Social and Economic Analysis of the Organic Sector in Bhutan

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Meinen lieben Eltern

SUMMARY

As in some other low-income countries, organic agriculture (OA) has been introduced in Bhutan and is increasingly being promoted by the state with a top-down approach. While the potential of OA to provide ecosystem services and empower smallholder farmers through market participation is well known, it is also widely recognized that smallholder farmers face many challenges. This thesis discusses the challenges of OA in the case of Bhutanese smallholder farmers and assesses the potential of the farmers' social network to address some of these challenges. What challenges do smallholder farmers face in a top-down approach to OA? What types of social networks are still practiced among smallholder farmers? What potential do social networks have in overcoming the challenges of OA that pose difficulties in implementation?

Answering these questions is important because organic farmers report serious challenges that are often neglected by the government in low-income countries. Because farmers are part of a community and embedded in the social structure, a change at the community level can have a huge impact on individual members. The actions of each individual can also have an impact on others, which in turn can affect the overall outcome for the community. Farmers in low-income countries rely on informal network relationships of various kinds as a substitute for the missing or inadequate formal institutions. To assess the potential of farmers' social networks in addressing the challenges of OA, this thesis identifies specific social networks that are characteristic of the farming community and relevant to addressing the challenges of OA for smallholder farmers.

This study is based on three main chapters that reflect the main objectives of the overall work: 1) To describe the large-scale conversion of the OA sector in Bhutan and discuss the challenges related to institutional capacity, management and farming practices, nutrient balances and yield gaps, 2) examining informal labor exchanges in farming villages with successful adoption of labor-intensive farming practices and determining the nature of social enforcement mechanisms used, and 3) outlining and testing how two conceptually distinct social mechanisms fit the observed reality of adoption of improved seeds in Bhutanese remote villages. The first chapter takes a descriptive approach, while the second chapter presents an empirical study. The last chapter has a primarily methodological focus. In addition to these three chapters, the relevance of social network in the case of OA and the aims of the thesis are

presented in the introductory chapter, and a final chapter contains the major conclusions, limitations and policy implications of the findings.

The second chapter, which deals with the first objective, analyzes the feasibility of large-scale conversion to OA in Bhutan. It illustrates that organic farmers must comply with the Bhutan Organic Standard (BOS) and that the number of certified farmers under the Local Organic Assurance System (LOAS) is increasing. The results also show that organic farmers are struggling with low yields, nutrient imbalances in nitrogen, lack of funds to implement organic programs, lack of extension services for OA, and other related institutional inadequacies. The chapter argues that analyzing and understanding the challenges of conversion to OA in Bhutan can lead to transferable findings to similar contexts characterized by smallholder farming systems.

The third chapter, which deals with the second objective, examines informal labor exchanges in Bhutanese farming villages that have successfully adopted labor-intensive agricultural practices such as OA. It then tests the existence of social enforcement mechanisms described in the literature by relating the observed network pattern of labor exchange to farmers supposed cooperative behavior. The results show that labor exchange networks in organic farming villages are characterized by a high prevalence of completely connected structures (i.e. triad closure) that seem to constitute the main enforcement mechanism. It discusses how this social network (well-functioning labor exchange) can be used to select further villages for OA implementation in the future.

The fourth chapter addresses the third objective and examines how two different forms of social network mechanisms–social contagion (direct communication) and structural equivalence (social standing)–can benefit the dissemination of improved seeds in a wider agricultural community. This study was formulated against the assumption that farmers do not make decisions in isolation and that technology diffusion models with social network considerations provide better explanations and policy guidance. The results provide evidence that an interventionist agricultural policy should not only favor farmers with multiple connections in the hope that their behavior will influence their multiple network partners, but also farmers in different social positions, including peripheral network positions, who can inspire other, less well-connected farmers to adopt.

The thesis concludes that considering the potential of farmers' social networks in solving some of the challenges of OA in low-income countries like Bhutan can open up new avenues

of research. The thesis also concludes that a large-scale conversion to OA in Bhutan may be more difficult to accomplish than previously thought, given the evidence of important challenges that are currently neglected. Given the evidence on the role of social networks and how they are still functioning in some remote villages in Bhutan, a bottom-up initiative with additional government support is preferable to the current top-down approach.

ZUSAMMENFASSUNG

Wie in einigen anderen Ländern mit niedrigem Einkommen wurde auch in Bhutan die ökologische Landwirtschaft (ÖL) eingeführt und wird zunehmend vom Staat mit einem Top-down-Ansatz gefördert. Während das Potenzial der ÖL, Ökosystemleistungen zu erbringen und Kleinbauern durch die Teilnahme am Markt zu stärken, bekannt ist, wird auch allgemein anerkannt, dass Kleinbauern vor vielen Herausforderungen stehen. In dieser Arbeit werden die Herausforderungen des ÖL am Beispiel Bhutanischer Kleinbauern erörtert und das Potenzial sozialer Netzwerke der Landwirte zur Bewältigung einiger dieser Herausforderungen bewertet. Welchen Herausforderungen sehen sich Kleinbauern bei einem Top-Down-Ansatz für den ÖL gegenüber? Welche Arten von sozialen Netzwerken werden unter Kleinbauern noch praktiziert? Welches Potenzial haben soziale Netzwerke bei der Bewältigung der Herausforderungen, die bei der Umsetzung Schwierigkeiten bereiten?

Die Beantwortung dieser Fragen ist wichtig, weil Öko-Landwirte über ernsthafte Probleme berichten, die von der Regierung in Ländern mit niedrigem Einkommen oft vernachlässigt werden. Da die Landwirte Teil einer Gemeinschaft und in die soziale Struktur eingebettet sind, kann eine Veränderung auf der Ebene der Gemeinschaft erhebliche Auswirkungen auf die einzelnen Mitglieder haben. Die Handlungen jedes Einzelnen können sich auch auf andere auswirken, was wiederum das Gesamtergebnis für die Gemeinschaft beeinflussen kann. Landwirte in Ländern mit niedrigem Einkommen verlassen sich auf informelle Netzwerkbeziehungen verschiedener Art als Ersatz für fehlende oder unzureichende formelle Institutionen. Um das Potenzial der sozialen Netzwerke von Landwirten bei der Bewältigung der Herausforderungen des ÖL zu bewerten, werden in dieser Arbeit spezifische soziale Netzwerke identifiziert, die für die landwirtschaftliche Gemeinschaft charakteristisch und für die Bewältigung der Herausforderungen der Kleinbauern relevant sind.

Diese Arbeit basiert auf drei Publikationen, die deren Hauptziele adressieren: 1) Beschreibung der groß angelegten Umstellung des ÖL-Sektors in Bhutan und Erörterung der Herausforderungen im Zusammenhang mit den institutionellen Kapazitäten, der Bewirtschaftung und den Anbaupraktiken, den Nährstoffbilanzen und den Ertragslücken, 2) Untersuchung des informellen Austauschs von Arbeitskräften in Bauerndörfern mit erfolgreicher Übernahme arbeitsintensiver Anbaupraktiken und Bestimmung der Art der verwendeten sozialen Durchsetzungsmechanismen und 3) Darstellung und Prüfung, wie zwei konzeptionell unterschiedliche soziale Mechanismen zur beobachteten Realität der Übernahme von verbessertem Saatgut in abgelegenen Dörfern Bhutans passen. Das erste Kapitel verfolgt einen deskriptiven Ansatz, während das zweite Kapitel eine empirische Studie vorstellt. Das letzte Kapitel hat einen primär methodischen Schwerpunkt. Zusätzlich zu diesen drei Kapiteln werden im einführenden Kapitel die Relevanz sozialer Netzwerke für den ÖL und die Ziele der Arbeit dargelegt. Das abschließende Kapitel enthält Beiträge, Einschränkungen und politische Implikationen der Ergebnisse.

Das zweite Kapitel, das sich mit dem ersten Ziel befasst, analysiert die Machbarkeit einer groß angelegten Umstellung auf ÖL in Bhutan. Es zeigt sich, dass die Öko-Landwirte den Bhutan Organic Standard (BOS) einhalten müssen und dass die Zahl der zertifizierten Landwirte im Rahmen des Local Organic Assurance System (LOAS) zunimmt. Die Ergebnisse zeigen auch, dass die Öko-Landwirte mit niedrigen Erträgen, Nährstoffungleichgewichten bei Stickstoff, fehlenden Mitteln für die Umsetzung von Förderprogrammen für den ÖL, fehlenden ÖL-Beratungsdiensten und anderen damit verbundenen institutionellen Unzulänglichkeiten zu kämpfen haben. Es wird argumentiert, dass die Analyse und das Verständnis der Herausforderungen bei der Umstellung auf ÖL in Bhutan zu übertragbaren Erkenntnissen für ähnliche Kontexte, die durch kleinbäuerliche Anbausysteme charakterisiert sind, führen kann.

Das dritte Kapitel, das sich mit dem zweiten Ziel befasst, untersucht den informellen Austausch von Arbeitskräften in bhutanischen Bauerndörfern, die erfolgreich arbeitsintensive landwirtschaftliche Praktiken wie den ÖL eingeführt haben. Anschließend wird die Existenz der in der Literatur beschriebenen sozialen Durchsetzungsmechanismen getestet, indem das beobachtete Netzwerkmuster des Arbeitsaustauschs mit dem unterstellten kooperativen Verhalten der Landwirte in Beziehung gesetzt wird. Die Ergebnisse zeigen, dass Arbeitsaustauschnetzwerke in Dörfern mit ÖL durch eine hohe Prävalenz vollständig

verbundener Strukturen (d.h. triad closure) gekennzeichnet sind, die den hauptsächlichen Durchsetzungsmechanismus darstellen. Es wird erörtert, wie dieses soziale Netzwerk (gut funktionierender Arbeitsaustausch) genutzt werden kann, um künftig weitere Dörfer für die Umsetzung des ÖL auszuwählen.

Das vierte Kapitel befasst sich mit dem dritten Ziel und untersucht, wie zwei verschiedene Formen sozialer Netzwerkmechanismen - soziale Ansteckung (direkte Kommunikation) und strukturelle Äquivalenz (soziales Ansehen) - die Verbreitung von verbessertem Saatgut in einer größeren landwirtschaftlichen Gemeinschaft begünstigen können. Diese Studie wurde unter der Annahme formuliert, dass Landwirte ihre Entscheidungen nicht isoliert treffen und dass Technologieverbreitungsmodelle mit Berücksichtigung sozialer Netzwerke bessere Erklärungen und politische Leitlinien liefern. Die Ergebnisse belegen, dass eine interventionistische Agrarpolitik nicht nur Landwirte mit vielfältigen Verbindungen begünstigen sollte, in der Hoffnung, dass ihr Verhalten ihre zahlreichen Netzwerkpartner beeinflusst, sondern auch Landwirte in unterschiedlichen sozialen Positionen, einschließlich peripherer Netzwerkpositionen, die andere, weniger gut vernetzte Landwirte zu einer Übernahme inspirieren können.

Die Arbeit kommt zu dem Schluss, dass die Berücksichtigung des Potenzials der sozialen Netzwerke von Landwirten bei der Lösung einiger der Herausforderungen des ÖL in Ländern mit niedrigem Einkommen wie Bhutan der Forschung neue Wege eröffnen kann. Darüber hinaus könnte eine groß angelegte Umstellung auf ÖL in Bhutan schwieriger zu bewerkstelligen sein als bisher angenommen, da es Hinweise auf wichtige Herausforderungen gibt, die derzeit vernachlässigt werden. In Anbetracht der Erkenntnisse über die Rolle sozialer Netzwerke und deren Funktionieren in einigen abgelegenen Dörfern in Bhutan ist eine Bottom-up-Initiative mit zusätzlicher staatlicher Unterstützung dem derzeitigen Top-down-Ansatz vorzuziehen.

SCIENTIFIC PAPERS

This dissertation is a cumulative dissertation consisting of the following three scientific articles [1] :

Paper 1 (Chapter 2)	Tshotsho, Lippert, C., Feuerbacher, A., Zikeli, S., Krimly, T., Barissoul, A., 2024. The role of management and farming practices, yield gaps, nutrient balance, and institutional settings in the context of large-scale organic conversion in Bhutan. Submitted for publication to Agricultural Systems.
Paper 2 (Chapter 3)	Tshotsho, Lippert, C. and Feuerbacher, A., 2023. Organic agriculture, labour exchange, and social networks: a case study of smallholder farming in Bhutan. *Organic Agriculture*, *13*(1), pp.83-98. https://doi.org/10.1007/s13165-022-00416-z
Paper 3 (Chapter 4)	Tshotsho, Lippert, C., Feuerbacher, A., Matous, P., 2024. Contagion or structural equivalence? Social network mechanisms in the adoption of improved seed varieties among smallholder farmers in Bhutan. Submitted for publication to the Australian Journal of Agricultural and Resource Economics.

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[1] Cross-references have been added to the manuscripts that comprise this dissertation, and the original numbering of the articles has been changed to fit the scope of this cumulative dissertation. All the chapters 2,3 and 4 are otherwise exact copies of the published and submitted manuscripts, respectively. Some words in UK English used for chapter 3, have been converted to US English used for rest of the dissertation.

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LIST OF ABBREVIATIONS

ARDC	Agricultural Research and Development Center
AEZ	Agro-ecological zones
ADB	Asian Development Bank
LFL	Bayerische Landesanstalt für Landwirtschaft
BAFRA	Bhutan Agriculture and Food Regulatory Authority
BOS	Bhutan Organic Standard
C	Contagion
°C	Degrees Celsius
DOA	Department of Agriculture
DARDS	Department of Research and Development Services
EU	European Union
ERGM	Exponential Random Graph Model
FYM	Farm-yard Manure
FAO	Food and Agriculture Organization
GWESP	Geometrically weighted Edgewise Shared Partner
GHG	Green House Gas
GNHC	Gross National Happiness Commission
HST	Humid Subtropical
IMO IN	IMO Control Private Limited
INDC	Intended Nationally Determined Contribution
ICS	Internal Control System
CIAT	International Center for Tropical Agriculture
ICIMOD	International Center for Integrated Mountain Development
IFOAM	International Federation of Organic Agriculture Movements
LOAS	Local Organic Assurance System
MCMC-MLE	Markov Chain Monte Carlo Maximum Likelihood Estimation
MASL	Meters Above Sea Level
MT	Metric Tons
MoAF	Ministry of Agriculture and Livestock
MoAL	Ministry of Agriculture and Forests
MOV	Model Organic Village
NOCA	National Center for Organic Agriculture
NFOAB	National Framework for Organic Agriculture for Bhutan
NOP	National Organic Program
NSC	National Seed Center
NSB	National Statistical Bureau
N	Nitrogen
OA	Organic Agriculture
P	Phosphorus
PRCP	Policy. Regulation and Coordination Programme
K	Potassium
ROC-AUC	Receiver Operating Characteristics -Area Under the Curve
RGOB	Royal Government of Bhutan
SOEs	State Owned Enterprises
SE	Structural Equivalence
WT	Warm Temperate

Chapter 1

1 General Introduction

> “For the last thirty years, empirical social research has been dominated by the sample survey. But as usually practiced, using random sampling of individuals, the survey is a sociological meatgrinder, tearing the individual from his social context and guaranteeing that nobody in the study interacts with anyone else in it. It is a little like a biologist putting his experimental animals through a hamburger machine and looking at every hundredth cell through a microscope; anatomy and physiology get lost, structure and function disappear, and one is left with cell biology.…If our aim is to understand people’s behavior rather than simply to record it, we want to know about primary groups, neighborhoods, organizations, social circles, and communities; about interaction, communication, role expectations, and social control.”
>
> Allen Barton (1968, page.1)

This thesis aims to improve our understanding of the potential of farmers' social networks in solving some of the agricultural challenges they face in low-income countries. This objective is formulated against the background that farmers in low-income countries face many challenges when they opt for a sustainable farming system such as organic agriculture (OA). The analytical lens is applied to the case of Bhutan, where OA has been promoted since 2012. Chapter 2 describes the organic sector in Bhutan to understand the various important aspects of organic agriculture in low-income countries. Subsequently, the following two chapters (Chapters 3 & 4) identify and analyze some social networks in the village community that have the potential to solve some of the challenges of organic agriculture. Before presenting the three papers in this project, section 1.1 of this chapter introduces the definition of OA and explains why it is being adopted in low-income countries. Section 1.2 then discusses what we know today about the impact of OA in general and what the motivations are for promoting OA in low-income countries. Section 1.4 then presents some evidence of the relationship between social network and sustainable agricultural practices, followed by the relevance of the social network in Section 1.4. After presenting the research objectives in Section 1.5. Section 1.6 introduces the study site, the data source and analytical framework. The chapter concludes with the structure of the thesis in Section 1.7.

