

Development and Field Application of the Farm Assessment Index (FAI) for Evaluation of Farming Systems

Submitted in partial fulfilment of the requirements for the degree of

Doctor of Philosophy

by

Siva Muthuprakash K M

(Roll No. 114350003)

Under the guidance of

Prof. Om P Damani



Indian Institute of Technology Bombay,

Powai, Mumbai – 400076.

April 2018

Declaration

I hereby declare that the thesis entitled “*Development and Field Application of the Farm Assessment Index (FAI) for Evaluation of Farming Systems*” submitted by me, for the partial fulfilment of the degree of Doctor of Philosophy to CTARA, IIT Bombay is a record of the research work carried out by me under the supervision of Prof. Om Damani, IIT Bombay, Mumbai.

I further declare that this written submission represents my ideas in my own words and wherever other’s ideas or words have been included, I have adequately cited and referenced the original sources. I affirm that I have adhered to all principles of academic honesty and integrity and have not misrepresented or falsified any idea/data/fact/source to the best of my knowledge. I understand that any violation of the above will cause for disciplinary action by the Institute and can also evoke penal action from the sources which have not been cited properly.

Date:

Siva Muthuprakash K M

Acknowledgments

My first and foremost gratitude to Prof. Om Damani for his guidance, motivation and continuous support in every aspect during my Ph.D. life. Secondly, I express my sincere thanks to all our collaborators especially the members of ASHA (Alliance for Sustainable and Holistic Agriculture) for their support in conceptualizing the project, facilitating field selection, outcome discussions etc. My special thanks to Tribal Health Initiative (Sittilingi, Dharmapuri, Tamil Nadu), Chetana Vikas and Dharamitra (Wardha, Maharashtra), for their invaluable support in various aspects including selection of farmer sample, organising farmer's orientation workshop, data collection and hosting me during field visits. My sincere thanks to the members of my Research Progress Committee (RPC) including Prof. Milind Sohoni, Prof. N C Narayanan, Prof. Narendra Shah, and Prof. Bakul Rao for their comments and feedback to improve my research work.

I would like to acknowledge that the genesis of this thesis research lies in an earlier project of Association for India Development (AID), USA on comparing organic and chemical practices. My profound thanks to ASHA especially Ms. Kavitha Kurunganti to bring us the research problem which is of great relevance to various stakeholders in agriculture. I extend my hearty thanks to all the members of Organic Productivity group including Prof Srijit Misra (from NCDR, Bhubaneswar), Mr Ashok Bang, Ms Niranjana Maru and Mr. Sumit (from Chetana Vikas, Wardha), Mr. Ananthoo (from ReStore, Chennai), Ms. Shamika Mone (from OFAI, Mumbai), Mr. Manjunath and Mr. Chinnathurai (from Tribal Health Initiative, Dharmapuri, TN) for their tremendous support for the field work and my respect to Late Dr. Om Rupela for his feedback on the methodology.

My abundant thanks to my world of friends starting from labmates Asha, Rahi, Gautam and Pooja, followed by department friends Sivaram, Hemant, Vamsee, Gautham, Biswanath, Vishal, Neelam and Soumya, and then friends from other departments including Puja, Sheeba, Archana, Tanu, Hamid, Majid, Riddhi, Harsha, Muni, Mani, Kutty, Thamarai, Sivalingam and Dinesh. Above all, my whole-hearted thanks to my mom Ms. Balambigai and dad Mr. Murugan for their continuous support and patience throughout my research life. I would also like to thank my family members Siva and Shanmu anna, Lakshmi and Poorani anni, and Ghuhan and Janani for their warmth through my Ph.D. life. Finally, my respects to my grandparents Late Mr. Ekambaram, Late Mr. Muthiar, Late Ms. Parvathi and Ms. Rajeswari for their inspirations which keeps me going ahead.

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. The indicators under each dimension are aggregated using weighted average 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 30 organic and 30 chemical farmers, each in Wardha region of Maharashtra and in Dharmapuri district of Tamil Nadu. The major crops including cotton, soybean, wheat, bengal gram, turmeric and paddy cultivated over 522 field plots during the year 2013-16 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. Further, the variance of FAI among chemical farms was significantly higher than that of organic farms. Within chemical farms, less intensive crops like wheat and gram have significantly higher index score than that of input-intensive cotton cultivation. The case studies show that FAI is a valuable tool for assessing farm practices as well as crop selection, and thereby aid in designing farm policies. Further, the comparative results show that the organic farming practices need to be encouraged for improving the long-term socio-economic viability of the farmers and ecological sustainability of agriculture.

Contents

Declaration	ii
Acknowledgements	iii
Abstract	iv
Contents.....	vi
List of Tables.....	x
List of Figures	xii
List of Abbreviations.....	xiv
Chapter 1 Introduction	1
1.1. State of agriculture in India.....	1
1.2. Motivation	8
1.3. Sustainability assessment tools	9
1.4. Indicators and composite index.....	11
1.5. Aim and objectives.....	12
1.6. Research design.....	13
1.7. Structure of the thesis.....	14
Chapter 2 Literature Review	15
2.1 Indicators and frameworks	15
2.2 Indicator selection frameworks	17
2.3 Framework application and case studies.....	23
2.4 Policy recommendations	27
2.5 Need for a framework	29
Chapter 3 Indicator Identification Using Stock and Flow Based Framework	31
3.1 Stock and flow based framework.....	31
3.2 System definition.....	32

3.3	Conceptualization of the system	34
3.4	Identification of indicators	35
3.5	Identifying proxy indicators	37
Chapter 4	Composite Index.....	39
4.1	Normalization of indicators.....	39
4.2	Weighing of indicators	46
4.3	Aggregation of indicators.....	49
4.4	Validation of the composite index	51
Chapter 5	Design of Farm Assessment Index.....	53
5.1	Indicators for comparing farming systems.....	53
5.1.1	System definition	53
5.1.2	Construction of stock and flow diagram.....	53
5.1.3	Identification of indicators	56
5.1.4	Identifying proxy variables	61
5.2	Farm Assessment Index (FAI)	66
5.2.1	Indicator estimation	66
5.2.2	Normalization	69
5.2.3	Weighing and aggregation.....	74
5.2.4	Validation.....	75
5.2.5	Sensitivity analysis.....	77
Chapter 6	Application of Farm Assessment Index (FAI).....	79
6.1	Farming practices	79
6.1.1	Organic farming.....	79
6.1.2	Organic farming in India.....	80
6.1.3	Chemical farming.....	81

6.1.4	Chemical farming in India	81
6.1.5	Comparative studies.....	93
6.2	Field selection and data collection	96
6.2.1	Selection of farmers	96
6.2.2	Data collection and processing	98
6.2.3	Soil sampling and testing	101
6.3	Methodological challenges.....	102
6.3.1	Challenges in the survey	102
6.3.2	Challenges in soil sampling and testing.....	105
6.3.3	Alternative questionnaire	105
6.4	Results and Discussion.....	109
6.4.1	Trends in indicators.....	110
6.4.2	Composite indices	126
6.4.3	Sensitivity analysis.....	131
Chapter 7	Conclusion and Recommendations	135
7.1	Conclusion.....	135
7.2	Recommendations	137
	Agricultural Research.....	137
	Agricultural Extension	138
	Recommendations based on the case study.....	138
References	140
Appendix 1	I
	Dimensional boundaries for various inflow and outflows	I
Appendix 2	III
	Participants in Delphi workshop	III

Appendix 3 IV
List of farmers in field sample IV
Appendix 4 VIII
Quantitative Questionnaire..... VIII
Appendix 5XV
Sample form for farmer visitXV
Publications XVI

List of Tables

Table 4.1 Brief description and functions of various normalization methodologies	40
Table 4.2 Pros and cons of various normalization methods	42
Table 4.3 Weighing methods based statistics	47
Table 4.4 Weighing methods based on opinions	48
Table 4.5 Aggregation methods based on the nature of indicators.....	51
Table 5.1 Indicators from stocks within the system	58
Table 5.2 Indicators from desirable outflow variable.....	58
Table 5.3 Indicators from undesirable outflow variable.....	58
Table 5.4 Impacts on environment from the inflows.....	59
Table 5.5 Primary indicators and the proxy indicators*	62
Table 5.6 Indicator definition and units.....	67
Table 5.7 Basis of references points to normalize the indicators used in field application	70
Table 5.8 Reference values for socio-economic indicators	71
Table 5.9 Reference for PIQ based on maximum recommended dosage	72
Table 5.10 Reference points for yield and fertilizer impact quotient	72
Table 5.11 NPK composition standard of nutrient inputs used in FIQ.....	73
Table 5.12 Reference points for soil parameters	74
Table 6.1 Impact of synthetic fertilizers on soil quality	82
Table 6.2 Impact of synthetic fertilizers on water resources	84
Table 6.3 Pesticide contamination in various products across different states of India	87
Table 6.4 Comparative studies on organic and chemical farming systems in India.....	94
Table 6.5 Methods used for soil parameter estimation.....	102
Table 6.6 Challenges in farm surveys and measure taken to address the issues	103
Table 6.7 Weightage (W) assigned to individual questions for each indicator	107
Table 6.8 List of questions along with choices and their scores for different indicator	107
Table 6.9 Response of the farmer to the questionnaire converted into binary form.....	108
Table 6.10 Raw value for indicators from different questions and final estimate of indicator ..	108
Table 6.11 Number of plots under major crops	110
Table 6.12 Normalized indicator values of turmeric cultivation in Sittilingi, Tamil Nadu.....	112
Table 6.13 Actual indicator values of turmeric cultivation in Sittilingi, Tamil Nadu	112

Table 6.14 Normalized indicator values of paddy cultivation in sittilingi, Tamil Nadu	115
Table 6.15 Actual indicator values of paddy cultivation in Sittilingi, Tamil Nadu.....	115
Table 6.16 Normalized indicator values of cotton cultivation in Wardha, Maharashtra	117
Table 6.17 Actual indicator values of cotton cultivation in Wardha, Maharashtra	117
Table 6.18 Normalized indicator values of soybean cultivation in Wardha, Maharashtra.....	118
Table 6.19 Actual indicator values of soybean cultivation in Wardha, Maharashtra	119
Table 6.20 Normalized indicator values of wheat cultivation in Wardha, Maharashtra	120
Table 6.21 Actual indicator values of wheat cultivation in Wardha, Maharashtra.....	121
Table 6.22 Normalized indicator values of bengal gram cultivation in Wardha, Maharashtra ..	123
Table 6.23 Actual indicator values of bengal gram cultivation in Wardha, Maharashtra	123
Table 6.24 Redistributed weightage based on data availability and proxy indicators.....	126
Table 6.25 Sensitivity analysis of indicators for Tamil Nadu and Maharashtra.....	132
Table 6.26 Sensitivity analysis of indicators within turmeric and paddy cultivation in Sittilingi, Tamil Nadu	132
Table 6.27 Sensitivity analysis of indicators within cotton and soybean cultivation in Wardha, Maharashtra.....	133
Table 6.28 Sensitivity analysis of indicators within wheat and Bengal gram cultivation in Wardha, Maharashtra.....	133

List of Figures

Figure 1.1 Agricultural GDP and workforce employed.....	2
Figure 1.2 Income per capita of Agri and Non-Agri sector	2
Figure 1.3 Proportion of population under various landholdings groups and the distribution of gross cropped and irrigated area among the groups.....	3
Figure 1.4 Monthly income and expenditure for various landholdings.....	3
Figure 1.5 Area under different crops over the decades in India.....	4
Figure 1.6 Rate of fertilizer application and average yield/hectare in cereal production.....	5
Figure 1.7 Yield per unit fertilizer consumed (1996-97 base year) in India.....	5
Figure 1.8 Distribution of cultivated area, subsidy, nutrients and pesticides across various landholding groups.....	6
Figure 1.9 FYM and pesticide usage over the last two decades in India.....	6
Figure 1.10 Public investment in agricultural and allied activities at (2004-05 Prices) and fertilizer subsidies in India.....	7
Figure 1.11 Overall research design	13
Figure 2.1 Fundamental System-Environment relationship	18
Figure 3.1 Outline of the proposed framework.....	32
Figure 3.2 Overview of system and its environment	33
Figure 3.3 Varying boundaries along different dimensions for an outflow variable (Lighter colour annuli represent variables outside the impact boundary).....	34
Figure 3.4 Example of stock and flow diagram.....	35
Figure 4.1 Example of a discrete utility function for a qualitative parameter	43
Figure 4.2 Examples of continuous utility functions for quantitative parameters	43
Figure 4.3 Membership function in fuzzy logic normalization with linear function and reference values	44
Figure 4.4 Types of reference value system for normalization	45
Figure 5.1 Inputs and Outputs with farming system as a black-box.....	54
Figure 5.2 A simplified stock and flow diagram for farming system.....	55
Figure 5.3 An example of interaction among the stock variables within the system	56
Figure 5.4 Impact boundary (darker annuli) for the desirable outflow from the farm system	57

Figure 5.5 Components in farming system and their interactions	60
Figure 5.6 Methodology for calculation of Fertilizer Impact Quotient (FIQ)	69
Figure 5.7 List of indicators and their hierarchical classification.....	76
Figure 6.1 Location of fields in Maharashtra.....	97
Figure 6.2 Location of fields in Tamil Nadu	98
Figure 6.3 Snapshot of a part of primary data input module	100
Figure 6.4 Snapshot of output module with indicator estimates, weightage and indices	100
Figure 6.5 Farmer orientation workshop in Tamil Nadu and Odisha	104
Figure 6.6 Radar charts for individual indicators of turmeric cultivation in Sittilingi, TN.....	111
Figure 6.7 Radar charts for individual indicators of paddy cultivation in Sittilingi, TN.....	114
Figure 6.8 Radar charts for individual indicators of cotton cultivation in Wardha, MH.....	116
Figure 6.9 Radar charts for individual indicators of soybean cultivation in MH	118
Figure 6.10 Radar charts for individual indicators of Wheat cultivation in MH.....	120
Figure 6.11 Radar charts for individual indicators of Bengal gram cultivation in MH.....	122
Figure 6.12 Soil parameters of three rounds of soil samples from Wardha, MH.....	124
Figure 6.13 Biological parameters of cotton plot (December 2015 samples)	125
Figure 6.14 FAI for turmeric and paddy in TN	127
Figure 6.15 FAI of cotton, soybean, wheat and Bengal gram in Wardha, MH	127
Figure 6.16 Economic index of turmeric and soybean in Sittilingi, TN.....	128
Figure 6.17 Social index of turmeric and soybean in Sittilingi, TN	129
Figure 6.18 Economic index of cotton, soybean, wheat and Bengal gram in Wardha, MH	129
Figure 6.19 Social index of cotton, soybean, wheat and Bengal gram in Wardha, MH.....	130
Figure 6.20 Ecological index of soybean and cotton cultivation in Wardha, MH.....	130

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	<i>Bacillus thuringiensis</i>
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).

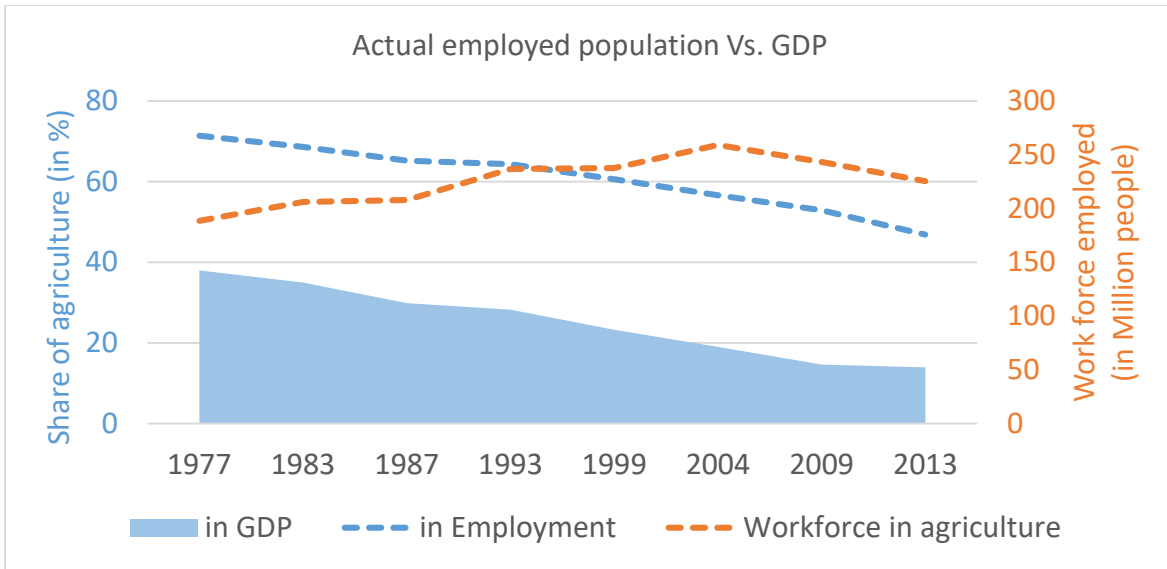


Figure 1.1 Agricultural GDP and workforce employed (Data sources: Labour Bureau, 2014; NSS 55th Round, 2000; Planning Commission, 2011; Population Census, 2011; Statistical year book, 2010)

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.

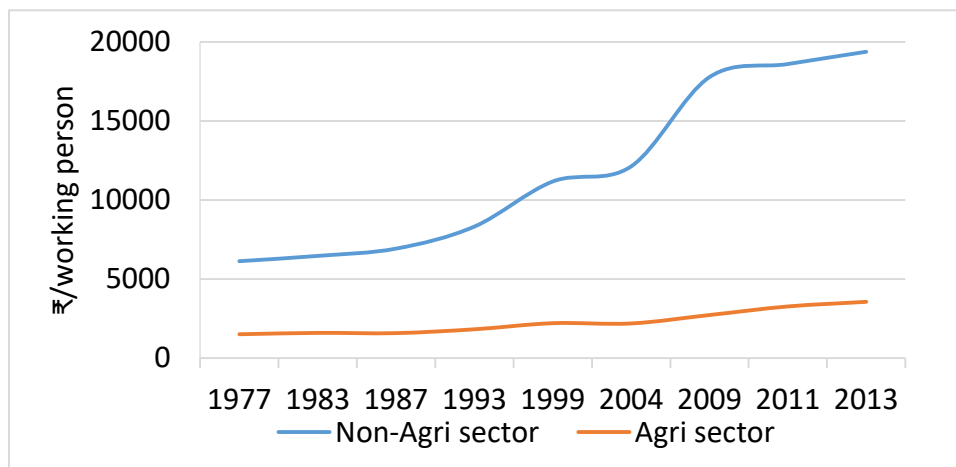


Figure 1.2 Income per capita of Agri and Non-Agri sector (Ratio of GDP to corresponding worker population) (Data sources: (GOI, 2010; Labour Bureau, 2014; NSS 55th Round, 2000; Planning Commission, 2014, 2011; Population Census, 2011)

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).

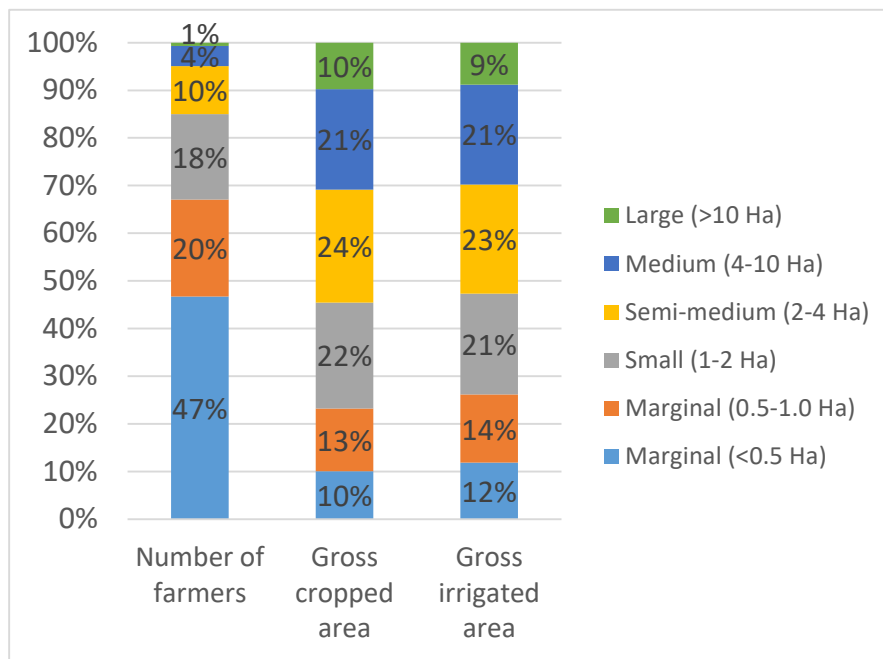


Figure 1.3 Proportion of population under various landholdings groups and the distribution of gross cropped and irrigated area among the groups (Data source: ICAR, 2012)

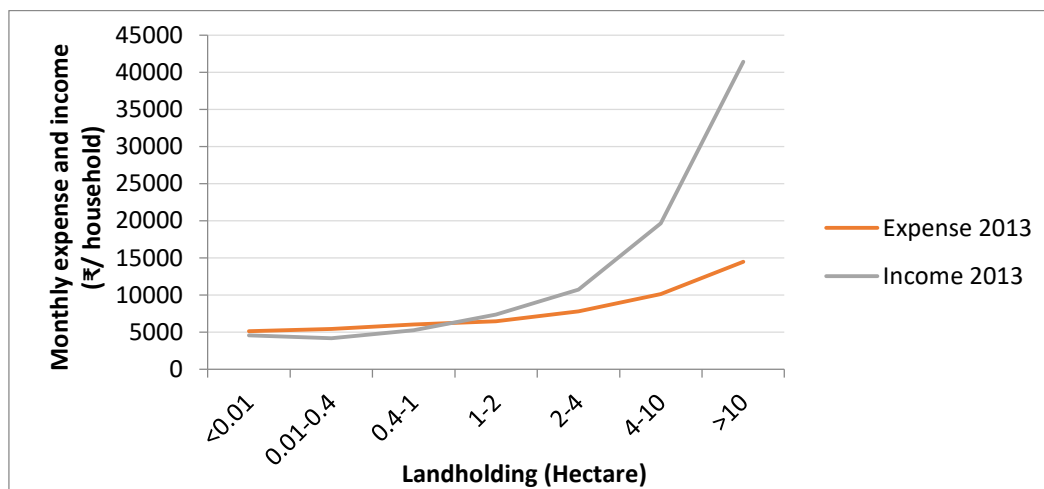


Figure 1.4 Monthly income and expenditure for various landholdings (Data Source: NSS 70th Round, 2013)

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.

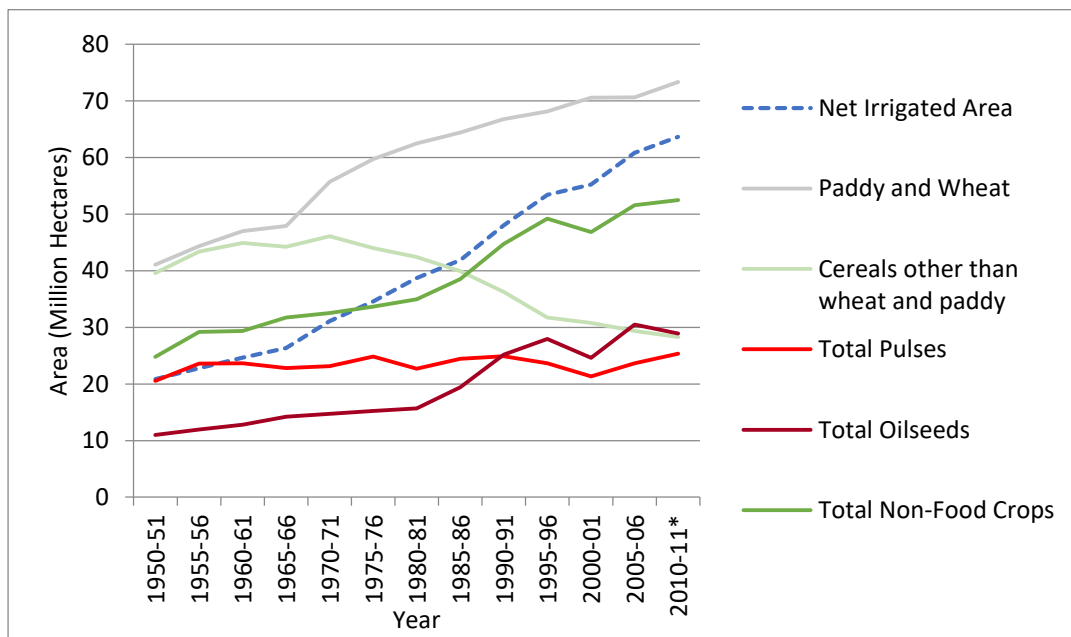


Figure 1.5 Area under different crops over the decades in India (Data source: GOI, 2014)

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).

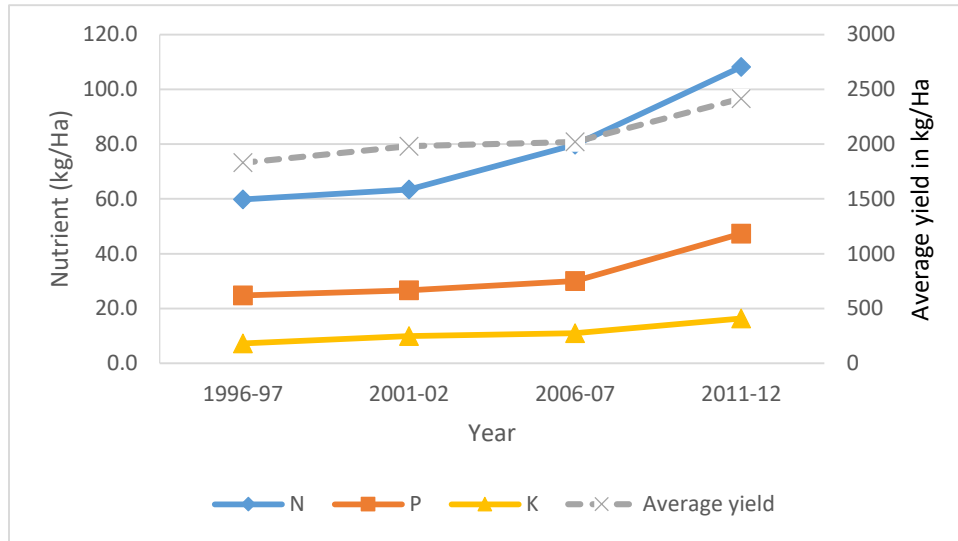


Figure 1.6 Rate of fertilizer application and average yield per hectare in cereal production
(Data source: Agriculture Census, 2012)

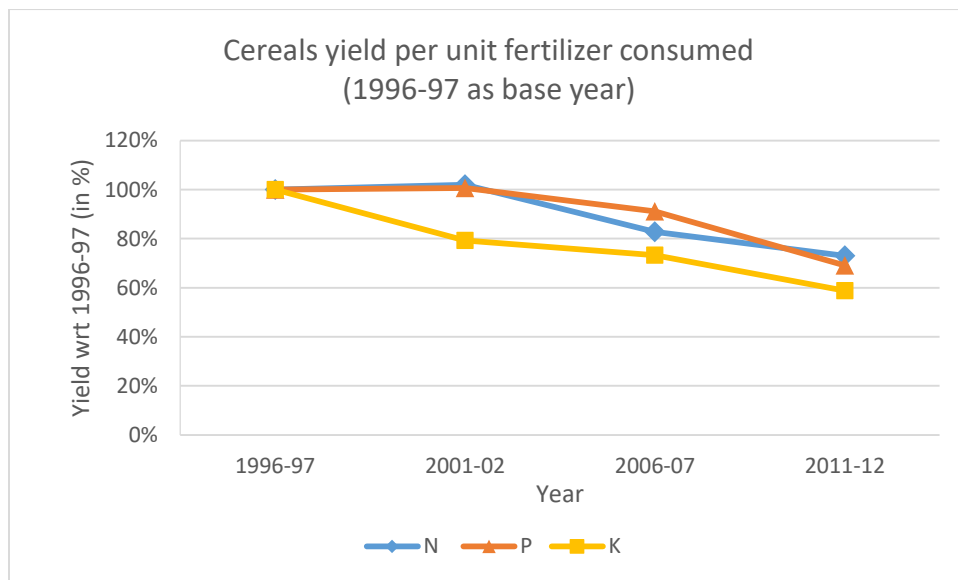


Figure 1.7 Yield per unit fertilizer consumed (1996-97 base year) in India
(Source: (Agriculture census, 2012; IndiaStat, 2017))

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.

