plot 2**	**Plot 3**
Fertilizer/promoter 1 name			
Source (Govt/Home/Pvt trader)			
Total Quantity with unit			
Unit description in kilos			
Cost per unit			
Man power (Number × days)			
Women power (Number × days)			
Machine name (if any)			
Hours			
Diesel consumed			

Fertilizer/promoter 2, 3…

7. WEEDING / INTER-CULTIVATION

Wage Rate for Men: ₹………/day **Wage Rate for Women:** ₹........./day **Bullock hire:** ₹........./Day **Tractor hire cost:** ₹………/hour

	Plot 1	**Plot 2**	**Plot 3**
Weeding Round 1 (manual de-weeding or herbicide or inter-cultivation)			
Crop name (if particular)			
Name of active ingredient, if herbicide			
Source			
Total Quantity with unit			
Cost per unit			
Man power (Number × days)			
Women power (Number × days)			
Bullock pairs used X days			
Machine name (if any)			
Hours			
Diesel consumed			

Weedicide/manual weeding/inter-cultivation 2, 3…

8. DETAILS OF IRRIGATION

Description	Plot 1	Plot 2	Plot 3
No. of irrigations/watering applied			
Method of irrigation			
If by pump, HP of pump used			
If by pump, inch diameter of the pipe used			
Estimated time in minutes to irrigate field each time			
Estimated quantity of water for each irrigation in Lit.			
Cost of water / irrigation			

9. PESTS & DISEASES

Wage Rate for Men: ₹………/day **Wage Rate for Women:** ₹........./day **Bullock hire:** ₹........./Day **Tractor hire cost:** ₹………/hour

	Plot 1	Plot 2	Plot 3
Kind of pest/disease 1 (name)			
Severity (High/Medium/Low)			
Crop name (if particular)			
Name of active ingredient			
Source			
Total Quantity with unit			
Cost per unit			
Man power (Number × days)			
Women power (Number × days)			
Machine name (if any)			
Hours			
Diesel consumed			

Kind of pest/disease 2, 3…

10. HARVESTING & MARKETING

Wage Rate for Men: ₹………/day **Wage Rate for Women:** ₹........./day **Bullock hire:** ₹........./Day **Tractor hire cost:** ₹………/hour

Plot 1	Main crop	Intercrop 1	Intercrop 2	Intercrop 3	Intercrop 4
Harvesting process					
Man power (No. × days)					

Women power (No. × days)						
Machine hours						
If machine, diesel litres consumed						
Post harvesting process						
Man power (No. × days)						
Women power (No. × days)						
Machine/livestock						
Hours	Hours					
Diesel consumed	Number of bulls					
Transportation						
Total cost						
Diesel consumption						

Plot 2, 3…

11. YIELD DETAILS (quantity in kilos and if in local units, the measure to be mentioned and the description in kilos to be given)

Plot 1	**Main crop**	**Inter crop 1**	**Inter crop 2**	**Inter crop 3**	**Inter crop 4**
Main product Quantity produced, with units mentioned					
Description of unit					
Quantity sold, with units mentioned					
Sold price per unit					
Market price					
Byproduct 1 name					
Quantity produced with units mentioned					
Description of unit					
Quantity sold					
Sold price per unit					
Byproduct 2 name					
Quantity produced, with units mentioned					
Description of unit					
Quantity sold					
Sold price per unit					

Plot 2, 3…

12. MISCELLANEOUS OUTPUTS (INCL. UNCULTIVATED GREENS, TUBERS ETC.)

S No	Tree/plant name	Number	Cost incurred, in ₹	Product name	Quantity produced, with unit mentioned	Quantity sold	Sale Price per unit	Unit description

13. EXPENSES ON LIVESTOCK

Type of Animal or Bird	Type:1: Name: Number:			Type:2: Name: Number:			Type:3: Name: Number:		
Cost	**Number**	**Calculation**	**Amount (₹)**	**Number**	**Calculation**	**Amount (₹)**	**Number**	**Calculation**	**Amount (₹)**
Infrastructure maintenance cost (annual)									
Cost of feed/fodder purchased									
Imputed Labour cost (own)									
Labour cost (external)									
Veterinary cost involved									
Cost of marketing produce									
Total Cost									

14. INCOME FROM LIVESTOCK

Type of Animal or Bird	Type:1: Name: Number:			Type:2: Name: Number:			Type:3: Name: Number:		
Income	**Number**	**Calculation**	**Amount (₹)**	**Number**	**Calculation**	**Amount (₹)**	**Number**	**Calculation**	**Amount (₹)**
Product Type									
Yearly yield (total) with unit									
Sales price of unit produce									
Total Income									