1.1 What is organic agriculture and why implement it

Most consumers want food that is cheaper, and cheap food can come only with abundance of food, which in turn depends on improving labor and land productivity (Dabbert et al., 2004). With technological advances in agriculture, machinery has replaced labor, mineral fertilizers have improved soil fertility and chemical pesticides have protected crops from pests and diseases (Dabbert et al., 2004). This approach can be disastrous for the environment, causing biodiversity loss and climate change through greenhouse gas (GHG) emissions (Seufert & Ramankutty, 2017).

The negative impacts of agriculture led to the development of organic farming in Europe in the 1920s and 1950s as a critique of the industrial form of food production. This critique gained popularity in the 1980s, particularly through the food and environmental movements (Fromartz, 2007). The aim of these movements was to develop an agricultural system based on the concept of the 'farm as organism' and relying on the resources from the farm (Dabbert et al., 2004; Zorn et al., 2009). The pioneers of organic farming such as Sir Albert Howard considered the maintenance of soil fertility as a distinguishing feature of organic farming, although today organic farming is differentiated by the principle of “no synthetic inputs” (Seufert et al., 2016). With the increasing popularity of organic food, fraudulent practices led to economic information problems as consumers were confronted with non-transparent organic markets (Dabbert et al., 2004; Zorn et al., 2009). This laid the foundation for the development of a formal market for organic products in Europe. In 1991, the Council Regulation (EEC) No. 2092/91 was adopted by the European Union, ensuring fair competition and transparency of the organic production system (Zorn et al., 2009). Today, organic food and organic farming in general are regulated in the European Union by the Council Regulation (EC) No. 834/2007 (Zorn et al., 2009). This regulation provides the framework for the existence of private and autonomous control bodies, which carry out inspections at regular intervals and issue certificates if the standards of organic farms comply with the organic regulations (Zorn et al., 2009). It can be deduced from this development that the aim of organic farming is to “create optimal agro-ecosystems that are socially, ecologically and economically sustainable” (FAO & WHO, 2001).

Organic farming is now practiced in over 191 countries on 1.6% of total agricultural land and the organic farming market is worth €125 billion (Willer et al., 2023). While 88% of organic farms are located in the global South (mainly in India, Uganda and Ethiopia), 86% of the market are in the global North, specifically in the U.S and the European Union (Willer et al., 2023). This is also the reason why the development of OA in low-income countries was export-oriented, mainly driven by premium prices in these high-income countries (Bacon, 2005; Valkila, 2009).

In low-income countries OA is also driven by the need for biodiversity-friendly agriculture, where declining biodiversity coincided with increasing expansion of agricultural land and the use of intensive methods (Daum et al., 2023). Agriculture is also a major emitter of GHG that increases the risk of global warming and climate change (Grosso & Cavigelli, 2012). This is the reason why OA is often proposed for reducing the emission of harmful gasses into the atmosphere (ICIMOD & MoAF, 2018). For example, in Bhutan, apart from the lure of the export market and premium price, OA is also proposed as part of the low-emission development strategy to ensure food security (RGoB, 2021). Switching away from synthetic fertilizer (conventional agriculture) is one of the low-emission strategies for food security as shown in Table 1 below:

Table 1. Mitigation measures and targets for low-emission development for food security

Mitigation measures	**Target**
Switch away from synthetic fertilizers	Annual switch of 5%
Bring agricultural area under improved practices	14971 hectares
Increase biomass through increased perennial crop production	17495 hectares
Install small and medium scale biogas production	10254 (count)
Reduce continuous rice flooding	200 hectares per year
Introduce improved livestock breeds and feeds to improve dairy production	8333 (count)

Source: Author construction using information from (RGoB, 2021). 1 hectare = 10^4 m^2

1.2 What we know about the impacts and challenges of organic agriculture

The adoption of OA as a sustainable agricultural alternative is based on the many benefits it offers. In terms of farmers' livelihoods, OA is considered more profitable than conventional farming (Crowder & Reganold, 2015). However, this advantage is only given if organic operators receive a premium price (Crowder & Reganold, 2015). Organic farming is also considered a resilient farming system (Milestad, 2003), mainly because of the diversity of crops grown, which reduces the impact in case of crop failure (Bacon, 2005).

In terms of biodiversity, organic farming is beneficial for plants (Tuck et al., 2014) and bees (Kennedy et al., 2013). However, these benefits are observed in cases with high agricultural land cover (Tuck et al., 2014), low habitat quality (Kennedy et al., 2013) and in cases where intensive agriculture is practiced prior to the transition to OA (Schneider et al., 2014). This suggests that in a context of low agricultural land cover, high habitat quality and no intensive agriculture, which is the case for smallholder systems in high biodiversity countries, the impact could be only minimal.

In terms of climate change mitigation benefits, for N_2O (from manure application, crop residues and fertilizers) and CH_4 (from rice cultivation), reported emissions per unit area are lower for most crops under OA (Skinner et al., 2014; Tuomisto et al., 2012), and generally, CH_4 emissions are higher under OA than under conventional cultivation (Qin et al., 2010). GHG emissions are even considered higher under the OA system when measured per unit output which is lower in the OA system (Qin et al., 2010; Skinner et al., 2014; Tuomisto et al., 2012). Recent research is also showing that soil organic carbon stocks are decreasing due to the expansion of agricultural land under OA (Gaudaré et al., 2023). However, there are benefits from the reduction of CO_2 emissions through reduction in energy use, mainly from avoiding synthetic inputs (Tuomisto et al., 2012).

Apart from these mixed and uncertain benefits of OA (Seufert & Ramankutty, 2017), there also appear to be many challenges faced by smallholder farmers in low-income countries in particular (Jouzi et al., 2017). These challenges often arise in relation to lower yields, maintaining nutrient balance, inaccessibility of certifications and markets, and inadequate training and research (Jouzi et al., 2017). The presence of benefits and challenges means that promoting OA involves to find ways to deal with the corresponding trade-offs (Ramankutty et al., 2019). For example, OA has the potential to conserve biodiversity and improve farmers' livelihoods, but yields are lower (Ramankutty et al., 2019); adopting biodiversity-friendly agriculture involves moving away from labor-saving technologies such as herbicides, but in return requires labor-intensive practices (Daum et al., 2023).

1.3 Social network and sustainable agricultural practices

The relevance of social networks in understanding and promoting OA and other sustainable agricultural practices is increasing. In this section, we present some evidence to demonstrate the potential of social networks in addressing challenges of implementing sustainable agricultural practices.

Take for example, the adoption of environmental-friendly agricultural practices. A study by Matous (2015) examines the impact of different social structures in farmer networks on the agricultural conservation methods used and farm productivity. Using field data from Sumatra, Matous (2015) shows that a lack of extra-group connections and reciprocity between farmers is associated with the use of unproductive agricultural practices and a lack of efforts to adopt more environmentally friendly practices. The study emphasizes the importance of conducting network analyzes at both the individual and community levels to capture effects at different scales.

Sustainable agricultural practices also require the adoption of resource-conserving agricultural methods by farmers. Take another study by Matous et al. (2012), who examine social and extension networks and their effects on the adoption of resource-conserving agricultural practices among Ethiopian farmers. They show that farmers who are socially well connected in farmers' networks do not adopt extension recommendations well. Their study also looks at the effectiveness of extension when the network actors, i.e. farmers and extension workers, have the same religion.

Adoption of different technologies in alternative farming systems is also an important aspect. In a study on the diffusion of composting among Ethiopian farmers, Matous and Todo (2015) show that the structure of the farmers' network matters, i.e. farmers from similar social groups learn from each other. Their study also shows that the social network may change over time, but that the social group is more effective in spreading composting practices in agriculture compared to new relationships formed through external manipulation or cell phone ownership. They also show that while the provision of technologies such as cell phones can lead to greater information sharing among farmers, farmers ultimately rely on their social group with similar social status and learn from each other.

The role of the social network is important among farmers with different geographical locations, which shows that farmers are very strategic on who they depend upon in their network. For example, in a study on the adoption of the no-till system in England, Skaalsveen et al. (2020) show that organic farmers adopting the no-till system, compared to conventional farmers who are locally connected, seek like-minded farmers to discuss and learn from, even if they are geographically separated. Their study shows that in different geographical locations, network structures with intermediary farmers in the farmers' network play a major role in sharing information between like-minded farmers and influencing other farmers to adopt no-till systems. In a study by Xu et al. (2018), it is shown that farmers decide to convert to OA, if they see improvement in the current situation from peers they consider credible. The study also shows that farmers who judge these credible social peers have negative assessments of OA, they then decide not to convert from conventional farming to OA. However, this does not mean that social influence alone is decisive. In the context of the spread of organic farming in Latvia and Estonia, Kaufmann et al. (2009) show that the combined effect of subsidies (policy environment) and social influence is much higher than the isolated effect of subsidies and social influence alone.

Nowak et al. (2015) show that organic farms practicing both arable and livestock farming, with the intention of reducing nutrient surpluses, seek out organic farms practicing only arable farming and struggling with nutrient deficiencies. This approach is much better than the one where farmers who specialize in livestock farming buy more land to reduce the burden of nutrient surpluses (Willems et al., 2016), which illustrates the benefit of a social network. The study by Nowak et al. (2015) also shows that organic farmers prefer nutrient exchange between local sources (farmers) rather than depending on external sources such as retail stores, wholesalers, cooperatives, conventional farms, etc.

Most research considers communication or interpersonal communication between actors as a particular form of social network with far-reaching benefits. For example, Unay Gailhard et al. (2015) show that early adoption of agri-environmental measures by organic farmers in Germany increases the likelihood of adoption by young and highly educated people due to frequent contact between them. In Vietnam, Tran-Nam and Tiet (2022) show that the presence of organic farmers as neighbors and frequent communication with them can motivate environmentally conscious farmers to adopt organic farming by changing their perception of sustainable agriculture or through social pressure. In another study on organic farmers' deregistration from organic farming, Koesling et al. (2012) argue that communicating information about the environmental and social benefits of organic farming is important to motivate farmers, illustrating the benefits of interpersonal communication between actors at the community and wider stakeholder level. They show that economic incentives such as market premiums are not enough to motivate farmers and that farmers consider their community and the way how their social network perceives their farming system as more important.

In the following subsection (see Section 1.4), a general background for the understanding of social network is presented. The presentation will focus on motivating the use or relevance of social network in this body of work.

1.4 The relevance of social network

In this section, five general explanations of the importance of the social network for this thesis are presented. These explanations relate to how 1) economic actions of individuals are related to social networks, 2) individuals are embedded in social structures and behaviors within social structures can lead to different outcomes, 3) actions of individuals have externalities, 4) social networks serve as substitutes for absent and inadequate formal institutions in low-income settings, and 5) micro-macro linkages between policies, actions, and outcomes look like.

In 1925, Veblen wrote about “conspicuous consumption” to illustrate the tendency of people to outdo each other by acquiring goods that signal their status in society (Veblen, 1925). People can go to enormous expense to acquire status goods in order to benefit from their status in society. It is also shown that people made their decisions not as individual rational utility-maximizing actor, but in relation to people in their social environment such as friends, competitors and so on. This is perhaps the oldest written work on how people's actions are influenced by the social network, or how people can influence the behavior of others by being embedded in a social structure.

Social network is relevant because it is related to the economic behavior of individuals. For example, Jackson (2007) argues that individual actors in a network choose who they associate with; arguing that an external enforcer cannot improve the welfare of two individuals by bringing them together, or the enforcer cannot make the individuals worse off by severing ties between them. Building on this theory, Banerjee et al. (2013) used a randomized controlled experiment to show how the diffusion of microfinance loans is influenced by the social network in Indian villages. Using household participation in microfinance as an economic action, Banerjee et al. (2013) showed that households with a high proportion of friends who had already participated in microfinance were more likely to be informed of the technology. This suggests that the social structure of the village friendship network and the embeddedness of households in these structures can have a huge influence on economic decisions. Some examples of the relevance of social network in different fields include, provision of public goods (e.g., Bramoullé & Kranton, 2005), labor markets (e.g., Calvo-Armengol & Jackson, 2004), exchange and markets (e.g., Kakade et al., 2004), gang violence (e.g., Grund & Densley, 2015), and diffusion of hybrid seed (Ryan & Gross, 1943).

In Sociology, this relationship between economic behavior and social network was studied by Granovetter using the concept of embeddedness (Granovetter, 1985). Granovetter (1985) argued that individuals' economic actions are embedded in social relationships. In economics, social networks are studied because of the role of externality (Jackson et al., 2016). We can argue that externalities and embeddedness are related to each other; because an individual is embedded in a social structure, their actions can have both positive and negative consequences for others in the network. Take the example of microfinance diffusion by

Banerjee et al. (2013); the study showed that households within a network of friends are not informed about a microfinance loan if none of the network members has participated in the microfinance program. This is a negative externality. However, for the households that were informed by the friends who participated in the program, there is a positive externality.

In a low-income setting, the context in which this thesis is conducted, social networks become even more important. Jackson et al. (2016) put it succinctly when they say: “When formal institutions do not exist or do not work very well, informal, network-based relationships serve as substitutes. For example, when insurance markets are missing and access to banking is limited, shocks to incomes are often smoothed via borrowing from family and friends” (page 549). To give another example; fosterage, a persisting informal institution in low-income countries, provides a kind of insurance for raising children among relatives in times of uncertainty (Dasgupta & Ehrlich, 2016). In low-income countries, assets such as village ponds, grazing lands, forests, etc. are communally owned and operated based on social norms or social capital (system of interpersonal relationships) (Dasgupta & Ehrlich, 2016, Dasgupta, 2005). The vitality of community in low-income countries still depends on various interactions in different areas of social, economic and cultural life, such as village festivals, marriage and labor exchange (Kinga, 2010). When social norms deteriorate or collapse, people overexploit community resources and create externalities by shifting the costs onto other individuals (Dasgupta & Ehrlich, 2016).

Social network is also relevant because of micro/macro linkages. Coleman (1986) defines the micro/macro linkage as a process “through which individual preferences become collective choice, … through which preferences, holdings of private goods, and the possibility of exchange create market prices and a redistribution of goods” (page: 1321). The micro-macro linkage can be illustrated with Figure 1.

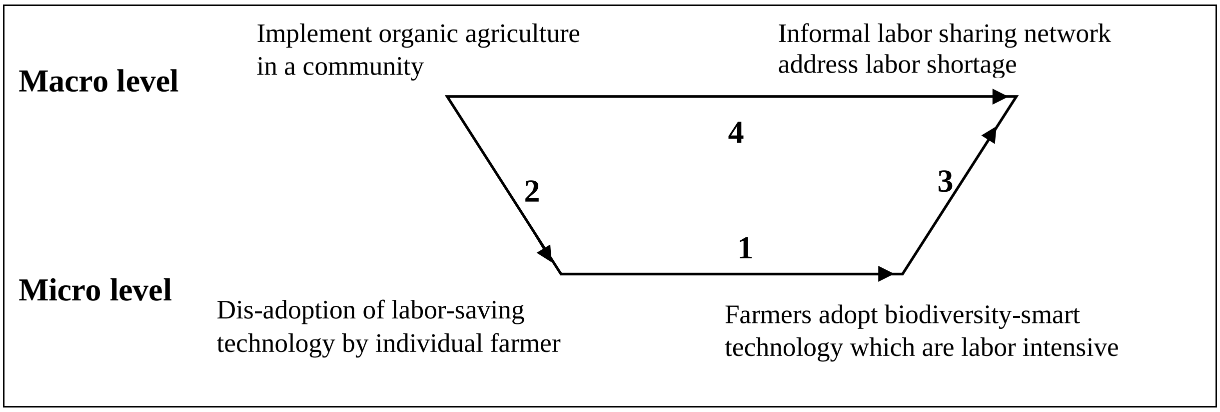

Figure 1. Schema of Coleman's boat showing the micro-macro linkage. This is illustrated with the example of implementation of organic agriculture in a community. Author construction using Coleman's analysis (Lindenberg et al., 1986). The figure shows how actions at the macro level (implementation of organic farming) can lead to behavioral changes at the micro-level (dis-adoption of labor-saving and adoption of labor-intensive technologies), which in turn affects the outcome at the macro-level (labor exchange helps successful adoption of organic farming). The numbers correspond to the type of relationships between variables at the macro and micro level. Type 2 (effect of a macro-level variable on a micro-level variable), Type 1 (effect of a micro-level variable on another micro-level variable), Type 3 (effect of a micro-level variable on a macro-level variable) and Type 4 (effect of a macro-level variable on another macro-level variable).

In Coleman's social theory (Lindenberg et al., 1986), he distinguishes between two units of analysis, a social unit at the macro level and an individual unit at the micro level. He then categorizes them as either dependent or independent variables in order to construct a social theory to examine the relationships between the different levels, indicated by the four different arrows (Type 1, Type 2, Type 3 and Type 4). In the type 1 relationship, the individual units are both the dependent and the independent variable, while in the type 4 relationship, the social units are both the dependent and the independent variable. In the type 2 relationship, the social unit is the independent variable, while the individual unit is the dependent variable. In the type 3 relationship, the individual unit is the independent variable, while the social unit is the dependent variable.