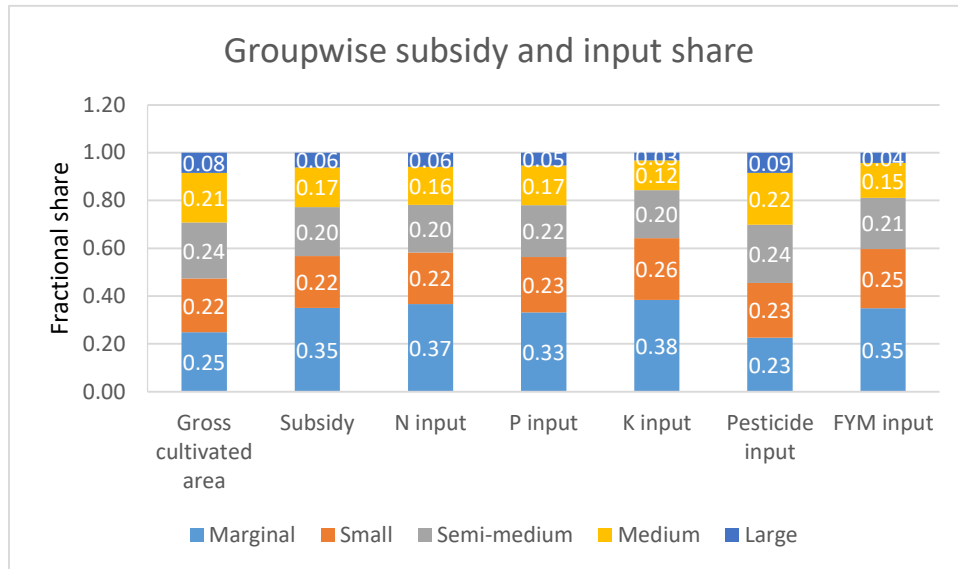


Figure 1.8 Distribution of cultivated area, subsidy, nutrients and pesticides across various landholding groups (Data source: Agriculture Census, 2012)

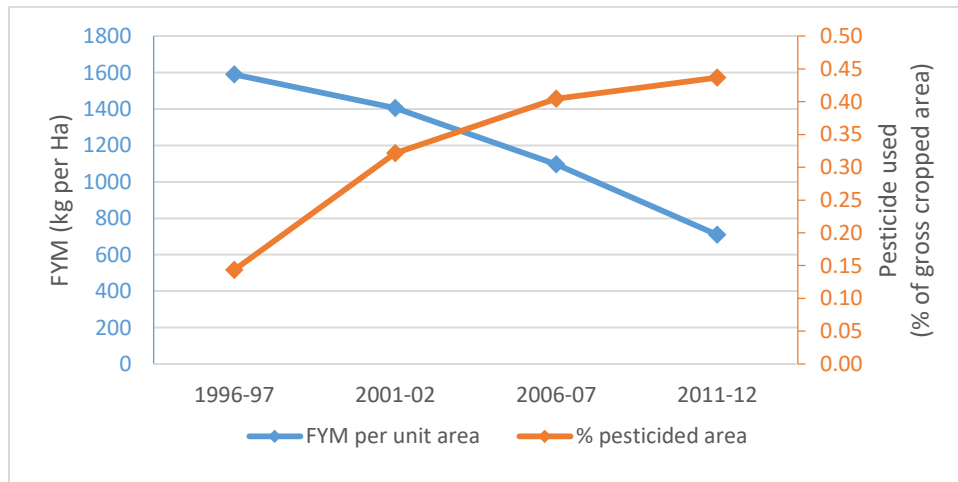


Figure 1.9 FYM and pesticide usage over the last two decades in India (Data source: Agriculture Census, 2012)

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 led to cutbacks on investments and extension but not in subsidies (Planning Commission, 2007).

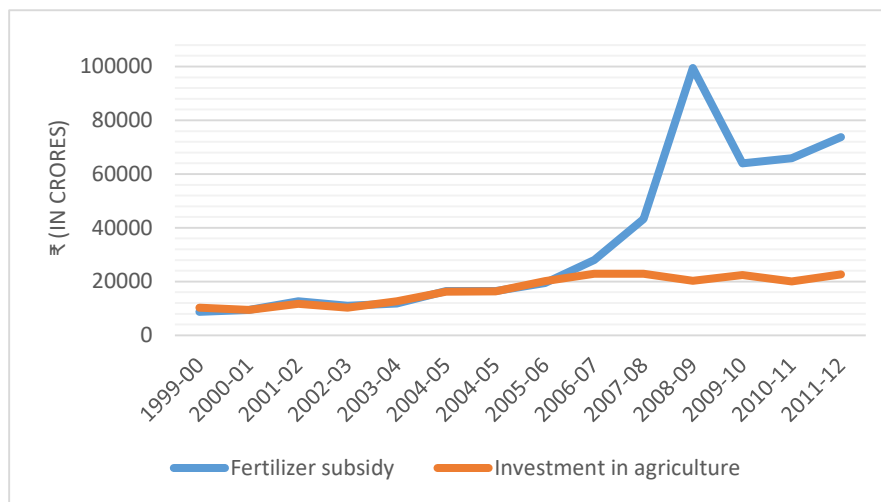


Figure 1.10 Public investment in agricultural and allied activities at (2004-05 Prices) and fertilizer subsidies in India (Data source: GOI, 2013; IndiaStat, 2017)

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 Maharashtra and Tamil Nadu, 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.

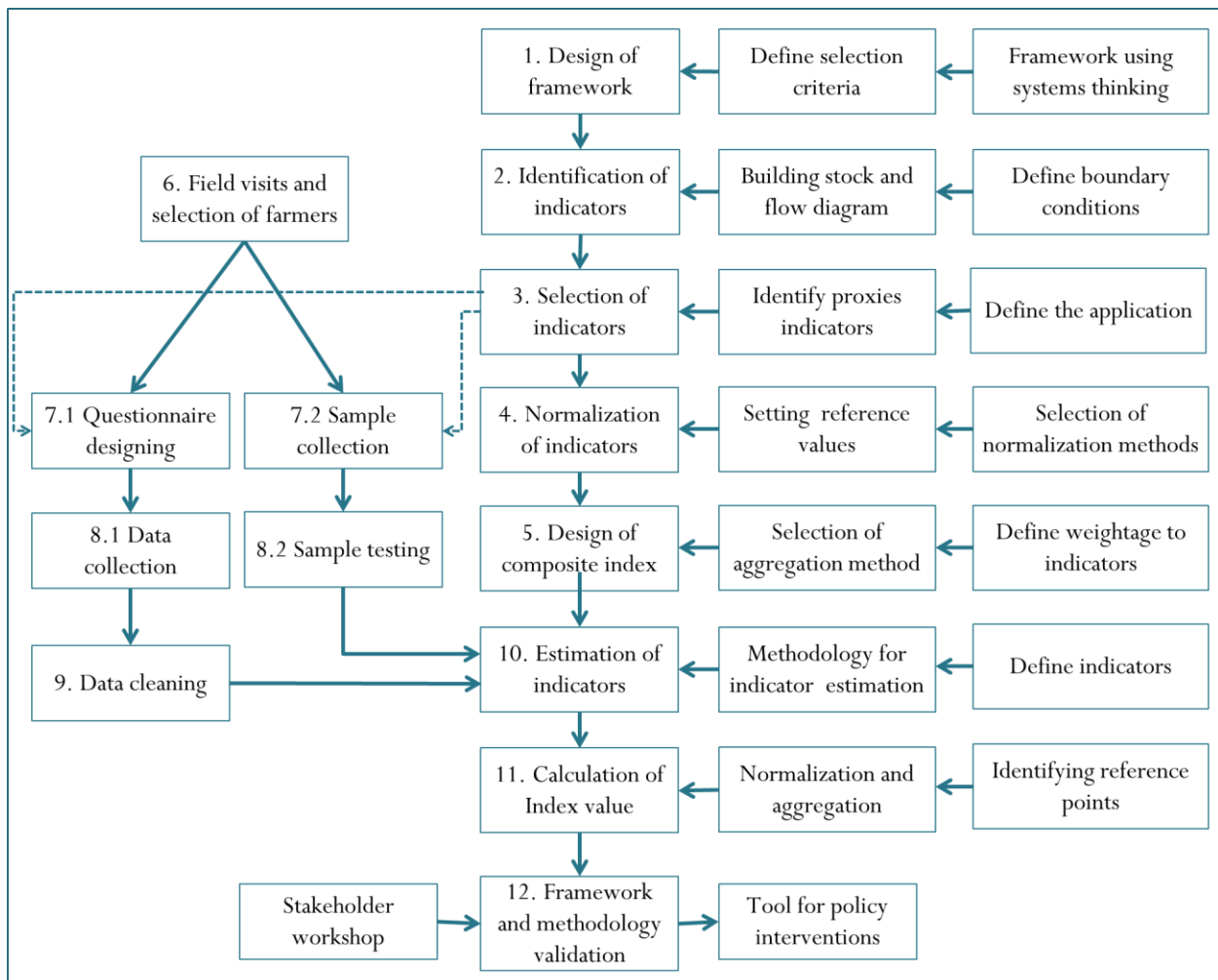


Figure 1.11 Overall research design

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 the states of Maharashtra and Tamil Nadu for comparing organic and chemical farming systems along with the results and discussion. 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.

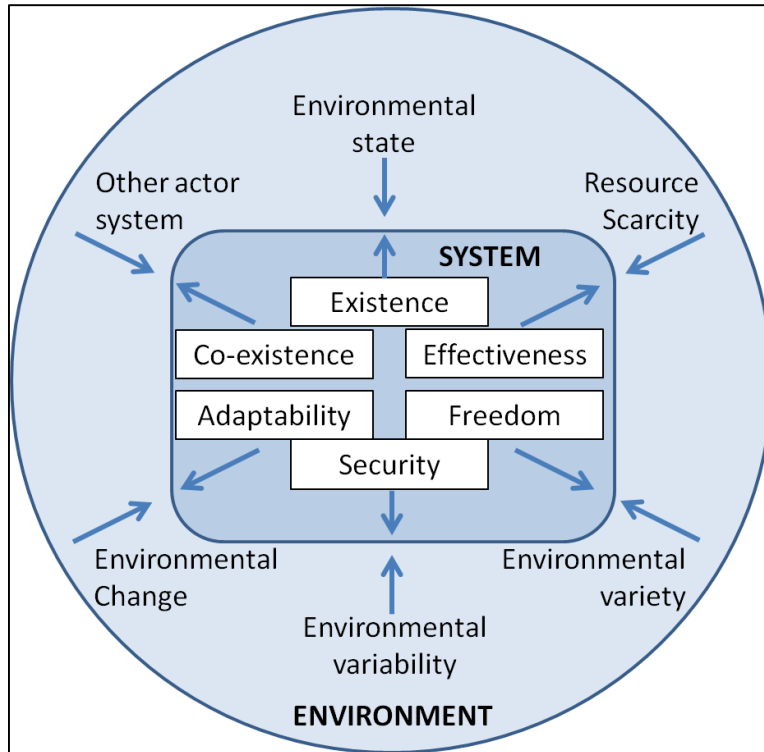


Figure 2.1 Fundamental System-Environment relationship

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 considered 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., 2005a; 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.

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.

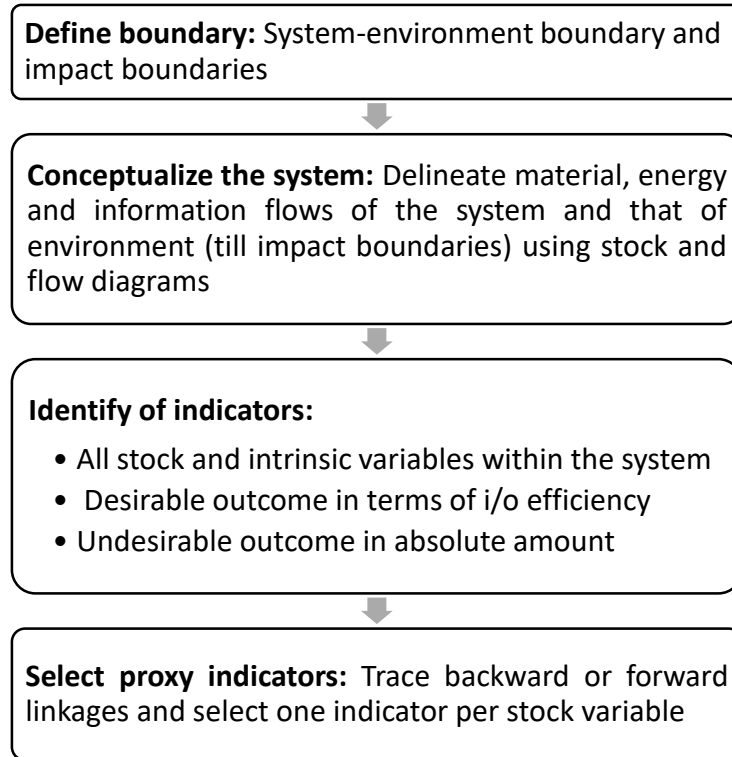


Figure 3.1 Outline of the proposed framework

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.

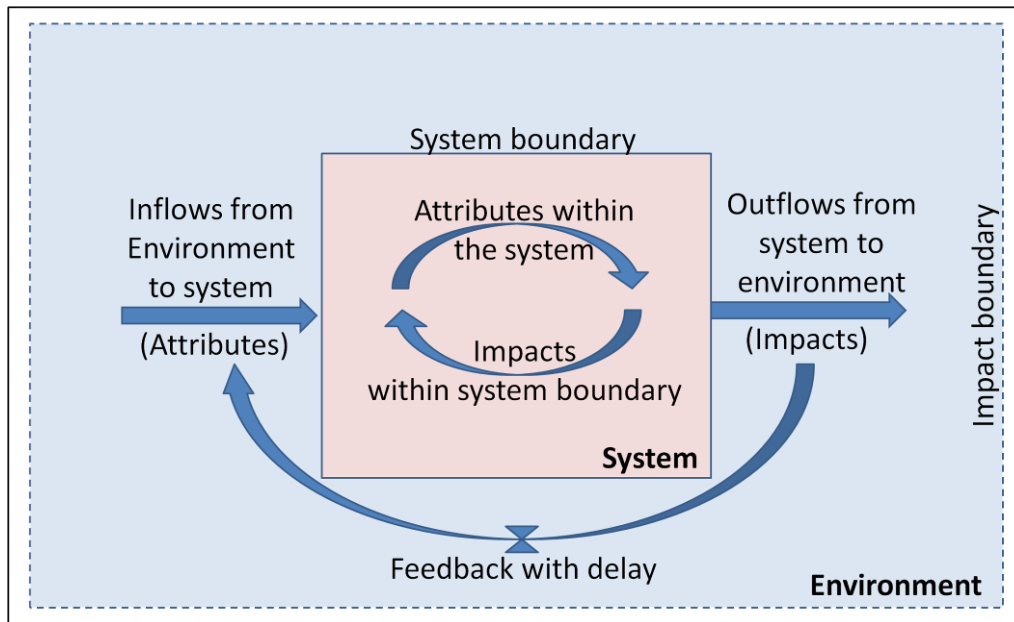


Figure 3.2 Overview of system and its environment

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.

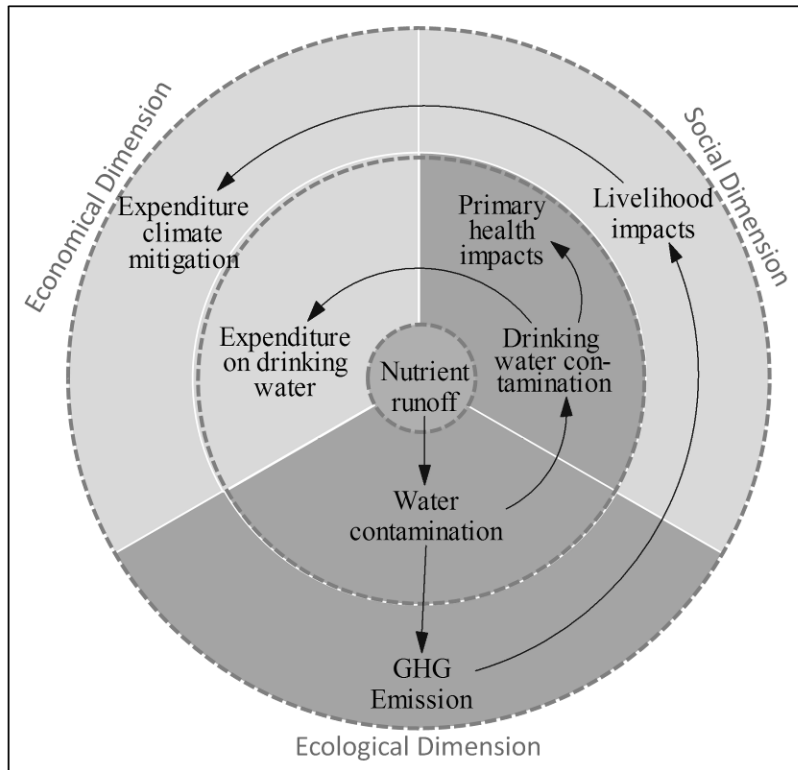


Figure 3.3 Varying boundaries along different dimensions for an outflow variable (Lighter colour annuli represent variables outside the impact boundary)

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.

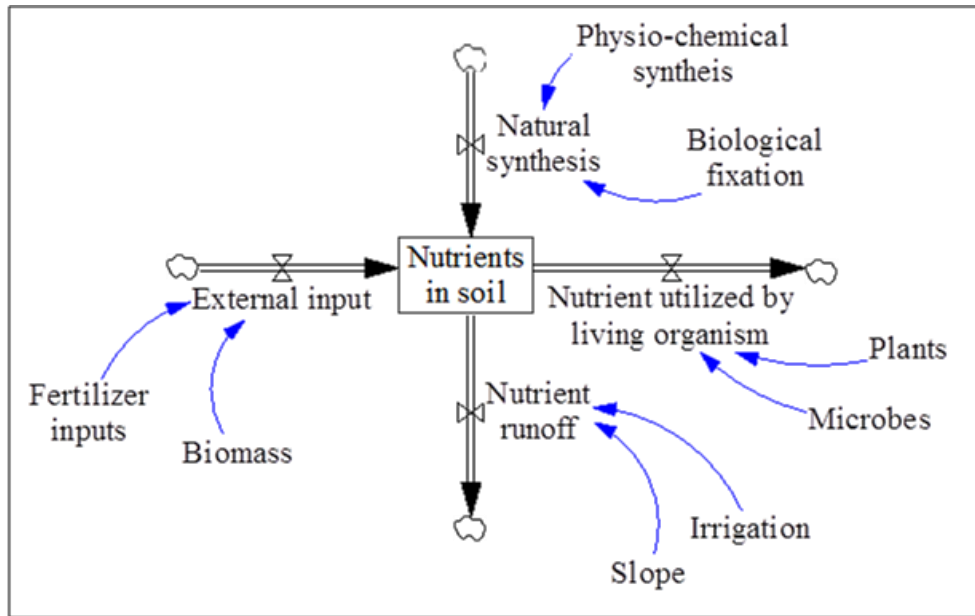


Figure 3.4 Example of stock and flow diagram

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 biophysical 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.	$I_{qc}^t = \frac{x_{qc}^t - x_{qc=\bar{c}}^t}{\sigma_{qc=\bar{c}}^t}$ <p>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”</p>
2	Min-max	This method performs a linear transformation of data with respect to a preset minimum and maximum points of the sample.	$I_{qc}^t = \frac{x_{qc}^t - \min_c(x_q^t)}{\max_c(x_q^t) - \min_c(x_q^t)}$ <p>$\max_c(x_q^t)$ and $\min_c(x_q^t)$ are the maximum and minimum value of x_{qc}^t</p>
3	Distance to reference	This method gives the relative position of the sample with respect to a defined reference point.	$I_{qc}^t = \frac{x_{qc}^t}{x_{qc=\bar{c}}^{t_0}} \text{ (or)}$ $I_{qc}^t = \frac{x_{qc}^t - x_{qc=\bar{c}}^{t_0}}{x_{qc=\bar{c}}^{t_0}}$ <p>$x_{qc=\bar{c}}^{t_0}$ is the indicator value of the reference sample at the initial time t_0</p>
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.	$I_{qc}^t = \begin{cases} 1 & w > (1 + p) \\ 0 & \text{if } (1 - p) \leq w \leq (1 + p) \\ -1 & w < (1 + p) \end{cases}$ <p>Where $w = \frac{x_{qc}^t}{x_{qc=\bar{c}}^{t_0}}$</p>
5	Cylindrical indicators	This method is very useful when a parameter needs to be monitored over a regular interval. It measures the	$I_{qc}^t = \frac{x_{qc}^t - E_t(x_{qc}^t)}{E_t(x_{qc}^t - E_t(x_{qc}^t))}$ <p>$E_t(x_{qc}^t)$ is the mean over time</p>

		irregularities or deviation of the indicator from the normal pattern over the past intervals.	$E_t(x_{qc}^t - E_t(x_{qc}^t))$ 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.	$I_{qc}^t = \frac{x_{qc}^t - x_{qc}^{t-1}}{x_{qc}^{t-1}} * 100$ <p>x_{qc}^t is the indicator value for current year x_{qc}^{t-1} is the indicator value during previous year</p>
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	<ul style="list-style-type: none"> • 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	<ul style="list-style-type: none"> • Linear and continuous function within the given range • Retains the actual relationship among the sample • Depends on the sample itself
3	Distance to reference	<ul style="list-style-type: none"> • 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	<ul style="list-style-type: none"> • Simple and direct method • Discrete scaling
5	Cylindrical indicators	<ul style="list-style-type: none"> • Useful for cyclic indicators • Scaling with reference to the previous status
6	Percentage of annual difference	<ul style="list-style-type: none"> • Measures the percentage change in the indicator value which can be useful for trend analysis
7	Categorical scaling	<ul style="list-style-type: none"> • 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., 2005b; van Asselt et al., 2014). Min-max method of normalization is widely used in indicator studies (Gómez-Limón and Sanchez-Fernandez, 2010; Hajkowitz, 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).

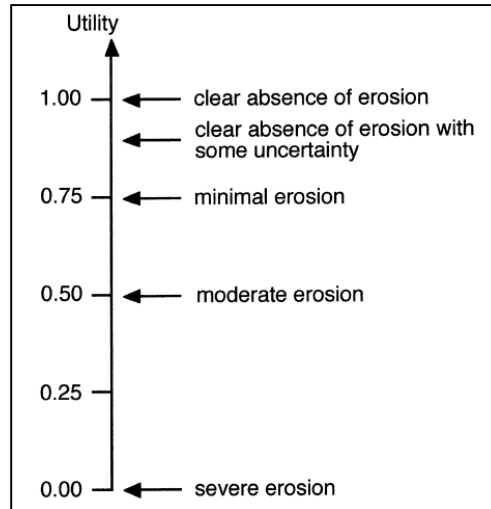


Figure 4.1 Example of a discrete utility function for a qualitative parameter
(Andreoli and Tellarini, 2000)

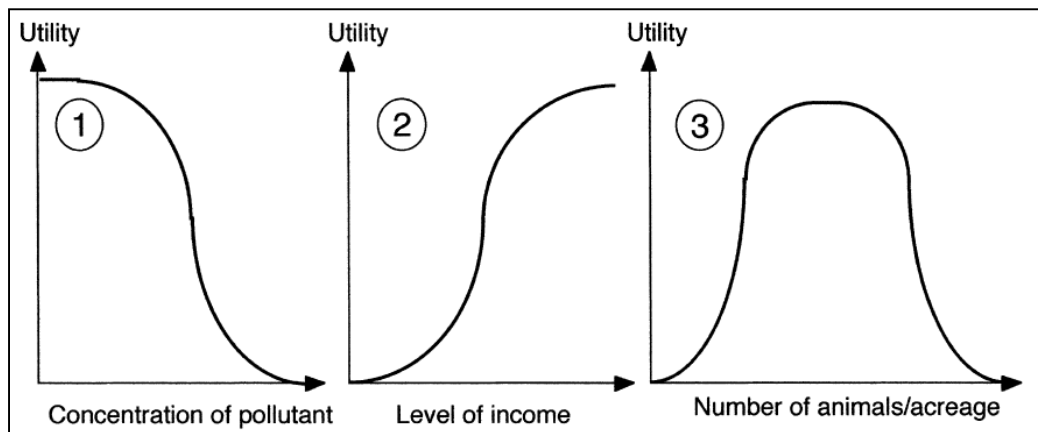


Figure 4.2 Examples of continuous utility functions for quantitative parameters
(Andreoli and Tellarini, 2000)

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).

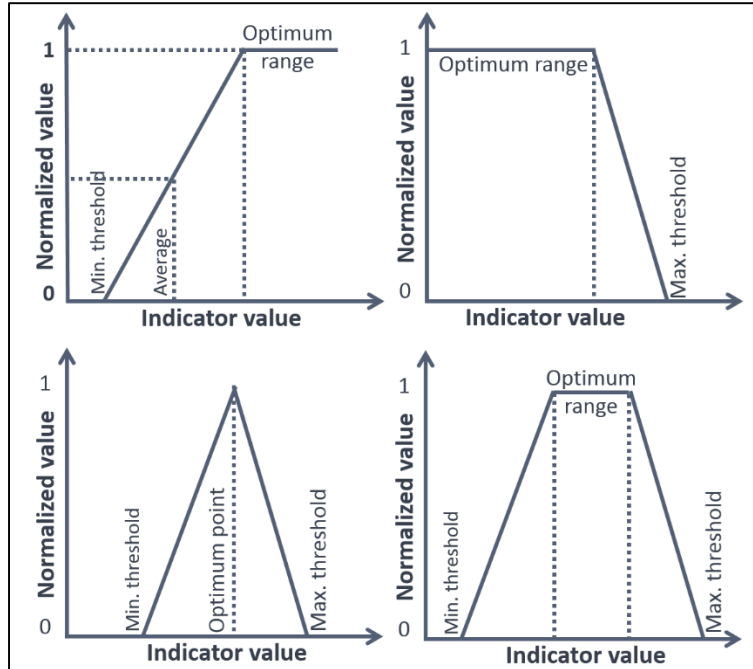


Figure 4.3 Membership function in fuzzy logic normalization with linear function and reference values

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.