15. INDEBTEDNESS, IF ANY (ONLY FOR CROP INVESTMENT, AND NOT FOR CAPITAL INVESTMENTS):

1. Did you borrow any money for agricultural investment for your farming this season?: Yes □/No □ (This includes credit for purchase of external inputs)
2. If yes, what is it for? (mention details):
3. If yes, what is the total amount borrowed?: Rs…………
4. Source of Credit: (A) Friend □ (B) Relative □
   (C) Moneylender □ (D) Input Dealer □ (E) Bank □ (F) Coop Society □ (G) Other (Mention) □
5. Interest Rate: ……. %

16. DETAILS OF EXTENSION SUPPORT RECEIVED DURING THE PAST SEASON

Type of Support	Received – Yes/No?	Who provided support? (A. NGO, B. Govt orgn, C. Farmers' movement, D. Others – mention)
Training		
Exposure visits		
Input support		
Marketing support		
Any other support		

Appendix 4

Sample form for farmer visit

Farmer Name: Village: Crop Name: Area:

Visit No.	Tractor hours	Tractor price per hour	Own Bullock days	Hired bullock days	Bullock price per day
	Name of the inputs	Composition/ Active ingredient	Self-borne quantity in kg	Purchased quantity in kg	Unit price
Process Name					
	Self man days	Hired Man days	Self Woman days	Hired Woman days	Wage per day (M/F)
Visit No.	Tractor hours	Tractor price per hour	Own Bullock days	Hired bullock days	Bullock price per day
	Name of the inputs	Composition/ Active ingredient	Self-borne quantity in kg	Purchased quantity in kg	Unit price
Process Name					
	Self Man days	Hired Man days	Self Woman days	Hired Woman days	Wage per day (M/F)
Visit No.	Tractor hours	Tractor price per hour	Own Bullock days	Hired bullock days	Bullock price per day
	Name of the inputs	Composition/ Active ingredient	Self-borne quantity in kg	Purchased quantity in kg	Unit price
Process Name					
	Self Man days	Hired Man days	Self Woman days	Hired Woman days	Wage per day (M/F)
Visit No.	Tractor hours	Tractor price per hour	Own Bullock days	Hired bullock days	Bullock price per day
	Name of the inputs	Composition/ Active ingredient	Self-borne quantity in kg	Purchased quantity in kg	Unit price

About FAI and its application

Traditionally, crop yield has been the main focus of agricultural policies and technological interventions. While there have been continuous efforts to improve farming practices towards food and farm sustainability, a metric to assess and promote farming system in a holistic manner has been missing. In order to address this need, we have developed a *Stock* and *Flow* based framework for a systemic identification of both short and long-term indicators across the socio-economic and ecological dimension. In this framework, stock variables inside the system capture the stability and resilience of the system, and the variables from biophysical flows across the system-environment boundary capture both the desirable outcomes and undesirable impacts. The framework also aids in the selection of appropriate proxy indicators for hard to measure primary indicators by tracing their forward and backward linkages rather than avoiding complex indicators altogether. This stock and flow based framework is used to identify a holistic set of indicators for comparing farming system. These indicators are classified under three widely accepted dimensions: economic, social and ecological dimension. The indicators under each dimension are aggregated to give three dimensional indices. These dimensional indices are further aggregated to give a single holistic index called Farm Assessment Index (FAI).

The FAI was applied to evaluate farming practices of a set of 100 organic and 100 chemical farmers, across Maharashtra, Tamil Nadu, Odisha and Karnataka. The major crops including cotton, soybean, wheat, bengal gram, turmeric and paddy cultivated over three years (2013 – 2016) totalling to 764 plots are studied. While there have been variations in yield and income trends, FAI score of most organic farms is better than corresponding chemical farms. Even in the cases where the gross income from chemical farms is relatively higher, the economic index is higher for organic farms due to their higher benefit-cost ratio, lower risk, as well as better resource use efficiency. Similarly, in case of the social and environmental index, organic farms have scored higher than chemical farms given the impacts caused by excessive fertilizer and pesticide usage in chemical farms.

The results from FAI application demonstrate that the focus on yield or income as the sole indicator for policy decisions will not lead to sustainable farming systems. Policy makers and technocrats need to shift towards holistic measures emphasising human health, livelihood of farmers and sustenance of agro-ecology. Further, the comparative studies have shown that organic farming practices need to be encouraged for improving the long-term socio-economic viability of the farmers and ecological sustainability of agriculture.

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