In Coleman's social theory, he does not stop at type 4, but insists on the micro-macro connections represented by the other three relations (type 1, type 2 and type 3). The three propositions that follow from the example in Figure 1 can be presented as follows:

Type 2 1. Implementing OA in the community constrains farmers by renouncing to labor-saving technologies, which are also harmful for biodiversity and climate change (e.g., inorganic fertilizers, weedicides etc.).

Type 1 2. Farmers who dis-adopt labor-saving technologies (referred to in 1 in Figure 1 above) adopt biodiversity-smart technologies, which are also labor intensive.

Type 3 3. Adoption of biodiversity-smart technologies (referred to in 2 above) on the part of individuals leads them to engage in informal labour exchange at community level (networks), which leads to successful adoption of OA at community-level.

Coleman was particularly interested in the Type 3 relationship because it links individual behavior to outcomes at the social level, which is also the focus of this thesis. The emphasis on this Type 3 relationship is best explained by Coleman's (1986) statement when he says

"The question arises whether systematic quantitative research based on individual-level data can be relevant not merely for explanation of individual behavior but also for explanation of social outcomes …" (page. 1329).

In order to justify the existence of relations in his theory, Coleman explains that each actor not only has an overlapping or similar interest, but also has resources that can be useful to the other in realizing their interest or goal (Coleman, 1986). The foundation of Coleman's social exchange was inspired by Homans' paradigm of exchange, which Homans explains as follows: "Suppose we are dealing with two men. Each is emitting behavior reinforced to some degree by the behavior of the other … It is enough that each does find the other's behavior reinforcing, and I shall call the reinforcers values" (Homans, 1958, page. 598-599).

1.5 Research objectives

The overall aim of this thesis is to improve our understanding of the potential of farmers' social networks in solving some of the challenges they face in low-income countries. To approach this goal, we assume that the implementation of OA at the macro level (community level) constrains the behavior of individual farmers at micro level. For example, farmers are prohibited from using labor-saving technologies such as chemical synthetics. These micro-level changes create challenges for farmers, often involving the adoption of labor-intensive, biodiversity-enhancing technologies, such as manual labor, leading to labor shortage issues. The thesis postulates that an individual farmer is embedded in a social system and that the actions of one individual can have an impact on the behavior of others. For example, two farmers facing a similar labor shortage might share labor to overcome the challenge of labor-shortage. The presence of a social network can enable the implementation of OA at the community level. In other words, farming systems are embedded in a social system.

This thesis presents a network analysis for the OA sector in Bhutan. Bhutan gained global popularity because it has set a goal to convert its agricultural system to organic farming on a large scale. Bhutan is also a country without much market penetration where most of its informal institutions are still surviving the rapid changes brought about by economic growth in other parts of the world. The thesis aims to answer a number of general questions: 1) What challenges do smallholders face in a top-down approach to OA? 2) What types of social networks are still practiced among smallholder farmers? 3) What potential do social networks have in overcoming the challenges that arise in the implementation of OA?

1.5.1 Research objective 1

Before presenting the network analysis of the OA sector in Bhutan, Chapter 2 describes the OA sector in Bhutan. The description of the OA sector in Chapter 2 serves as a background for the social network analysis. The objective of this chapter is to analyze the feasibility of large-scale conversion to OA, by describing management and farming practices, yield gaps, nutrient balances, and institutional capacity of OA, in Bhutan. The first objective addresses a research gap in the understanding of OA. In many low-income countries, OA has emerged as a top-down government initiative supported by strong political interest, which risks seriously neglecting the challenges faced by many organic farmers. In some countries, the promotion of OA, particularly the large-scale conversion in Sri Lanka, Sikkim and Bhutan, has received considerable attention. In such a context, a system-level analysis of conversion to OA can provide a fair assessment, but such studies are often lacking. There are also serious problems with the lack of data that prevent a deeper analysis of the feasibility of large-scale OA and its challenges at the system level. The aim is to present the case of OA in Bhutan, which is suitable as a case study due to the generally good availability of data on the agricultural sector. The chapter takes advantage of the good data availability as the government conducts annual crop and livestock surveys that cover about 20-30% of farmers, while the agricultural census data is collected every ten years. The government also publishes annual reports, status and consultation reports.

1.5.2 Research objective 2

The objective in Chapter 3 is to present the first social network of farmers that has the potential to address the challenge of labor shortage in OA for smallholder farmers. The aim is to examine informal labor exchanges in farming villages that successfully adopt labor-intensive farming practices. The chapter draws on findings from previous studies that have characterized the network pattern of labor exchange to relate such cooperative behavior to the social structure of the community. Specifically, this chapter uses network patterns from the literature and replicates the internal network structure of labor exchange in selected Bhutanese villages to determine the type of social enforcement mechanisms used.

1.5.3 Research objective 3

Chapter 3 then examines a second type of farmer social network that also has the potential to address the challenges of disseminating improved seeds to organic farmers. Specifically, this chapter identifies two types of social structures in which: 1) farmers can learn from each other through direct communication relationships and the exchange of advice, and 2) farmers can also be encouraged to mimic the behavior of others because they are in a similar social position to themselves, even if they do not directly exchange information with each other. The chapter fills a gap in the literature and makes use of the latter mechanism, which is usually not explicitly considered in research on the role of networks in the adoption of agricultural technologies and usually only implies diffusion through direct links. The chapter argues that different potential network mechanisms at play in a given context have different implications for the targeting of effective interventions for the adoption of recommended practices. The chapter shows that diffusion through social contagion and structural equivalence can explain behavior change among farmers and that interventionists should not only favor farmers with numerous connections in the hope that their behavior will influence their numerous network partners, but also farmers in different social positions, including peripheral network positions, who can inspire other, less well-connected farmers to adopt.

1.6 Study sites, data and method

This thesis consists of three main chapters (chapters 2, 3 and 4) in which the above objectives are presented. Chapter three presents a system-level analysis of OA in Bhutan using secondary data (see Table 2). In this chapter, two challenges of organic agriculture in terms of management and cultivation practices and institutional frameworks are examined using manuals (organic standards), annual reports of research centers, a consultation and status report of OA within the country, and a consultation report on OA published by an external research center. The two challenges related to the yield gap and nutrient balance are based on survey and census data and associated reports collected and published by the Ministry of Agriculture and Livestock (MoAL) (formerly Ministry of Agriculture and Forests) and the National Statistical Bureau (NSB). This is presented for all 20 districts in Bhutan and for the model organic villages (MOVs) (out of the total six MOVs) for which survey and census data were available. The annual reports of the research centers and the agricultural censuses and surveys are collected regularly. However, consultations and status reports were rare.

Table 2. Study sites and data source used in chapter 2

Challenges	Study sites	Data source
Management and farming practices	All six model organic villages (MOVs) (Lull, Chanachen, Ngangney, Galeythang, Langpa-Nobgang, Phasuma-Zamsa); Khatoed organic sub-district.	Bhutan organic standard manual published in 2019; Annual reports published by National Center for Organic Agriculture (NCOA) (for 2019-2023) and Agriculture Research and Development Center (ARDC) Bajo (for 2012-2015); consultation report

		published by ARDC, Bajo (in 2012); status report published by NCOA (2021).
Yield analysis	All districts in Bhutan;	Agriculture census microdata collected by MoAL (in 2018)
	Two MOVs (Langpa-Nobgang, Galeythang) and Khatoed organic sub-district	Agricultural survey and census microdata (surveys: 2014, 2015, 2016; census: 2018) collected by the Ministry of Agriculture and Livestock (MoAL), and agriculture survey and census (survey: 2021; census: 2022) collected by the National Statistical Bureau (NSB).
Nutrient balance	All districts in Bhutan; Four MOVs (Ngangney, Galeythang, Langpa-Nobgang, Phasuma-Zamsa) and Khatoed organic sub-district	Agriculture survey and census reports published by NSB (in 2019, 2020, 2021); crop nutrient contents published by Bayerische Landesanstalt für Landwirtschaft (LFL) (in 2019) and Linquist (in 2020).
Institutional setting	All six model organic villages (Lull, Chanachen, Ngangney, Galeythang, Langpa-Nobgang, Phasuma-Zamsa); Khatoed organic sub-district.	Annual reports published by NCOA (for 2019-2023) and ARDC Bajo (for 2012-2016); consultation report published by ARDC Bajo (in 2012), International Center for Integrated Mountain Development (ICIMOD) and MoAL published (in 2018); status report published by NCOA (in 2021).

For the two chapters (3 and 4), no data on social networks is collected by the relevant authorities or research centers. Therefore, we conducted a network survey in selected villages (see Table 3 & 4). The period of data collection (February – May 2021) coincided with an unfortunate scenario imposed by the COVID-19 pandemic restrictions, so visiting villages was limited. For Chapter 3, network data on labor exchange and agricultural practices were collected in two organic villages and three villages with traditional farming (see Table 3). Covering four agro-ecological zones, these villages are located in four (out of a total of 20) different districts of Bhutan. In these villages, a complete village network was established in which from each farm household a representative was interviewed.

Table 3. Study sites used in chapter 3

No	Study sites	District	Farming system	Agro-ecological zones (AEZ)	Sample village	Sample household
1	Khatoed	Gasa	Organic farming	Cool temperate	5	50
2	Berti	Zhemgang	Organic farming	Humid sub-tropical	1	23
3	Lingmukha	Punakha	Traditional farming	Dry sub-tropical	1	19
4	Drachukha	Punakha	Traditional farming	Wet temperate	1	19
5	Hebisa	Wangdiphodrang	Traditional farming	Dry sub-tropical	1	22

In chapter 4 we examine 15 villages at five study sites (see Table 4). The study sites come from two different agro-ecological zones and are composed of three farming system constellations, namely organic farming, conventional farming and one site where some inhabitants practice organic farming and others conventional farming. The study sites were drawn from five (out of a total of 20) districts in the country. Due to the nature of the analysis, a complete survey of the village network was conducted in these study sites. In two study sites, however, it was not possible to create a complete village network because the residents live too far away and could not be contacted. However, the analysis including these two study sites is presented in the supplementary section of the chapter. The duration of the introduction of improved seeds spans eight years (2015-2022) and includes different crops.

Table 4. Study sites used in chapter 4

Study sites	Berti	Lobnekha	Sergithang Maed	Goongring	Khar
Adopters interviewed	24	64	58	36	32
District	Zhemgang	Chukha	Tsirang	Sarpang	Pema Gatshel
Improved seed	Watermelon	Potato	Quinoa	Vegetables	Vegetables
Number of Villages	1	4	1	5	4
Diffusion period	2017-21	2017-22	2015-21	2015-18	2015-20
Farming system	Organic	Conventional	Mixed	Organic	Conventional
Agro-Ecological Zone (AEZ)	Sub-tropical	Temperate	Sub-tropical	Sub-tropical	Sub-tropical

In chapter two, we set the background for the two subsequent chapters, that illustrate the use of social networks in OA. The motivation of the chapter is to provide a description of the OA sector in Bhutan and therefore to employ back-of-the-envelope methods. The chapter conducts a qualitative content analysis of annual reports, status and consultation reports, gray literature and literature to describe the management and farming practices as well as the institutional framework of OA in Bhutan. The chapter also analyzes the yield differences between organic and conventional farming systems using agricultural census data with the help of a non-parametric Wilcoxon rank sum test. A tentative aggregate nutrient balance at the district and organic village level is also performed using a simple difference between nutrient inputs and outputs.

In chapter three, a method from the field of random graph models, the so-called exponential random graph model (ERGM), is used to investigate the structure of social networks. ERGM assumes that a given social network consists of many network substructures (or fingerprints) such as reciprocity, homophily, triads, including node-characteristics, which in combination or individually explain how the observed network has emerged. Network structures represent social processes that determine the actions of actors in the network. This chapter examines the mechanisms responsible for the emergence of cooperative behavior in the case of labor exchange to address labor shortages of organic farmers in both organic and traditional farming.

Chapter four tests the diffusion of improved seeds among smallholder farmers through social networks. In this chapter, in addition to the contagion model, a less researched network structure, structural equivalence, is introduced to find out which social mechanism seems to be more relevant for explaining seed adoption. The contagion model assumes that the adoption behavior of one farmer influences the behavior of others through communication and advice networks. In this model, well-connected farmers (opinion leaders) are often selected as seeds to influence other farmers in the community or network of interest. On the other hand, the structural equivalence model assumes that farmers generally seek out those farmers who are in a similar social position for inspiration. Structural equivalence can also be interpreted as a sense of envy and competition among farmers, which can also influence adoption behavior. The effects of these two network structures are tested using logistic regression. The logistic framework estimates the log-likelihoods of adopting an improved seed as a function of the adoption norm represented by the two network structures.

1.7 Outline of the thesis

After the general introduction and the research objectives outlined above, this cumulative thesis is structured as follows:

Chapter 2 provides the reader with a description of the OA sector in Bhutan. The chapter describes the role of management and farming practices, yield gaps, nutrient balance and institutional framework in the context of large-scale organic conversion. This paper has been submitted to Agricultural Systems.

Chapter 3 examines informal labor exchanges in farming villages with the successful adoption of labor-intensive farming practices, such as traditional and organic farming. This work was published in 2022 in Organic Agriculture, Vol. 13, https://doi.org/10.1007/s13165-022-00416-z

Chapter 4 examines two social network mechanisms, contagion and structural equivalence, in the adoption of improved seed varieties among smallholder farmers in Bhutan. This work has been submitted to the Australian Journal of Agricultural and Resource Economics.

The thesis concludes with Chapter 5, which discusses the contributions of the thesis as it stands to the general understanding of OA, its challenges and the potential of social networks. In particular, the results of the three papers presented and their contribution to the existing literature are discussed including some policy implications of the results from the thesis.

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Chapter 2

2 The role of management and farming practices, yield gaps, nutrient balance, and institutional settings in the context of large-scale organic conversion in Bhutan

2.1 Abstract

CONTEXT. In many low-income countries, organic agriculture (OA) has emerged as a top-down government initiative backed by strong political interest, which entails the risk of seriously neglecting the challenges faced by many organic farmers. In some cases, the promotion of OA, particularly large-scale OA conversion programs in Sri Lanka, Sikkim and Bhutan, has received widespread attention. A system-level analysis of conversion to OA can provide a fair assessment and is desirable but rare. Often, there are serious issues with data paucity hindering deeper analyses of the feasibility of large-scale OA and its system-level challenges.

OBJECTIVE. This article aims to analyze the feasibility of large-scale conversion to OA by describing management and farming practices, yield gaps, nutrient balances, and institutional capacity for OA in Bhutan. Bhutan is a suitable case study given the generally good availability of data on the agricultural sector.

DATA AND METHODS. We conduct qualitative content analysis of annual, status, and consultation reports, and gray literature to describe management and farming practices, and the institutional setting of OA in Bhutan. We also analyze the yield gap between organic and conventional farms using agricultural census data. A tentative aggregated nutrient balance at the district and organic village levels is also carried out relying on data from agricultural surveys and censuses and associated reports.

RESULTS AND CONCLUSION. OA in Bhutan requires compliance with the standard requirements defined in the Bhutan Organic Standard (BOS), which is part of the family of standards established by the International Federation of Organic Agriculture Movements (IFOAM). Farmers are increasingly opting for certified organic farming, with 6 % and 3% of arable land being registered and certified, respectively, under the local organic assurance system (LOAS). The National Center for Organic Agriculture (NCOA) has instituted model organic villages (MOVs) and provides capacity building training and in-kind farm support to organic farmers. The results of the yield gap analysis show that yields in organic systems are lower compared to conventional cropping systems. The results of the nutrient balance show an imbalance. OA faces many challenges, such as a shortage of funds for implementing organic programs, missing extension for OA, and a lack of research to improve the existing methods.

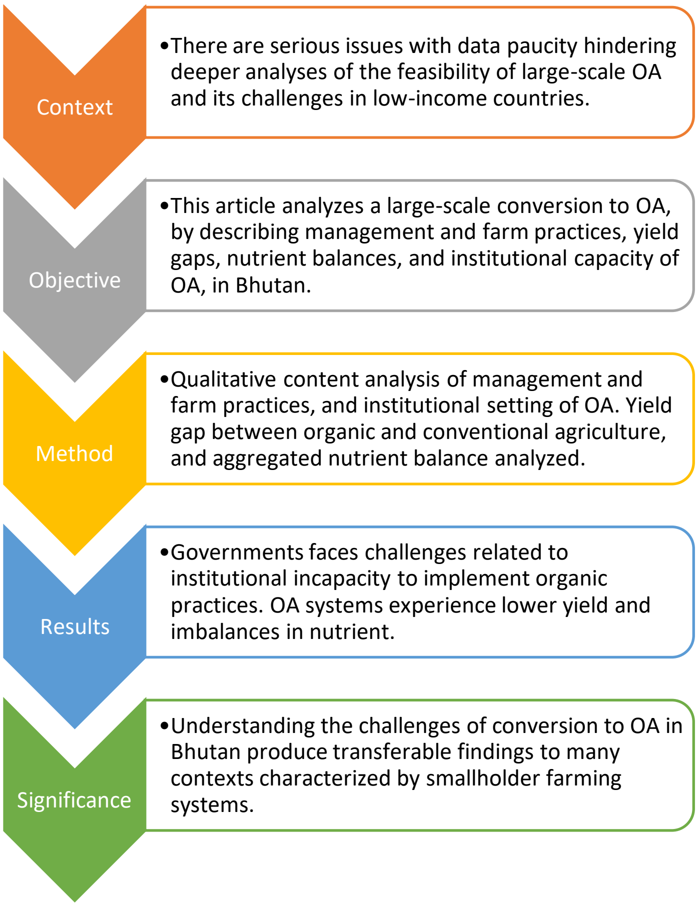
SIGNIFICANCE. This paper provides clarity on the challenges faced by farmers under state-driven large-scale OA conversion. Understanding the challenges of converting to OA in Bhutan can lead to transferable findings to many similar contexts characterized by smallholder farming systems.