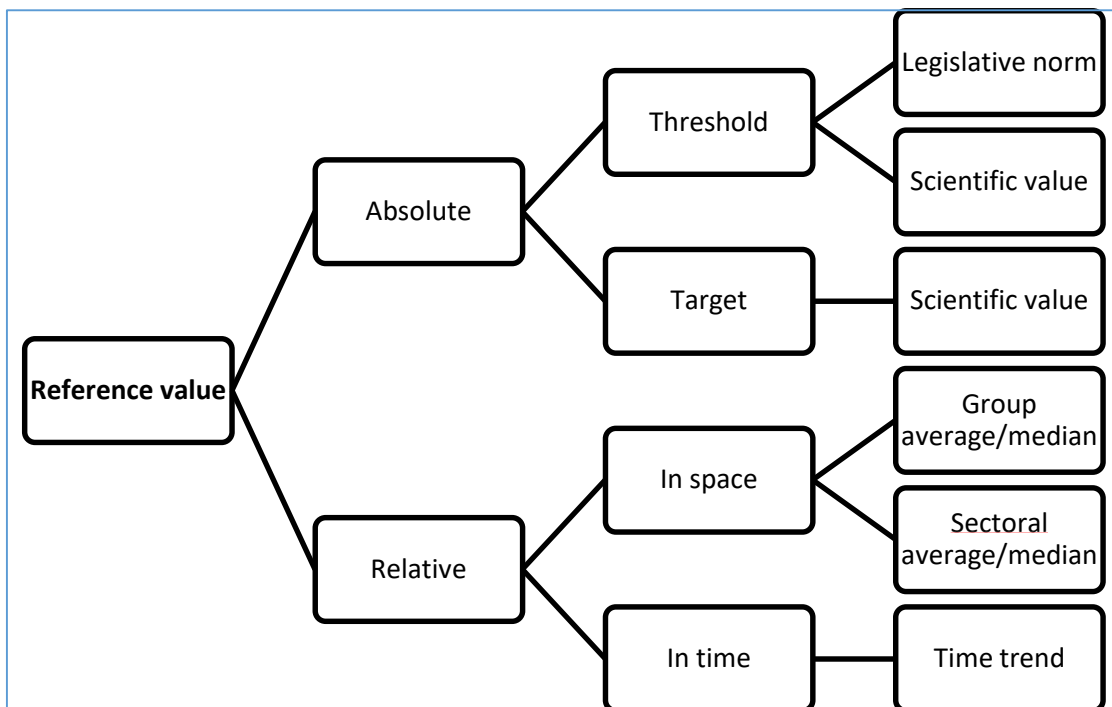


Figure 4.4 Types of reference value system for normalization (Sauvenier et al., 2005b)

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) <ul style="list-style-type: none"> • Statistically retain the variables with maximum variance • The dynamics of interest is along the dynamics of largest variance. 	<ul style="list-style-type: none"> • Eliminates redundancy • Weight based on variance • Minimize the dimension without losing much of information 	<ul style="list-style-type: none"> • Weightage doesn't have theoretical significance • Indicators should be of same unit
2	Data Envelopment Analysis (DEA) <ul style="list-style-type: none"> • Construction of a benchmark and measurement of the distance between countries in multi-dimensional framework • Based on linear programming 	<ul style="list-style-type: none"> • Independent of unit of measurement • Measures the efficiency • Endogenous weighing 	<ul style="list-style-type: none"> • Concern that this is more to do with the efficiency than choice of weights • Less discriminatory
3	Benefit of Doubt (BOD) <ul style="list-style-type: none"> • Application of DEA with exogenous restrictions • Least discrimination of systems 	<ul style="list-style-type: none"> • Maximizes performance ranking position • Incorporate restrictions based on policies 	<ul style="list-style-type: none"> • Multiplicity of solution makes it hard for selecting the weighing • Arbitrary restrictions
4	Unobserved component model (UCM) <ul style="list-style-type: none"> • 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 	<ul style="list-style-type: none"> • Statistical and precision weighing approach • Emphasizes the uncertainty associated with ranking • Retains the cardinal differences 	<ul style="list-style-type: none"> • 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	<p>Budget Allocation Process (BAP)</p> <ul style="list-style-type: none"> • Experts from different stakes and a wide spectrum of knowledge and experience are asked to allocate a budget of 100 points to indicators 	<ul style="list-style-type: none"> • Transparent, straightforward and fast process • Practical in approach • Consensus with various groups 	<ul style="list-style-type: none"> • Expert opinion may be region specific • Cognitive stress to experts • Subjective and easy to manipulate
2	<p>Public Opinion</p> <ul style="list-style-type: none"> • People are asked to express their degree of concern about issues or indicators through opinion polls 	<ul style="list-style-type: none"> • Bottom-up approach • Help understand the actual preference of the major stakeholder 	<ul style="list-style-type: none"> • General public may not be well informed/aware of the actual situation • Inconsistencies • Chances of biased polls
3	<p>Delphi Technique</p> <ul style="list-style-type: none"> • A group communication process with an objective of converging opinions and building consensus among stakeholders along with an expert panel 	<ul style="list-style-type: none"> • Participatory method which makes it more acceptable • Relatively quick and direct method 	<ul style="list-style-type: none"> • Depends upon the participating group • Moderator bias • No theoretical basis
4	<p>Analytical Hierarchical Process (AHP)</p> <ul style="list-style-type: none"> • Pairwise comparison of indicators after classifying them in a hierarchical manner 	<ul style="list-style-type: none"> • Hierarchies help in fixing weights among the groups • Helps in capturing and verifying the perception of the stakeholders 	<ul style="list-style-type: none"> • Difficult to manage as the number of indicators increases • Difficult to manage inconsistencies
5	<p>Conjoint Analysis (CA)</p> <ul style="list-style-type: none"> • Ranking of different product/system followed by estimation of the preference function using decompositional multivariate analysis. 	<ul style="list-style-type: none"> • Weights represent the trade-offs • Estimates and represents the perceptual value of attributes • Agree with intuitive measure 	<ul style="list-style-type: none"> • Estimation process is complex • Respondents are susceptible to confusion. • Subjective and needs a large sample of respondents
6	<p>Maximum Difference Scaling</p> <ul style="list-style-type: none"> • Relative preference over a set of paired comparison followed by estimation of the preference function 	<ul style="list-style-type: none"> • 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.

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

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

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

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).

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

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. 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.

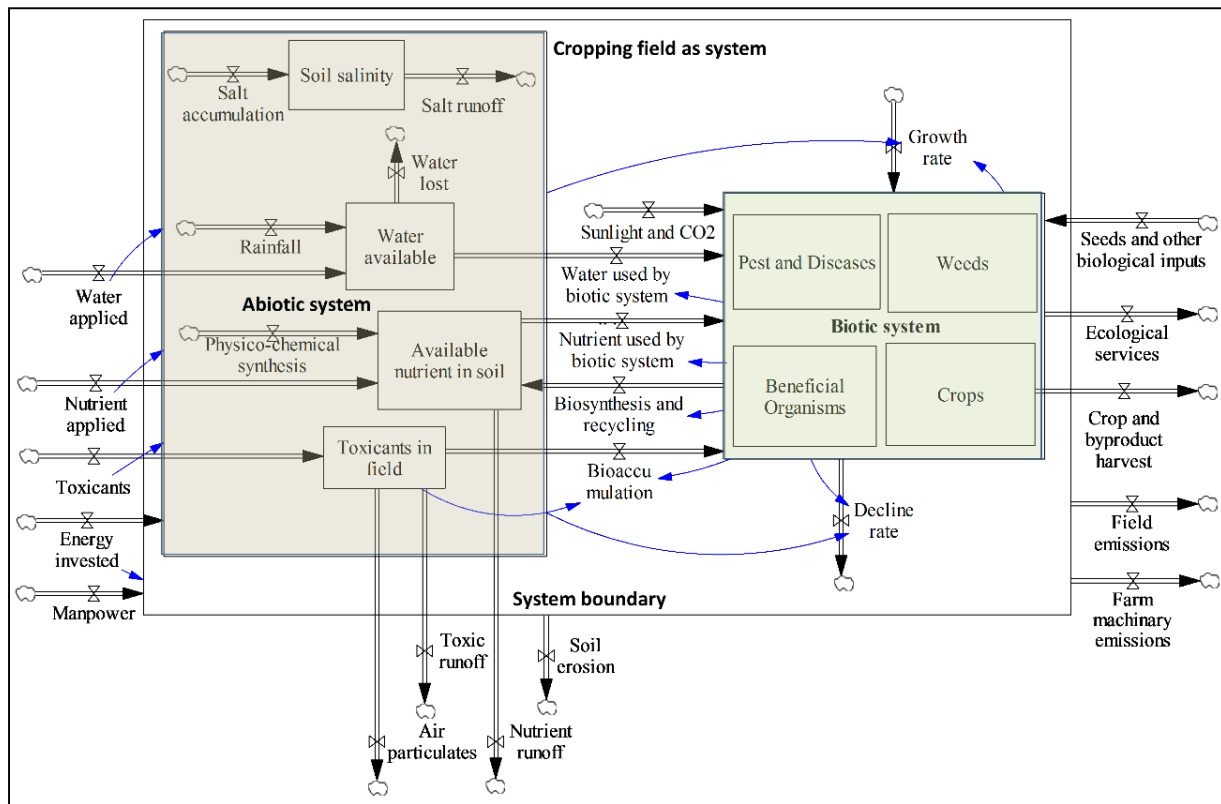


Figure 5.2 A simplified stock and flow diagram for farming system

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.

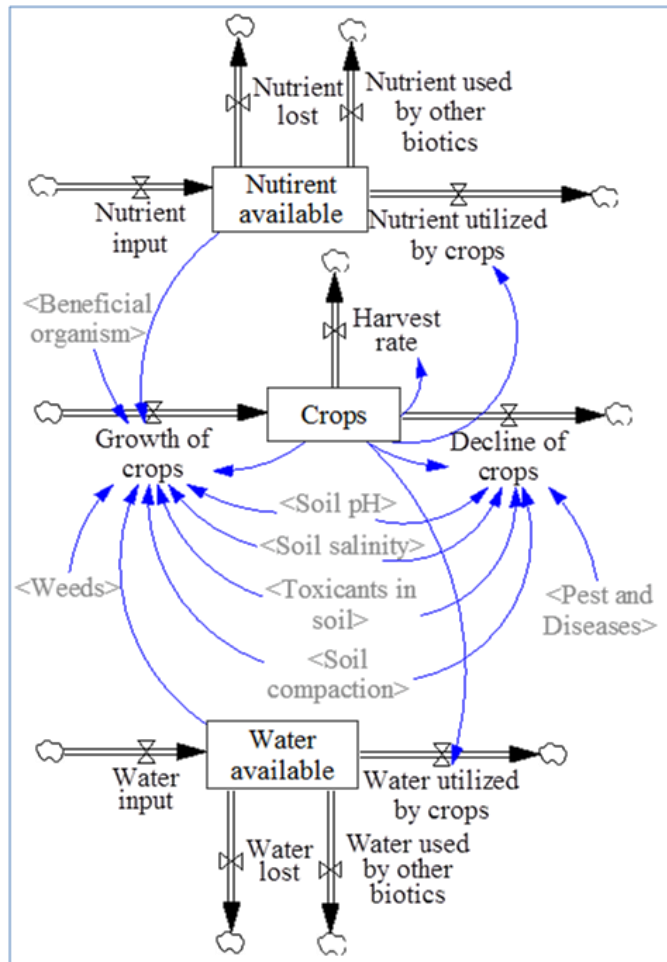


Figure 5.3 An example of interaction among the stock variables within the system

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.

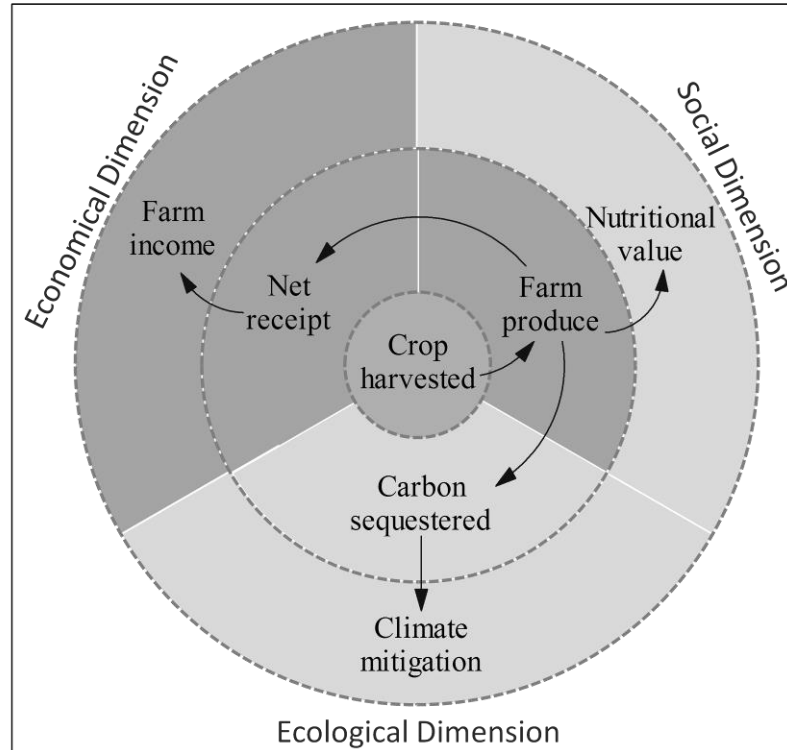


Figure 5.4 Impact boundary (darker annuli) for the desirable outflow from the farm system

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

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

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.

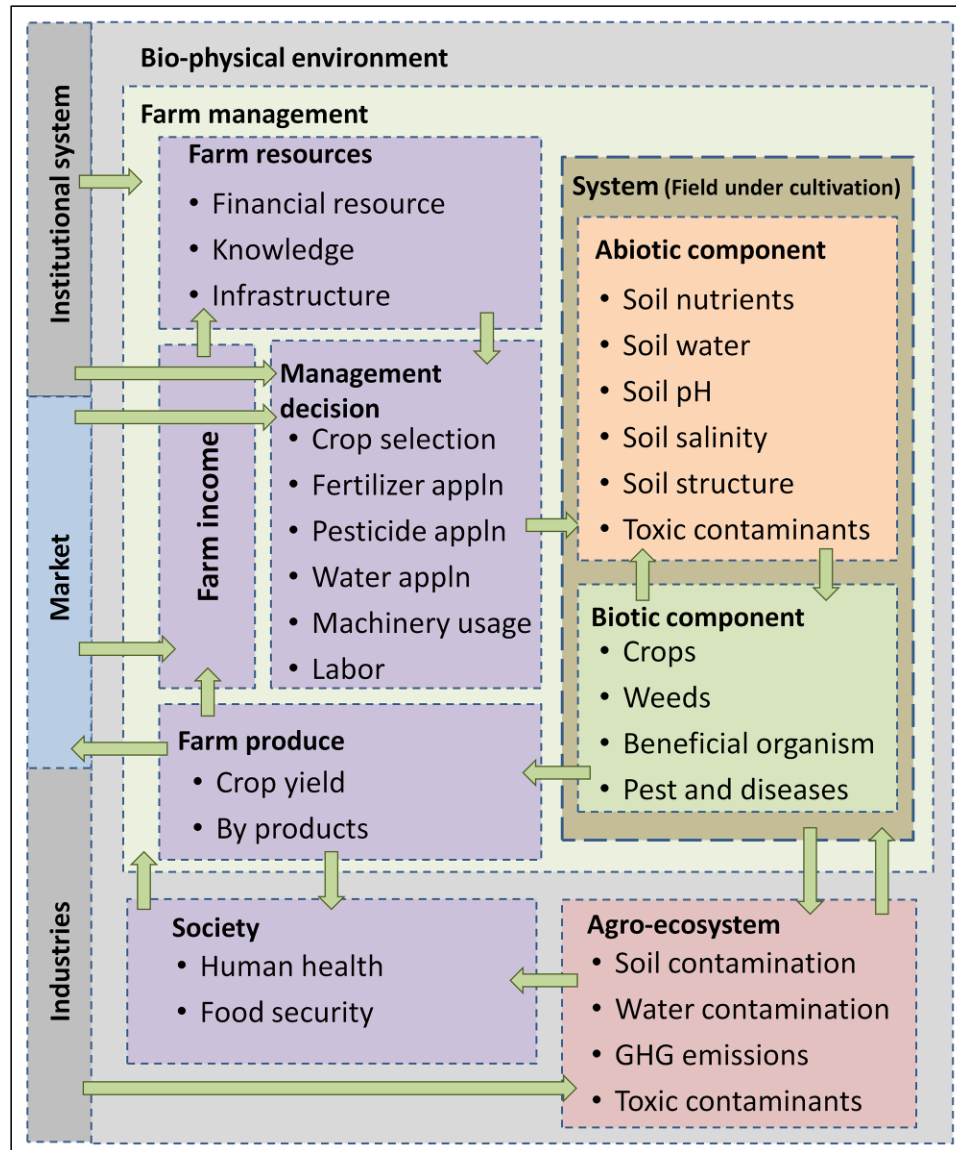


Figure 5.5 Components in farming system and their interactions

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 19 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 “payout 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 payout 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 payout cost of cultivation	Dimensionless (DMNL)	Field survey
2	Income per acre	Total value of the farm produce minus the payout 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	
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.

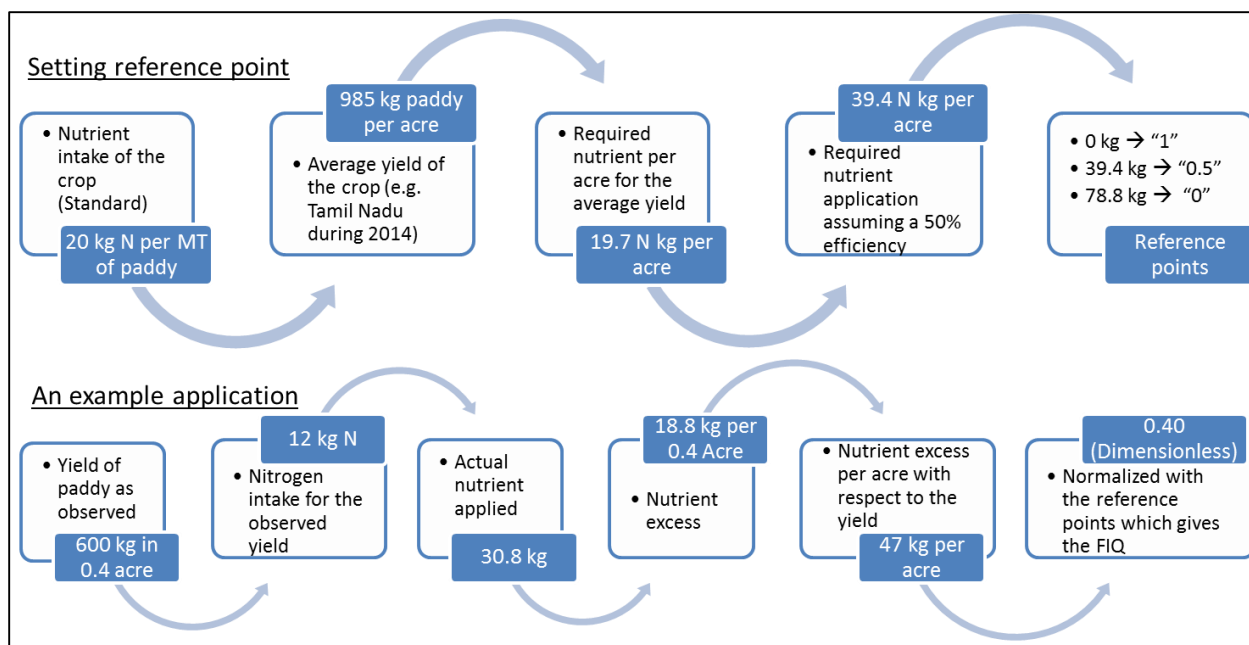


Figure 5.6 Methodology for calculation of Fertilizer Impact Quotient (FIQ)

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							
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		Minimum/maximum pH threshold			Optimum Soil pH range		
16	Available K							
17	Soil pH		Maximum threshold			Tolerance limit		
18	Soil salinity							

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., 2005a), 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).

Farm Assessment Index (FAI)																											
Economic Index (40.5%)					Social Index (28.5%)					Ecological Index (31%)																	
Financial benefits (23.1%)			Resource efficiency (17.4%)		Producer development (14.5%)			Consumer impact (6.6%)		National impact (7.4%)		Ecological parameters (14%)			Field parameters (17%)												
Benefit Cost Ratio (7%)	Income per acre (8%)	Riskiness (8%)	Nutrient use efficiency (4%)	Water use efficiency (7%)	Energy use efficiency (3%)	Chemical use efficiency (3%)	Farmer knowledge (3%)	Social capital (2%)	Farm resources (3%)	Financial resources (2%)	Self-reliance (2%)	Drudgery (2%)	Health impacts from fertilizers (3%)	Health impacts from pesticides (4%)	Agricultural output (2%)	Employment (2%)	Gender equality (1%)	Institutional strength (2%)	Soil erosion (2%)	Soil contamination (2%)	Water contamination (3%)	GHG (2%)	Bioaccumulation (2%)	Ecological services (4%)	Soil health* (6%)	Soil available water (6%)	Biodiversity** (5%)

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 the states of Maharashtra and Tamil Nadu 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.

Impacts of fertilizer usage

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. Table 6.1 gives a few examples from India where 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, enzyme activities etc.

Table 6.1 Impact of synthetic fertilizers on soil quality

Reference	Location and Year	Crop	Soil type	Remarks
(Hati et al., 2006)	Bhopal, MP (1998-2000)	Soybean	Vertisols	Plots fertilized inorganically (NPK without FYM) had lesser mean weight diameter, lesser percentage of water stable aggregates, lower saturated hydraulic conductivity and lesser root length density and higher bulk density.
(Masto et al., 2006)	New Delhi (2001-02, 31 years Long Term Experiment (LTE) plots)	Maize-wheat-cowpea rotation	Semi-arid Inceptisol	Microbial biomass carbon and soil respiration were significantly lesser in case of plots with only synthetic fertilizers in comparison with those with FYM. Dehydrogenase activity increased slightly with increase in NPK rates but excessive fertilization decreased it.
(Masto et al., 2007)	New Delhi (2002, 31 years LTE plots)	Maize/pearl millet-wheat-cowpea rotation	Semi-arid Inceptisol	N alone treatment resulted in degradation compared to no fertilizer/manure with no crop soil. NP alone or sub-optimal rates of NPK were on the verge of degradation.
(Bhattacharyya et al., 2007)	Almora, Uttaranchal (2003, 8 years LTE plots)	Wheat-soybean rotation	Silty clay loam soil	Mean weight diameter (MWD), SOC, Soil water absorptivity and steady state infiltration rate were lesser in NPK only plots.
(Mandal et al., 2007)	New Delhi (2004-05, 34 years LTE plots)	Maize/pearl millet-wheat rotation	Semi-arid Inceptisol	Microbial biomass carbon (MBC), nitrogen (MBN) and dehydrogenase, mineralizable N and phosphatase activities were all at their highest in case of NPK with FYM.
(Hati et al., 2007)	Jabalpur, MP (2000, 28 years LTE plots)	Soybean-wheat-maize (fodder) crop rotation	Pellic Vertisols	Soil parameters such as SOC content, aggregation, water retention, microporosity, available water capacity and electrical conductivity of the soil were significantly less in NPK only plots compared to NPK with FYM plots.
(Manna et al., 2007)	Ranchi, Jharkhand (2001, 30	Soybean-wheat	Alfisol	Soil microbial biomass carbon (SMBC), nitrogen (SMBN) and acid hydrolysable carbohydrates (HCH) were lesser in case of plots with NPK

	years LTE plots)			without FYM compared to those with FYM
(Bhattacharyya et al., 2008)	Almora, Uttaranchal (2003, 30 years LTE plots)	Soybean-wheat	Sandy loam soil	Mineral-fertilizer recommendations are inadequate, and application of FYM along with NPK fertilizers sustained yield and soil productivity.
(Masto et al., 2008)	New Delhi (2002, 31 years LTE plots)	Soybean-wheat-maize (fodder) crop rotation	Semi-arid Inceptisol	Imbalanced NPK application and absence of FYM resulted in soil quality degradation.
(P. K. Bandyopadhyay et al., 2010)	Nadia, WB (2007, 21 years LTE plots)	Rice-wheat rotation	Silty clay soil of Inceptisol	Soil aggregates and carbon concentration were better in the order of FYM > rice straw > green manuring.
(K. K. Bandyopadhyay et al., 2010)	Bhopal, MP (2001-2004)	Soybean	Vertisols	FYM improved the biomass partitioning towards pod, root length density, root mass density, grain yield, water use efficiency and nitrogen use efficiency of soybean.
(Nayak et al., 2012)	Ludhiana, Punjab; Kanpur, UP; Sabour, Bihar and Kalyani, WB. (2009, 25 LTE)	Rice-wheat rotation	Typic-Ustochrept, Udic-Ustrochepts, Aeric-Haplaquept	Soil organic carbon (SOC), particulate organic carbon (POC) and microbial biomass carbon (MBC) were lesser in the plots without FYM.
(Srinivasarao et al., 2014)	Sardar Krushi Nagar, Gujarat (2006, 18 LTE)	Pearl millet-cluster bean-castor	Entisol	Addition of 33.5Mg per ha of C inputs could not compensate the SOC depletion by oxidation and resulted in the net loss of 4.4Mg C per ha in 18 years.

Numerous studies across India that have reported surface and groundwater contamination with nitrate, phosphorous and pesticides in the areas of heavy chemical usage as briefed in Table 6.2. 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).

Table 6.2 Impact of synthetic fertilizers on water resources

Reference	Location and Year	No. of samples and source	Contaminant	Remarks
(Singh and Sekhon, 1976)	Ludhiana and Hoshiarpur, Punjab. (1975)	57 well water	Nitrate	90% of samples were found contaminated but within the safety limit. Nitrate concentration was positively correlated to nitrogenous fertilizer application.
(Datta et al., 1997)	Delhi (1990-1992)	95 groundwater and 2 river water	Nitrate and potassium	33% of sample with high level of nitrate and 15% with more than safety limits. A scatter diagram of NO vs K ⁺ suggests a common source of these ions.
(Rao, 2006)	Srikakulam, AP (1998-2000)	350 groundwater	Nitrate and potassium	Concentration varied from 0 to 450 mg NO ₃ /L. Groundwater from clayey soil had higher NO ₃ concentration.
(Jameel and Sirajudeen, 2006)	Tiruchirapalli, TN (2000-2002)	15 wells	Nitrate, phosphate, sulphate, etc.	Most of the parameters were well above the acceptable limits.
(Sankararamakrishnan et al., 2008)	Kanpur, UP (2004)	99 Handpump water	Nitrate and fluoride	Nitrate content in most of the samples was higher than Indian standard but fluoride was within the limits.
(Kundu et al., 2008)	Hooghly, WB (2005)	920 samples from 412 surface and groundwater	Nitrate and fluoride	More than 50% samples had very high concentration of nitrate in certain areas.

(Kundu and Mandal, 2009)	Nadia, WB (2007)	342 groundwater samples	Nitrate and fluoride	Habitation areas had higher concentration of NO ₃ than the agricultural area, due to leaching and runoff.
(Suthar et al., 2009)	Sri Ganganagar, RJ (2008)	64 groundwater samples	Nitrate and sulphate	Average nitrate concentration indicates that the groundwater is severely polluted.
(Raju et al., 2009)	Varanasi, UP	75 groundwater samples	Nitrate	57% of samples had nitrate content more than safe limits.
(Kundu et al., 2009)	Murshidabad, WB (2007)	250 groundwater samples	Nitrate and fluoride	Nitrate content in groundwater content increased with increased fertilizer application and in areas of shallow-rooted crops.
(Dar et al., 2010)	Baramulla, Kashmir (2007)	15 groundwater samples	Nitrate	87% and 67% of samples were more than the permissible limits in summer and winter respectively.
(Nagarajan et al., 2010)	Thanjavur, TN (2008)	102 groundwater samples	Nitrate and other salts	34% of samples not fit for drinking and 20% not fit for irrigation.
(Sajil Kumar et al., 2014)	Dharapuram TN (2010)	26 groundwater sources	Various parameters	57% samples showed nitrate concentration above the safe limit.
(Saxena et al., 2014)	Jaipur, RJ	50 groundwater samples	Nitrate, fluorides and other parameters	62% and 42% of samples had more than permissible limits of nitrate and fluoride.

Impacts of pesticide usage

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. These residues in crop produce also led to bioaccumulation in fishes, bovines etc. and result in various harmful health impacts due to the usage of plant protection products. We list a few reports of pesticide contamination in various products across different states of India in Table 6.3, which shows the alarming state of food safety due to pesticide usage.

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 6.4, 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.

Table 6.3 Pesticide contamination in various products across different states of India

Reference	Location and Year	Contaminated product	Contaminant	Remarks
(Amaraneni and Pillala, 2001)	Kolleru Lake, AP	Fish species Channa striata and Catla catla	α -BHC, γ -BHC, malathion, chlorpyrifos, isodrin, endosulfan, diel- rin, and p,p-DDT	Higher than FAO standards
(John et al., 2001)	Jaipur (1993-96) RJ	Bovine milk	DDT, DDE, DDD, HCH, heptachlor and its epoxide and aldrin	Winter samples had higher residues
(Shukla et al., 2002)	Kanpur (1999) UP	Normal Diet	HCH, aldrin, and dieldrin	Non- vegetarian had higher magnitude of contamination than vegetarian diet
(Bakore et al., 2002)	Jaipur (1993-96) RJ	Vegetables (potato, tomato, cabbage, cauliflower, spinach, and okra)	DDT, DDE, DDD, HCH, heptachlor and its epoxide and aldrin	Higher than FAO standards.
(Pandit and Sahu, 2002)	Mumbai MH	Milk and milk products	DDT, DDE, DDD, α -HCH, β -HCH, γ -HCH	α -HCH exceeded the US EPA guideline value but others were all within the acceptable limits.
(Kumari et al., 2004)	Hisar (1997–1998) HR	Seasonal vegetables (Brinjal, lady finger, cauliflower, cabbage, cucumber, smooth guard, and potato)	Organophosphates (monocrotophos, quinalphos, and chlorpyriphos), pyrethroids and organochlorines	26% samples had residues above MRL values.
(Sanghi et al., 2003)	Bhopal MP	Human milk	HCH isomers, endosulfan, malathion, chlorpyrifos, and methyl-parathion	8.6 fold more endosulfan and 4.1 fold more malathion than the average daily intake.

(Mukherjee, 2003)	Delhi National Capital Territory (NCR)	Vegetables (cabbage, cauliflower, chilli, brinjal, tomato, mustard, onion and ladyfinger)	Endosulfan, methyl parathion, cypermethrin, malathion, chlorpyrifos, quinalphos and fenvalerate	31% of the samples contained pesticides above the prescribed tolerance limit.
(Kumari et al., 2003)	Hisar (1997–1998) HR	Winter vegetables (Cabbage, cauliflower, pea grains, brinjal, tomato, potato and green chilly)	Organophosphorous, carbamates, synthetic pyrethroids and organochlorines	32% samples had organophosphorus and carbamate above MRL values.
(Bakore et al., 2004)	Jaipur (1993-96) RJ	Wheat flour and drinking water	DDT, DDE, DDD, HCH, heptachlor and its epoxide and aldrin	All wheat samples were contaminated with most pesticides, seasonal variation due to storage practices, fewer residues in water, higher residue in surface water than ground water.
(Rajendran et al., 2005)	Bay of Bengal (1998) TN	Marine water and sediments	PCBs, HCH, DDT and metabolites	Though DDT residues have decreased, PCBs still remain constant.
(Bhanti and Taneja, 2005)	Agra (2002-2003) UP	Vegetables	Organochlorines (Lindane, Endosulphan, and DDT)	Winter vegetables had higher concentrations of residues. However residue level was below the tolerance limit.
(Kumari et al., 2005)	Hisar, Fatehabad and Sirsa, HR	Butter and ghee	Organochlorine, synthetic pyrethroid and organophosphate	Almost all samples were contaminated with over 40% exceeding the MRL.
(Rekha et al., 2006)	Various places (2002) HR, UP, MH, UTK, and CG	Wheat and rice	Organochlorine, carbamates, organophosphorus and pyrethrites	All conventional market samples contaminated but within the MRL.
(Shukla et al., 2006)	Hyderabad, TL	Groundwater	DDT, Endosulfan, and Lindane	All samples had residues above ADI.