Keywords: Bhutan, large-scale, organic agriculture, yield gap, management and farming practices, institutional setting, nutrient balance

HIGHLIGHTS

- Large-scale organic agriculture (OA) in low-income countries is often implemented with a top-down approach backed by strong political interest.
- A system-level analysis of large-scale conversion to OA can provide a fair assessment of the challenges faced by smallholders.
- A more in-depth analysis of the large-scale OA policy initiatives in Bhutan with a comparatively better data situation is analyzed and presented.
- OA in Bhutan faces challenges in terms of management and farming practices, yield, nutrient balance and institutional inadequacies.
- Analyzing and understanding the challenges of OA transition in Bhutan can lead to transferable lessons for similar contexts of smallholder farming.

GRAPHICAL ABSTRACT



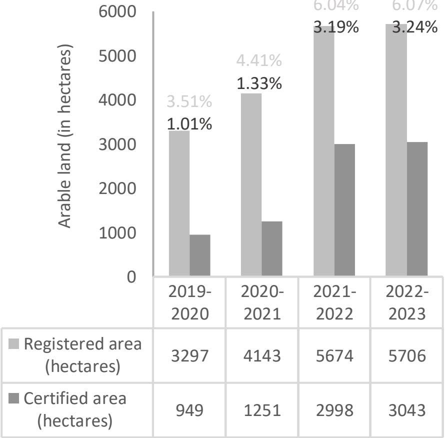
- There are serious issues with data paucity hindering deeper analyses of the feasibility of large-scale OA and its challenges in low-income countries.

- This article analyzes a large-scale conversion to OA, by describing management and farm practices, yield gaps, nutrient balances, and institutional capacity of OA, in Bhutan.

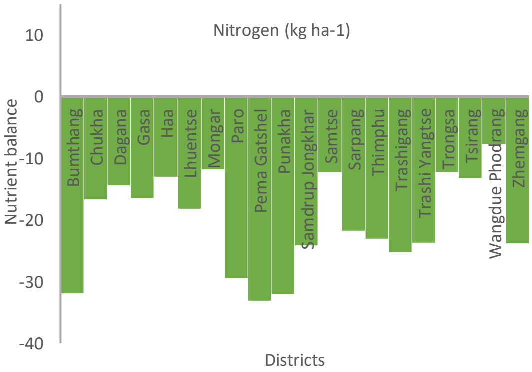
- Qualitative content analysis of management and farm practices, and institutional setting of OA. Yield gap between organic and conventional agriculture, and aggregated nutrient balance analyzed.

- Governments faces challenges related to institutional incapacity to implement organic practices. OA systems experience lower yield and imbalances in nutrient.

- Understanding the challenges of conversion to OA in Bhutan produce transferable findings to many contexts characterized by smallholder farming systems.



	2019-2020	2020-2021	2021-2022	2022-2023
▨ Registered area (hectares)	3297	4143	5674	5706
■ Certified area (hectares)	949	1251	2998	3043



2.2 Introduction

Organic agriculture (OA) is proposed as a sustainable land use practice due to its potential to improve biodiversity, soil and water quality and farmer resilience (Blockeel et al., 2023; Seufert & Ramankutty, 2017; Seufert et al. 2023). By incorporating diverse crops and livestock, OA can reduce the risk of being dependent on a single crop, creating a buffer against agricultural shocks (Jacobi et al. 2015). Improving soil structure is an essential prerequisite for maintaining reliable crop yields in the face of severe weather conditions and climate change (Lotter et al., 2003; Milestad & Darnhofer, 2003). Organic farmers can strengthen their autonomy by forming farmer organizations and cooperatives and minimizing dependence on external inputs (Bray et al., 2002; Stock et al., 2014; Valkila, 2009). However, some dispute the benefits of OA (Trewavas, 2001). Others point out that both the critics and proponents of OA are only partly correct and that the evidence for the environmental benefits of OA is much more uncertain (Seufert & Ramankutty, 2017) or have noted that OA involves significant trade-offs between benefits (including environmental, health, nutritional, and livelihood) and lower yields and higher prices of certain farm inputs (Ramankutty et al., 2019).

Most of the studies on the impact of OA are based on evidence from single fields or farms (Seufert & Ramankutty, 2017). While there is a consensus that analysis at the food system level would provide a fair assessment, there have only been a few studies conducted in the context of high-income countries (Kratochvil et al., 2004; Thieu et al., 2011) and even fewer in the context of low-income countries (Feuerbacher et al., 2018) or at the global or regional level (Erb et al., 2016; Halberg et al., 2006). These studies generally conclude that large-scale conversion to OA can lead to lower food production but do not consider other important questions, such as nutrient availability or institutional constraints (Seufert & Ramankutty, 2017). A system-level analysis can provide in-depth analysis of the constraints and challenges of OA and generate pathways for scaling up OA for a particular country and other countries with similar contexts.

Many farmers in low-income countries doubt the benefits of OA. In sub-Saharan Africa, farmers often view OA as an alien system with rules set by foreign organizations and food produced for consumers in other countries (Schader et al., 2021). In Sikkim, which has converted its agricultural sector to 100% organic, “organic discontents” have become widespread among farmers, who consider the policy of implementing organic farming to be an “autocratic implementation” (Das, 2024). In Bhutan, farmers consider OA to be “more expensive” due to higher labor requirements and lower productivity (ICIMOD & MoAF, 2018). Some countries tout OA and promise to convert their agricultural system to full-scale OA (Bhutan, Sikkim), and some force farmers to abandon mineral fertilizers (Sri Lanka, Sikkim); however, there is “literally no example” of a successful top-down large-scale transition (Babajani et al., 2023; Nordhaus & Shah, 2022; Weerahewa & Dayananda, 2023).

Organic agriculture originally began as a bottom-up movement of farmers in high-income countries (Seufert et al., 2016). In many low-income countries, however, strong political interests make this a top-down initiative (Das, 2024) that entails the risk of governments seriously neglecting the challenges faced by many organic farmers (Bhatt & John, 2023). After many years of neglect, the challenges faced by many organic farmers in low-income countries are slowly receiving scrutiny, at least from researchers (Babajani et al., 2023; Baird, 2024; Bhatt & John, 2023; Das, 2024; Meek & Anderson, 2020; Nordhaus & Shah, 2022; Schader et al., 2021). Using the organic sector in Bhutan as an example, this article focuses on four key challenges that need to be addressed simultaneously for a successful transition: (1) lower yields in OA, (2) a possible mismatch between the management practices embodied in the organic standard and the programs implemented in the field, (3) institutional capacity, and (4) difficulties in soil nutrient management. Analyzing and understanding the challenges of conversion to OA in Bhutan can lead to transferable findings to many similar contexts characterized by smallholder farming systems.

In 2012, Bhutan received widespread attention for setting the ambitious goal of 100% conversion to OA (Feuerbacher et al., 2018). In addition, many other regions, particularly in Asia, have announced [e.g., Kyrgyzstan, India, Philippines] or even implemented [Sikkim, Sri Lanka] similar initiatives. However, often, there are serious issues with data paucity hindering deeper analyses of the feasibility of such plans. For example, the availability of reliable yield data is a major challenge in most low-income countries, limiting our understanding of the economic performance of OA (Schader et al., 2021) and its impact and sustainability (Blockeel et al., 2023). Bhutan is a suitable case study given the generally good availability of data on the agricultural sector. The government conducts annual crop and livestock farming surveys covering approximately 20-30% of farmers, while agricultural census data are collected every ten years. The government also publishes annual reports, consultation and status reports frequently for OA. In contrast to previous studies on Bhutan, this article analyses both, certified organic and organic-by-default systems. We begin by describing the agricultural sector in Bhutan in Section 2. Then, we present the data and methods in Section 3, followed by the results in Section 4. In Section 5, we present the discussion, and finally, we conclude the paper in Section 6.

2.3 Agriculture sector in Bhutan

Bhutan, which is a landlocked country in the Eastern Himalayas, has 71% of its land under forest cover and 94000 hectares of arable land available for agricultural production (World Bank, 2023). Arable land stretches over a wide range of elevations, from 100 meters above sea level (masl) in the Himalayan foothills to 7500 meters in the northern peaks. This land is further classified into three agroecological zones (AEZs) (Neuhoff et al., 2014), delineating the variations in the natural features, climate, and soil characteristics that impact agricultural production (Table 5). The subtropical zone has an altitude range of 150-1800 meters, mean annual rainfall ranging from 850-5500 millimeters, and mean temperature ranging from 3.1-34.6 degrees Celsius (°C). On the other hand, the temperate zone has an altitude range of 1800-3600 meters, a mean annual rainfall between 650 and 850 millimeters, and a mean temperature ranging from 0.1-26.3 °C. The Alpine zone in this area ranges from 3600-4600 meters. The mean annual rainfall is less than 650 millimeters, with mean temperatures ranging from -0.9-12 °C.

Table 5. Agro-ecological zones in Bhutan

Agro-ecological zone (AEZ)	Altitude [in masl [a)]]	Mean annual rainfall [in mm [b)]]	Mean annual temperature [in °C [c)]]	Farming system
Alpine	3600 - 4600	Below 650	-0.9 - 12	Cultivation of barley, buckwheat, mustard, and vegetables. Animal husbandry of yak.
Temperate	1800 - 3600	650 - 850	0.1 - 26.3	Cultivation of irrigated rice, wheat, mustard, barley, potatoes, buckwheat, temperate fruits, and vegetables. Animal husbandry of cattle.
Subtropical	150 - 1800	850 - 5500	3.1 - 34.6	Cultivation of irrigated rice, mustard, wheat, pulses, vegetables, tropical fruits, maize, millet, and lemon grass. Animal husbandry of cattle, pigs, and poultry.

Note: Author construction using information by Neuhoff et al. (2014). Note: [a)] Meters above sea level (masl); [b)] millimeters (mm); [c)] degrees Celsius.

Although nearly half of Bhutan's population relies on agriculture as their main source of livelihood, this sector contributed only 19% to the country's GDP in 2021 (RGoB, 2022). The agricultural sector is characterized by smallholder farming systems, in which 98% of farmers own less than 5 hectares and only 2% own more than 5 hectares of farmland (CIAT & World Bank, 2017). Ensuring food self-sufficiency remains a key policy objective, with current levels of 35% for rice, 72% for maize, 84% for vegetables, 85% for dairy, 34% for meat, and 100% for eggs (RGoB, 2022). Most of Bhutan’s food imports originate from India and are facilitated by a free trade agreement (Christensen et al., 2012). The complex topography of the region presents fundamental obstacles for the development of roads and infrastructure, which hinders the commercialization and specialization of farmers and negatively impacts food security goals (Christensen et al., 2012). Although the majority of households (98%) have access to food, problems such as inadequate child nutrition for children aged between 6 and 23 months (88%), children under five years impacted by stunting (one in five), underweight (9%), or wasting (4.3%); anemia among children under five years (44%); women

(35%); and insufficient food among the poor (10%) continue to exist (CIAT & World Bank, 2017).

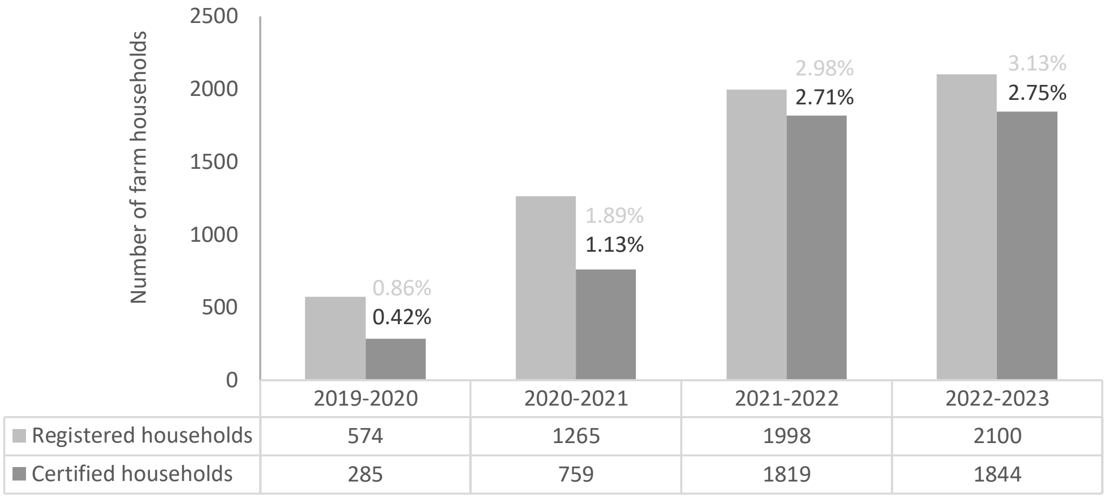
Although Bhutan is a carbon-negative country, agriculture generates the highest emissions among all economic sectors, with 2183.25 kiloton CO_2eq, accounting for 57.2% of the total emissions in Bhutan (MoAL, 2021). These emissions primarily result from enteric fermentation (61%), crop residues (2.3%), rice cultivation (11.4%), crop residue burning (1%), manure left on pasture (14.6%), manure management (5.8%), and synthetic fertilizers (0.6%) (CIAT & World Bank, 2017). Climate change impacts agriculture in Bhutan by altering precipitation, temperature, water availability, the transformation of soil organic matter, soil erosion, aridification, pest and disease incidences, invasive plants, and changes in the beginning and duration of seasons (ADB, 2021). In this context, 31% of crop production on sloping areas is vulnerable to landslides and soil erosion, and agriculture in arid regions (61%) relies on monsoon rains, which are becoming increasingly unpredictable (CIAT & World Bank, 2017).

Farmers in Bhutan encounter numerous constraints, such as land degradation, scarcity of irrigation water and labor, human–wildlife conflict, and marketing difficulties for farm produce (MoAL, 2019). Farming constraints often lead to fallow land accounting for 26.4% (26678 hectares) of the total land owned, including dry land, wet land and orchards (MoAL, 2019). Various projects have introduced sustainable land management practices and smart irrigation initiatives; however, these initiatives have only reached a small fraction of farmers (RGoB, 2022). To alleviate the problem of labor shortages, the government subsidizes both the purchasing and hiring of farm machinery. Farming systems are still characterized by a low level of machinery use largely due to rugged terrain, fragmented land ownership and overall small landholdings (Feuerbacher & Luckmann, 2023). The emergence of government support for low-cost electric fencing to mitigate human–wildlife conflicts has led to successful efforts to reduce labor requirements for crop guarding (Feuerbacher et al., 2021). Market infrastructure is inter alia enhanced through postharvest storage facilities, contract farming schemes and support for cooperatives (RGoB, 2022).

The state of soil fertility is a significant concern, with 45% of soils categorized as having low fertility (Neuhoff et al., 2014). Farmers rely on domesticated animals for farmyard manure (FYM) to maintain soil fertility. Labor shortages are prompting farmers to switch to synthetic chemicals to maintain soil fertility, weed control, and pest and disease management

(Feuerbacher and Luckmann, 2023). Farmers also lack an understanding of crop nutrition, which results in imbalanced fertilization (Norbu & Floyd, 2004).

In this context, OA is becoming increasingly popular and is promoted with strong political interest. In the following sections, we present each of the four challenges that urgently need to be addressed to make progress toward a 100% organic country. Figure 2 shows the numbers of registered and certified households from 2019 to 2023, by which time 2100 farmer households had registered 5706 hectares of land for the local organic assurance system (LOAS) certification. By 2023, the National Center for Organic Agriculture (NCOA) had certified 3043 hectares of land belonging to 1844 households. To put this into context, out of an agricultural area of 94000 hectares, 6% (5706 ha) and 3% (3043 ha) have been registered and certified with the NCOA under the local organic standard LOAS through the NCOA, respectively. Farmers must first register with NCOA before they can be certified as organic. The conversion period between registration and certification is 18 months for perennial crops, 12 months for annual crops, and only 6 months for fallow and uncultivated land as per Bhutan Organic Standard (BOS) (NCOA, 2019). This represents 3% (2100 farms) and 2% (1844 farms) of the farms registered and certified under the LOAS, respectively. These certifications are conducted by the NCOA without charging fees for inspections, laboratory analysis or record keeping. The NCOA relies on another department of the ministry (the Bhutan Agriculture and Food Regulatory Authority (BAFRA)) as an inspection agency (third-party control body) for certification. Figure 2 shows that many farmers have registered with the NCOA and that the NCOA has successfully certified an increasing number of farmers as organic under the local organic assurance system (LOAS). It is worth noting that Bhutan exports a multitude of organic products, including ginger, turmeric, chamomile, dried flowers for food production, vegetables, fruits, cornflower petals and a mixture of Himalayan flowers (covering an area of 4.55 hectares)[2]. However, these products are certified by the IMO IN organic standard, which is equivalent to the organic standard of the European Union in accordance with Regulations (EC) No. 834/2007 & 889/2008 and Bio Suisse. The organic exporters included two processing companies that export pine essential oil, artemisia essential oil, wintergreen essential oil, lemongrass oil, dried lemongrass and lemongrass powder. In addition to certification, the NCOA has instituted six model organic villages (MOVs) and provides capacity building and in-kind farm support.



	2019-2020	2020-2021	2021-2022	2022-2023
▨ Registered households	574	1265	1998	2100
■ Certified households	285	759	1819	1844

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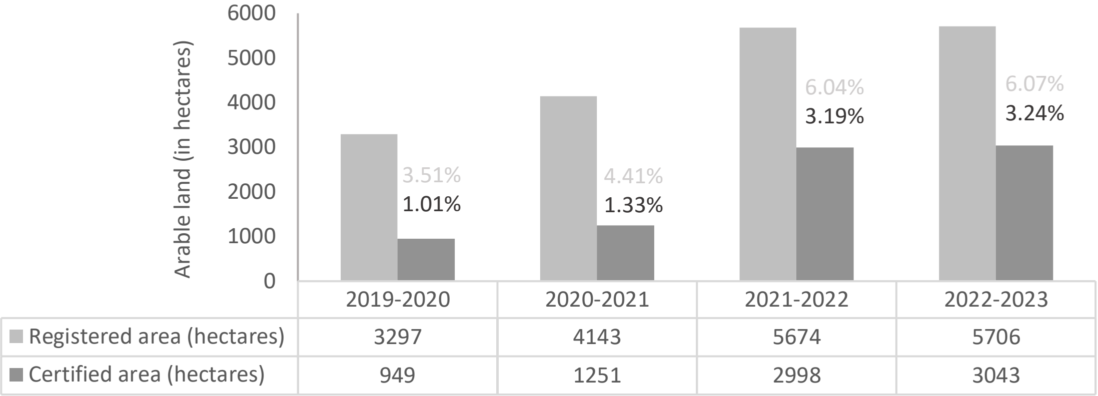
[2] IMO Control Pvt. Ltd. List of Active Operators and Products IMO IN OS. www.inocontrol.in. Data available at: List of Active Operators and Products IMO IN OS – IMO Control India.



	2019-2020	2020-2021	2021-2022	2022-2023
■ Registered area (hectares)	3297	4143	5674	5706
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Figure 2**.** Cumulative number of registered and certified farm households and corresponding land area (hectares) under the Local Organic Assurance System (LOAS) in Bhutan from 2019-2020 to 2022-2023.

Note: Number of households and area registered (left panel) and certified "organic" (right panel) by the National Centre for Organic Agriculture (NCOA) under the Local Organic Assurance Scheme (LOAS). Authors construction based on NCOA data. Data constructed from a list of Registered and Certified Organic Operators and Annual Report (2020-2023) of NCOA. Percentage values reported in the charts show the share of the cumulative number of corresponding households or area, respectively in the total number of Bhutanese farm households or area for the given financial year. Percentages reported for registered and certified organic households are calculated out of 67093 farm households reported in RNR Census (2022); percentages reported for registered and certified land area are calculated out of 94000 hectares of arable land reported in World Bank (2023).

2.4 Data and methods

In this section, we provide an overview of the materials and methods used for analysis (Table 6). Our description of the organic sector in Bhutan focuses on four key challenges (see Table 6). Our analyses are based mainly on annual reports published by the NCOA and the Agriculture Research Center. In addition, consultation and status reports from research centers, the NCOA, and external research centers were also obtained. These materials are easily accessible and available online. We provide a qualitative content analysis of these documents and construct statistics wherever necessary to help understand the challenges of management and farming practices of OA, along with the institutional settings.

Table 6. Summary of methods and materials used for yield analysis

Challenges	Type of analysis	Data source
Management and farming practices	Qualitative content analysis	Bhutan organic standard manual published in 2019; Annual reports published by NCOA (for 2019-2023) and ARDC Bajo (for 2012-2015); consultation report published by ARDC, Bajo (in 2012); status report published by NCOA (2021).
Yield analysis	- Yield gap analysis (Wilcoxon rank-sum test)	Agriculture census microdata collected by MoAL (in 2018)
	- Yield trend analysis in MOV	Agricultural survey and census microdata (surveys: 2014, 2015, 2016; census: 2018) collected by the MoAL, and

		agriculture survey and census (survey: 2021; census: 2022) collected by the NSB.
Nutrient balance	Aggregated nutrient input and output analysis (at district and MOV level)	Agriculture survey and census reports published by NSB (in 2019, 2020, 2021); crop nutrient contents published by LFL (in 2019) and Linquist (in 2020).
Institutional setting for organic agriculture	Qualitative content analysis	Annual reports published by NCOA (for 2019-2023) and ARDC Bajo (for 2012-2016); consultation report published by ARDC Bajo (in 2012), ICIMOD and MoAL published (in 2018); status report published by NCOA (in 2021).

Note: NCOA (National Center for Organic Agriculture); ARDC (Agriculture, Research and Development Center); MoAL (Ministry of Agriculture and Livestock); NSB (National Statistical Bureau); LFL (Bayerische Landesanstalt für Landwirtschaft); ICIMOD (International Center for Integrated Mountain Development); MOV (Model Organic Village).

We used agricultural surveys and census data to explore some of the relevant challenges related to yield gaps and nutrient balances (Table 6). The analysis was conducted for two contexts: 1) at the district level to understand yield gaps and nutrient balances under total conversion to OA and 2) at the MOV level to understand how the existing certified organic farms perform in terms of yield and nutrient balance. However, we limited the yield analysis of MOVs to simple trend analysis due to the limitations of representative farms and the non-availability of important information related to the use of mineral fertilizers and chemical pesticides before conversion to organic farming, weather and other agronomic conditions, and farming practices. We describe the methods applied in detail for these challenges in the following subsections.

2.4.1 Calculation of yield gaps

The analysis of yield differences was based on data from the 2018 National Agricultural Census, which includes crop production information from 66587 farmers (MoAL, 2018). This recent survey included questions about agrochemical use at the farm level. The Ministry of Agriculture and Forests (MoAL) in Bhutan provided the deidentified dataset. If chemical fertilizers, pesticides, or both were used on the cropland, then crops were classified as conventionally produced. The dataset was used to generate variables identifying three main AEZs based on altitude data at the subdistrict (interchangeably used with gewog) level. AEZ1 refers to the humid, subtropical zone below 1200 masl. AEZ2 refers to the arid subtropical zone between 1200 and 1800 masl. AEZ3 refers to the temperate zone at elevations above 1800 masl.

Following the approach by Feuerbacher et al. (2018), the yield data were calculated by dividing the production in kilograms by the area in hectares; to ensure accuracy, the outliers at the 1% and 99% percentiles within each crop and AEZ were excluded. The yield differences were then calculated as the ratio of organic yield to conventional yield per crop and AEZ level, but only if there were at least 25 observations per farming system (OA or conventional agriculture); all crops without a sufficient number of observations were excluded from the analysis. Observations of crops grown without agrochemicals, also known as organic crops, were included in the study, while observations of organic crops grown by farmers who used agrochemicals in other crops were excluded to avoid possible effects of synthetic fertilizers through crop rotations and to eliminate any effects of pesticide application or pesticide drift. Fieller confidence intervals were calculated for the yield ratios, and the levels of significance were tested using the nonparametric Wilcoxon rank sum test on the basis of the absolute levels of the yield ratios. A nonparametric procedure was used because the Shapiro–Wilk W test showed that the majority of the crop yields did not follow a normal distribution or a log-normal distribution. The hypothesis for this yield gap analysis is that the organic yield will be lower than the conventional yield (i.e., a ratio less than one for organic to conventional yields).

In addition, we performed a simple trend analysis of the yields of two MOVs (Galeythang and Longpa Nobgang), including the Khatoed subdistrict, which converted to organic farming when OA was promoted by public policy in Bhutan. Specifically, we traced the yield performance of these MOVs for 2014 and 2015 (before the MOVs were established in 2017) and for 2016, 2018, 2021, and 2022 (after the MOVs were established). In addition, we included yield data for Khatoed for 2016, 2018, 2021 and 2022. Crops for which data were not available for the analysis periods before or after the institution of the MOV were ignored, which resulted in 11 crops for the analysis. The median yields in each year are based on what sampled farmers reported for the specific crop. After the necessary criteria, as indicated above, were screened, the median yield (kg ha^{-1}) was calculated for the following samples: 2014 (Galeythang =11, Longpa Nobgang =18), 2015 (Galeythang =6, Longpa Nobgang =17), 2016 (Galeythang =16, Longpa Nobgang =20, Khatoed =39), 2018 (Galeythang =54, Longpa Nobgang =59, Khatoed =54), 2021 (Galeythang =20, Longpa Nobgang =25, Khatoed =34), and 2022 (Galeythang =39, Longpa Nobgang =56, Khatoed =47). Yields were calculated with microdata from agricultural surveys and censuses (surveys: 2014, 2015, 2016; census: 2018) collected by the MoAL and from agricultural surveys and censuses (survey: 2021; census:

2022) collected by the NSB. The microdata used for analysis were deidentified and shared by MOAL and NSB.

2.4.2 Calculation of nutrient balance

Managing nutrient output and input to organic farms is a critical aspect of the overall balance in OA systems. This section evaluates the rough nutrient balance of nitrogen (N), phosphorus (P), and potassium (K) for all 20 districts and five OA sites. To calculate the nutrient balance, we used an aggregated farm gate balance at the district level (for district-level nutrient balance) and MOV level (for the five organic sites) with simple input and output nutrient balance that considered inputs from FYM and nutrient output through harvested products for 27 crops in the 20 districts and 25 crops in the organic sites. Because of the lack of specific Bhutanese data, nutrient contents for all crops except for rice were derived from the LFL (Bayerische Landesanstalt für Landwirtschaft), i.e., basic data for 2019 published by the Bavarian State Institute for Agriculture in Germany. The nutrient output for rice grain was derived from Linquist (2020). Crop and livestock data were obtained from Agriculture Statistical Reports published by the Ministry of Agriculture and National Statistical Bureau. For districts, crop data were averaged over three periods (2019-2021), and livestock data were from 2021.

We calculated our nutrient balance using a simple input and output system for 20 districts (district “i” is the system border) and 5 organic sites (with the respective MOV “i" as the system border) and a focus on the cropping system and the available fertilizers as follows:

$$\text{Nutrient balance}_{\,\text{i}} = \frac{\text{Nutrient Input}_\text{i}}{\text{arable land}_\text{i}} - \frac{\text{Nutrient Output}_\text{i}}{\text{harvested area}_\text{i}} \qquad (1)$$

$$\text{Nutrient output}_\text{i} = \sum\nolimits_\text{j} \text{harvested product}_\text{j} \ \mathbf{X} \ \text{nutrient content per unit of product}_\text{j} \qquad (2)$$

$$\text{Nutrient input}_\text{i} = \sum\nolimits_\text{k} \text{livestock units}_\text{k} \ \mathbf{X} \ \text{manure per unit}_\text{k} \ \mathbf{X} \ \text{nutrient content per manure unit}_\text{k} \qquad (3)$$

The nutrient balances for N, P and K are expressed in kg ha^{-1} for each district and organic site for one year. In Equation (1), the nutrient balance is a simple difference between nutrient input and output. Since only 27 important crops (common in all districts and MOVs) are considered for nutrient balance, we adjusted the area separately for nutrient input and output in Equation 1. In Equation (1), for nutrient output, harvested area is calculated as the sum of the harvested area for only the crops used in our analysis. For nutrient input, arable land in each district or MOV is considered, which is calculated as the sum of the total area owned, including the area under permanent crops, the area under temporary meadows and pastures, and the area under permanent meadows and pastures. Since we considered only 27 crops instead of all crops grown in the district, the agricultural area in Equation (1) is greater in nutrient input than in nutrient output calculation. Because of the detailed census data available in 2018, the agricultural area data were based on microdata from that census (MoAL, 2018). In Equation (2), nutrient output in each organic site or district “i” is calculated using the quantity of harvested products (MT, metric tons) for product type “j” multiplied by its nutrient content (N, P and K, respectively) in kg per MT. Nutrient output was summed over all harvested products “j” for each district “i”. The nutrient content for crops is based on fresh matter and includes products without byproducts such as straw. In Equation (3), nutrient input is considered only for manure input from livestock but nutrient output through animal products are not included, since only minority of farmers are specializing in sale of animal products like cheese, butter and milk in Bhutan. We did not include mineral fertilizer for nutrient input since the amount applied per hectare is so low (see Supplementary Table 18). Normally, given that manure in low-input systems is mainly derived from internal recycling (animals feeding on harvest residues etc.) and manure is returned to the field, it is not really an input within the given system (farm, village, district). But in the Bhutan, as animals are mainly fed with fodder from outside the farming system (leaves, grasses and herbs from non-farm land and grazing on non-farm land) we consider the nutrient contents in manure as inputs in our analysis. We also ignore nutrient from plaggen soil which are often collected by farmers in Bhutan for soil fertility. For example, in an organic farming village (Berti in Zhemgang district) farmers depend entirely on plaggen soil for production of watermelon. Our exclusion of these above-mentioned sources of nutrient input are primarily due to lack of research and data. The total nutrient input was calculated for all animal types *k* as a product of livestock units, their amount of manure (in MT) in terms of dry matter (DM), and nutrient content (N, P, and K, respectively, in kg per MT of DM). To calculate livestock units, the livestock population was taken from the Agriculture Statistics Report (NSB, 2021). The populations of livestock in each district and MOV were multiplied by conversion factors. The conversion factors were based on Wangchuk & Dorji (2008). The livestock types for calculating manure production included Holstein-Friesian, Brown Swiss, Jersey, Jatsha-Jatsham, Yangku-Yangkum, Doeb-Doebum, Doethra-Doethram, Nublang-Thrabum, Mithun, and Buffalo, which have different categories and conversion factors (1 year or younger [livestock conversion unit = 0.5]; heifer [livestock conversion unit = 0.7]; milking, dry, infertile, breeding, bull and bullock [livestock conversion unit = 1]). Manure (dry matter) was generated based on experiments conducted in Bhutan (Chettri et al., 2003; DRDS, 2001).

Based on these sources, the annual FYM production is assumed to be 3.2 kg/day * share of time spent on the farm (73% and 67% for improved and local livestock breeds, respectively) * 365 days in a year. We assume that the manure collection rate mentioned above is the same in all districts and MOVs. Fresh manure was converted to dry matter according to the methods of Samdrup et al. (2010), who assumed that 68% of the manure was dry matter. Based on long-term experimental data, the nutrient content of FYM in Bhutan is assumed to be 1.6% N, 0.8% P and 2.9% K of dry matter.

2.5 Results

2.5.1 Management practices embodied in the organic standard and the programs implemented in the field

One challenge for OA is the risk of abandoning environmentally friendly management practices provided by the sustainability standards of OA (Meemken, 2020). Studies have noted the mismatch between actual regulations and the intended goals of converting to OA (Seufert et al., 2016) and conventionalizing OA (Guthman, 2004). This is evident in the case of organic Sikkim, where the state has forgotten the goal of agroecology and reduced OA in Sikkim to a narrow definition of no mineral fertilizers or synthetic pesticides, which is often driven by certification and a focus on export markets (Meek & Anderson, 2019). The disregard of such regulations is often linked to the active pursuit of increased yields through coercive government measures (Bhatt & John, 2023; Meek & Anderson, 2019) but can also directly conflict with the goals of OA (Seufert et al., 2016).