(Aulakh et al., 2006)	Ludhiana (2001) PB	Poultry feed, chicken muscle and eggs	HCH, DDT, endosulfan and heptachlor epoxide	Muscle samples did not exceed MRL but all egg samples had residues above MRL.
(Subramaniam and Solomon, 2006)	Aandipatti, Madurai TN	Human blood serum	DDE and BHC	High concentrations of both BHC & DDE in agriculturalist and public health workers.
(Kumar et al., 2006)	Anupgarh, RJ	Milk and blood of lactating women	HCH, endosulfan and heptachlor, DDT and metabolites	Alarmingly high level of pesticide residues in both milk and blood samples.
(Bhanti and Taneja, 2007)	Agra, UP	Vegetables (spinach, cucumber, brinjal, bottle gourd, ridge gourd, cauliflower, and cabbage)	Organophosphorus (methyl parathion, chlorpyrifos and malathion)	Residue levels were within safe limits but for the threat of accumulation over the years.
(Sivasankaran et al., 2007)	Puducherry (UT)	Surface and groundwater	HCH, Aldrin, and DDT	Contaminated but residue levels within the acceptable limits.
(Jayashree and Vasudevan, 2007)	Thiruvallur TN	Groundwater	HCH, endosulfan, DDT, and metabolites	Organochlorines and endosulfans were well above acceptable limits in almost all samples.
(Kumari et al., 2007)	Hisar (2002) HR	Rainwater	HCH, endosulfan, heptachlor, DDT and metabolites, pyrethroids and organophosphates.	13 different pesticide residues with 80% samples above MRL.
(Singh et al., 2007)	Unnao (2003) UP	Soil and, surface and ground water	HCH, heptachlor and its epoxide, aldrin chlordane, DDT and its metabolites, and methoxychlor	Both soil and water samples had higher concentration of HCH, DDT, and aldrin.
(Aulakh et al., 2007)	Ludhiana PB	Human adipose tissue	DDT and HCH	All tissues were contaminated, residue levels increased with age.

(Sharma et al., 2007)	14 districts (1998-99) HR	Bovine milk	HCH, endosulfan, aldrin, DDT and its metabolites	All samples contaminated with 4-26% above MRL of different pesticides.
(Singh et al., 2008b)	Jaunpur UP	Blood of fish (from river Gomti), chick, goat, and man	HCH, endosulfan, DDT, and metabolites, aldrin and Chlorpyrifos	Increase in pesticide level in vertebrates causes reproductive dysfunction.
(Kumari et al., 2008)	Hisar (2002-2003) HR	Soil and groundwater	HCH, endosulfan, heptachlor, DDT and metabolites, pyrethroids and organophosphates.	All soil samples were contaminated and over 80% of water samples had residues above safe limits.
(Singh et al., 2008a)	Jaunpur UP	Fishes from river Gomti and Ganga	DDT, γ -HCH, and chlorpyrifos	Increase in pesticide level decreases the sperm motility and their survival time
(Singh and Singh, 2008)	Jaunpur UP	Liver, brain, and ovary of catfishes and carps	HCH, endosulfan, DDT, and metabolites, aldrin and Chlorpyrifos	Bioaccumulation was higher on catfishes than the carps and was beyond the permissible limits HCH. Reproductive axis of the fishes was disrupted.
(Sarkar et al., 2008)	Coastal environment of India Peninsular India	Aquatic system, marine sediments, zooplankton, bivalves, fishes, and mammals	Organochlorines	East coast was found to be more contaminated than west coast
(Choudhary and Sharma, 2008)	Various markets HP	Honey	HCH, endosulfan, DDT and metabolites, and pyrethroids	Almost 50% of the samples were contaminated and about 6% was above the prescribed limits
(Gurusubramanian et al., 2008)	Assam and Darjeeling (2001-2004) Assam and WB	Tea	Organochlorines and Organophosphates	Highly contaminated and Indian Tea classified as "High incidence of pesticide"

(Nag and Raikwar, 2008)	Bundelkhand region UP and MP	Bovine milk	Organochlorines	About 63% samples were contaminated with several exceeding the MRL
(Mathur et al., 2008)	Jaipur RJ	Blood samples of reproductive tract cancer patients	Organochlorines	Residue levels in cancer patients were significantly higher than normal women
(Pathak et al., 2008)	Delhi (2006-2007) National Capital Territory	Healthy maternal and cord blood	HCH, endosulfan, DDT, and metabolites	All the samples were contaminated and the study indicates 60-70% transfer rate from mother to newborn.
(Kashyap et al., 2008)	Ahmedabad, GJ	Chicken egg	Dioxin and furan	All the sample tested were contaminated with the mean level exceeding the threshold by two folds.
(Bishnu et al., 2009)	Dooars and Hill regions (2006) WB	Made tea, fresh tea leaves, soils and water bodies	Organochlorines, Organophosphates, and pyrethroids	All samples were contaminated and several had residues exceeding the MRL.
(Bhattu et al., 2009)	Ludhiana (1999-2002) PB	Total diet of men	Lindane, DDT, endosulfan, Deltamethrin, and chlorpyriphos	Residue levels were higher than ADI limits and indicated milk to be the major source of residues.
(Charan et al., 2010)	Central Aravalli region (2006-2008) RJ	Tomato, lady finger, brinjal, potato, cabbage, and cauliflower	Endosulfan, Endosulfan, Cypermethrin, Methyl parathion, Fenvalerate, Monocrotophos	About 40% were contaminated and over 35% of these contaminated were above MRL.
(Mishra and Sharma, 2011)	Dibrugarh and Nagaon, Assam	Human breast milk	HCH, DDT, and its metabolites	ADI of residue intake by infants through breast milk exceeded the TDI (Tolerable Daily Intake) and the correlation between age and residue levels.

(Nag and Raikwar, 2011)	Bundelkhand region in UP and MP	Feed and fodder	Organochlorines	About 56% of samples were contaminated but only a few were above MRL.
(Pandey et al., 2011)	Delhi National Capital Region	Surface sediments of Yamuna river	Organochlorines	Residue levels were higher than standards in most sites.
(Kumari et al., 2002)	Hisar (1996-97) Haryana	Ladyfinger, bitter gourd, smooth/ridge gourd, cucumber, tomato and brinjal	HCH, endosulfan, aldrin, DDT and its metabolites and organophosphates.	All the samples were contaminated and 23% had residues above MRL.
(Srivastava et al., 2011)	Lucknow (2009) UP	Vegetables	Organochlorines, Organophosphates, pyrethroids etc.	23 pesticides detected in 60 samples with a few samples above MRL.
(Dhananjayan et al., 2012)	Bengaluru (rural) (2009) KA	Blood (agricultural and sheep wool workers)	HCH, DDT and its metabolites, endosulfan, and epoxide	30% of the sample had residue exceeding the tolerance limit.
(Mishra et al., 2012)	Dibrugarh and Nagaon (2009-2010) Assam	Soils from agricultural field, fallows and urban areas	HCH, DDT, and its metabolites	Soil samples were found to be one of the highest at national level and sample from rice field had significantly higher residues.
(Sinha et al., 2012)	Hyderabad, TL	Vegetables (eggplant, ladyfinger, cauliflower, cabbage, tomato, and chili)	Organophosphates	The mean level of residue is above the safety limits.
(Bedi et al., 2013)	Ludhiana (2011) PB	Breast milk	HCH, DDT, and its metabolites	Residue levels have decreased over years but still very well above the permissible limit.

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-conventional 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 6.4. 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 6.4 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, five states including Andhra Pradesh, 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 from our multi-state study. Similar reasons also led to change of field location in Tamil Nadu. Further, due to several management constraints and delays in coordination of the field research, this thesis is focussed and limited to two states of the study i.e. Maharashtra and Tamil Nadu. However, the data from Odisha and Karnataka are being processed and will be included in the final project report.

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. Chetana Vikas and Dharamitra, Wardha, were selected for Maharashtra, and Tribal Health Initiative, Sittilingi, was selected for Tamil Nadu as the host organization. These organisations helped in farmer identification, data collection, and coordination. A set of 30 chemical and 30 organic farmers were selected in regions around Wardha for Maharashtra and Dharmapuri district for Tamil Nadu. Purposive sampling was done for selecting the set of farmers. Appendix 3 gives the list of farmers under the study with their basic farm profile.

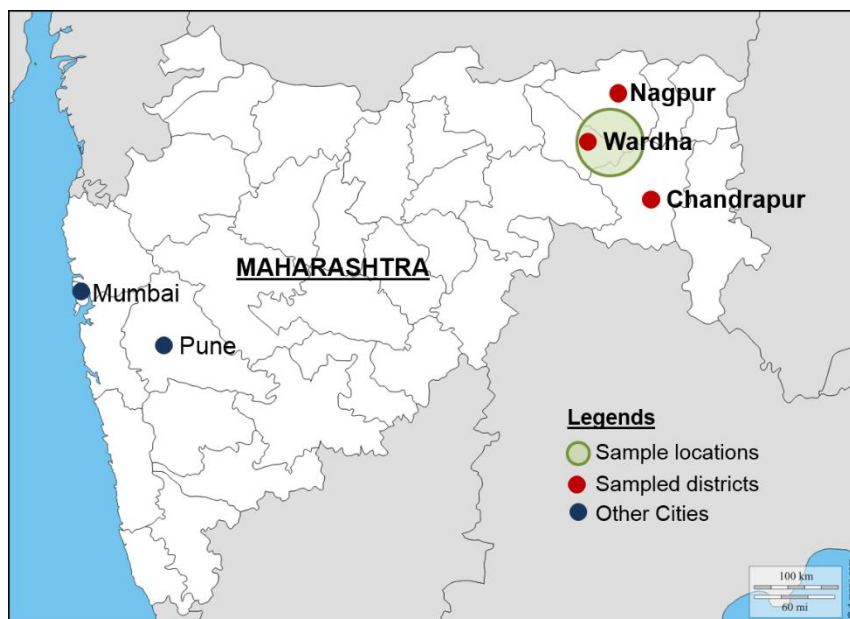


Figure 6.1 Location of fields in Maharashtra

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 and Figure 6.2 show the location of field areas in Maharashtra and Tamil Nadu. 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. In contrast, the samples in Tamil Nadu are located within four villages in 10 km range.

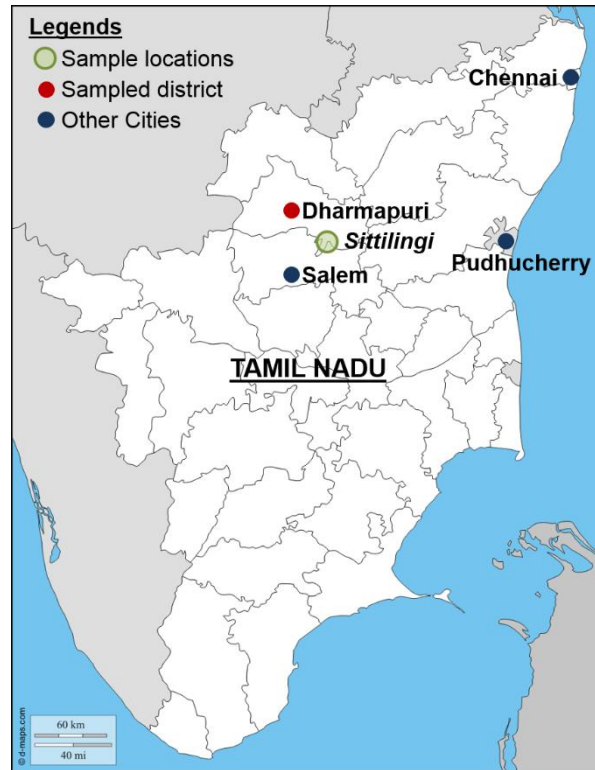


Figure 6.2 Location of fields in Tamil Nadu

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 4) 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 5) 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 6.3 and Figure 6.4 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. 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.

INPUT DETAILS				MATERIALS									
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
Village Name	Sittilingi	Land preparati	LP:Ploughing	Turmeric	600	600		Organic	Farm_input				0
Season	Jun-16	Land preparati	LP:Harrowing	Turmeric				Organic	Farm_input				0
Main crop	Turmeric	Basal manuring	NM:Broadcasting	Turmeric			0 CDM	Organic	Cow dung man	700		1.33	931
Size of the plot (in	0.5	Sowing	SW:Seed planting	Turmeric			0 Naatu	Organic	Farm_input	200		50	10000
		Sowing	SW:Seed planting	Tomato			0 Tomato	Hybrid	Farm_input		2	20	40
		Sowing	SW:Seed planting	Tapioca			0 Tapioca	Hybrid	Farm_input	6		10	60
		Top dressing	NM:Broadcasting	Turmeric			0 CGDM	Hybrid	Cow and goat d	350		1.33	465.5
		Weed manager	WM:Manual weeding	Turmeric			0	Organic	Neem cake				0
		Weed manager	WM:Manual weeding	Turmeric			0	Organic	Biosuper				0
		Pest managem	PM:Pesticide spraying	Turmeric			0 Moorkaraisal	Organic	Moore karaisal	3		30	90
		Harvesting	HV:Manual harvesting	Turmeric			0	Organic	Farm_input				0
		Weed manager	PH:Threshing	Turmeric			0 Veragu	Organic	Farm_input		10		0
		Sowing	SW:Seed planting	Turmeric			0 Onion	Organic	Farm_input	2		30	60
		Weed manager	WM:Manual weeding	Turmeric			0	Organic	Farm_input				0
		Harvesting	HV:Manual harvesting	Turmeric			0	Organic	Farm_input				0
		Harvesting	HV:Manual harvesting	Turmeric			0	Organic	Farm_input				0
		Harvesting	HV:Manual harvesting	Turmeric			0	Organic	Farm_input				0
		Harvesting	HV:Manual harvesting	Turmeric			0	Organic	Farm_input				0
		Post harvesting	PH:Threshing	Turmeric			0	Organic	Farm_input				0

Figure 6.3 Snapshot of a part of primary data input module

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

Figure 6.4 Snapshot of a part of output module with indicator estimates, weightage and indices

Data entry and cleaning

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 6.4.1. 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 6.5 gives the methods used to estimate the soil parameters and their reference for the experimental protocol.

Table 6.5 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, payout expenditure, fertilizer and pesticide impact quotient, etc. Table 6.6 gives a list of few challenges faced during the data collection and the mechanism by which they were addressed.

Table 6.6 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 6.5) 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 6.5 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, \dots, I_n) is computed using a set of multiple-choice questions (Q_1, Q_2, \dots, 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).

$$W = \begin{bmatrix} w_{11} & w_{12} & \dots & w_{1m} \\ w_{21} & w_{22} & \dots & w_{2m} \\ \vdots & \vdots & & \vdots \\ w_{n1} & w_{n2} & \dots & w_{nm} \end{bmatrix}$$

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

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

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

$$I_i = \sum_{j=1}^m w_{ij} * v_i^j \quad \dots(2)$$

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

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 6.8. A weightage is assigned to each of the questions to each indicator as shown in Table 6.7. Each question has five different options marked with specific score for each indicator as shown in Table 6.8. We assume a response by a farmer and represent it in binary as shown in Table 6.9. Then we derive a raw value for each indicator for a corresponding question followed by a weighted value as shown in Table 6.10. The sum of weighted value from each question corresponding to a specific indicator gives the final value of the indicator.

Table 6.7 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 6.8 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
<i>Q1</i>	<i>How many intercroops are present during the current season?</i>			
	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
<i>Q2</i>	<i>How many times legume crop has been cultivated as main crop in last three years?</i>			
	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
<i>Q3</i>	<i>What is the tillage practice carried out in the field for the current season?</i>			
	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

<i>Q4</i>	<i>What is the amount of Farmyard manure/compost/other organic inputs applied in the field during this season?</i>			
	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
<i>Q5</i>	<i>What is the amount of chemical fertilizer applied in the field during this season?</i>			
	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
<i>Q6</i>	<i>How many number of batches were the fertilizers applied?</i>			
	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 6.9 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 6.10 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
<i>Q1</i>	0	1	0	0	0.5	0	0	0.50	0
<i>Q2</i>	0.5	0.5	0	0.25	0.2	0	0.125	0.10	0
<i>Q3</i>	0.5	0	0.2	0.25	0.3	0.3	0.125	0.00	0.06
<i>Q4</i>	1	0	0	0.4	0	0	0.4	0.00	0
<i>Q5</i>	0	0	0.75	0	0	0.5	0	0.00	0.385
<i>Q6</i>	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.

6.4 Results and Discussion

In this section, we describe the results of the data from Sittilingi, Tamil Nadu over three years for two crops and that of Wardha, Maharashtra over two years for four crops. Though the data collection was done for three years in Maharashtra also, the first year data had several gaps due to which it was not included in the data analysis to avoid misinterpretations. First, we discuss the comparison of organic and chemical farms with respect to individual indicators, followed by the discussion on various composite indices. While we collected data from 60 organic and 60 chemical farmers, a total of 522 set of plot data with different crops as shown in Table 6.11 are discussed in this section.

Table 6.11 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
	Total		85		217		220

6.4.1 Trends in indicators

Although FAI helps us in summarising the overall ranking of farming system, trends of individual indicators are also important. One of the commonly used tools to compare these trends is radar chart. A radar chart is a powerful visual tool to communicate 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, payout cost etc., are normalized with a negative function and so higher the score, the better they are. While the normalized indicator values and their corresponding indicator means are given in this section individual farmer data is provided as a supplementary material. Further, several observations and inferences from the patterns of individual indicators as also discussed.

Turmeric

Figure 6.6 shows the trends of various indicators in turmeric cultivation over three years in Sittilingi, Tamil Nadu. Table 6.12 gives the corresponding normalized indicators values and Table 6.13 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 is 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.

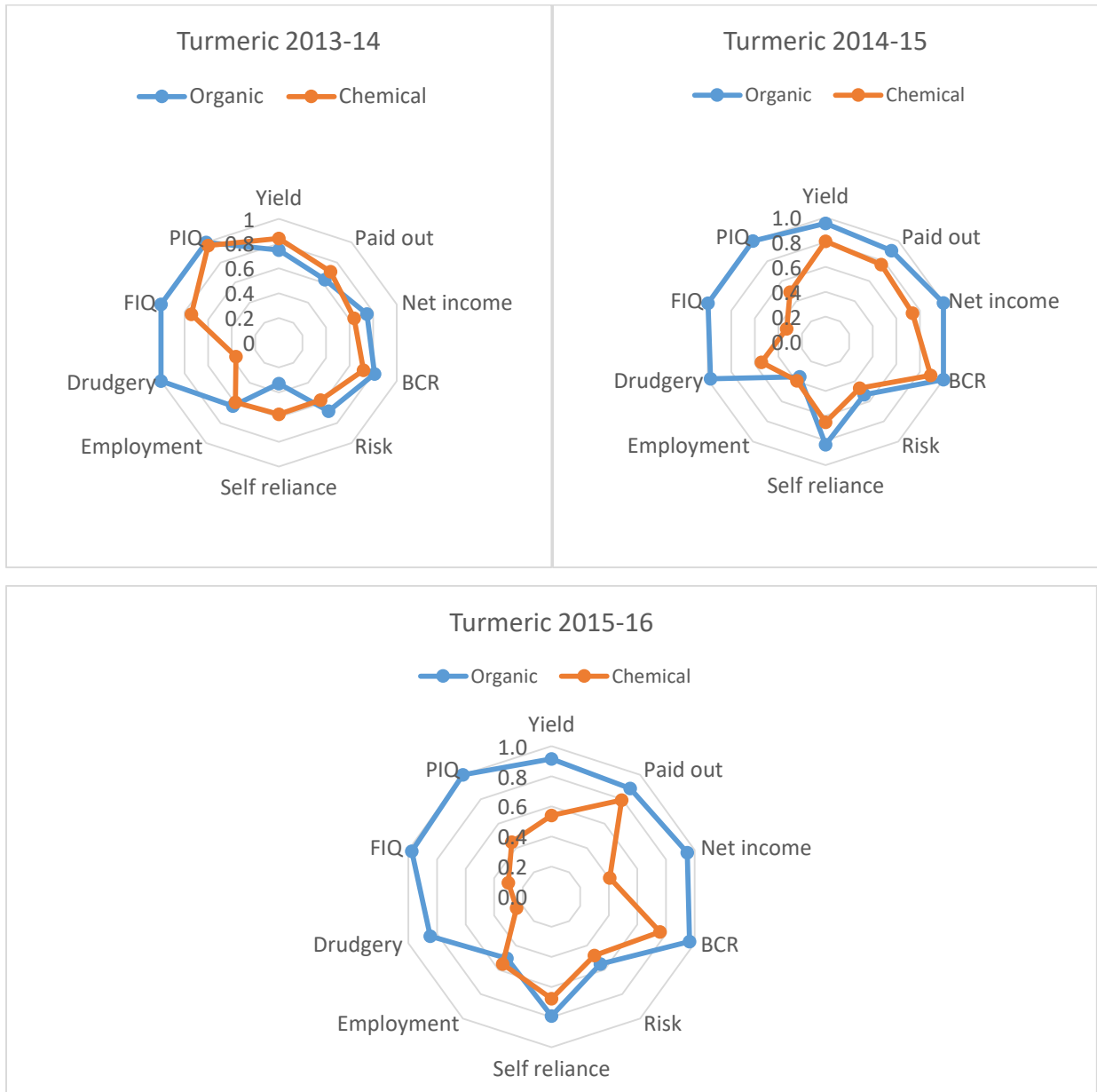


Figure 6.6 Radar charts for individual indicators of turmeric cultivation in Sittilingi, Tamil Nadu

Table 6.12 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 6.13 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 6.13 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 6.7 shows the trends of various indicators in paddy cultivation over three years in Sittilingi, Tamil Nadu. Table 6.14 gives the corresponding normalized indicators values and Table 6.15 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.

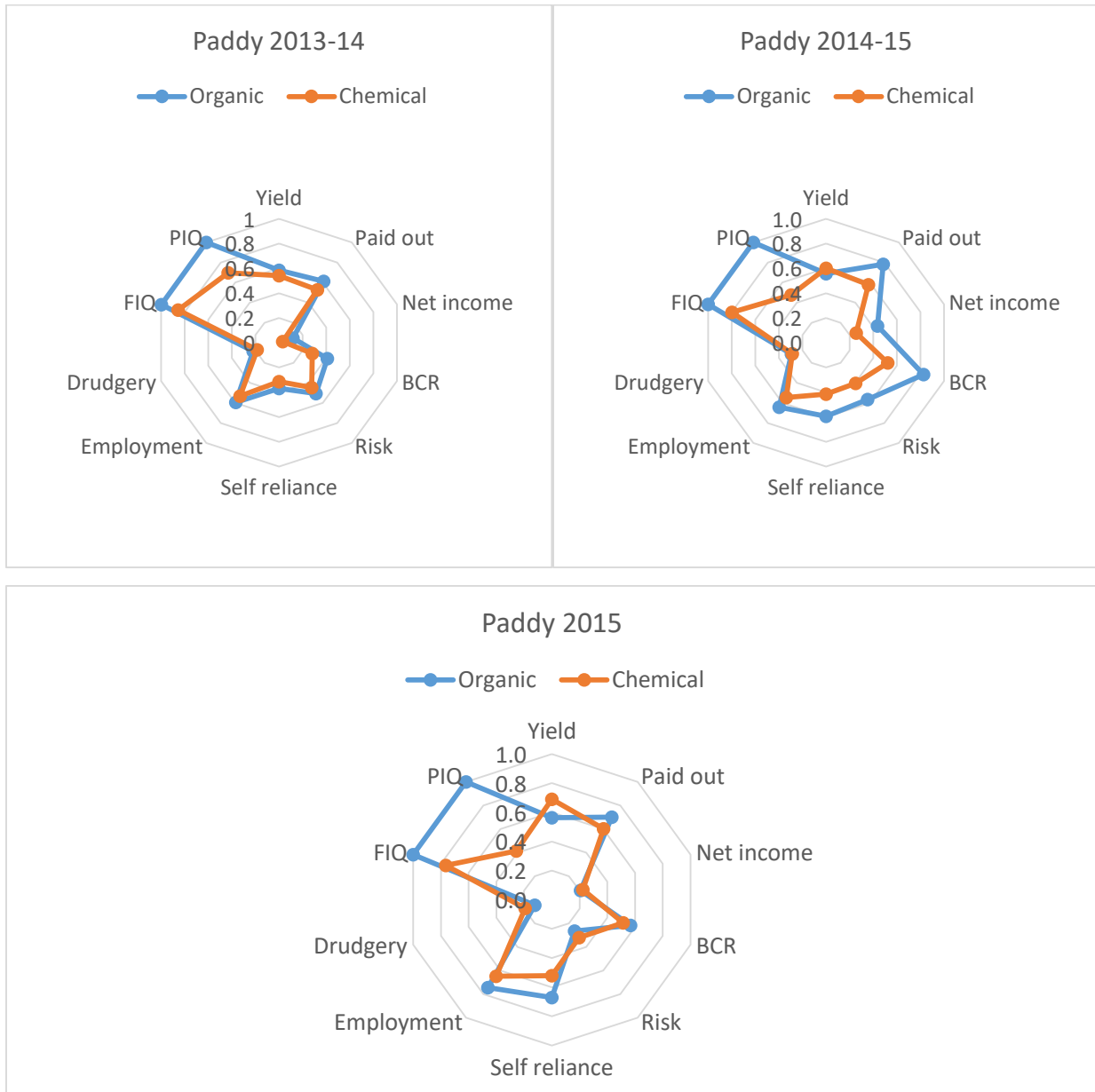


Figure 6.7 Radar charts for individual indicators of paddy cultivation in Sittilingi, Tamil Nadu

- 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 6.14 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 6.15 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

Cotton

Figure 6.8 shows the trend of various indicators in cotton cultivation over two years in villages around Wardha, Maharashtra. Table 6.16 gives the corresponding normalized indicators values and Table 6.17 gives the actual value of each indicator with their unit.

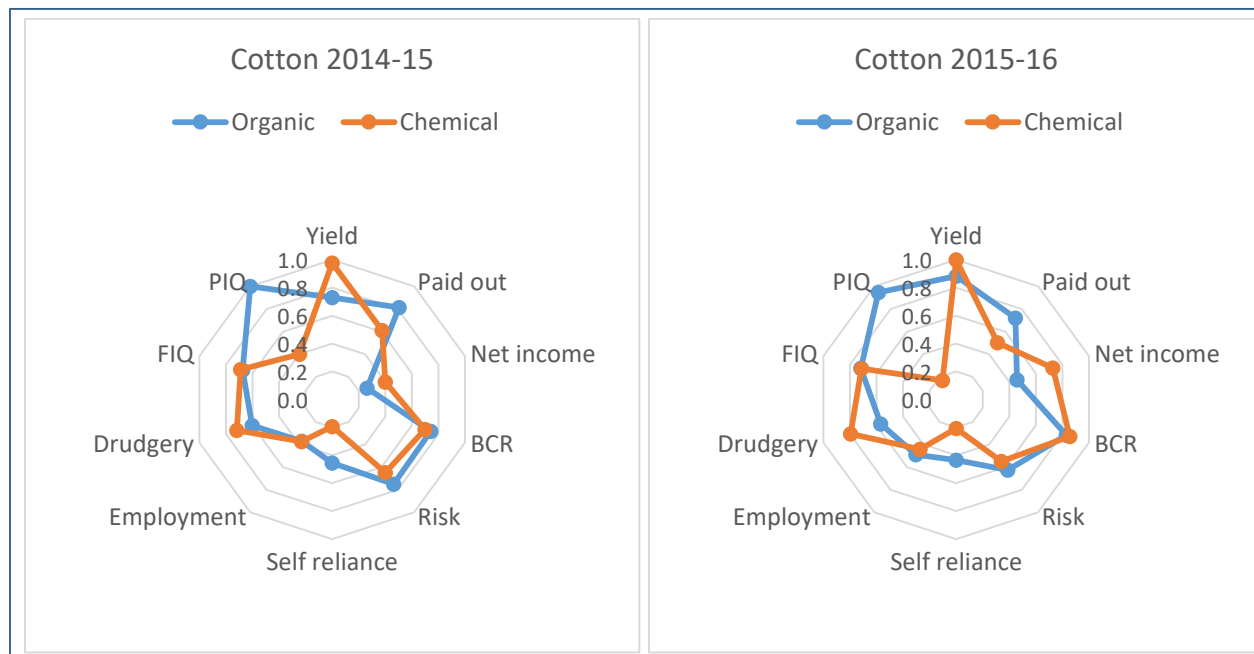


Figure 6.8 Radar charts for individual indicators of cotton cultivation in Wardha, Maharashtra

- 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.
- Payout 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 its corresponding excess phosphorous has affected the FIQ in organic farms as well.