Organic agriculture is more popular with consumers than other food standards due to its transparent and codified farming practices (Schader et al., 2021). In Bhutan, these regulations are codified in the Bhutan Organic Standard (BOS) (NCOA, 2019). The organic principles of the regulations emphasize the use of “natural” and “locally” sourced resources. For example, the BOS states that the production of organic fertilizers and pesticides should use resources that are readily available in the local area. The BOS also emphasizes the ecological sustainability of “soil”, “water” and “biodiversity”. For example, agricultural practices, including irrigation, crop rotation and tillage, require careful management to maintain soil fertility, avoid water pollution and preserve biodiversity. The BOS is also committed to the welfare of “humans” and “animals”. The standard states that the welfare of animals is crucial in the housing, transportation and slaughter of farm animals. The welfare of humans is also critical according to the standard, particularly with regard to the protection of health during fertilization, the use of pesticides and other potentially hazardous agricultural activities. The standard also states that Bhutanese labor laws should protect agricultural workers both locally and internationally.

Unique to the BOS is the content of a separate section on “ecosystem management". Table 7 shows a group of environmentally best management practices for crop and livestock production identified by the NCOA. All of the required management practices are adequately addressed in the BOS, with the exception of alley cropping. The BOS emphasizes ecological management that utilizes the environment to achieve sustainable crop and livestock production. Management practices include crop rotations, composting and the integration of animals to increase productivity while protecting the environment through various methods, such as alley cropping, agroforestry, living barriers, and crop cultivars. However, in a nationwide transition to OA, it would be a challenge to impart this knowledge to farmers.

In theory, the BOS includes all the necessary regulations for principles and management practices. However, it is difficult to determine whether these methods are implemented in practice without detailed qualitative studies. This is where the NCOA's annual reports (2020-21; 2021-22; 2022-23) can help to shed light. Table 8 shows the different types of capacity-building activities carried out by the NCOA as part of the outreach program funded by various projects. For example, between 2019 and 2023, the NCOA started training organic officers and extension workers in different districts on organic principles, management practices, and registration and certification activities. Table 8 also shows the number of beneficiaries of various organic farmer training programs, including training on organic principles, soil fertility management, crop diversity, and value chain development. As shown in Table 8, several features stand out: 1) farmers receive training on soil fertility and crop protection, but it remains unclear what type of practices are involved; 2) training for those responsible for OA and extension seems to focus more on regulations and compliance, such as certification and internal control systems (ICSs); 3) the measures seem to be at a very early stage of OA implementation; 4) the number of beneficiaries seems to be small; and 5) the training for farmers is still at an earlier stage and focuses on awareness of organic principles, technologies, nutrition, and crop diversity.

To better understand this, annual reports were searched for information on the support provided to organic farmers. Table 9 illustrates the nonmonetary support provided to farmers participating in MOV programs and the corresponding number of beneficiaries. According to Table 9, several characteristics stand out: 1) agricultural support is not provided in the form of cash; 2) support for organic fertilizers and pesticides is input-oriented, and there is evidence of provision of organic fertilizer; 3) the number of beneficiaries is much lower than in Table 8 because only farmers in selected organic model villages (MOVs) benefit; and 4) other agricultural support services, such as seeds, seedlings, protected cultivation, irrigation, electric fencing and machinery, are provided to organic farmers in the MOV. Based on annual reports, we find that of the 67093 farms, 2% (1231 farms) received training and 2% (1108 farms) received support from the NCOA between 2020 and 2023.

Table 7**.** Standard requirements [a)] in organic farming according to the Bhutan Organic Standard (BOS)

Management practices	Standard requirements	Bhutan Organic Standard (2022) (For crop production and ecosystem management)
Living mulch	Required	Mulching with Locally Sourced Materials.
Dead soil cover	Required	Mulching with Locally Sourced Materials.
Cover crops	Required	Use vegetative cover as an effective soil and water conserving measure.
Conservation tillage	Required	Adopt conservation tillage practices instead of continuous deep plowing.
Alley cropping	Not Mentioned	
Agroforestry	Required	Utilize sustainable methods for recycling nutrients, including crop rotations, mixed crop/livestock systems, and agroforestry, as well as intercropping systems that utilize legumes.
Living barriers	Required	Promote diversification along the edges and periphery of the agricultural plot. This can be achieved by planting windbreaks, shelter belts, and living fences along the crop-field boundaries. Such resources can improve the habitat for beneficial insects and provide them with sources of food, organic matter, and pollen. Moreover, these features help modify the microclimate and wind speed.
Rotations	Required	Introduce versatility to the crop-rotation by including legumes, green manures and deep-rooting crops to improve soil health and fertility.
Crop associations	Required	Select crops and associated plants, which have high nutrient use efficiency.
Cultivar mixtures	Not mentioned	
Animal integration	Required	Plant or animal-derived materials that have undergone degradation through microbial activity or other natural processes should serve as the foundation for the fertilization plan.

Note: Author constructed using Seufert et al. (2017) and BOS (NCOA, 2019). The management practices are a set of sustainable management practices as identified by Altieri & Rosset (1996). [a)] Standard requirements are defined as best practices that should be adopted by the farmers.

Table 8. Types of Capacity Building Trainings Offered by the National Center for Organic Agriculture (NCOA) under the "Organic" Intervention Program in Bhutan between 2020 and 2023

Types of capacity building provided	Number of Beneficiaries			Type of beneficiary
	2020-21	2020-21	2022-23	
Training on BOGS (Bhutan Organic Guarantee System) and ICS (Internal Control System)	54			Organic Focal Persons and Researchers
Training on Instituting ICS [a)]	168	79	274	Farmers
Awareness training on organic principles and crop production [b)]	86	195	25	Farmers
Training on enhancing soil fertility, plant protection and crop diversity	25	15	159	Farmers
Vegetable nursery management	60			Farmers
Awareness training on gender empowerment and safe nutritional food diversity	25			Farmers
Training on organic farming and enterprise development	4			Youth Farmers
ICS implementation	50			Farmers
Training on participatory natural resource planning and data management		60		Organic Focal Persons
Awareness training on women's role in decision making for agriculture, product development and value chain		15		Farmers
Exposure training and field visits on organic and climate smart technologies		51		Farmers
Training on registration and certification		58		Organic Focal Persons and Extension Officers

Note: Author constructed using data from Annual Report published by NCOA under the list of programmes carried out by Policy, Regulation and Coordination Programme department. Source: NCOA (2020-2023), Annual Reports. Reports (ncoa.gov.bt). [a)] Internal Control System (ICS) is a mechanism for farmers in a farmers' group to guarantee compliance to organic standards. [b)] This group of beneficiaries may include farmers who are outside the "organic" farming system. Unless stated otherwise, farmers listed here operate under the "organic" farming system defined by Bhutan Organic Standard (BOS), which is part of the family of standards under IFOAM.

Table 9. Types of non-monetary farm support provided under the organic intervention program by the National Center for Organic Agriculture (NCOA) in Bhutan between 2020 and 2023

Support Category	Input types	Number of Beneficiary		
		2020-21	2021-22	2022-23

Seed/Seedlings	Vegetable, potato, sub-tropical fruits, garlic, buckwheat mustard, vegetables, *Sesbania bispinosa*	57	97	56
Bio-pesticides	Materials for bio-pesticides	36	39	
	Sprayer	36	34	
	Traps	41	18	
Bio-input production	Compost storage facility		59	
	Materials for liquid manure production		16	
	Organic manure	5		
	Vermi compost	57		
	Chicken manure	57		
	Bio-digester		37	
Protected cultivation	Tunnel farming house	17	32	2
	Fencing net	2	52	
	Nursery tray		18	
	Mulching plastic	20		16
Irrigation	Water storage tank	2	36	
	Sprinklers	36		
	Drip irrigation set	2		
	Pipes	2		
Electric fencing	Materials for fencing		53	
Machinery	Vegetable dryer		36	
	Vegetable crate	36		
	Fabricated green house for solar dryer		5	
	Buckwheat de-husking machine		17	
	Flour milling machine	57		
	Oil expeller			5
Enterprise development	Packaging materials		17	

Note: The inputs are purchased and supplied to farmers from the MOV (Model Organic Villages: Galeythang, Langpa-Nobgang, Lull, Chanachen, Phasuma-Zamsa, Ngange). Author constructed using data from Annual Report published by NCOA under the list of programmes carried out by Policy, Regulation and Coordination Programme department. Source: NCOA (2020-2023), Annual Reports. Reports (ncoa.gov.bt).

2.5.2 Yield gaps

Figure 3 shows the yield gap analysis for different AEZs across the 20 crops used for our analysis. The results from the yield gap analysis of self-reported data by farmers show that, overall, organic yields are typically lower than conventional yields. Specifically, compared with those in conventional farming systems, yields in organic systems are 28% lower in humid subtropical AEZs, 18% lower in dry subtropical AEZs, and 45% lower in temperate AEZs. The average organic-to-conventional yield ratios across the AEZs from our analysis are high for cereals (69-92%); that is, organic yields are 8 to 21% lower than conventional yields. The average organic-to-conventional yield ratios across the AEZs were the lowest for potato (e.g., 52% in AEZ2).

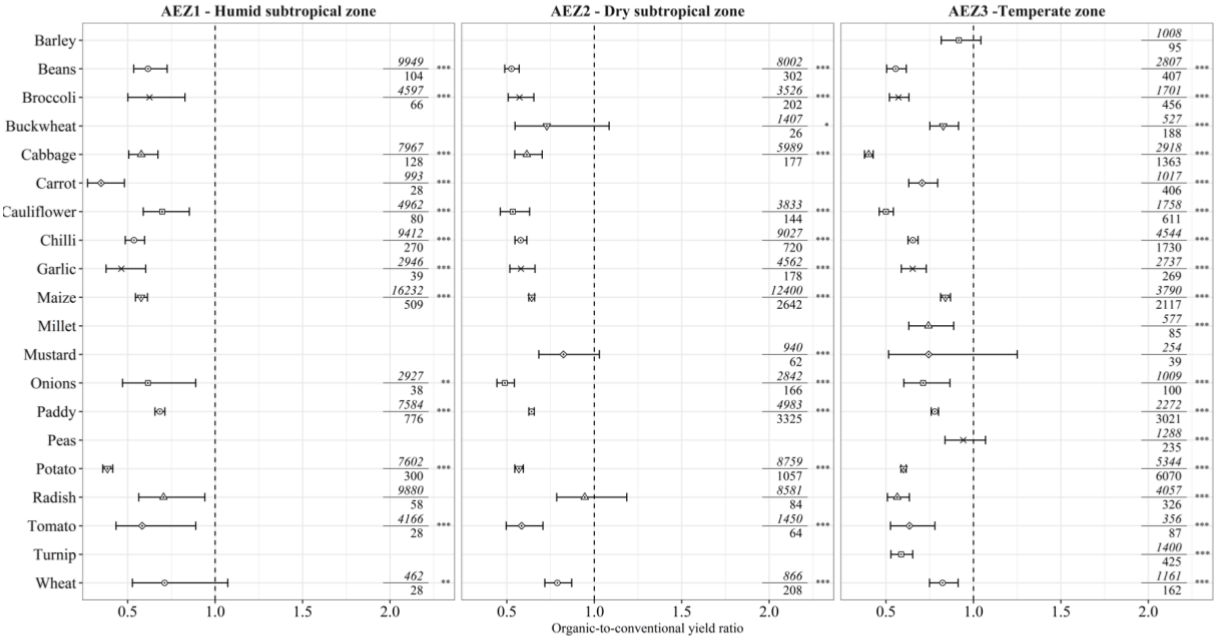


Figure 3. Organic-to-conventional yield ratios for 20 crops across agroecological-zones in Bhutan.

Note: Calculations based on microdata from agriculture census in 2018, published by the Ministry of Agriculture and Livestock (MoAL). The panel on the right-hand side shows the significance level of the Wilcoxon rank-sum test (*** P < 0.001) and the fraction shows the number of organic (numerator) and conventional (denominator) observations.

The performance of organic systems varies substantially across crops (Figure 3; see Supplementary Table 20 for details). For example, in temperate AEZ3, the yield gaps of organic cereals such as barley, buckwheat (pseudocereal), maize, millet, and wheat were relatively low (92%, 83%, 84%, 74% and 82%, respectively, organic-to-conventional yield ratios); however, the yield gaps were statistically significant (except for barley). However, organic carrots and potatoes had significantly lower yields than did conventional crops (only 35% and 38% of conventional yields, respectively) in the humid subtropical AEZ1.

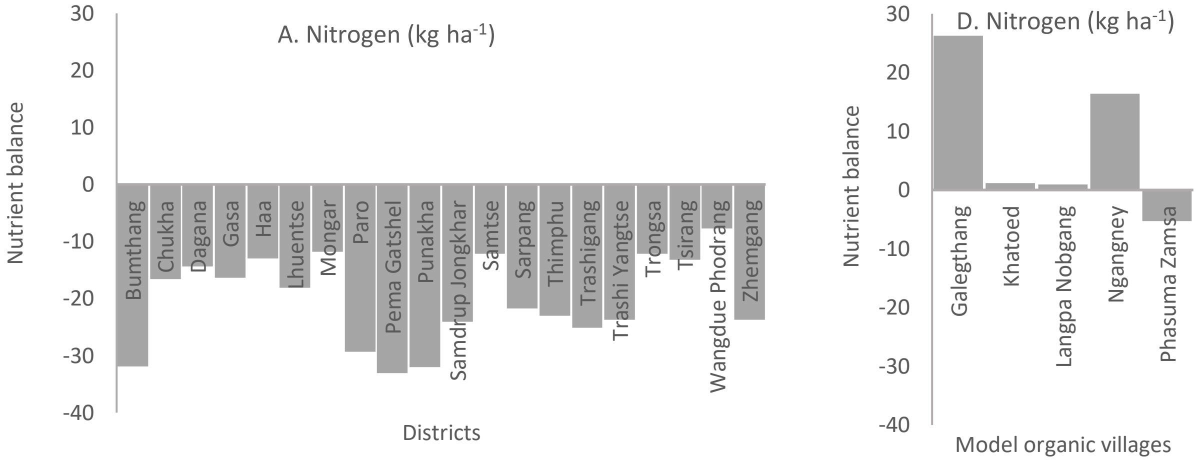
Overall, the MOV yields both increased and decreased after transitioning to OA (see Supplementary Table 21 and Supplementary Figure 5 for details). Specifically, the yields of 4 out of the 11 crops analyzed decreased, while the yields of 5 out of the 11 crops increased. Among the yields showing a decreasing trend were cereals (barley, sweet and bitter buckwheat), and vegetables (potato). For yields with an increasing trend, crops included legumes (beans) and vegetables (cauliflower, carrot, and broccoli, and cabbage). For radish and peas, yields did not change.

After transitioning to organic system, yields for potato declined the most (5615.13 kg ha^{-1} compared to 9731.80 kg ha^{-1}), while yields for carrot increased the most (4940 kg ha^{-1} compared to 2470 kg ha^{-1}) (Figure 3; see Supplementary Table 21 for details). Among the crops with high nitrogen requirements, yields decreased for barley (1235 kg ha^{-1}compared with 1979.53 kg ha^{-1}) (Figure 3; see Supplementary Table 21 for details). For legumes, yields also increased after the transition. These values were 2964.00 kg ha^{-1} (compared to 2470.00 kg ha^{-1}) for beans (see Supplementary Table 21 and Supplementary Figure 5 for details).

2.5.3 Nutrient balances

Figure 4 (A, B and C) shows the calculated nutrient balances in the 20 districts in Bhutan. The results revealed N deficiencies in all 10 districts (-21.72 kg ha^{-1} to -33.12 kg ha^{-1}), N balance in 10 districts (-7.74 kg ha^{-1} to -18.17 kg ha^{-1}), P deficiencies in one district (-6 kg ha^{-1}), P balance in 10 districts (-1.71 kg ha^{-1} to 1.87 kg ha^{-1}), P surplus in nine districts (2.02 kg ha^{-1} to 12.12 kg ha^{-1}), K deficiencies in three districts (-9.56 kg ha^{-1} to -5.6 kg ha^{-1}), K balance in one district (1.72 kg ha^{-1}), and K surplus in 16 districts (5.63 kg ha^{-1} to 30.54 kg ha^{-1}) (details are shown in Supplementary Tables S1, 13 and 14).

Figure 4 (D, E and F) shows the calculated nutrient balances in the five MOVs in Bhutan. The results revealed N surplus in one MOV (26.28 kg ha^{-1}), N balance in four MOVs (-5.27 kg ha^{-1} to 16.38 kg ha^{-1}), P balance in one MOV (1.78 kg ha^{-1}), P surplus in four MOVs (5.51 kg ha^{-1} to 13.25 kg ha^{-1}), and K surplus in all five MOVs (10.80 kg ha^{-1} to 48.79 kg ha^{-1}) (details are shown in Supplementary Tables S1, 13 and 14).



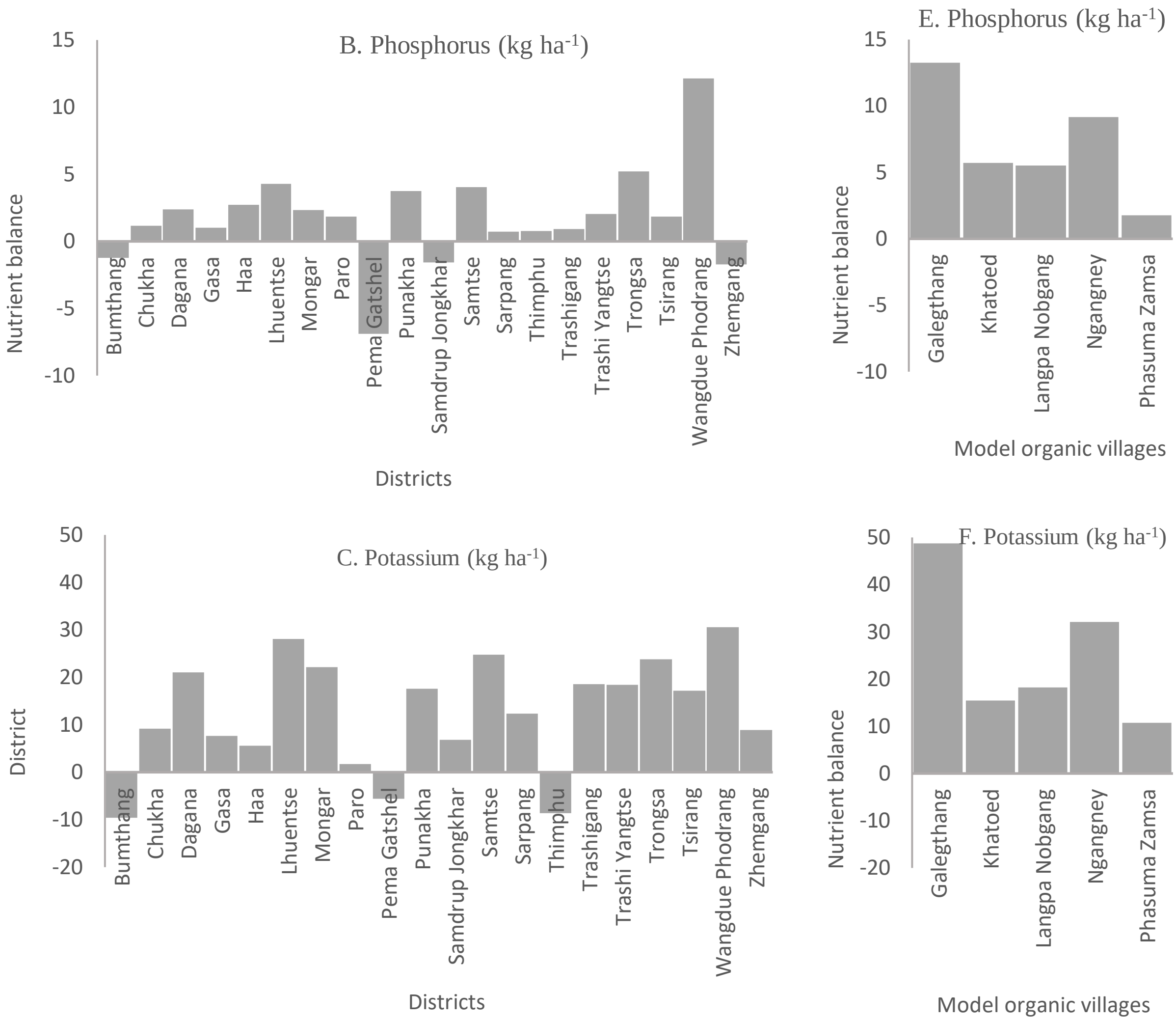


Figure 4. Nutrient balances (kg ha^{-1}) for 2019-23, in Bhutan.

Note: Left Panel: Aggregated N, P, and K balances (in kg ha^{-1}) in 20 Bhutanese districts for 2019-2021. Nutrient balances based on calculations presented in Table 10. Right Panel: N, P, and K balances (in kg ha^{-1}) in 5 organic sites in Bhutan for 2022. Nutrient balances based on calculations presented in Table 11. Nutrient balances represent differences between nutrient outputs through harvested products and nutrient inputs to soil through farmyard manure (FYM), aggregated at district and at organic village level. 1 kg = 10^3 g; 1 MT = 10^3 kg; 1 ha = 10^5 m^2.

2.5.4 Institutional setting for organic agriculture

In low-income countries, especially when OA is promoted as an aspirational goal, the state prefers to position itself as a transformer of traditional agricultural practices (Das, 2024). Organic agriculture is knowledge intensive and not input intensive (Jouzi et al., 2017). In this context, however, the state apparatus often suffers from inefficient management capacities (ICIMOD & MoAF, 2018; Neuhoff et al., 2014) to build knowledge and capacity (Scialabba, 2000). In a top-down, area-wide transformation of the farming system, policy-makers often assume that the underlying farming system and farmers' motivations are the same, making it difficult to provide institutional support (Seufert et al., 2023). Research on yield improvement through more diverse crop rotations and multiple cropping is commonly absent in low-income countries (Ponisio et al., 2015), highlighting the challenges of resource-poor government agencies.

Although we illustrated the recent programs implemented by the NCOA in the previous section, OA was introduced in Bhutan much earlier. Thus, we used annual reports from two Agricultural Research and Development Centers (ARDCs) in Yusipang and Bajo to examine the institutional problems of organic development since its inception. Historical analysis of this area showed that organic programs have faced many challenges in terms of implementing them, achieving goals, and obtaining sufficient funding.

Prior to the establishment of the National Organic Program (NOP), OA was first introduced in Bhutan in 2004. The Gasa district was declared organic in its entirety (ARDC, 2012). This decision was made by the local farmers and endorsed by the District Development Committee as a grassroots initiative (ARDC, 2012). Farmers realized the potential of marketing organic produce due to the low usage of mineral fertilizer and chemical pesticides, but the concept of certification for identifying themselves as organic farmers came only later. OA in Gasa initially emerged due to favorable conditions such as a clean environment, limited or negligible use of mineral fertilizers and pesticides, and road access, which provided opportunities for marketing organic produce (ARDC, 2012). However, all farmers in three out of the four subdistricts in Gasa had abandoned OA by 2016; only the Khatoed subdistrict continued to operate under the organic system. The remaining subdistrict, Khatoed, was classified as a "certified organic" by a third-party control body (i.e., BAFRA) in 2016 to sell its potatoes and garlic in the local market and high-end hotels (Kuensel, 2017). Since its inception, farmers in Khatoed have been provided with capacity-building training, practical demonstrations and training on organic concepts, training on integrated pest management and composting, and opportunities for study tours outside the country (ARDC, 2012). Subsequently, inputs were provided in the form of seeds, irrigation pipes, and tunnel farms, as well as improved market access and group formation (ARDC, 2012). While the NOP provided financial support to farmers and extension workers for capacity building and inputs, service delivery was considered weak, and there was a lack of adequate monitoring and evaluation of progress (ARDC, 2012). As a result, no measurable results were observed (ARDC, 2012).

In 2012, the Agriculture Research and Development Center (ARDC), which is based in Bajo and closest to the organic farmers of Gasa, assumed responsibility for the development of OA in the region. As coordinator and donor, the NOP continued to oversee the project. In addition to evaluating farmers' yield performance, the ARBC Bajo set up a program to transfer the research center's technologies to farmers, and crop diversification was one of the main measures initiated. The center also emphasized commercialization by growing vegetables and fruits out of season. However, the outreach program with ARDC Bajo ended in 2016 (ARDC, 2012; 2013; 2014; 2015; 2016). After ARDC Bajo took over the organic program in Gasa, the focus obviously shifted to crop diversification. However, before coming under the ARDC Bajo, farmers in Gasa faced many challenges related to lower yields, pests and diseases, and a lack of markets for organic produce (ARDC, 2012).

In 2016, the National Organic Program (NOP) developed a landscape approach to OA that aimed to transform entire villages or chiwogs (associations of villages) into MOVs. The NOP sought proposals, but initially, only one district (Haa) submitted one, which led to the formation of the Longpa-Nobgang MOV. With the aim of improving farmers' knowledge and ability to market certified quality products, the Asian Food and Agriculture Cooperation Initiative project granted funds to all households in this MOV from 2016 to 2019 (NCOA, 2021). As of 2023, five additional MOVs were established in different parts of the country. After a long time, the organic intervention seemed to have found new rigor by shifting its focus to improving farmers' knowledge (NCOA, 2022-23).

In 2020, the Department of Agriculture (DoA) identified one of its ARDCs, specifically the one located in Yusipang, to oversee and facilitate the development of OA in Bhutan. Subsequently, it was renamed the NCOA and replaced the NOP. To spearhead the nationwide certification of OA, the Policy, Regulation and Coordination Programme (PRCP) unit was established. The PRCP offers certification through the LOAS, which follows the BOS. The organic program underwent a new shift toward standards and compliance.

Apart from the sudden change in the agencies responsible for the development of OA, there are also indications that the underlying motivations for implementing OA in the country have changed. In recent years, for example, OA has also been promoted under the Intended Nationally Determined Contribution (INDC) program, which aims to develop low-emission agriculture. The strategy for low-emissions development in Bhutan aims to reduce the use of synthetic fertilizers by 5% annually (RGoB, 2021). In another program, OA is promoted to increase productivity, including through the promotion of farmer associations and market access under the Food Security and Agriculture Productivity Project[3]. In addition, OA is being used as a tool to expand the knowledge base of smallholder farmers and strengthen the resilience of fragile mountain ecosystems in the Eastern Himalayas[4]. However, the government's goal seems to be certification and production for the export market (NCOA, 2020; 2021; 2022; 2023). The goal of promoting OA has thus changed constantly since the introduction of the National Organic Program (NOP) and the creation of a National Framework for Organic Agriculture (NFOAB) in 2006 (DOA, 2006).

The lack of technical competence during the implementation of the organic program led not only to several changes in the implementing agency, motivations and activities for its development but also to a lack of funding. Funding for OA activities decreased significantly from 0.1825 million euros (1€ = 88 Ngultrum) in 2012-13 to 0.0275 million euros in 2016-17 (ICIMOD & MoAF, 2018). Between 2016 and 2021, the Longpa-Nobgang MOV received funds from three different mechanisms, each from different donors (NCOA, 2021), which illustrates the lack of reliability of the funds. This in turn affects the number of beneficiaries receiving support for capacity building and farm-input support.

2.6 Discussion

Understanding the challenges of OA can help to better inform policies that improve the choice of sustainable agriculture in low-income countries. To date, OA in low-income countries has commonly been designed and implemented by governments and nongovernmental organizations using top-down approaches (Babajani et al., 2023; Bendjebbar & Fouilleux, 2022; John & Bhatt, 2023; Nordhaus & Shah, 2022). Understanding the challenges of converting to OA in Bhutan can lead to transferable findings to many similar

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[3] Food Security and Agriculture Productivity Project (FSAPP). Department of Agriculture (DoA) [doa.gov.bt].

[4] Ministry of Agriculture and Livestock (MoAL), International Centre for Integrated Mountain Development. Resilient Mountain Solution (2019) (https://www.icimod.org/initiative/rms; About RMS Bhutan (moal.gov.bt)).

contexts characterized by smallholder farming systems. In Bhutan, there are indications that the government and organic farmers are facing challenges in very important aspects of OA: management and farming practices, yield gaps, nutrient balances, and the institutional setting for OA.

A comparison of the regulations and principles codified in the BOS with the measures actually implemented in practice provides some interesting insights. In terms of regulations, the BOS consists of a separate section on ecosystem management and production linkages. This is in contrast to most organic regulations within the IFOAM family of standards, where the focus is mostly on the avoidance of mineral fertilizers and synthetic pesticides (Seufert et al., 2017). The results suggest that there is a mismatch between theory and implementation. For example, training for organic focal persons and extension workers focuses on registration and certification, and farmer training focuses on internal control systems. The number of beneficiaries of free access to local organic certification is much greater than the number of beneficiaries of other agricultural support and capacity building through NCOA. This discrepancy is a serious challenge and confirms the findings of studies that point to the risk of ignoring the agro-ecological objectives of OA (Meek & Anderson, 2020). Studies conducted in low-income countries have shown that farmers participate in project-based programs such as OA because they expect incentives and inputs (Sonam & Martwana, 2012) and abandon OA once the project ends (Bottazzi et al., 2023). The results also suggest that while many have opted for LOAS, it is not apparent how they benefit from locally available organic certification.

The results also indicate that there is an increase in arable land area under the organic system, which increased from 1.01% to 3.24% of the certified OA area in 2019-2020 and from 2022-2023 and from 3.51% to 6.07% of the registered OA area in 2019-2020 from 2022-2023. The results also indicate that not all farming households who register for organic also sign-up for certification. Unlike in other regions of the world, such as in the European Union, where registered farmers ultimately have to comply with the EU OA regulation and must be certified organic, in Bhutan, this does not seem to be the case. The registration and certification processes are not obligatory. The duration between registration, in which farmers indicate their interest in converting to OA, and certification, where farmers are eventually fully recognized as organic farmers, seems to be very short compared to the European Union Standards, which require two to three years (Stolze & Lampkin, 2009). It is evident that the focus on land and farmer certification is gaining momentum; however, without any earnings from organic exports and lack of premia for organic produce in the country, the certification program is similar to the "certification nationalism" in Thailand (Baird, 2024), where certification at the national level increased without any benefits for the farmers. At the moment, it is not clear how the LOAS benefits organic farmers since only a few organic farmers export, and they have to rely on standards and control body from outside the country.

The average organic-to-conventional yield ratios from our analysis are significantly less than one; that is, overall, organic yields are usually lower than conventional yields, confirming studies highlighting the lower yields of OA (Feuerbacher et al., 2018; Seufert et al., 2012) while contradicting higher yield reporting for low-income countries (Badgley et al., 2007). For instance, Seufert (2019) reported that, on average, the organic-to-conventional yield ratio is 0.81-0.75 (i.e., yield ratios less than one), while Badgley et al. (2007) reported a yield ratio of 1.80. Our results on yield differences between AEZs are supported by previous studies (De la Cruz et al., 2023; Doltra et al., 2011; Feuerbacher et al., 2018). The yield differences across crops also confirm previous findings (Seufert et al., 2012). For instance, potato is among the crops with the highest yield in organic system falling within the range of 30% to 60% lower yields, according to Seufert et al. (2019). One important yield-limiting factor in OA is N availability. Our rough nutrient balance calculations seem to support this argument (Clark et al., 1999). In low-income countries, nitrogen inputs through FYM and legumes are inadequate (Falconnier et al., 2023), and only a small share of N, especially from FYM, is available for crops due to leaching and volatilization (Seufert et al., 2019). Pest outbreaks are often reported as another yield-limiting factor (Seufert et al., 2019). This can be confirmed in fields in Bhutan, where farmers report pests and diseases as problems in organic farming (ARDC, 2012) and where in-effective pest control methods have been promoted (NCOA, 2021). In general, the relevance of decreasing yields on organic farms can be confirmed through consultations with farmers and status reports published by NCOA (ARDC, 2012; NCOA, 2021).

We employed a simple statistical approach to analyze yield gaps, which limits the interpretability of our results. Although many factors and management practices limit yields in organic systems (Seufert, 2012), future research should address these limitations. Our study also emphasizes the need for field trials and for collecting yield data for all conversion stages, time periods and crops to evaluate how management practices in organic farming may reduce yield gaps (Seufert et al., 2012). The yields resulting from experimental field trials should then be further used to validate that the yield data from self-reported yields from farmers are often lower. For instance, experiments studying the effects of FYM on the yield of chili have reported an average of 9270 kg ha^{-1} [as compared to the highest mean of 4961.23 kg ha^{-1} from an agriculture census] (Dorji et al., 2009). For chilies treated with conventional inorganic inputs, average chili yields range from a low of 9490 kg ha^{-1} to as high as 12780 kg ha^{-1} (Dorji et al., 2009). Additionally, long-term experiments in Bhutan have reported yields of 4000-6000 kg ha^{-1} (Chettri et al., 2003), which are much greater than the average yields (2057.47 kg ha^{-1}, 2356.57 kg ha^{-1} and 3155.86 kg ha^{-1}) in OA reported from agricultural censuses.