Table 6.16 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 6.17 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 6.9 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.

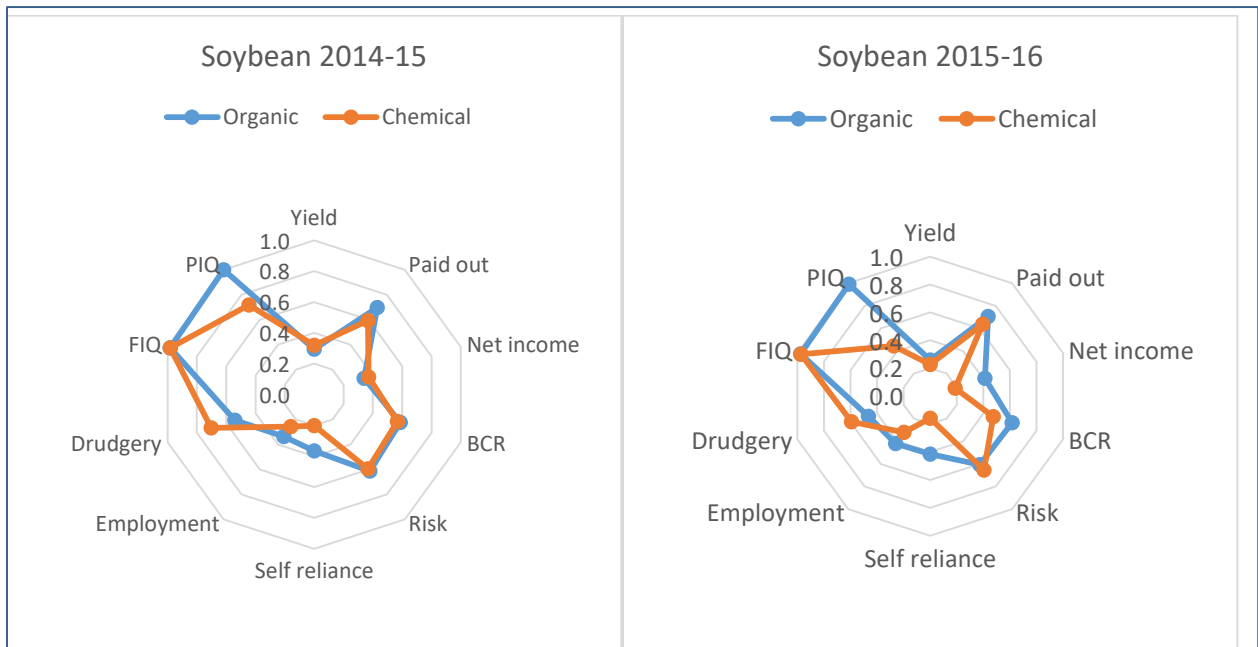


Figure 6.9 Radar charts for individual indicators of soybean cultivation in Maharashtra

Table 6.18 gives the corresponding normalized indicators values and Table 6.19 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 6.18 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 6.19 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 6.10 shows the trend of various indicators in wheat cultivation over two years in Wardha region of Maharashtra. Table 6.20 gives the corresponding normalized indicators values and Table 6.21 gives the actual value of each indicator with their unit.

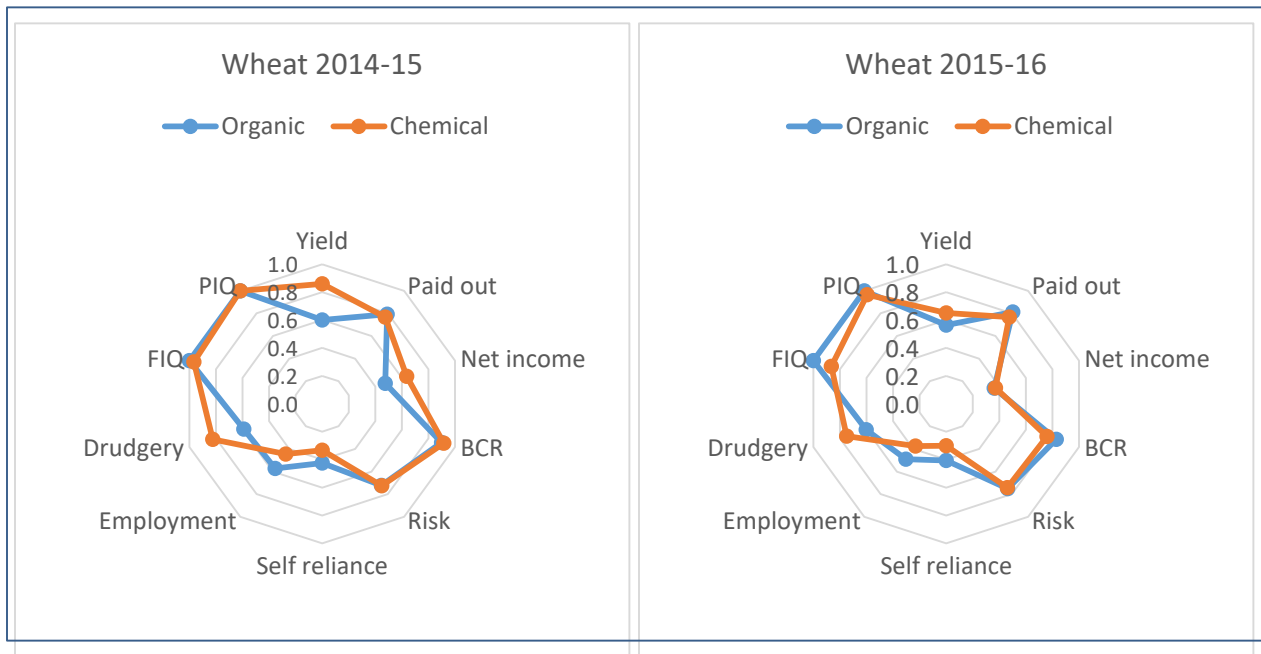


Figure 6.10 Radar charts for individual indicators of Wheat cultivation in Maharashtra

- 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 6.20 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 6.21 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 6.11 shows the trend of various indicators in Bengal gram cultivation over two years in Wardha region of Maharashtra. Table 6.22 gives the corresponding normalized indicators values and Table 6.23 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 payout 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.

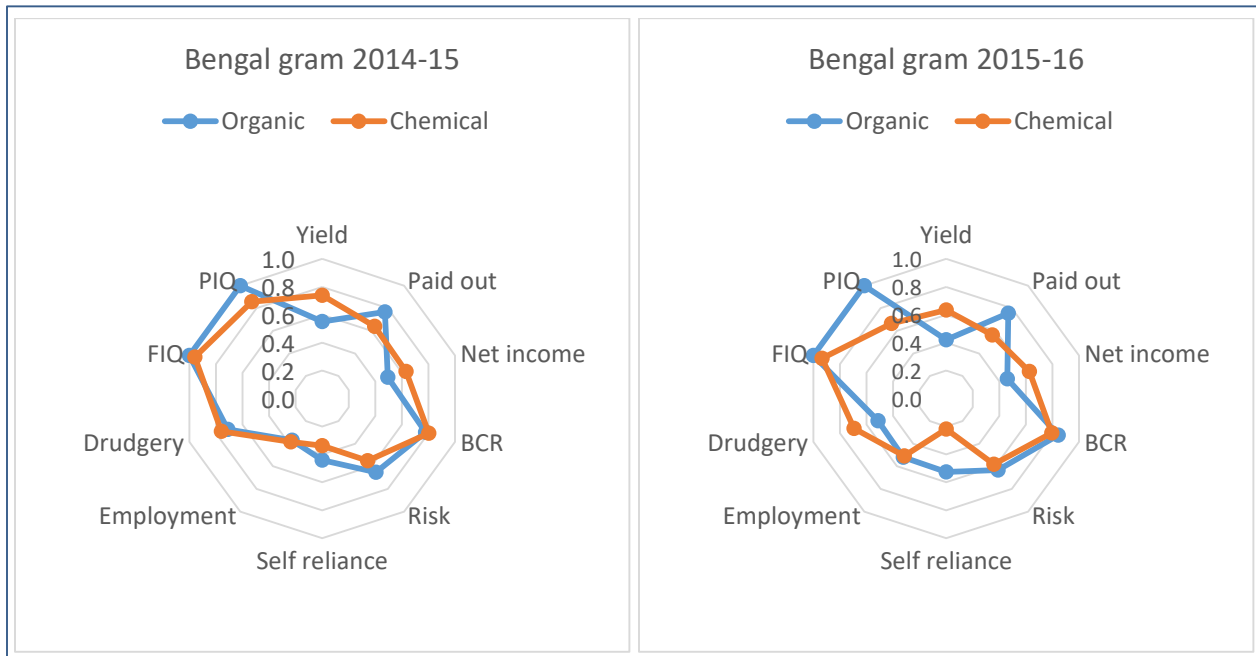


Figure 6.11 Radar charts for individual indicators of Bengal gram cultivation in Maharashtra

Table 6.22 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 6.23 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

Soil parameters

Figure 6.12 shows the physio-chemical properties of soil in organic and chemical farms of soybean and cotton plots that were sampled during three different seasons.

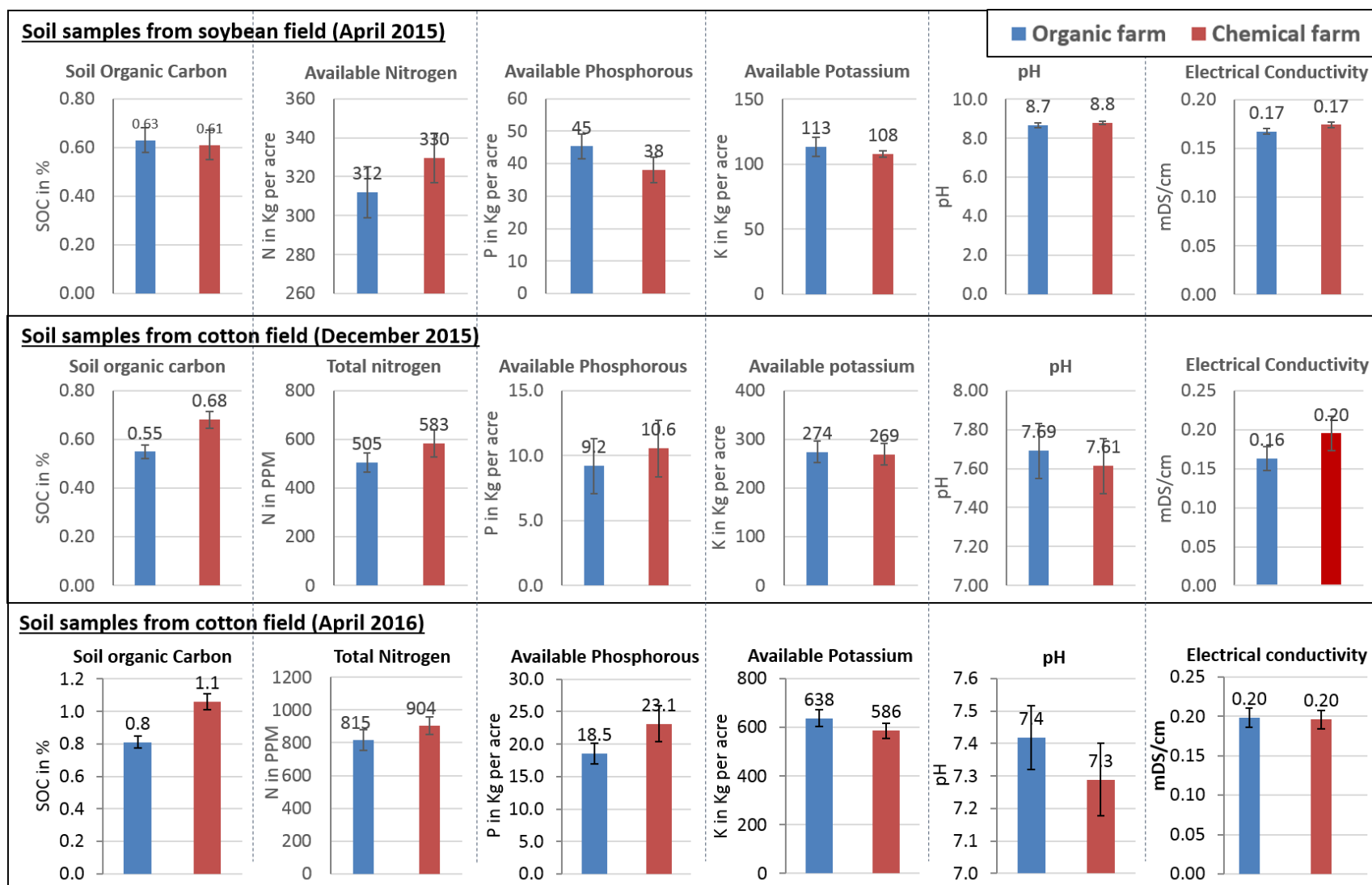


Figure 6.12 Soil parameters of three rounds of soil samples from Wardha, Maharashtra

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 6.13 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.

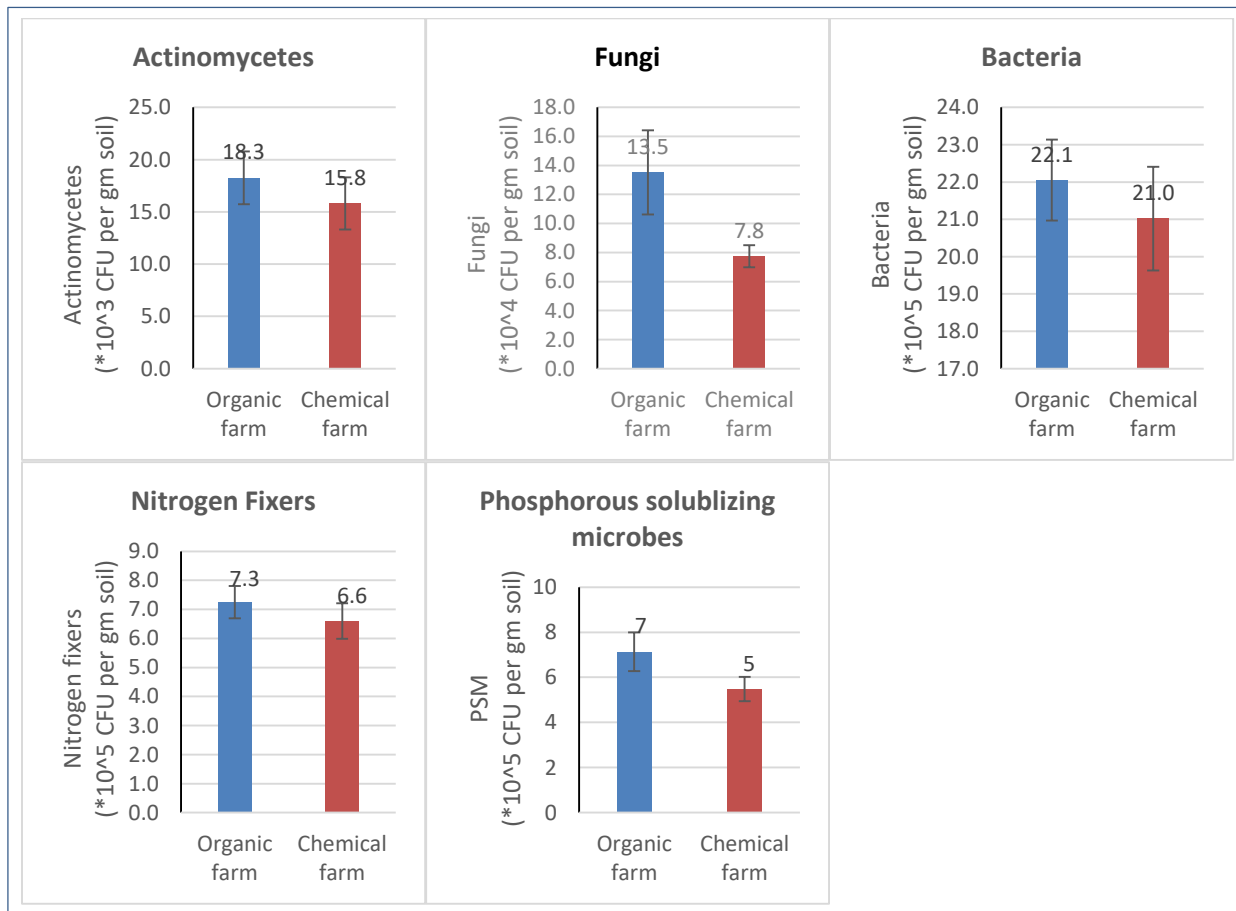


Figure 6.13 Biological parameters of cotton plot (December 2015 samples)

6.4.2 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 are 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 6.24 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 6.24 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)

Figure 6.14 and Figure 6.15 show the FAIs of two crops from Tamil Nadu over the years 2013-16 and four crops of Maharashtra over the years 2014-16 respectively. FAI is calculated for each plot of all the farmers and categorised based on the maincrop of the plot. We compare the crop-wise average of organic and chemical farms. FAI of organic farms were significantly higher than that of chemical farms for both turmeric and paddy farms over all three years in Sittilingi, 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. Similarly, in Maharashtra, organic farming has scored significantly higher than chemical farming in most of the cases.

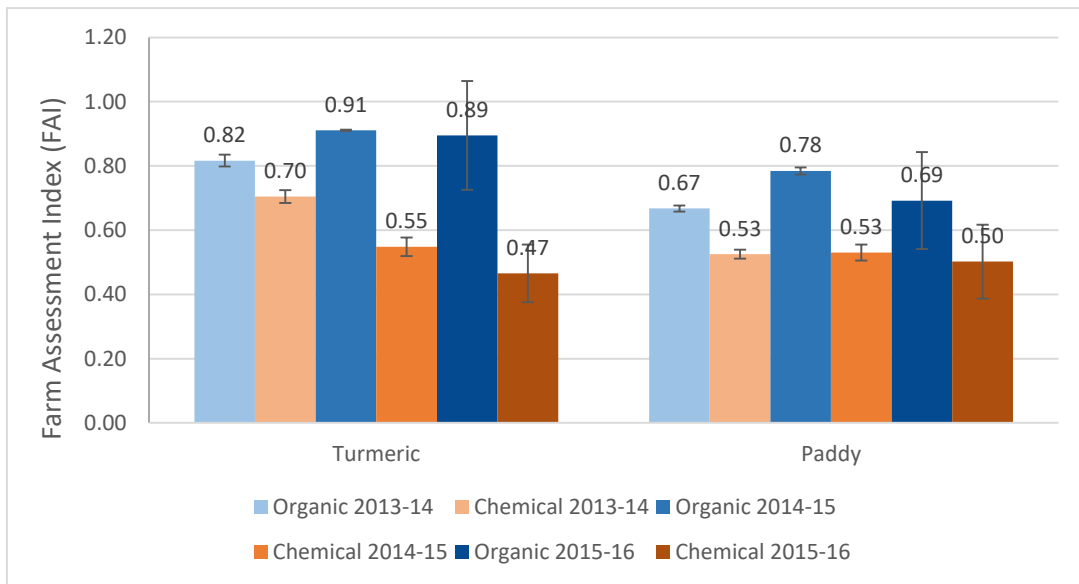


Figure 6.14 FAI for turmeric and paddy in Tamil Nadu

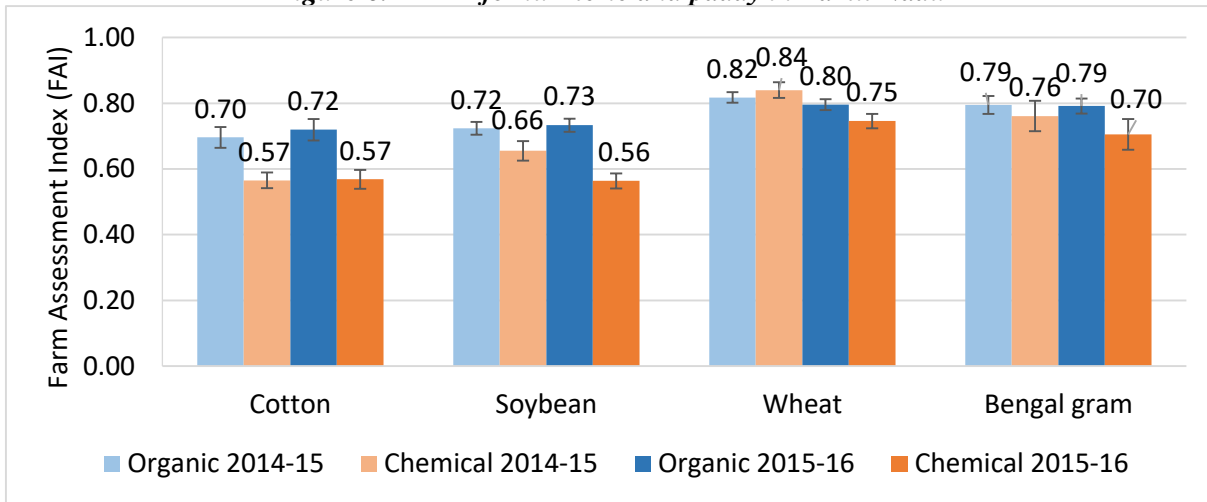


Figure 6.15 FAI of cotton, soybean, wheat and Bengal gram in Wardha, Maharashtra

The gap between the FAI of organic and chemical farms is smaller in Maharashtra than in Tamil Nadu due to higher yield in chemical farms of Maharashtra. Chemical farms with wheat cultivation in Maharashtra had higher FAI during the year 2014-15 as the pesticide usage was minimal during this year. In addition, 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.

Economic, Social and Ecological Indices

Figure 6.16 and Figure 6.17 illustrate the economic and social indices of organic and chemical farms in Sittilingi, Tamil Nadu over the years 2013-16. Similar to FAI, dimensional indices are calculated for each plot of all the farmers and categorised based on the maincrop of the plot. We compare the crop-wise average of organic and chemical farms. 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 payout cost.

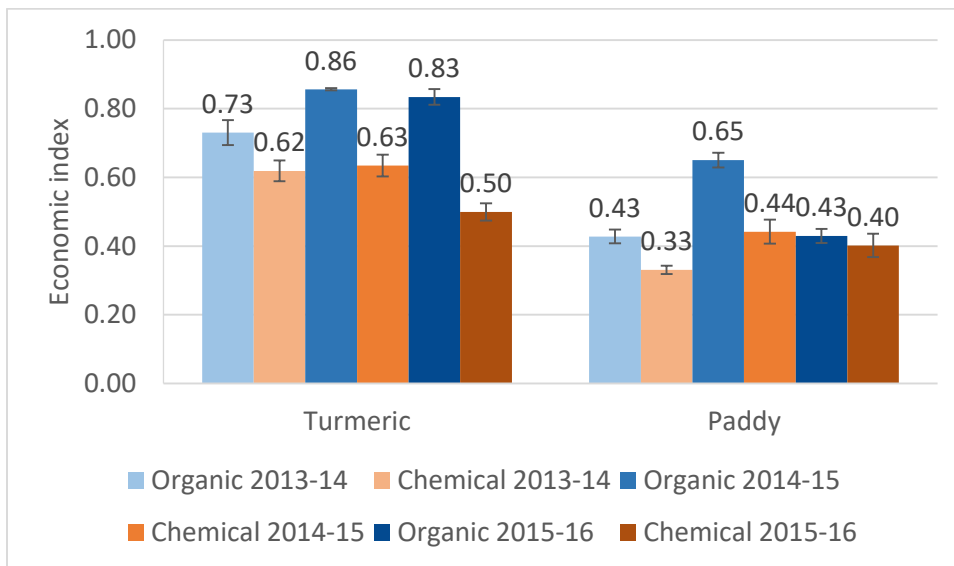


Figure 6.16 Economic index of turmeric and soybean in Sittilingi, Tamil Nadu

The social index for sample farms in Tamil Nadu (Figure 6.17) indicates that the organic farms 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.

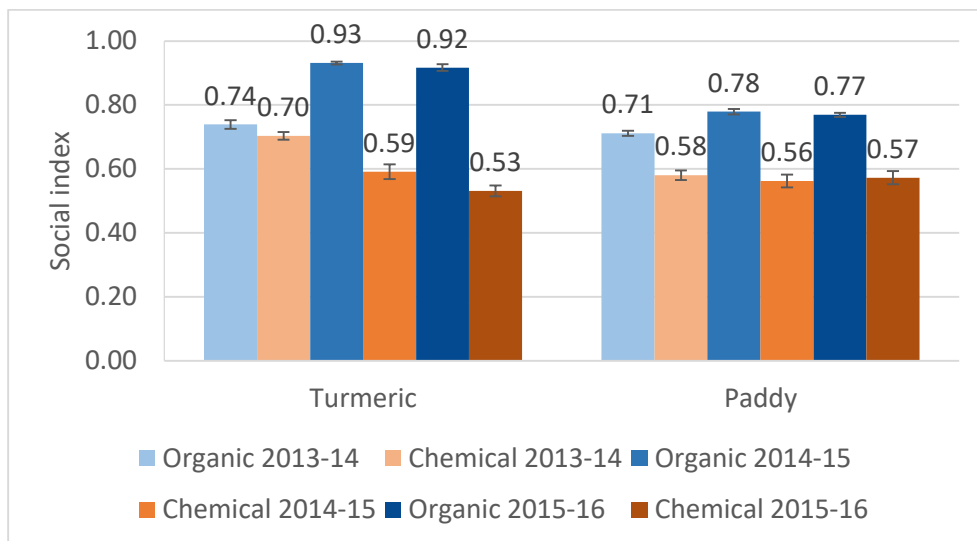


Figure 6.17 Social index of turmeric and soybean in Sittilingi, Tamil Nadu

Figure 6.18 – Figure 6.20 gives the economic, social and ecological indices of various crops sampled in Wardha, Maharashtra. Organic and chemical farms have scored similarly in economic dimension. In case of social and ecological dimensions, organic farms have scored significantly better than chemical farms in most cases.

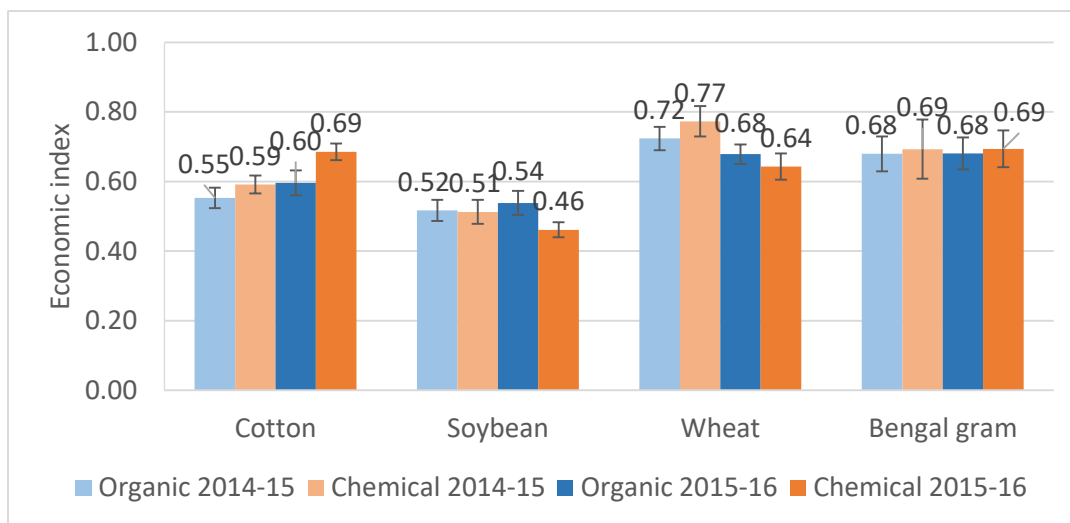


Figure 6.18 Economic index of cotton, soybean, wheat and Bengal gram in Wardha, Maharashtra

Figure 6.18 shows that 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.

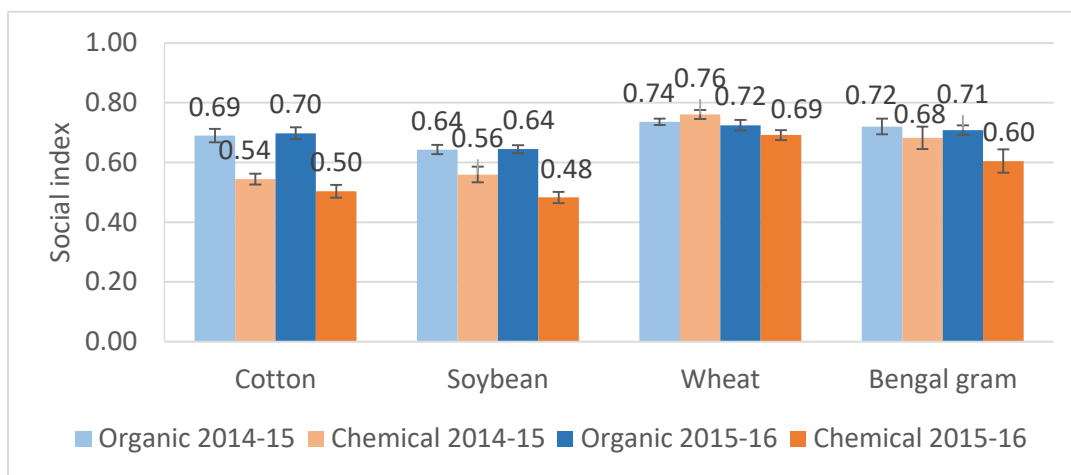


Figure 6.19 Social index of cotton, soybean, wheat and Bengal gram in Wardha, Maharashtra

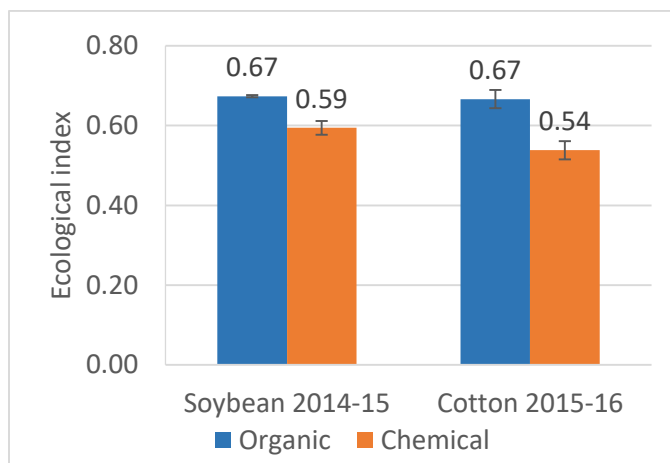


Figure 6.20 Ecological index of soybean and cotton cultivation in Wardha, Maharashtra

Figure 6.19 shows that 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.

Figure 6.20 shows that the ecological index was higher in organic farms with soybean and cotton cultivation during 2014-15 and 2015-16 respectively. 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.

6.4.3 Sensitivity analysis

Table 6.25 to Table 6.28 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 6.25). 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 6.25).

Riskiness, yield, and employment are found to be the top three influencing factors in turmeric cultivation for the year 2014-15, while in the year 2015-16 (Table 6.26) it is riskiness, FIQ and PIQ. In case of paddy fields, PIQ, riskiness and net income are found to be the top three influencing factors (Table 6.26). FIQ did not have much impact in case of soybean due to less fertilizer application, but in case of paddy, lesser influence of FIQ is due to a corresponding increase in yield as discussed earlier in the section 6.4.1.

Table 6.25 Sensitivity analysis of indicators for Tamil Nadu and Maharashtra

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 6.26 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
Total expenditure	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-borne	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 6.27 Sensitivity analysis of indicators within cotton and soybean cultivation in Wardha, Maharashtra

Crop	Cotton						Soybean					
	2014-15			2015-16			2014-15			2015-16		
Year	CR	S	ST	CR	S	ST	CR	S	ST	CR	S	ST
Total expenditure	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-borne	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 6.28 Sensitivity analysis of indicators within wheat and Bengal gram cultivation in Wardha, Maharashtra

Crop	Wheat						Bengal gram					
	2014-15			2015-16			2014-15			2015-16		
Year	CR	S	ST	CR	S	ST	CR	S	ST	CR	S	ST
Total expenditure	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-borne	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

In case of cotton cultivation, PIQ emerges to be the most influencing factor followed by FIQ and net income as second and third dominant indicators respectively during both the years (Table 6.27). In soybean cultivation, net income is found to be the most influencing indicator followed by PIQ and BCR (Table 6.27). Net income and FIQ were the most influencing indicators in wheat cultivation during 2014-15 and 2015-16 respectively (Table 6.28). Similarly, net income and PIQ were the most influencing indicators in Bengal gram cultivation during 2014-15 and 2015-16 respectively (Table 6.28). It is notable that the PIQ has not made any significant difference among the sample farmers in wheat cultivation.

Chapter 7 **Conclusion and Recommendations**

7.1 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 120 farmers in the states of Maharashtra and Tamil Nadu. 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, 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.

Similarly, in 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.

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 Griebhamme, 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.

7.2 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 60 organic and 60 chemical farmers in Wardha region, Maharashtra, and Sittilingi, Tamil Nadu.

- 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. ***Credit 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.***

References

- Abhilash, P.C., Singh, N., 2009. Pesticide use and application: an Indian scenario. *J. Hazard. Mater.* 165, 1–12.
- Abrol, Y.P., Johri, B.N., 2005. Organic farming, Approaches and possibilities in the context of Indian agriculture. (No. 30), NAAS Policy paper.
- Adger, W.N., 2010. Social and ecological resilience : are they related? 3, 347–364.
- Agricultural census, 2012. Agricultural census database [WWW Document]. Agric. Census Div. Minist. Agric. Farmers Welfare, GOI. URL <http://agcensus.dacnet.nic.in/> (accessed 12.7.17).
- Agriculture census, 2012. Input Survey Database [WWW Document]. Agric. Census Div. Minist. Agric. Farmers Welfare, GOI. URL <http://inputsurvey.dacnet.nic.in/> (accessed 5.20.17).
- Alluvione, F., Moretti, B., Sacco, D., Grignani, C., 2011. EUE (energy use efficiency) of cropping systems for a sustainable agriculture. *Energy* 36, 4468–4481. doi:10.1016/j.energy.2011.03.075
- Amaraneni, S.R., Pillala, R.R., 2001. Concentrations of pesticide residues in tissues of fish from Kolleru Lake in India. *Environ. Toxicol.* 16, 550–556. doi:10.1002/tox.10016
- Andreoli, M., Tellarini, V., 2000. Farm sustainability evaluation : methodology and practice. *Agric. Ecosyst. Environ.* 77, 43–52.
- Andrieu, N., Piraux, M., Tonneau, J.-P., 2007. Design of Sustainability Indicators of the Production Systems in Brazilian Semi-arid Area by the Analysis of Biomass Flows. *Int. J. Sustain. Dev.* 10, 106–121.
- APEDA, 2016. Agricultural & Processed Food Products Export Development Authority, Ministry of Commerce & Industry, GOI [WWW Document]. Natl. Program. Org. Prod. URL http://apeda.gov.in/apedawebsite/organic/Organic_Products.htm (accessed 5.20.17).
- Arti, B., Niveta, J., Himanshu, P., 2013. Methane and nitrous oxide emissions from Indian rice paddies, agricultural soils and crop residue burning. *Greenh. Gases Sci. Technol.* 3, 196–211.
- Astier, M., Speelman, E.N., López-Ridaura, S., Masera, O.R., Gonzalez-Esquivel, C.E., 2011. Sustainability indicators, alternative strategies and trade-offs in peasant agroecosystems: analysing 15 case studies from Latin America. *Int. J. Agric. Sustain.* 9, 409–422. doi:10.1080/14735903.2011.583481
- Aulakh, R.S., Bedi, J.S., Gill, J.P.S., Joia, B.S., Pooni, P.A., Sharma, J.K., 2007. Occurrence of DDT and HCH insecticide residues in human biopsy adipose tissues in Punjab, India. *Bull. Environ. Contam. Toxicol.* 78, 330–334. doi:10.1007/s00128-007-9187-6
- Aulakh, R.S., Gill, J.P.S., Bedi, J.S., Sharma, J.K., Joia, B.S., Ockerman, H.W., 2006. Organochlorine pesticide residues in poultry feed, chicken muscle and eggs at a poultry farm in Punjab, India. *J. Sci. Food Agric.* 86, 741–744. doi:10.1002/jsfa.2407
- Bakore, N., John, P., Bhatnagar, P., 2002. Evaluation of organochlorine insecticide residue levels in locally marketed vegetables of Jaipur City, Rajasthan, India. *J. Environ. Biol.* 23, 247–252.

Bakore, N., John, P.J., Bhatnagar, P., 2004. Organochlorine pesticide residues in wheat and drinking water samples from Jaipur, Rajasthan, India. *Environ. Monit. Assess.* 98, 381–389. doi:10.1023/B:EMAS.0000038197.76047.83

Bandyopadhyay, K.K., Misra, A.K., Ghosh, P.K., Hati, K.M., 2010. Effect of integrated use of farmyard manure and chemical fertilizers on soil physical properties and productivity of soybean. *Soil Tillage Res.* 110, 115–125. doi:10.1016/j.still.2010.07.007

Bandyopadhyay, P.K., Saha, S., Mani, P.K., Mandal, B., 2010. Effect of organic inputs on aggregate associated organic carbon concentration under long-term rice-wheat cropping system. *Geoderma* 154, 379–386. doi:10.1016/j.geoderma.2009.11.011

Bastian, O., Corti, C., Lebboroni, M., 2007. Determining environmental minimum requirements for functions provided by agro-ecosystems. *Agron. Sustain. Dev.* 27, 279–291. doi:10.1051/agro:2007027

Bedi, J.S., Gill, J.P.S., Aulakh, R.S., Kaur, P., Sharma, A., Pooni, P.A., 2013. Pesticide residues in human breast milk: Risk assessment for infants from Punjab, India. *Sci. Total Environ.* 463–464, 720–726. doi:10.1016/j.scitotenv.2013.06.066

Bell, S., Morse, S., 2008. *Sustainability Indicators: Measuring the Immeasurable?*, 2nd ed. Earthscan, London. doi:10.1017/CBO9781107415324.004

Benoît, C., Norris, G.A., Valdivia, S., Citroth, A., Moberg, A., Bos, U., Prakash, S., Ugaya, C., Beck, T., 2010. The guidelines for social life cycle assessment of products: Just in time! *Int. J. Life Cycle Assess.* 15, 156–163. doi:10.1007/s11367-009-0147-8

Berke, P., Manta, M., 1999. *Planning for sustainable development: measuring progress in plans.* Lincoln Institute of Land Policy Cambridge, MA.

Bhanti, M., Taneja, A., 2007. Contamination of vegetables of different seasons with organophosphorous pesticides and related health risk assessment in northern India. *Chemosphere* 69, 63–68. doi:10.1016/j.chemosphere.2007.04.071

Bhanti, M., Taneja, A., 2005. Monitoring of organochlorine pesticide residues in summer and winter vegetables from Agra, India - A case study. *Environ. Monit. Assess.* 110, 341–346. doi:10.1007/s10661-005-8043-6

Bhattacharyya, R., Chandra, S., Singh, R.D., Kundu, S., Srivastva, A.K., Gupta, H.S., 2007. Long-term farmyard manure application effects on properties of a silty clay loam soil under irrigated wheat-soybean rotation. *Soil Tillage Res.* 94, 386–396. doi:10.1016/j.still.2006.08.014

Bhattacharyya, R., Kundu, S., Prakash, V., Gupta, H.S., 2008. Sustainability under combined application of mineral and organic fertilizers in a rainfed soybean-wheat system of the Indian Himalayas. *Eur. J. Agron.* 28, 33–46. doi:10.1016/j.eja.2007.04.006

Bhattu, R., Singh, B., BK, K., Joia, B., 2009. Risk assessment through dietary intake of total diet contaminated with pesticide residues in Punjab, India, 1999–2002. *Southeast Asian J. Trop. Med. Public Health* 40, 449–457. doi:10.1016/j.ecoenv.2004.12.004

Bishnu, A., Chakrabarti, K., Chakraborty, A., Saha, T., 2009. Pesticide residue level in tea ecosystems of

Hill and Dooars regions of West Bengal, India. *Environ. Monit. Assess.* 149, 457–464. doi:10.1007/s10661-008-0222-9

Blum, A., 2009. Effective use of water (EUW) and not water-use efficiency (WUE) is the target of crop yield improvement under drought stress. *F. Crop. Res.* 112, 119–123. doi:10.1016/j.fcr.2009.03.009

Bockstaller, C., Girardin, P., 2003. How to validate environmental indicators. *Agric. Syst.* 76, 639–653.

Bockstaller, C., Guichard, L., Makowski, D., Aveline, A., Girardin, P., Plantureux, S., 2008. Agri-environmental indicators to assess cropping and farming systems . A review To cite this version: Agri-environmental indicators to assess cropping and farming systems . A review 28, 139–149.

Bohringer, C., Jochem, P.E.P., 2007. Measuring the immeasurable - A survey of sustainability indices. *Ecol. Econ.* 63, 1–8. doi:10.1016/j.ecolecon.2007.03.008

Bossel, H., 2000. Assessing Viability and Sustainability: a Systems-based Approach for Deriving Comprehensive Indicator Sets. *Conserv. Ecol.* 5, 12.

Bossel, H., 1999. Indicators for Sustainable Development : Theory, Method, Applications, International Institute for Sustainable Development. Winnipeg, Canada.

Bowers, J., 1995. Sustainability, agriculture, and agricultural policy. *Environ. Plan. A* 27, 1231–1243.

Brian Ogle, R., 2001. The need for socio-economic and environmental indicators to monitor degraded ecosystem rehabilitation: A case study from Tanzania. *Agric. Ecosyst. Environ.* 87, 151–157. doi:10.1016/S0167-8809(01)00275-4

Büchs, W., 2003. Biotic indicators for biodiversity and sustainable agriculture - Introduction and background. *Agric. Ecosyst. Environ.* 98, 1–16. doi:10.1016/S0167-8809(03)00068-9

Caceres, E.A.R., 1982. Improved Medium for Isolation of Azospirillum. *Applied Environ. Microbiol.* 44, 990–991.

Calder, K.J. Van, Berentsen, P.B.M., Giesen, G.W.J., Huirne, R.B.M., 2005. Identifying and ranking attributes that determine sustainability in Dutch dairy farming. *Agric. Human Values* 22, 53–63. doi:10.1007/s10460-004-7230-3

Carvalho, F.P., 2006. Agriculture, pesticides, food security and food safety. *Environ. Sci. Policy* 9, 685–692. doi:10.1016/j.envsci.2006.08.002

Ceyhan, V., 2010. Assessing the agricultural sustainability of conventional farming systems in Samsun province of Turkey. *J. Agric. Res.* 5, 1572–1583. doi:10.5897/AJAR09.434

Chang, Y.C., Hong, F.W., Lee, M.T., 2008. A system dynamic based DSS for sustainable coral reef management in Kenting coastal zone, Taiwan. *Ecol. Modell.* 211, 153–168. doi:10.1016/j.ecolmodel.2007.09.001

Charan, P.D., Ali, S.F., Kachhawa, Y., Sharma, K.C., 2010. Monitoring of Pesticide Residues in Farmgate Vegetables of Central Aravalli Region of Western India. *Environ. Sci* 7, 255–258.

Charyulu, D.K., Biswas, S., No, W.P., 2010. Economics and Efficiency of Organic Farming vis-à-vis

Conventional Farming in India Economics and Efficiency of Organic Farming vis-à-vis Conventional Farming in India, Working paper series, Indian Institute of Management. Ahmedabad.

Choudhary, A., Sharma, D.C., 2008. Pesticide residues in honey samples from Himachal Pradesh (India). *Bull. Environ. Contam. Toxicol.* 80, 417–422. doi:10.1007/s00128-008-9426-5

Cloquell-Ballester, V.-A., Cloquell-Ballester, V.-A., Monterde-Díaz, R., Santamarina-Siurana, M.-C., 2006. Indicators validation for the improvement of environmental and social impact quantitative assessment. *Environ. Impact Assess. Rev.* 26, 79–105. doi:10.1016/j.eiar.2005.06.002

Cooper, J., Dobson, H., 2007. The benefits of pesticides to mankind and the environment. *Crop Prot.* 26, 1337–1348. doi:10.1016/j.cropro.2007.03.022

Cooper, J.S., Fava, J. a, 2006. Life-Cycle Assessment Practitioner Survey. *J. Ind. Ecol.* 10, 12–14. doi:10.1162/jiec.2006.10.4.12

DAC, 2011. *Methods Manual: Soil Testing in India*. Department of Agriculture & Cooperation, Ministry of Agriculture, GOI, New Delhi.

Dantsis, T., Douma, C., Giourga, C., Loumou, A., Polychronaki, E.A., 2010. A methodological approach to assess and compare the sustainability level of agricultural plant production systems. *Ecol. Indic.* 10, 256–263. doi:10.1016/j.ecolind.2009.05.007

Dar, I.A., Dar, M.A., Sankar, K., 2010. Nitrate contamination in groundwater of Sopore town and its environs, Kashmir, India. *Arab. J. Geosci.* 3, 267–272. doi:10.1007/s12517-009-0067-8

Das, R.J., 2002. The green revolution and poverty: A theoretical and empirical examination of the relation between technology and society. *Geoforum* 33, 55–72. doi:10.1016/S0016-7185(01)00006-9

Datta, P.S., Deb, D.L., Tyagi, S.K., 1997. Assessment of groundwater contamination from fertilizers in the Delhi area based on NO_3^- and K^+ composition. *J. Contam. Hydrol.* 27, 249–262. doi:10.1016/S0169-7722(96)00099-X

De Ponti, T., Rijk, B., Van Ittersum, M.K., 2012. The crop yield gap between organic and conventional agriculture. *Agric. Syst.* 108, 1–9. doi:10.1016/j.agsy.2011.12.004

Debnath, P., Deb, P., Sen, D., Pattannaik, S.K., Sah, D., Ghosh, S.K., 2012. Physico-chemical properties and its relationship with water holding capacity of cultivated soils along altitudinal gradient in Sikkim. *Int. J. Agriculture , Environ. Biotechnol.* 5, 99–104.

Denzin, N.K., Lincoln, Y.S., 2008. *Collecting and interpreting qualitative materials*. Sage publications, USA.

Devakumar, N., Shubha, S., Gounder, S., Rao, G., 2014. Microbial analytical studies of traditional organic preparations beejamrutha and jeevamrutha, in: Rahmanan, G., Aksoy, U. (Eds.), *Proceedings of the 4th ISOFAR Scientific Conference*. pp. 13–15.

Devuyst, D., 2000. Linking impact assessment and sustainable development at the local level: the introduction of sustainability assessment systems. *Sustain. Dev.* 8, 67–78. doi:10.1002/(SICI)1099-1719(200005)8:2<67::AID-SD131>3.0.CO;2-X

Dhananjayan, V., Ravichandran, B., Rajmohan, H.R., 2012. Organochlorine pesticide residues in blood samples of agriculture and sheep wool workers in bangalore (rural), India. *Bull. Environ. Contam. Toxicol.* 88, 497–500. doi:10.1007/s00128-012-0546-6

Directorate of Economics and Statistics, 2016. Cost of Cultivation/Production and related data [WWW Document]. Minist. Agric. Farmers Welfare, GOI. URL http://eands.dacnet.nic.in/Cost_of_Cultivation.htm (accessed 12.25.16).

Ebert, U., Welsch, H., 2004. Meaningful environmental indices: A social choice approach. *J. Environ. Econ. Manage.* 47, 270–283. doi:10.1016/j.jeem.2003.09.001

Ecobichon, D.J., 2001. Pesticide use in developing countries. *Environ. Health Perspect.* 160, 27–33. doi:10.2307/3434166

Elsaesser, M., Herrmann, K., Jilg, T., 2013. The DAIRYMAN-Sustainability- Index (DSI) as a possible tool for the evaluation of sustainability of dairy farms in Northwest-Europe.

Eshenaur, B., Grant, J., Kovach, J., Petzoldt, C., Degni, J., Tette, J., 2016. Environmental Impact Quotient: A Method to Measure the Environmental Impact of Pesticides. [WWW Document]. New York State Integr. Pest Manag. Program, Cornell Coop. Extension, Cornell Univ. URL <https://nysipm.cornell.edu/eiq/calculator-field-use-eiq> (accessed 6.20.06).

European Commission, 2006. Development of agri-environmental indicators for monitoring the integration of environmental concerns into the common agricultural policy: COM(2006) 508 final.

European Commission, 2001. A framework for indicators for the economic and social dimensions of sustainable agriculture and rural development, Agriculture Directorate-General. Brussels.

Eurostat, 2001. Economy-wide material flow accounts and derived indicators. Luxembourg. doi:ISBN 92-894-0459-0

Eyhorn, F., Ramakrishnan, M., Maeder, P., 2007. The viability of cotton-based organic farming systems in India. *Int. J. Agric. Sustain.* 5, 25–38. doi:10.1080/14735903.2007.9684811

FAO, 2014. Food Wastage Footprint: Full-cost accounting. Food and Agriculture Organization, United Nations, Rome, Italy.

FAO, 2013. Sustainability Assessment Of Food and Agriculture Systems. Guidelines Version 3.0. Food and Agriculture Organization, United Nations, Rome, Italy.

FAO, 1999. Committee on agriculture, Fifteenth session, Organic agriculture. Rome, Italy.

Farber, S.C., Costanza, R., Wilson, M.A., 2002. Economic and ecological concepts for valuing ecosystem services. *Ecol. Econ.* 41, 375–392. doi:10.1016/S0921-8009(02)00088-5

Forster, D., Andres, C., Verma, R., Zundel, C., Messmer, M.M., Mäder, P., 2013. Yield and economic performance of organic and conventional cotton-based farming systems - Results from a field trial in India. *PLoS One* 8. doi:10.1371/journal.pone.0081039

Freebairn, D.M., King, C.A., 2003. Reflections on collectively working toward sustainability: Indicators for indicators! *Aust. J. Exp. Agric.* 43, 223–238. doi:10.1071/EA00195

- Freudenberg, M., 2003. Composite Indicators of Country Performance (No. 2003/16), OECD Science, Technology and Industry Working Papers. Paris, France.
- Gallop, G., 2003. A systems approach to sustainability and sustainable development. Sustainable Development and Human Settlements Division, Santiago, Chile.
- Gardner, C.M.K., Laryea, K.B., Unger, P.W., 1999. Soil Physical Constraints To Plant Growth and Crop Production. Food and Agriculture Organization, United Nations, Rome.
- Gell-Mann, M., 1995. The Quark and the Jaguar: Adventures in the Simple and the Complex. Macmillan.
- Gellings, C., Parmenter, K., 2004. Energy Efficiency in Fertilizer Production and Use, in: Gellings, C.W., Blok, K. (Eds.), Efficient Use and Conservation of Energy. Eolss Publishers, Oxford, UK.
- Ghersa, C.M., Ferraro, D.O., Omacini, M., Mart, M.A., 2002. Farm and landscape level variables as indicators of sustainable land-use in the Argentine Inland-Pampa 93, 279–293.
- Ghosh, B.N., Singh, R.J., Mishra, P.K., 2015. Soil and input management options for increasing nutrient use efficiency, Nutrient Use Efficiency: from Basics to Advances, A. Rakshit et al. (eds.). Springer, India. doi:10.1007/978-81-322-2169-2
- Ghosh, N., 2004. Reducing dependence on chemical fertilizers and its financial implications for farmers in India. *Ecol. Econ.* 49, 149–162. doi:10.1016/j.ecolecon.2004.03.016
- Ghosh, S., Majumdar, D., Jain, M.C., 2003. Methane and nitrous oxide emissions from an irrigated rice of North India. *Chemosphere* 51, 181–195. doi:10.1016/S0045-6535(02)00822-6
- Giovannucci, D., Potts, J., Killian, B., Wunderlich, C., Soto, G., Schuller, S., Pinard, F., Schroeder, K., Vagneron, I., 2008. Seeking Sustainability: COSA Preliminary Analysis of Sustainability Initiatives in the Coffee Sector. Winnipeg, Canada.
- GOI, 2017. Fertilizer Policy [WWW Document]. Minist. Chem. Fertil. URL <http://fert.nic.in/page/fertilizer-policy> (accessed 11.7.17).
- GOI, 2015. State of Indian Agriculture 2015-16. Ministry of Agriculture and Farmers Welfare, GOI, New Delhi.
- GOI, 2014. Data Bank on Agriculture and Allied sectors. New Delhi.
- GOI, 2013. State of Indian Agriculture, Government of India, Ministry of Agriculture Department of Agriculture & cooperation New Delhi.
- GOI, 2010. Chapter 32 Labour and Employment in Statistical Year Book. Ministry of Statistics and Policy Implementation, GOI. New Delhi.
- Gómez-Limón, J.A., Riesgo, L., 2010. Sustainability assessment of olive grove in Andalusia: A methodological proposal, in: 120th EAAE Seminar “External Cost of Farming Activities: Economic Evaluation, Environmental Repercussions and Regulatory Framework.” Crete, Greece, pp. 39–50.
- Gómez-Limón, J. a., Sanchez-Fernandez, G., 2010. Empirical evaluation of agricultural sustainability using composite indicators. *Ecol. Econ.* 69, 1062–1075. doi:10.1016/j.ecolecon.2009.11.027

- Goss, M.J., 1993. Biophysical criteria for evaluation of intense cropping and livestock management systems, in: Wood, Dumanski (Eds.), *Sustainable Land Management for the 21st Century*. Lethbridge, Canada., pp. 189–201.
- Gupta, M., Kiran, S., Gulati, A., Singh, B., Tewari, R., 2012. Isolation and identification of phosphate solubilizing bacteria able to enhance the growth and aloin-A biosynthesis of *Aloe barbadensis* Miller. *Microbiol. Res.* 167, 358–363. doi:10.1016/j.micres.2012.02.004
- Gurusubramanian, G., Rahman, A., Sarmah, M., Ray, S., Bora, S., 2008. Pesticide usage pattern in tea ecosystem, their retrospects and alternative measures. *J. Environ. Biol.* 29, 813–826.
- Haberl, H., Fischer-Kowalski, M., Krausmann, F., Weisz, H., Winiwarter, V., 2004. Progress towards sustainability? What the conceptual framework of material and energy flow accounting (MEFA) can offer. *Land use policy* 21, 199–213. doi:10.1016/j.landusepol.2003.10.013
- Hajkowicz, S., 2006. Multi-attributed environmental index construction. *Ecol. Econ.* 57, 122–139. doi:10.1016/j.ecolecon.2005.03.023
- Hammond, A., Adriaanse, A., Rodenburg, E., Bryant, D., Woodward, R., 1995. Environmental indicators: A systematic approach to measuring and reporting on environmental policy performance in the context of sustainable development. World Resources Institute, Washington DC.
- Häni, F., Braga, F., Stämpfli, A., Keller, T., Fischer, M., Porsche, H., 2003. RISE, a tool for holistic sustainability assessment at the farm level. *Int. Food Agribus. Manag. Rev.* 6.
- Hannon, B., Costanza, R., Ulanowicz, R., 1991. A general accounting framework for ecological systems: A functional taxonomy for connectivist ecology. *Theor. Popul. Biol.* 40, 78–104. doi:10.1016/0040-5809(91)90047-J
- Harger, J.R.E., Meyer, F.M., 1996. Definition of indicators for environmentally sustainable development. *Chemosphere* 33, 1749–1775. doi:10.1016/0045-6535(96)00194-4
- Harwood, J., Heifner, R., Coble, K., Perry, J., Somwaru, A., 1999. Managing risk in farming: concepts, research, and analysis. Market and Trade Economics Division and Resource Economics Division, Economic Research Service, U.S. Department of Agriculture., Washington DC.
- Hati, K.M., Mandal, K.G., Misra, A.K., Ghosh, P.K., Bandyopadhyay, K.K., 2006. Effect of inorganic fertilizer and farmyard manure on soil physical properties, root distribution, and water-use efficiency of soybean in Vertisols of central India. *Bioresour. Technol.* 97, 2182–2188. doi:10.1016/j.biortech.2005.09.033
- Hati, K.M., Swarup, A., Dwivedi, A.K., Misra, A.K., Bandyopadhyay, K.K., 2007. Changes in soil physical properties and organic carbon status at the topsoil horizon of a vertisol of central India after 28 years of continuous cropping, fertilization and manuring. *Agric. Ecosyst. Environ.* 119, 127–134. doi:10.1016/j.agee.2006.06.017
- Hazelton, P., Murphy, B., 2007. *Interpreting Soil Test Results What Do All the Numbers Mean?*, 2nd ed. CSIRO Publishing, Collingwood, Australia.
- Helsel, Z.R., 1992. Energy and alternatives for fertilizer and pesticide use. *Energy farm Prod.* 6, 177–201.

Hengsdijk, H., Kruseman, G., 1993. Operationalizing the DLV program: an integrated agro-economic and agro-ecological approach to a methodology for analysis of sustainable land use and regional agricultural policy. CABO-DLO, Wageningen, Netherlands.

Herendeen, R.A., Wildermuth, T., 2002. Resource-based sustainability indicators: Chase County, Kansas, as example. *Ecol. Econ.* 42, 243–257. doi:10.1016/s0921-8009(02)00056-3

ICAR, 2011. ICAR Vision 2030. Directorate of Knowledge Management in Agriculture, Indian Council of Agricultural Research, New Delhi.

IndiaStat, 2017. Agriculture [WWW Document]. Datanet India. URL <https://www.indiastat.com/agriculture/2/stats.aspx> (accessed 11.7.17).

Ine, C., Fleur, M., Lies, D., Jo, B., Laure, T., Ludwig, L., 2014. Development and evaluation of an on-demand sustainability tool in Flanders. 11th Eur. IFSA Symp. Farming Syst. Facing Glob. Challenges Capacit. Strateg. Proceedings, Berlin, Ger. 1-4 April 2014 38–48.

Iooss, B., Lemaître, P., 2015. A Review on Global Sensitivity Analysis Methods. *Uncertain. Manag. Simulation-Optimization Complex Syst.* 101–122. doi:10.1007/978-1-4899-7547-8_5

Jackson, L.E., Kurtz, J., Fisher, W.S., 2000. Evaluation guidelines for ecological indicators. Environment Protection Agency, US, Washington DC.

Jacobs, J., Sadler, B., 1990. Sustainable development and environmental assessment: perspectives on planning for a common future. Jacobs J, Sadler B (1990) Sustainable development and environmental assessment: perspectives on planning for a common future. Canadian Environmental Assessment Research Council.

Jahanshahloo, G.R., Hosseinzadeh Lotfi, F., Maddahi, R., Jafari, Y., 2012. Efficiency and benchmarking in the presence of undesirable (bad) outputs: A DEA approach. *Int. J. Appl. Math. Res.* 1, 178–188.

Jameel, A.A., Sirajudeen, J., 2006. Risk assessment of physico-chemical contaminants in groundwater of pettavaithalai area, Tiruchirappalli, Tamilnadu - India. *Environ. Monit. Assess.* 123, 299–312. doi:10.1007/s10661-006-9198-5

Jayashree, R., Vasudevan, N., 2007. Organochlorine pesticide residues in ground water of Thiruvallur district, India. *Environ. Monit. Assess.* 128, 209–215. doi:10.1007/s10661-006-9306-6

John, P.J., Bakore, N., Bhatnagar, P., 2001. Assessment of organochlorine pesticide residue levels in dairy milk and buffalo milk from Jaipur City, Rajasthan, India. *Environ. Int.* 26, 231–236. doi:10.1016/S0160-4120(00)00111-2

Jørgensen, A., Bocq, A. Le, Nazarkina, L., Hauschild, M., 2008. Methodologies for Social Life Cycle Assessment. *Int. J. Life Cycle Assess.* 13, 96–103. doi:http://dx.doi.org/10.1065/lca2007.11.367 Please

Kaplan, R., Norton, D.P., 1999. The Balanced Scorecard: translating strategy into action. Harvard Business Review Press, Boston, USA.

Kashyap, R., Bhatnagar, V., Sadhu, H.G., Arora, B., Jhamb, N., Karanjkar, R., 2008. Residues of dioxin in egg samples collected from west zone of India. *Bull. Environ. Contam. Toxicol.* 80, 428–430.

doi:10.1007/s00128-008-9423-8

Kates, R.W., Clark, W.C., Corell, R., Hall, J.M., Jaeger, C.C., Lowe, I., Mccarthy, J.J., Schellnhuber, H.J., Bolin, B., Dickson, N.M., Faucheux, S., Gallopin, G.C., Grübler, A., Huntley, B., Jäger, J., Narpat, S., Kasperson, R.E., Mabogunje, A., Matson, P., Mooney, H., Moore, B., Riordan, T.O., Svedin, U., Iii, B.M., 2012. Sustainability Science. *Science* 292, 641–642. doi:10.1126

Kerr, A., 1990. Canada's national environmental indicator project. Ottawa.

Kızılaslan, N., 2009. Energy use and input-output energy analysis for apple production in Turkey. *J. Food, Agric. Environ.* 7, 419–423.

Klinglmair, M., Sala, S., Brandão, M., 2014. Assessing resource depletion in LCA: a review of methods and methodological issues. *Int. J. Life Cycle Assess.* 19, 580–592. doi:10.1007/s11367-013-0650-9

Kovach, J., Petzoldt, C., Degni, J., Tette, J., 1992. A method to measure the environmental impact of pesticides. *New York's Food Life Sci. Bull.* 139, 1–8.

Kruseman, G., Hengsdijk, H., Ruben, R., 1993. Disentangling the concept of sustainability: conceptual definitions, analytical framework and operational techniques in sustainable land use. CABO-DLO, Wageningen, Netherlands.

Kruseman, G., Ruben, R., Kuyvenhoven, A., 1996. Analytical Framework for Disentangling the Concept of Sustainable Land Use 50, 191–207.

Kumar, A., Baroth, A., Soni, I., Bhatnagar, P., John, P.J., 2006. Organochlorine pesticide residues in milk and blood of women from Anupgarh, Rajasthan, India. *Environ. Monit. Assess.* 116, 1–7. doi:10.1007/s10661-006-7463-2

Kumar, P., 2005. Empowering the Small Farmers Towards a Food Secure India, in: Chand, R. (Ed.), *India's Agricultural Challenges: Reflections on Policy, Technology and Other Issues*. Centre for Trade and Development, New Delhi.

Kumari, B., Kumar, R., Madan, V.K., Singh, R., Singh, J., Kathpal, T.S., 2003. Magnitude of pesticidal contamination in winter vegetables from Hisar, Haryana. *Environ. Monit. Assess.* 87, 311–318. doi:10.1023/A:1024869505573

Kumari, B., Madan, V.K., Jagdeep, S., Singh, S., Kathpal, T.S., 2004. Monitoring of Pesticidal Contamination of Farmgate Vegetables From Hisar. *Environ. Monit. Assess.* 90, 65–71.

Kumari, B., Madan, V.K., Kathpal, T.S., 2008. Status of insecticide contamination of soil and water in Haryana, India. *Environ. Monit. Assess.* 136, 239–244. doi:10.1007/s10661-007-9679-1

Kumari, B., Madan, V.K., Kathpal, T.S., 2007. Pesticide residues in rain water from Hisar, India. *Environ. Monit. Assess.* 133, 467–471. doi:10.1007/s10661-006-9601-2

Kumari, B., Madan, V.K., Kumar, R., Kathpal, T.S., 2002. Monitoring of seasonal vegetables for pesticide residues. *Environ. Monit. Assess.* 74, 263–270.

Kumari, B., Singh, J., Singh, S., Kathpal, T.S., 2005. Monitoring of butter and ghee (clarified butter fat) for pesticidal contamination from cotton belt of Haryana, India. *Environ. Monit. Assess.* 105, 111–120.

doi:10.1007/s10661-005-3159-2

Kundu, M.C., Mandal, B., 2009. Agricultural activities influence nitrate and fluoride contamination in drinking groundwater of an intensively cultivated district in India. *Water, Air, Soil Pollut.* 198, 243–252. doi:10.1007/s11270-008-9842-5

Kundu, M.C., Mandal, B., Hazra, G.C., 2009. Nitrate and fluoride contamination in groundwater of an intensively managed agroecosystem: A functional relationship. *Sci. Total Environ.* 407, 2771–2782. doi:10.1016/j.scitotenv.2008.12.048

Kundu, M.C., Mandal, B., Sarkar, D., 2008. Assessment of the potential hazards of nitrate contamination in surface and groundwater in a heavily fertilized and intensively cultivated district of India. *Environ. Monit. Assess.* 146, 183–189. doi:10.1007/s10661-007-0070-z

Labour Bureau, 2014. Report on employment-unemployment survey volume 1. Ministry of Labour & Employment Labour bureau, GOI. Chandigarh.

Levitan, L., 1997. An Overview of Pesticide Impact Assessment Systems (a.k.a. “Pesticide Risk Indicators”) based on Indexing or Ranking Pesticides by Environmental Impact, in: Workshop on Pesticide Risk Indicators. Organisation of Economic Cooperation and Development, Copenhagen, Denmark, pp. 1–77.

Li, F.J., Dong, S.C., Li, F., 2012. A system dynamics model for analyzing the eco-agriculture system with policy recommendations. *Ecol. Modell.* 227, 34–45. doi:10.1016/j.ecolmodel.2011.12.005

López-ridaura, S., Masera, O., Astier, M., 2002. Evaluating the sustainability of complex socio-environmental systems. the MESMIS framework 2, 135–148.

López-Ridaura, S., Van Keulen, H., Van Ittersum, M.K., Leffelaar, P.A., 2005. Multiscale methodological framework to derive criteria and indicators for sustainability evaluation of peasant natural resource management systems. *Environ. Dev. Sustain.* 7, 51–69. doi:10.1007/s10668-003-6976-x

Lundin, M., 2003. Indicators for measuring the sustainability of urban water systems: A life cycle approach. Chalmers University of Technology.

MAFF, 2000. Towards Sustainable Agriculture. A pilot set of indicators. Ministry of Agriculture Fisheries and Food, London, UK.

Mandal, A., Patra, A.K., Singh, D., Swarup, A., Ebhin Masto, R., 2007. Effect of long-term application of manure and fertilizer on biological and biochemical activities in soil during crop development stages. *Bioresour. Technol.* 98, 3585–3592. doi:10.1016/j.biortech.2006.11.027

Manhart, A., Griebhamme, R., 2006. Social impacts of the production of notebook PCs – Contribution to the development of a Product Sustainability Assessment (PROSA). Freiburg, Germany.

Manna, M.C., Swarup, A., Wanjari, R.H., Mishra, B., Shahi, D.K., 2007. Long-term fertilization, manure and liming effects on soil organic matter and crop yields. *Soil Tillage Res.* 94, 397–409. doi:10.1016/j.still.2006.08.013

Maraseni, T.N., Mushtaq, S., Maroulis, J., 2009. Greenhouse gas emissions from rice farming inputs: a

cross-country assessment. *J. Agric. Sci.* 147, 117. doi:10.1017/S0021859608008411

Masto, R.E., Chhonkar, P.K., Singh, D., Patra, A.K., 2008. Alternative soil quality indices for evaluating the effect of intensive cropping, fertilisation and manuring for 31 years in the semi-arid soils of India. *Environ. Monit. Assess.* 136, 419–435. doi:10.1007/s10661-007-9697-z

Masto, R.E., Chhonkar, P.K., Singh, D., Patra, A.K., 2007. Soil quality response to long-term nutrient and crop management on a semi-arid Inceptisol. *Agric. Ecosyst. Environ.* 118, 130–142. doi:10.1016/j.agee.2006.05.008

Masto, R.E., Chhonkar, P.K., Singh, D., Patra, A.K., 2006. Changes in soil biological and biochemical characteristics in a long-term field trial on a sub-tropical inceptisol. *Soil Biol. Biochem.* 38, 1577–1582. doi:10.1016/j.soilbio.2005.11.012

Mathur, V., John, P.J., Soni, I., Bhatnagar, P., 2008. Blood Levels of Organochlorine Pesticide Residues and Risk of Reproductive Tract Cancer Among Women from Jaipur, India, in: Li, J.J., Li, S.A., Mohla, S., Rochefort, H., Maudelonde, T. (Eds.), *Hormonal Carcinogenesis V.* Springer New York, New York, NY, pp. 387–394. doi:10.1007/978-0-387-69080-3_37

Matthews, E., Amann, C., Bringezu, S., 2000. The weight of nations: material outflows from industrial economies, 2000, World Resources Institute, Washington, DC.

Mayer, A.L., 2008. Strengths and weaknesses of common sustainability indices for multidimensional systems. *Environ. Int.* 34, 277–91. doi:10.1016/j.envint.2007.09.004

Mendoza, T.C., 2005. An energy-based analysis of organic, Low External Input Sustainable Agriculture (LEISA) and conventional rice production in the Philippines. *Philipp. Agric. Sci.* 88, 257–267.

Merante, P., Van Passel, S., Pacini, C., 2015. Using agro-environmental models to design a sustainable benchmark for the sustainable value method. *Agric. Syst.* 136, 1–13. doi:10.1016/j.agry.2015.02.001

Merlín-Uribe, Y., González-Esquivel, C.E., Contreras-Hernández, A., Zambrano, L., Moreno-Casasola, P., Astier, M., 2013. Environmental and socio-economic sustainability of *chinampas* (raised beds) in Xochimilco, Mexico City. *Int. J. Agric. Sustain.* 11, 216–233. doi:10.1080/14735903.2012.726128

Meul, M., Nevens, F., Reheul, D., 2009. Validating sustainability indicators: Focus on ecological aspects of Flemish dairy farms. *Ecol. Indic.* 9, 284–295. doi:10.1016/j.ecolind.2008.05.007

Meul, M., Passel, S., Nevens, F., Dessein, J., Rogge, E., Mulier, A., Hauwermeiren, A., 2008. MOTIFS: a monitoring tool for integrated farm sustainability. *Agron. Sustain. Dev.* 28, 321–332. doi:10.1051/agro:2008001

Midgley, G., Reynolds, M., 2004. Systems/operational research and sustainable development: Towards a new agenda. *Sustain. Dev.* 12, 56–64. doi:10.1002/sd.218

Ministry of Agriculture, 2013. Agricultural Statistics at a glance 2013. Directorate of Economics and Statistics, Department of Agriculture and Cooperation, GOI, New Delhi.

Mishra, K., Sharma, R.C., 2011. Assessment of organochlorine pesticides in human milk and risk exposure to infants from North-East India. *Sci. Total Environ.* 409, 4939–4949. doi:10.1016/j.scitotenv.2011.07.038

- Mishra, K., Sharma, R.C., Kumar, S., 2012. Contamination levels and spatial distribution of organochlorine pesticides in soils from India. *Ecotoxicol. Environ. Saf.* 76, 215–225. doi:10.1016/j.ecoenv.2011.09.014
- Mitchell, P.L., Sheehy, J.E., 1997. Comparison of predictions and observations to assess model performance: a method of empirical validation, in: *Applications of Systems Approaches at the Field Level*. Springer, pp. 437–451.
- Moldan, B., Janouskova, S., Hak, T., 2012. How to understand and measure environmental sustainability: Indicators and targets. *Ecol. Indic.* 17, 4–13. doi:10.1016/j.ecolind.2011.04.033
- Monteith, J.L., 1996. The quest for balance in crop modeling. *Agron. J.* 88, 695–697. doi:10.2134/agronj1996.00021962008800050003x
- Moore, A., Dormody, T., Van Leeuwen, D., Harder, A., 2013. Agricultural sustainability of small-scale farms in Lacluta, Timor Leste. *Int. J. Agric. Sustain.* 12, 130–145. doi:10.1080/14735903.2013.842341
- Mukherjee, I., 2003. Pesticides residues in vegetables in and around Delhi. *Environ. Monit. Assess.* 86, 265–271. doi:10.1023/A:1024057420937
- Munda, G., Nijkamp, P., Rietveld, P., 1995. Monetary and non-monetary evaluation methods in sustainable development planning. *Econ. Appliquée* 48, 143–160.
- Myers, M.D., 1997. Qualitative research in information systems. *Manag. Inf. Syst. Q.* 21, 241–242.
- NAAS India, 2011. Carrying Capacity of Indian Agriculture (Policy Paper No. 51). National Academy of Agricultural Sciences, New Delhi.
- NABARD, 2012. District Agriculture Development Index (Approach paper). Central Statistical Information Department, National Bank for Agriculture and Rural Development., Mumbai, India.
- Nag, S.K., Raikwar, M.K., 2011. Persistent organochlorine pesticide residues in animal feed. *Environ. Monit. Assess.* 174, 327–335. doi:10.1007/s10661-010-1460-1
- Nag, S.K., Raikwar, M.K., 2008. Organochlorine pesticide residues in bovine milk. *Bull. Environ. Contam. Toxicol.* 80, 5–9. doi:10.1007/s00128-007-9276-6
- Nagarajan, R., Rajmohan, N., Mahendran, U., Senthamilkumar, S., 2010. Evaluation of groundwater quality and its suitability for drinking and agricultural use in Thanjavur city, Tamil Nadu, India. *Environ. Monit. Assess.* 171, 289–308. doi:10.1007/s10661-009-1279-9
- Nambiar, K.K.M., Gupta, a. P., Fu, Q., Li, S., 2001. Biophysical, chemical and socio-economic indicators for assessing agricultural sustainability in the Chinese coastal zone. *Agric. Ecosyst. Environ.* 87, 209–214. doi:10.1016/S0167-8809(01)00279-1
- Nathan, H.S.K., Reddy, B.S., 2011. Criteria selection framework for sustainable development indicators. *Int. J. Multicriteria Decis. Mak.* 1, 257–279.
- Nayak, A.K., Gangwar, B., Shukla, A.K., Mazumdar, S.P., Kumar, A., Raja, R., Kumar, A., Kumar, V., Rai, P.K., Mohan, U., 2012. Long-term effect of different integrated nutrient management on soil organic carbon and its fractions and sustainability of rice-wheat system in Indo Gangetic Plains of India. *F. Crop. Res.* 127, 129–139. doi:10.1016/j.fcr.2011.11.011

- NCRB, 2015. Farmer Suicides in India. National Crime Records Bureau, Ministry of Home Affairs, GOI, New Delhi.
- Ness, B., Urbel-Piirsalu, E., Anderberg, S., Olsson, L., 2007. Categorising tools for sustainability assessment. *Ecol. Econ.* 60, 498–508. doi:10.1016/j.ecolecon.2006.07.023
- Niemeijer, D., de Groot, R.S., 2008. A conceptual framework for selecting environmental indicator sets. *Ecol. Indic.* 8, 14–25. doi:10.1016/j.ecolind.2006.11.012
- Norris, G.A., 2006. Social Impacts in Product Life Cycles Towards Life Cycle Attribute Assessment. *Harvard Sch. Public Heal.* 1, 97–104. doi:10.1065/lca2006.04.017
- Novotny, V., Wang, X., Englande, A.J., Bedoya, D., Promakasikorn, L., Tirado, R., 2010. Comparative assessment of pollution by the use of industrial agricultural fertilizers in four rapidly developing Asian countries. *Environ. Dev. Sustain.* 12, 491–509.
- NSS 55th Round, 2000. Employment and Unemployment in India, 1999-2000 – Key Results. Department of Agriculture and Cooperation, Ministry of Agriculture, GOI. New Delhi. doi:10.2307/1529480
- NSS 59th Round, 2005. Income, Expenditure and Productive Assets of Farmer Households, Situation Assessment Survey of Farmers, National Sample Survey Organisation, Ministry of Statistics and Programme Implementation, Government of India. New Delhi.
- NSS 70th Round, 2013. Some Characteristics of Agricultural Households in India. National Sample Survey office, Ministry of Statistics and Programme Implementation, Government of India, New Delhi.
- NSSO, 2016. Household Indebtedness in India NSS 70th Round (January - December 2013). National Sample Survey Office, Ministry of Statistics and Programme Implementation, GOI, New Delhi.
- OECD, 2008. Handbook on Constructing Composite Indicators: Methodology and user guide. JRC, European Commission.
- OECD, 1993. Core Set of Indicators for Environmental Performance Reviews: A synthesis report by the Group on the State of the Environment 1–39.
- Oreskes, N., Shrader-frechette, K., Belitz, K., 1994. Verification, Validation, and Confirmation of Numerical Models in the Earth Sciences. *Science* (80-). 263.
- Ott, W.R., 1978. Environmental indices: theory and practice. Ann Arbor Science Publishers, Inc., Ann Arbor, USA.
- Pacini, C., Lazzarini, G., Migliorini, P., Vazzana, C., 2009. An indicator-based framework to evaluate sustainability of farming systems: Review of applications in Tuscany. *Ital. J. Agron.* 4, 23–39. doi:10.4081/ija.2009.1.23
- Pandey, J., Singh, A., 2012. Opportunities and Constraints in Organic Farming : an Indian Perspective. *J. Sci. Res.* 56, 47–72.
- Pandey, P., Khillare, P.S., Kumar, K., 2011. Assessment of Organochlorine Pesticide Residues in the Surface Sediments of River Yamuna in Delhi, India. *J. Environ. Prot. (Irvine, Calif).* 2, 511–524. doi:10.4236/jep.2011.25059

- Pandit, G.G., Sahu, S.K., 2002. Assessment of risk to public health posed by persistent organochlorine pesticide residues in milk and milk products in Mumbai, India. *J. Environ. Monit.* 4, 182–185. doi:10.1039/b109280d
- Panneerselvam, P., Halberg, N., Vaarst, M., Hermansen, J.E., 2012. Indian farmers' experience with and perceptions of organic farming. *Renew. Agric. Food Syst.* 27, 157–169. doi:10.1017/S1742170511000238
- Panneerselvam, P., Hermansen, J.E., Halberg, N., 2010. Food Security of Small Holding Farmers: Comparing Organic and Conventional Systems in India. *J. Sustain. Agric.* 35, 48–68. doi:10.1080/10440046.2011.530506
- Pannell, D.J., Glenn, N.A., 2000. A framework for the economic evaluation and selection of sustainability indicators in agriculture. *Ecol. Econ.* 33, 135–149. doi:10.1016/S0921-8009(99)00134-2
- Pathak, R., Suke, S.G., Ahmed, R.S., Tripathi, A.K., Guleria, K., Sharma, C.S., Makhijani, S.D., Mishra, M., Banerjee, B.D., 2008. Endosulfan and other organochlorine pesticide residues in maternal and cord blood in North Indian population. *Bull. Environ. Contam. Toxicol.* 81, 216–219. doi:10.1007/s00128-008-9459-9
- Patil, S., Reidsma, P., Shah, P., Purushothaman, S., Wolf, J., 2014. Comparing conventional and organic agriculture in Karnataka, India: Where and when can organic farming be sustainable? *Land use policy* 37, 40–51. doi:10.1016/j.landusepol.2012.01.006
- Pervanchon, F., Bockstaller, C., Girardin, P., 2002. Assessment of energy use in arable farming systems by means of an agro-ecological indicator: The energy indicator. *Agric. Syst.* 72, 149–172. doi:10.1016/S0308-521X(01)00073-7
- Philippe, G., Christian, B., Hayo, V. der W., 2008. Indicators: Tools to Evaluate the Environmental Impacts of Farming Systems. *J. Sustain. Agric.* 13, 37–41. doi:10.1300/J064v13n04
- Pimentel, D., 1995. Amounts of pesticides reaching target pests: Environmental impacts and ethics. *J. Agric. Environ. Ethics* 8, 17–29. doi:10.1007/BF02286399
- Pinter, L., Bizikova, L., Karoly, K., Vari, A., 2008. Developing a System of Sustainability Indicators. *Tájökológiai Lapok* 6, 271–293.
- Planning Commission, 2014. Data-book Compiled for Planning Commission [WWW Document]. Gov. India. URL http://planningcommission.nic.in/data/datatable/data_2312/comp_data2312.pdf (accessed 11.7.17).
- Planning Commission, 2011. Report Of The Working Group On Employment, Planning & Policy For The Twelfth Five Year Plan (2012-2017). New Delhi.
- Planning Commission, 2007. Eleventh Five Year Plan (2008-2012). Government of India, New Delhi.
- Planning Commission, 2002. Tenth Five Year Plan (2002-07), Dimensions and Strategies. Planning Commission. Government of India, New Delhi.
- Population Census, 2011. Decadal Variation in Population Since 1901. Ministry of Home Affairs, Government of India, New Delhi.

Pöyhönen, M., Hämäläinen, R.P., 1998. Notes on the weighting biases in value trees. *J. Behav. Decis. Mak.* 11, 139–150.

Praneetvatakul, S., Janekarnkij, P., Potchanasin, C., Prayoonwong, K., 2001. Assessing the sustainability of agriculture: A case of Mae Chaem Catchment, northern Thailand. *Environ. Int.* 27, 103–109. doi:10.1016/S0160-4120(01)00068-X

Prato, T., 1999. Multiple attribute decision analysis for ecosystem management. *Ecol. Econ.* 30, 207–222. doi:10.1016/S0921-8009(99)00002-6

Press Trust of India, 2016. Use of 51 pesticides banned elsewhere allowed in India, Centre tells high court. *Bus. Line, Hindu.*

Qiu, H., Zhu, W., Wang, H., Cheng, X., 2007. Analysis and Design of Agricultural Sustainability Indicators System. *Agric. Sci. China* 6, 475–486. doi:10.1016/S1671-2927(07)60072-8

Raj, D.A., Sridhar, K., Ambatipudi, A., Lanting, H., Brenchandran, S., 2004. Case study on organic versus conventional cotton in Karimnagar, Andhra Pradesh, India. *Second Int. Symp. Biol. Control Arthropods.*

Rajendran, R.B., Imagawa, T., Tao, H., Ramesh, R., 2005. Distribution of PCBs, HCHs and DDTs, and their ecotoxicological implications in Bay of Bengal, India. *Environ. Int.* 31, 503–512. doi:10.1016/j.envint.2004.10.009

Raju, N.J., Ram, P., Dey, S., 2009. Groundwater quality in the lower Varuna River basin, Varanasi district, Uttar Pradesh. *J. Geol. Soc. India* 73, 178–192. doi:10.1007/s12594-009-0074-0

Ramesh, P., Panwar, N.R., Singh, A., Ramana, S., Yadav, S.K., Shrivastava, R., Rao, A.S., 2010. Status of organic farming in India. *Curr. Sci.* 98, 1190–1194.

Rao, N.S., 2006. Nitrate pollution and its distribution in the groundwater of Srikakulam district, Andhra Pradesh, India. *Environ. Geol.* 51, 631–645. doi:10.1007/s00254-006-0358-2

Rawls, W.J., Pachepsky, Y. a., Ritchie, J.C., Sobecki, T.M., Bloodworth, H., 2003. Effect of soil organic carbon on soil water retention. *Geoderma* 116, 61–76. doi:10.1016/S0016-7061(03)00094-6

Reddy, B.S., 2010. Organic Farming: Status, Issues and Prospects - A Review. *Agric. Econ. Res. Rev.* 23, 343–358.

Reddy, D.N., Mishra, S., 2010. Economic reforms, small farmer economy and agrarian crisis in Agrarian crisis in India (Eds.) R.S. Deshpande and Saroj Arora. Sage publications, New Delhi.

Rekha, Naik, S.N., Prasad, R., 2006. Pesticide residue in organic and conventional food-risk analysis. *J. Chem. Heal. Saf.* 13, 12–19. doi:10.1016/j.chs.2005.01.012

Rigby, D., Woodhouse, P., Young, T., Burton, M., 2001. Constructing a farm level indicator of sustainable agricultural practice. *Ecol. Econ.* 39, 463–478. doi:10.1016/S0921-8009(01)00245-2

Rosen, R., 1991. *Life itself: a comprehensive inquiry into the nature, origin, and fabrication of life.* Columbia University Press, New York.

Rossing, W.A.H., Jansma, J.E., De Ruijter, F.J., Schans, J., 1997. Operationalizing sustainability: exploring

- options for environmentally friendly flower bulb production systems. *Eur. J. Plant Pathol.* 103, 217–234.
- Rossing, W. a H., Zander, P., Josien, E., Groot, J.C.J., Meyer, B.C., Knierim, a., 2007. Integrative modelling approaches for analysis of impact of multifunctional agriculture: A review for France, Germany and The Netherlands. *Agric. Ecosyst. Environ.* 120, 41–57. doi:10.1016/j.agee.2006.05.031
- Roush, R., Tabashnik, B.E., 2012. Pesticide resistance in arthropods. Springer Science & Business Media.
- Roy, R., Chan, N.W., 2011. An assessment of agricultural sustainability indicators in Bangladesh: review and synthesis. *Environmentalist* 32, 99–110. doi:10.1007/s10669-011-9364-3
- Roy, R.N., Finck, A., Blair, G.J., Tandon, H.L.S., 2006. Plant nutrition for food security. FAO, Rome, Italy.
- Safa, M., Samarasingh, S., Mohssen, M., 2011. A field study of energy consumption in wheat production in Canterbury, New Zealand. *Energy Convers. Manag.* 52, 2526–2532. doi:10.1016/j.enconman.2011.01.004
- Sajil Kumar, P.J., Jegathambal, P., James, E.J., 2014. Chemometric evaluation of nitrate contamination in the groundwater of a hard rock area in Dharapuram, south India. *Appl. Water Sci.* 4, 397–405. doi:10.1007/s13201-014-0155-0
- Saltelli, A., Ratto, M., Tarantola, S., Campolongo, F., 2006. Sensitivity analysis practices: Strategies for model-based inference. *Reliab. Eng. Syst. Saf.* 91, 1109–1125. doi:10.1016/j.res.2005.11.014
- Sanghi, R., Pillai, M.K.K., Jayalekshmi, T.R., Nair, A., 2003. Organochlorine and organophosphorus pesticide residues in breast milk from Bhopal, Madhya Pradesh, India. *Hum. Exp. Toxicol.* 22, 73–76. doi:10.1191/0960327103ht321oa
- Sankararamkrishnan, N., Sharma, A.K., Iyengar, L., 2008. Contamination of nitrate and fluoride in ground water along the Ganges Alluvial Plain of Kanpur district, Uttar Pradesh, India. *Environ. Monit. Assess.* 146, 375–382. doi:10.1007/s10661-007-0085-5
- Sarkar, S.K., Bhattacharya, B.D., Bhattacharya, A., Chatterjee, M., Alam, A., Satpathy, K.K., Jonathan, M.P., 2008. Occurrence, distribution and possible sources of organochlorine pesticide residues in tropical coastal environment of India: An overview. *Environ. Int.* 34, 1062–1071. doi:10.1016/j.envint.2008.02.010
- Sauvenier, X., Valckx, J., Van Cauwenbergh, N., Wauters, E., Bachev, H., Biala, K., Bielders, C., Brouckaert, V., Garcia Ciudad, V., Goyens, S., Hermy, M., Mathijs, E., Muys, B., Vanclooster, M., Peeters, A., 2005a. Framework for assessing sustainability levels in Belgian agricultural systems (Safe). Belgian Science Policy, Brussels, Belgium.
- Sauvenier, X., Valckx J., Van Cauwenbergh N., Wauters E., Bachev H., B., K., Bielders C., Brouckaert V., Franchois L., Garcia-Cidad V., Goyens, S., Hermy M., Mathijs E., Muys B., Reijnders, J., Vanclooster M., V. der V., A., S. and P., 2005b. SAFE - Framework for assessing sustainability levels in Belgian agricultural systems. Belgian Science Policy Office, Brussels.
- Saxena, U., Saxena, S., Campus, C.T., 2014. Ground water quality evaluation with special reference to Fluoride and Nitrate contamination in Bassi Tehsil of district Jaipur , Rajasthan , India. *Int. J. Environ. Sci.* 5, 144–163. doi:10.6088/ijes.2014050100013

Sharma, C., Tiwari, M.K., Pathak, H., 2008. Estimates of emission and deposition of reactive nitrogenous species for India. *Curr. Sci.* 94, 1439–1446.

Sharma, D., Shardendu, S., 2011. Assessing farm-level agricultural sustainability over a 60-year period in rural eastern India. *Environmentalist* 31, 325–337. doi:10.1007/s10669-011-9341-x

Sharma, H.R., Kaushik, A., Kaushik, C.P., 2007. Pesticide residues in bovine milk from a predominantly agricultural state of Haryana, India. *Environ. Monit. Assess.* 129, 349–357. doi:10.1007/s10661-006-9368-5

Sharpe, A., 2004. Literature Review of Frameworks for Macro-indicators. Centre for the study of Living Standards, Ontario.

Shi, T., Gill, R., 2005. Developing effective policies for the sustainable development of ecological agriculture in China: The case study of Jinshan County with a systems dynamics model. *Ecol. Econ.* 53, 223–246. doi:10.1016/j.ecolecon.2004.08.006

Shukla, G., Kumar, A., Bhanti, M., Joseph, P.E., Taneja, A., 2006. Organochlorine pesticide contamination of ground water in the city of Hyderabad. *Environ. Int.* 32, 244–247. doi:10.1016/j.envint.2005.08.027

Shukla, M., Satya Pal, S., Nigam, R.C., Tiwari, D.D., 2002. Monitoring of Human Diet for Organochlorine Insecticide Residues. *Pestic. Res. J.* 14, 302–307.

Simoncini, R., 2009. Developing an integrated approach to enhance the delivering of environmental goods and services by agro-ecosystems. *Reg. Environ. Chang.* 9, 153–167. doi:10.1007/s10113-008-0052-x

Singh, B., Sekhon, G.S., 1976. Nitrate pollution of groundwater from nitrogen fertilizers and animal wastes in the Punjab, India. *Agric. Environ.* 3, 57–67. doi:10.1016/0304-1131(76)90007-2

Singh, K.P., Malik, A., Sinha, S., 2007. Persistent organochlorine pesticide residues in soil and surface water of northern Indo-Gangetic alluvial plains. *Environ. Monit. Assess.* 125, 147–155. doi:10.1007/s10661-006-9247-0

Singh, P.B., Sahu, V., Singh, V., Nigam, S.K., Singh, H.K., 2008a. Sperm motility in the fishes of pesticide exposed and from polluted rivers of Gomti and Ganga of north India. *Food Chem. Toxicol.* 46, 3764–3769. doi:10.1016/j.fct.2008.09.066

Singh, P.B., Singh, V., 2008. Pesticide bioaccumulation and plasma sex steroids in fishes during breeding phase from north India. *Environ. Toxicol. Pharmacol.* 25, 342–350. doi:10.1016/j.etap.2007.11.003

Singh, P.B., Singh, V., Nayak, P.K., 2008b. Pesticide residues and reproductive dysfunction in different vertebrates from north India. *Food Chem. Toxicol.* 46, 2533–2539. doi:10.1016/j.fct.2008.04.009

Sinha, S.N., Rao, M.V.V., Vasudev, K., 2012. Distribution of pesticides in different commonly used vegetables from Hyderabad, India. *Food Res. Int.* 45, 161–169. doi:10.1016/j.foodres.2011.09.028

Sivapalan, A., Morgan, W.C., Franz, P.R., 1993. Monitoring Populations of Soil Microorganisms during a Conversion from a Conventional to an Organic System of Vegetable Growing. *Biol. Agric. Hortic.* 10, 9–27. doi:10.1080/01448765.1993.9754647

Sivasankaran, M.A., Reddy, S.S., Govindaradjane, S., Ramesh, R., 2007. Organochlorine residuals in

groundwater of pondicherry region. *J. Environ. Sci. Eng.* 49, 7–12.

Smyth, A.J., Dumanski, J., Swift, M.J., Thornton, P.K., Spendjian, G., 1993. FESLM: An International Framework for Evaluating Sustainable Land Management. World Soil Resource Report, FAO.

Speelman, E.N., López-Ridaura, S., Colomer, N.A., Astier, M., Masera, O.R., 2007. Ten years of sustainability evaluation using the MESMIS framework: Lessons learned from its application in 28 Latin American case studies. *Int. J. Sustain. Dev. World Ecol.* 14, 345–361. doi:10.1080/13504500709469735

Srinivasarao, C., Venkateswarlu, B., Lal, R., Singh, A.K., Kundu, S., Vittal, K.P.R., Patel, J.J., Patel, M.M., 2014. Long-term manuring and fertilizer effects on depletion of soil organic carbon stocks under pearl millet-cluster bean-castor rotation in Western India. *L. Degrad. Dev.* 25, 173–183. doi:10.1002/ldr.1158

Srivastava, A.K., Trivedi, P., Srivastava, M.K., Lohani, M., Srivastava, L.P., 2011. Monitoring of pesticide residues in market basket samples of vegetable from Lucknow City, India: QuEChERS method. *Environ. Monit. Assess.* 176, 465–472. doi:10.1007/s10661-010-1597-y

Stephan, A., Meyer, A.H., Schmid, B., 2000. Plant diversity affects culturable soil bacteria in experimental grassland communities. *J. Ecol.* 88, 988–998. doi:10.1046/j.1365-2745.2000.00510.x

Sterman, J.D., 2000. *Business dynamics: systems thinking and modeling for a complex world.* Irwin/McGraw-Hill, Boston.

Subramaniam, K., Solomon, R.J., 2006. Organochlorine pesticides BHC and DDE in human blood in and around Madurai, India. *Indian J. Clin. Biochem.* 21, 169–172. doi:10.1007/BF02912936

Subramanian, S., 2015. *Emerging Trends and Patterns of India's Agricultural Workforce: Evidence From the Census, Working paper 347, The Institute for Social and Economic Change. Bangalore, India.*

Sudheer, P.S.K., 2013. Economics of organic versus chemical farming for three crops in Andhra Pradesh, India. *J. Org. Syst.* 8, 36–49.

Suthar, S., Bishnoi, P., Singh, S., Mutiyar, P.K., Nema, A.K., Patil, N.S., 2009. Nitrate contamination in groundwater of some rural areas of Rajasthan, India. *J. Hazard. Mater.* 171, 189–199. doi:10.1016/j.jhazmat.2009.05.111

Thiollet-Scholtus, M., Bockstaller, C., 2014. Using indicators to assess the environmental impacts of wine growing activity: The INDIGO® method. *Eur. J. Agron.* 62, 13–25. doi:10.1016/j.eja.2014.09.001

Tzilivakis, J., Lewis, K.A., 2004. The development and use of farm-level indicators in England. *Sustain. Dev.* 12, 107–120. doi:10.1002/sd.233

UNDP, 2013. *Technical notes, Human Development Report. United Nations, New York, USA.*

United Nations, 2010. *Human Development Report 2010 The Real Wealth of Nations: Pathways to Human Development. New York, USA.*

United Nations, 2001. *Indicators of Sustainable Development: Framework and Methodologies. Comm. Sustain. Dev.* 294.

van Asselt, E.D., van Bussel, L.G.J., van der Voet, H., van der Heijden, G.W. a. M., Tromp, S.O.,

- Rijgersberg, H., van Evert, F., Van Wagenberg, C.P. a., van der Fels-Klerx, H.J., 2014. A protocol for evaluating the sustainability of agri-food production systems—A case study on potato production in peri-urban agriculture in The Netherlands. *Ecol. Indic.* 43, 315–321. doi:10.1016/j.ecolind.2014.02.027
- van Calker, K.J., Berentsen, P.B.M., Romero, C., Giesen, G.W.J., Huirne, R.B.M., 2006. Development and application of a multi-attribute sustainability function for Dutch dairy farming systems. *Ecol. Econ.* 57, 640–658. doi:10.1016/j.ecolecon.2005.05.016
- Van Cauwenbergh, N., Biala, K., Biielders, C., Brouckaert, V., Franchois, L., Garcia Ciudad, V., Hermy, M., Mathijs, E., Muys, B., Reijnders, J., Sauvenier, X., Valckx, J., Vanclooster, M., Van der Veken, B., Wauters, E., Peeters, a., 2007. SAFE—A hierarchical framework for assessing the sustainability of agricultural systems. *Agric. Ecosyst. Environ.* 120, 229–242. doi:10.1016/j.agee.2006.09.006
- Vecchione, G., 2010. EU Rural policy: proposal and application of an agricultural sustainability index, Munich Personal RePEc Archive.
- Venugopalan, M. V, Rajendran, T.P., Chandran, P., Goswami, S.N., Challa, O., Damre, P.R., 2010. Comparative evaluation of organic and non-organic cotton (*Gossypium hirsutum*) production systems 80, 287–292.
- Viglizzo, E.F., Frank, F., Bernardos, J., Buschiazzo, D.E., Cabo, S., 2006. A rapid method for assessing the environmental performance of commercial farms in the pampas of Argentina. *Environ. Monit. Assess.* 117, 109–134. doi:10.1007/s10661-006-7981-y
- von Geibler, J., Liedtke, C., Wallbaum, H., Schaller, S., 2006. Accounting for the social dimension of sustainability: Experiences from the biotechnology industry. *Bus. Strateg. Environ.* 15, 334–346. doi:10.1002/bse.540
- Von Wirén-Lehr, S., 2001. Sustainability in agriculture - An evaluation of principal goal-oriented concepts to close the gap between theory and practice. *Agric. Ecosyst. Environ.* 84, 115–129. doi:10.1016/S0167-8809(00)00197-3
- Walker, J., Reuter, D.J., 1996. Key indicators to assess farm and catchment health. *Indic. Catchment Heal. A Tech. Perspect.* (J. Walk. DJ Reuter eds) pp 21–33.
- Walter, C., Stutzel, H., 2009. A new method for assessing the sustainability of land-use systems (I): Identifying the relevant issues. *Ecol. Econ.* 68, 1275–1287. doi:10.1016/j.ecolecon.2008.11.016
- Weber, M., Eisenführ, F., Von Winterfeldt, D., 1988. The effects of splitting attributes on weights in multiattribute utility measurement. *Manage. Sci.* 34, 431–445.
- Weidema, B., Finnveden, G., Stewart, M., 2005. Impacts from Resource Use - A common position paper. *Int. J. Life Cycle Assess.* 10, 382.
- Werf, H.M.G. Van Der, Petit, J., 2002. Evaluation of the environmental impact of agriculture at the farm level : a comparison and analysis of 12 indicator-based methods 93, 131–145.
- Wetering, R., Opschoor, J.B., 1994. Towards environmental performance indicators based on the notion of environmental space. Advisory Council for Research on Nature and Environment (RMNO), The Netherlands.

- Wiek, A., Binder, C., 2005. Solution spaces for decision-making - A sustainability assessment tool for city-regions. *Environ. Impact Assess. Rev.* 25, 589–608. doi:10.1016/j.eiar.2004.09.009
- Wilson, C., Tisdell, C., 2001. Why farmers continue to use pesticides despite environmental, health and sustainability costs. *Ecol. Econ.* 39, 449–462. doi:10.1016/S0921-8009(01)00238-5
- Wolstenholme, E.F., 1983. System Dynamics: A System Methodology or a System Modeling Technique. *Dynamica* 9, 84–90.
- Yadav, C.P.S., Gupta, H., Sharma, R.S., 2010. Organic Farming and Food Security : A Model for India, Organic Farming Association of India. Goa, India.
- Yes Bank, 2016. Indian Organic Sector Vision 2025. Yes Bank Ltd., APEDA, AIOI and Ingenus, New Delhi.
- Zahm, F., Viaux, P., Vilain, L., Girardin, P., Mouchet, C., 2007. Farm Sustainability Assessment using the IDEA Method: from the concept of farm sustainability to case studies on French farms. *Sustain. Dev.* 16, 271–281. doi:978-1-894784-05-4
- Zeleny, M., 1976. The theory of the displaced ideal, in: *Multiple Criteria Decision Making Kyoto 1975*. Springer, Berlin, Germany.
- Zhen, L., Routray, J.K., 2003. Operational Indicators for Measuring Agricultural Sustainability in Developing Countries. *Environ. Manage.* 32, 34–46. doi:10.1007/s00267-003-2881-1
- Zhen, L., Routray, J.K., Zoebisch, M.A., Chen, G., Xie, G., Cheng, S., 2005. Three dimensions of sustainability of farming practices in the North China Plain: A case study from Ningjin County of Shandong Province, PR China. *Agric. Ecosyst. Environ.* 105, 507–522. doi:10.1016/j.agee.2004.07.012

Appendix 1

Dimensional boundaries for various inflow and outflows

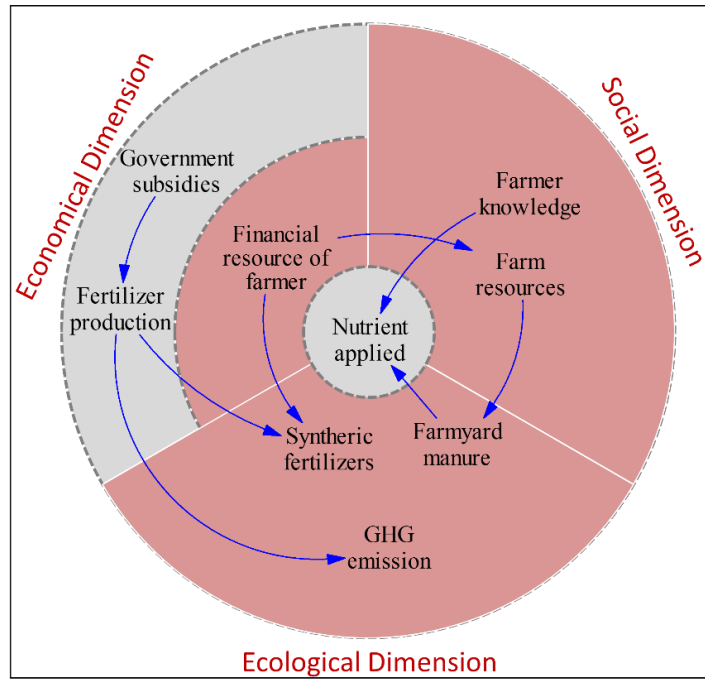


Figure A.1 Dimensional boundaries for nutrient applied

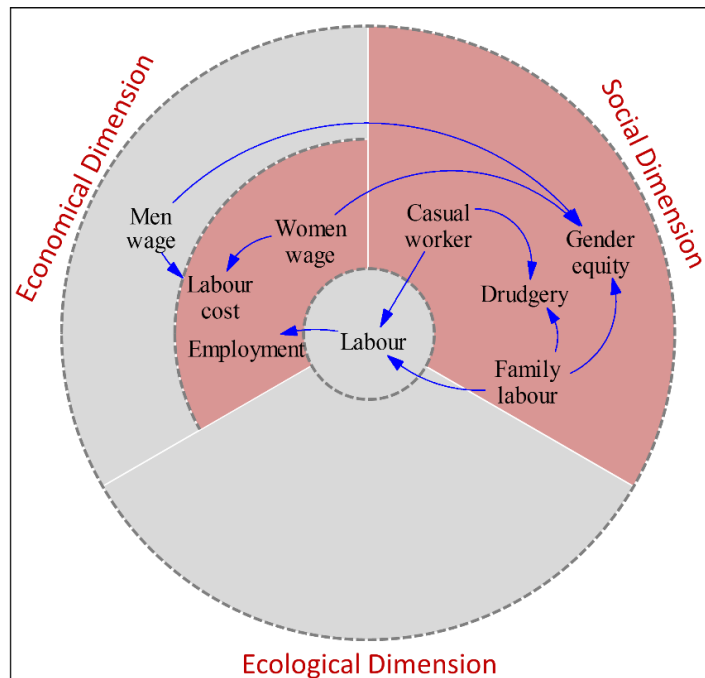


Figure A.2 Dimensional boundaries for labour used

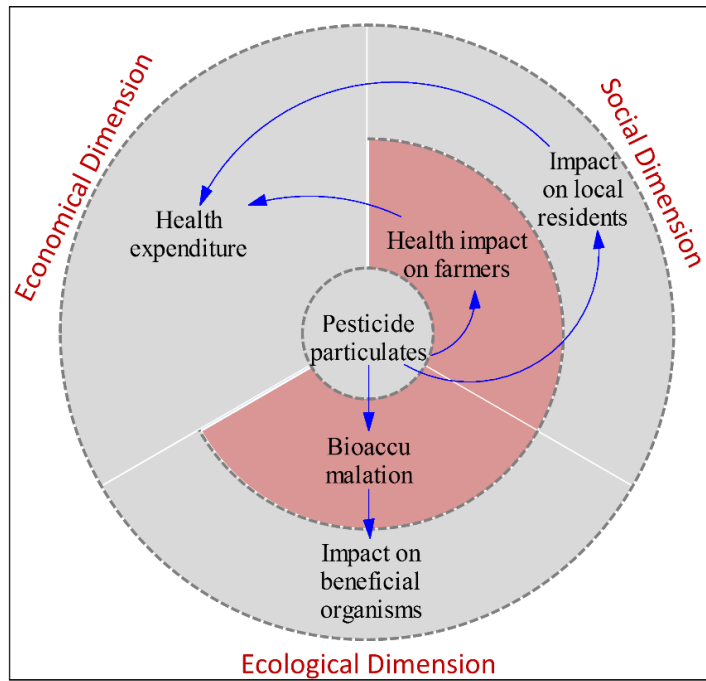


Figure A.1 Dimensional boundaries for pesticide particulates

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

List of farmers in field sample

Maharashtra

S No	Code	Farmer name	Village	Acreage	Type
1	CVO02	Narendra shankar Kute	Mandwa	4	I
2	CVC02	Mahendra shankar rao kute	Mandwa	4	I
3	CVO04	Vitabhai Avthood Latkar	Dahigaon	2	D
4	CVC04	Manik Avthood Latkar	Dahigaon	3	I
5	CVO03	Nandabhai Ramdhaji Jungarae	Dahigaon	2	PI
6	CVC03	Purushotham Dadaji Gobade	Dahigaon	3	D
7	CVO01	Yogitha Rajesh moraskar	Saati	2	D
8	CVC01	Ramkrishna Surabanji Moraskar	Saati	5	D
9	CVO05	Janarthan Bapuraoji Kinkar	Narshinpur	4	D
10	CVC05	Purushotam Bapuraoji Kinkar	Narshinpur	4	D
11	CVO06	Pandurang Shirsagar	Narshinpur	2.5	D
12	CVC06	Vithal Nathuji Mune	Narshinpur	2.5	D
13	CVO07	Santhosh Keshraoji Rout	Giroli	3	I
14	CVC07	Annaji Kamade	Giroli	3	D
15	CVO08	Harish Chandra Bajananth Choudry	Bondar Thana	2.5	D
16	CVC08	Sahebrao Vithalrao Kose	Bondar Thana	2	D
17	CVO09	Bharat Ram Narayan Dharpure	Bondar Thana	2	D
18	CVC09	Narayan Domaji Dharpure	Bondar Thana	2	D
19	CVO10	Arun Dhasharath Choudary	Kapri	3	D
20	CVC10	Vaman Ramaji Kawli	Kapri	4	D
21	CVO11	Varlu Jayaram Nikode	Kapri	2	D
22	CVC11	Ashok Amrutharao Deshmukh	Kapri	4	I
23	CVO12	Mangala Purushotham Sirame	Thadgaon	1	D
24	CVC12	Sriram Dadmal	Thadgaon	1.5	D
25	CVO13	Harihar Bhamaji Pophle	Umri	2.5	D
26	CVC13	Arvind Bhramaji Pople	Umri	2.5	D
27	CVO14	Mangesh Damodar Jogi	Mokada	2	D
28	CVC14	Shankar Ambadas Jogi	Mokada	2	D
29	CVO15	Sanjay Bhajirao Kajbhiye	Borgaon	5.5	D
30	CVC15	Dhamoji Ganapathrao Gajbiye	Borgaon	1.5	D
31	CVO16	Vinayak Mahadev Khavle	Sakra	6	D
32	CVC16	Gulab Mahadev Khavle	Sakra	6	D
33	DMO17	Gansham Saligram Chopde	Mandwa	4	I

34	DMC17	Narendra Divakar Deshmukh	Mandwa	3.5	I
35	DMO18	Utamrao Ajabrao Salame	Ekburji	3.5	I
36	DMC18	Sudharkar Ajabrao salame	Ekburji	2	I
37	DMO19	Purushotham Ajabrao Salame	Ekburji	3	I
38	DMC19	Sahebrao Lakshmanrao Ukle	Ekburji	4	D
39	DMO20	Mandar vasanthrao Deshpande	Masala	3	D
40	DMC20	Nathujith Lakshmanrao Golkar	Aamgaon	5	I
41	DMO21	Narendra Madhavrao Misal	Aamgaon	12	I
42	DMC21	Bhagavanthrao Madhavrao Misal	Aamgaon	11	I
43	DMO22	Arunrao nathujith Bhorkute	Dahigaon	7	I
44	DMC22	Suresh Vitobhajith Borkute	Dahigaon	10	I
45	DMO23	Narendra Vithalrao Ohle	Jaamni	3.5	I
46	DMC23	Sanjay Vithal Pohkute	Jaamni	6	I
47	DMO24	Gnyaneshwar Dhadaji Dahe	Giroli	4.5	I
48	DMC24	Shambu Chapathrao Kodathkar	Giroli	3.5	I
49	DMO25	Abhay Ramdhaji Ugle	Sewagram	6	I
50	DMC25	Bhujanga Thanbaji Vakle	Sewagram	4	I
51	DMO26	Avinash Kundalikarao Kakde	Sewagram	3.5	I
52	DMC26	Vishnu Bhikaji Borlae	Sewagram	8	I
53	DMO27	Vijay Chanpathrao Ogle	Sewagram	3	I
54	DMC27	Surendra Ogle	Sewagram	3.5	I
55	DMO28	Saligram Ganpathrao Saple	Rekhi	4.25	I
56	DMC28	Shankar Vasathanrao Chandan Kade	Rekhi	3	I
57	DMO29	Dipak Ramchandra Mude	Rekhi	5	I
58	DMC29	Vinod Kasinath Khode	Rekhi	10	I
59	DMO30	Marutirao Lakshman Shirsam	Persodi	4.5	I
60	DMC30	Babarao Ambadhaju Maraskohle	Persodi	4	I

Tamil Nadu

S No	Farmer name	Village	Acreage	Type
1	Nagesh	Sittilingi	1.1	I
2	Radhakrishnan	Sittilingi	1.5	I
3	Sunderaj	Sittilingi	1.5	I
4	Annadurai	Sittilingi	1	I
5	Theerthan	Sittilingi	1.1	I
6	Kuppan	Sittilingi	1.1	I
7	Vedan	Sittilingi	1.1	I
8	Palani	Sittilingi	1	I
9	Rathinam	Sittilingi	1.2	I
10	Arumugam	Sittilingi	1.5	D
11	Palanisami	Sittilingi	1	PI
12	Selvam	Moola Sittilingi	1	I
13	Neelavathi	Sittilingi	1.4	I
14	Rajamanikkam	Moola Sittilingi	1	I
15	Laxmanan	Sittilingi	1.05	I
16	Govinthan	Sittilingi	1.5	I
17	Samikannu	Moola Sittilingi	1	I
18	Thangavel	Sittilingi	1	I
19	Gopal	Sittilingi	1.2	I
20	Murugasundaram	Nammakaadu	1.2	I
21	Eswaran	Sittilingi	1.1	I
22	Ravi	Sittilingi	1	I
23	Murugesan	Sittilingi	1.2	I
24	Meena	Sittilingi	1.2	I
25	Aruchalam	Sittilingi	1.1	I
26	Kanagaraj	Sittilingi	1	I
27	Sivalingam	Moola Sittilingi	1.25	I
28	Chinnaiyan	Sittilingi	1	I
29	Veedi	Sittilingi	1.2	I
30	Dhanakodi	Sittilingi	1.4	I
31	Chinnaraj	Sittilingi	1.2	PI
32	Cinnandi	Malaihangai	2.55	I
33	Kalaimani	Sittilingi	0.5	I
34	Arumugam Sahunthala	Sittilingi	0.9	I
35	Paramasivam	Moola Sittilingi	1.1	PI
36	Thangaraj	Sittilingi	1.5	PI

37	Kumar	Moola Sittilingi	0.9	PI
38	Rathinanm	Moola Sittilingi	1.5	I
39	Theerthan	Moola Sittilingi	0.9	PI
40	Chinnaraj	Moola Sittilingi	1.2	PI
41	Rajendran	Moola Sittilingi	0.9	PI
42	Annamalai	Moola Sittilingi	1	I
43	Mani	Moola Sittilingi	1.5	PI
44	Hari	Sittilingi	0.7	PI
45	Pichan	Moola Sittilingi	0.95	I
46	Ramanan	Sittilingi	0.6	I
47	Raman	Sittilingi	1.2	I
48	Anbu	Sittilingi	1.4	PI
49	Murugan	Sittilingi	1	I
50	Periyathambi	Sittilingi	0.8	I
51	Ramasamy	Sittilingi	1	PI
52	Manoharan	Sittilingi	0.9	I
53	Annadurai	Moola Sittilingi	1.2	I
54	Moorthy	Sittilingi	0.9	PI
55	Singaravel	Sittilingi	3.2	I
56	Selvam	Sittilingi	1	I
57	Govinthan	Sittilingi	1	I
58	Narayanan	Moola Sittilingi	1.2	I
59	Madhayan	Moola Sittilingi	0.8	I
60	Annamalai Aandi	Moola Sittilingi	0.8	I

Appendix 4

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 <input type="checkbox"/> / Female : <input type="checkbox"/>		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 <input type="checkbox"/> B. Primary <input type="checkbox"/> C. Secondary <input type="checkbox"/> D. Graduate <input type="checkbox"/> E. Post-graduate <input type="checkbox"/>					

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:		
	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):

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

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

Publications

Journal

- Siva Muthuprakash K M and Om Damani. (2017) *A Stock and Flow based Framework to Identify Indicators for a Holistic Comparison of Farming Practices*. Agricultural Research. DOI: 10.1007/s40003-017-0266-6

Conferences

- Siva Muthuprakash K M and Om Damani. (2017) *Challenges in Large Scale Soil Sampling and Testing (based on Field Application of the Farm Assessment Index (FAI))*. India's Soils: Science-Policy-Practice Interfaces for Sustainable Futures. IIT Delhi.
- Siva Muthuprakash K M, Om Damani, Ashok Bang and Niranjana Maru. (2017) *Assessment of Farming Practices of Sixty Farmers in Maharashtra Using a Composite Index*. XIII Agricultural Science Congress at University of Agricultural Sciences, Bengaluru. [**Best Poster Award**]
- Siva Muthuprakash K M and Om Damani (2015). *Significance of Soil Parameters in Evaluating the Farming Practices: A Systems Approach*. Soil Conference. Wageningen University, Netherlands.
- Siva Muthuprakash K M and Om Damani. (2015) *Measure of Socio-economic and Ecological Sustainability of Marginal and Small Scale Farmer*. XII Agricultural Science Congress at National Dairy Research Institute, Karnal, India.
- Siva Muthuprakash K M and Om Damani. (2014) *A Stock and Flow Based Framework for Indicator Identification for Evaluation of Crop Production System*. 32nd International System Dynamics Society Conference at Delft, Netherlands. [**Barry Richmond Scholarship Award**]

Working paper

- Design and field application of Farm Assessment Index (FAI) for comparing farming systems in Maharashtra and Tamil Nadu.