Considering nutrient balances for N within ±20 kg ha^{-1} and for P and K balances within ±2 kg ha^{-1} as 'balanced', our results show that 50% of the districts have a balanced N budget, while the remaining 50% have a deficit. In the 20 districts, the results showed deficits in N, confirming results from field trials in the Mysore and Chitradurga districts of Karnataka, India (Patil et al., 2014). However, for MOVs, the results show a balanced N budget, which contradicts not only results from Karnataka (Patil et al., 2014) and Hyderabad (Surekha & Satishkumar, 2014) but also results from organic farms in Europe (Reimer et al., 2020, Reimer et al., 2023). The results of these studies revealed N surpluses of 38.9 kg ha^{-1} (Surekha & Satishkumar, 2014), 26.7 kg ha^{-1} (Reimer et al., 2020), and 45 kg ha^{-1} (Reimer et al., 2023). In these 20 districts, the results show balanced P, contradicting results from Hyderabad (Surekha & Satishkumar, 2014) but confirming results from Europe (Reimer et al., 2020, Reimer et al., 2023). However, the surplus P from the MOVs confirms the results of field trials, which reported 30.7 kg ha^{-1} (as compared to 7.08 kg ha^{-1}) in Hyderabad (Surekha & Satishkumar, 2014). For K, a surplus budget for both districts and MOVs confirms the findings of studies from Hyderabad (Surekha & Satishkumar, 2014), which have reported 28 kg ha^{-1} K, but contradicts results from Europe, which have generally reported either a balanced K budget (Reimer et al., 2023) or a deficit (Reimer et al., 2020). In case of the MOVs, the N is balanced, while there is a surplus in P and K. Given the fact that N is released slowly from farmyard manure and is prone to leaching and volatilization, we assume that N availability is a major cause for the low organic-to-conventional yield ratios. If the farmers managed to improve the N availability and the N supply to the main crops by a higher share of legumes in the crop rotation this surplus might be translated into higher organic yields.

The differences at the country level may be caused by several factors, which are highlighted in existing studies (Berry et al., 2002; Foissy et al., 2014; Möller, 2018; Reimer et al., 2020). These factors include variations in geographical origin, internal recycling, external organic nutrients, stocking density, use of biological N fixation, soil types, and crop rotations. Although our analyses of nutrient balances in existing organic farms (i.e. MOVs) indicate greater inputs than outputs for all the nutrients studied, this does not necessarily mean that everything on the farm is functioning optimally. There may be underlying factors that have not been addressed in this current work, which opens important research avenues for the future. For example, nutrient inputs and outputs may be balanced simply due to low crop yields (which, for farm income and food security reasons, should increase in the future), which are prevalent in low-income countries. This opens up research for studying the potential for cultivating more legumes, using human excreta as fertilizer, producing organic fertilizer, and increasing the livestock population to increase nitrogen without relying on mineral fertilizer (Brock et al., 2021). Related consequences, such as associated risks of importing pollutants into the soil with recycled nutrients (Bünemann et al., 2023) present important further research questions. There are also nutrients generated from atmospheric deposition, which is considered an important source in Africa (Stoorvogel & Smaling, 1990) and Nepal, which have geographical locations similar to those of Bhutan (Karna & Bauer, 2020).

One element of our analysis that needs some updates in future work is the nutrient (NPK) level for FYM. Because of the lack of studies, we had to use values from one field experiment conducted 20 years ago, which was validated with farm surveys. Another study has reported lower nutrient levels of 1.49% (N), 0.57% (P) and 1.70% (K) (Dorji et al., 2009); however, we ignored this study because of the lack of validation with farm surveys. Dorji et al. (2009) also reported a very low dry matter content for FYM at 38% (compared to the 68% used for our analysis). These values need to be updated and finalized with other field studies since they determine imbalances, given the primary role of FYM in nutrient input in low-income countries. Available data from low-income countries show differing nutrient contents in the FYM, and as a result, they also produce differing nutrient balances. For example, our assumed values of 1.6% [N], 0.8% [P], and 2.9% [K] are higher than those used in other low-income contexts, which use similar values for N (1.81) but lower values for P [0.39%] and K [0.90%] (Nyamasoka-Magonziwa et al., 2023). Based on these values, Nyamasoka-Magonziwa et al. (2023) reported a deficit K of -20 kg ha^{-1} (compared to our surplus of 12.52 kg ha^{-1}) and a surplus P of 2.3 kg ha^{-1} (compared to our balanced P of 1.74 kg ha^{-1}).

This study used FYM as the only fertilizer input; however, future research should address other sources for a realistic description of nutrient balances. We did not consider nonagricultural sources, which, for example, in Europe, account for more than 31-41% of the external nutrient inputs by organic farmers (Reimer et al., 2023). In Bhutan, the sizes of pasture available are different among the districts (see Supplementary Tables 18 and 19 for details), but we assumed the same collection rate for manure across districts and MOVs. Unlike in Europe, where livestock are fed from feed grown on cropland, it is customary practice to send livestock to the forest and also collect leaf litter for the FYM including plaggen soil in Bhutan. Hence, how much nutrients are imported from these (external) sources and how much nutrients are exported once livestock are released for grazing need to be properly considered. Research shows that nutrient input through grazing in forests within agroforestry systems is common and potentially contributes to sustainable practices such as OA (Smith et al., 2022). In our analysis, we assumed that all nutrients from the FYM would be available for crops, which future research should address. For instance, we estimated nutrient contents without considering leaching, volatilization, or soil characteristics (Kostensalo et al., 2024). In Bhutan, another important factor is nutrient loss through erosion, which, given the hilly and mountainous landscape on which fields are located, can result in a significant loss of nutrients (Nyamasoka-Magonziwa et al., 2023). By far, the most important factor that produces differences in nutrient balances is stocking density (see Supplementary Table 18 and 19). The average stocking densities (LU to the area of arable land) in our study were 1.88 LU ha^{-1} for districts and 2.18 LU ha^{-1} for MOVs, both of which are higher than the European averages; for example, Germany has an average stocking density of 0.6 LU ha^{-1} (Brock et al., 2021). However, high calculated stocking densities are plausible for Bhutan since open grazing is allowed and because the cropland area used for growing fodder crops is small. Thus, livestock play an important role in nutrient transfer in organic farming (Foissy et al., 2013).

The assumptions of our calculations including several factors may contribute to the varying nutrient balances among districts and MOVs (refer to Supplementary Tables 18 and 19). For example, districts and MOVs with a higher proportion of land allocated to N-demanding crops such as cereals and mustards experience greater imbalances between nutrient input and output. In general, farmers in Bhutan are oriented toward subsistence, as evidenced by the small proportion of farmers in the districts and MOVs who produce solely for the market. Without a market orientation, farmers may not be inclined or motivated to improve their nutrient management system. For instance, analyses show that only in districts such as Bumthang, Wangdue Phodrang, and Chukha, where potato is an important cash crop, farmers tend to invest in purchasing N fertilizers (see Supplementary Table 18 for details).

Most of the MOVs and other organic farms in Bhutan so far have been cooperatives specializing in cash crops, which consist mainly of vegetables. Since vegetables require less nutrients compared to cereals, this could explain why the nutrient balance in the MOVS is favorable compared to the districts. Another reason is that the stocking density in MOVs is higher than in districts.

In low-income contexts, there is still a lack of research analyzing the level of nutrient input and fertilization strategies in organic and conventional systems and how they result in different yield levels. Our analysis of paddy (rice) yields in Bhutan showed that organic yields are 78% of conventional yields [2523.30 kg ha^{-1} compared to 3580.02 kg ha^{-1}] (see Supplementary Table 20 for further details). However, we were unable to determine the extent to which nutrient input differences caused these differences due to data unavailability. For paddy rice, long-term experiments in Bhutan showed a stable yield of 4000-6000 kg ha^{-1} from an FYM application of 7000 kg ha^{-1} [which amounts to 76 kg ha^{-1} (N), 38 kg ha^{-1} (P) and 138 kg ha^{-1} (K)] (Chettri et al., 2003); however, no comparison with conventional rice yields was given. Evidence from field experiments in India indicates that rice yields are 15-20% with inorganic fertilizers than with organic fertilizers during the first two years but become comparable in subsequent years (Surekha & Satishkumar, 2014). In the experiment, the N input in organic farming was found to be 85% of that in conventional farming [i.e., 82.9 kg ha^{-1} in organic farming, compared to 96.7 kg ha^{-1}] (Surekha & Satishkumar, 2014). We can infer that in a low-income setting, there are differences in crop fertilization between organic and conventional systems, and yields can vary accordingly. However, the reality at the farm level may differ significantly and requires further research. Research conducted in Europe has shown that farmers in organic systems apply only 56% of the amount of nitrogen used in conventional systems, with an application rate of 96 kg ha^{-1} compared to 171 kg ha^{-1} (Oberson et al., 2024). Hence, reducing the yield gap between organic and conventional farming in a low-income country requires sources of nutrient inputs other than FYM, which is clearly insufficient in low-income countries (Falconnier et al., 2023).

While field experiments in a low-income country context show comparable yields between organic and conventional farming after the second year (Surekha & Satishkumar, 2014), this seems not to be the case for the majority of the crops grown in our MOVs in Bhutan (see Supplementary Figure 5). Although MOVs are secured under project funding for a minimum of three years (NCOA, 2021), their progress does not look promising. Future research should explore why MOV yields are seemingly decreasing and what the underlying explanations are - Is it because of lack of premium markets, which is demotivating farmers? Is the current training not effective? Is the farm support not aligned with the needs of the farmers? Are the management practices outlined in the BOS missing in these villages? Are the yield decreases specific to certain crops? Are the farmers applying less FYM? These are some questions that should be addressed in future work.

Although knowledge building is important in OA (Scialabba, 2000), the results indicate that the Bhutanese OA lacks institutional capacity, which confirms the findings of studies from other low-income countries (Babajani et al., 2023, ICIMOD & MoAF, 2018). In the course of OA development, the NCOA has moved between different agricultural research centers, and changes in the underlying motivation for promoting OA, as well as changes in funding modalities, have taken place. For example, the OA flagship program in Bhutan wants the NCOA to focus on the export market and strengthen certification, but donor-funded programs focus on building knowledge and promoting the resilience of farmers. Organic farmers in Bhutan do not receive any income support through direct payments. Although such payments have been suggested to improve the income of smallholder farmers (Liang & Meng, 2024), government tend to focus on skill training, which does not improve the income of smallholders (Liang & Meng, 2024).

2.7 Conclusion

In many low-income countries, the promotion of OA, particularly large-scale OA conversion in Sri Lanka, Sikkim and Bhutan, has received widespread attention. Many critics have argued that these ambitious goals are often driven by political interests and that they are implemented with a top-down approach that severely neglects the challenges faced by many smallholder farmers. This article argues that there are serious problems with the lack of data in low-income countries, which hinders a deeper analysis of the feasibility of such ambitious OA policy initiatives and their challenges. Using the example of Bhutan, which generally has good data availability in the agricultural sector, this article describes a large-scale transition to OA and provides a comprehensive assessment of organic conversion at the system level in a low-income country setting, with a focus on four important aspects of OA related to management and farming practices, yield gaps, nutrient balances, and the institutional setting of the OA sector.

The results showed that OA in Bhutan requires compliance with the standard requirements defined in the BOS, which is part of the family of standards under the IFOAM. Farmers are increasingly opting for certified organic farming under the LOAS. The NCOA has instituted MOVs and provides capacity-building training and in-kind farm support to organic farmers. The results from yield gap analyses based on self-reported data by farmers show that, overall, organic yields are typically lower than conventional yields. Analyses of MOVs for crops with high N requirements (barley, mustard, buckwheat, and wheat) and a chemical pesticide-dependent crop (potato) showed that yields decreased after conversion to the organic system. The nutrient balance analyses revealed a general imbalance of N, a balanced P budget, and a P surplus in the districts, and a general surplus of NPK in the MOVs. The results also showed that OA implementation faces many challenges, such as a shortage of funds, frequent changes in the underlying motivations for promoting OA, and a lack of capacity for agricultural research centers to implement organic management practices.

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2.9 Supplementary materials

Table 10. Nutrient balance (kg ha^{-1}) in 20 Bhutanese Districts for 2019-2021.

	Nutrient output a)			Nutrient input b)			Nutrient balance		
District	N	P	K	N	P	K	N	P	K
Bumthang	45.16	7.86	33.62	13.27	6.64	24.06	-31.89	-1.22	-9.56
Chukha	30.87	5.95	16.61	14.23	7.11	25.78	-16.64	1.16	9.17
Dagana	31.33	6.10	9.83	16.99	8.50	30.80	-14.34	2.40	20.97
Gasa	27.41	4.46	12.29	11.00	5.50	19.93	-16.41	1.04	7.64
Haa	29.36	5.47	24.13	16.42	8.21	29.76	-12.94	2 .74	5.63
Lhuentse	41.89	7.56	14.91	23.72	11.86	43.00	-18.17	4.30	28.09
Mongar	31.94	7.75	14.31	20.15	10.07	36.52	-11.79	2.32	22.21
Paro	43.28	5.10	23.49	13.91	6.95	25.21	-29.37	1.85	1.72
Pema Gatshel	39.26	9.94	16.72	6.14	3.07	11.12	-33.12	-6.87	-5.60
Punakha	49.02	4.74	13.18	16.98	8.49	30.78	-32.04	3.75	17.60
Samdrup Jongkhar	34.44	6.75	11.93	10.32	5.16	18.70	-24.12	-1.59	6.77
Samtse	30.95	5.32	9.26	18.74	9.37	33.97	-12.21	4.05	24.71
Sarpang	34.41	5.61	10.61	12.69	6.34	22.99	-21.72	0.73	12.38
Thimphu	35.42	5.44	31.14	12.41	6.21	22.50	-23.01	0.77	-8.64
Trashigang	46.99	9.99	21.04	21.82	10.91	39.55	-25.17	0.92	18.51
Trashi Yangtse	44.92	8.57	20.02	21.19	10.59	38.40	-23.73	2.02	18.38
Trongsa	32.42	4.88	12.83	20.23	10.11	36.67	-12.19	5.23	23.84
Tsirang	28.12	5.60	9.88	14.93	7.47	27.07	-13.19	1.87	17.19
Wangdue Phodrang	44.25	6.14	35.64	36.51	18.26	66.18	-7.74	12.12	30.54
Zhemgang	34.39	7.03	10.45	10.64	5.32	19.29	-23.75	-1.71	8.84

Note: Nutrient balance represents difference between nutrient output through harvested product and nutrient input from farmyard manure (FYM). **a)** Nutrient output values are taken from Table 13. **b)** Nutrient input values taken from Table 14.

Table 11. Nutrient balance (kg ha^{-1}) in 5 organic sites in Bhutan for 2022.

	Nutrient output a)			Nutrient input b)			Nutrient balance		
Model Organic Village	N	P	K	N	P	K	N	P	K
Galegthang	2.19	0.98	2.81	28.47	14.23	51.60	26.28	13.25	48.79
Khatoed	16.90	3.31	17.20	18.05	9.02	32.71	1.15	5.71	15.51
Langpa Norbugang	16.30	3.10	13.02	17.22	8.61	31.21	0.92	5.51	18.19
Ngangney	5.03	1.53	6.76	21.41	10.70	38.80	16.38	9.17	32.04
Phasuma Zamsa	12.88	2.03	3.00	7.61	3.81	13.80	-5.27	1.78	10.80

Note: Nutrient balance (field budget) represents difference between nutrient output through harvested product and nutrient input from farmyard manure (FYM). **a)** Nutrient output values are taken from Table 16. **b)** Nutrient input values taken from Table 17.

Table 12. An example demonstration of calculating nutrient output (kg ha^{-1}) for maize.

	Harvested area (ha) [a)]			Production (MT) [a)]			Harvested area (ha)	Production (MT)	Yield	N	P	K	N	P	K
District	2021	2020	2019	2021	2020	2019	Average	Average	(MT ha^{-1})		(MT per district) [b)]			(kg ha^{-1})	
Bumthang	0.94	0.7	0.25	0.94	0.4	0.38	0.63	0.57	0.91	0.01	0.00	0.00	12.56	3.18	3.78
Chukha	972.16	1219.51	2022.21	1049.64	1509.06	2500.62	1404.63	1686.44	1.2	23.27	5.89	7.00	16.57	4.19	4.98
Dagana	1887.23	3019.56	4041.46	2332.92	3374.84	4894.27	2982.75	3534.01	1.18	48.77	12.33	14.67	16.35	4.14	4.92
Gasa	1.45	1.76	5.73	2.3	1.28	4.11	2.98	2.56	0.86	0.04	0.01	0.01	11.87	3	3.57
Haa	78.77	232.93	242.72	99.44	329.06	260.25	184.81	229.58	1.24	3.17	0.80	0.95	17.14	4.34	5.16
Lhuentse	837.7	1399.8	1375.76	1314.1	2357.91	2886.6	1204.42	2186.2	1.82	30.17	7.63	9.07	25.05	6.33	7.53
Mongar	4077.86	4413.99	6986.99	5133.02	6162.32	9770.95	5159.61	7022.1	1.36	96.90	24.51	29.14	18.78	4.75	5.65
Paro	17.21	39.44	20.49	12.73	24.5	31.1	25.71	22.78	0.89	0.31	0.08	0.09	12.22	3.09	3.68
Pema Gatshel	1246.78	2165.57	2692	2005.02	3436.34	4554.87	2034.78	3332.07	1.64	45.98	11.63	13.83	22.6	5.72	6.8
Punakha	117.6	121.15	141.69	164.36	173.12	255.02	126.81	197.5	1.56	2.73	0.69	0.82	21.49	5.44	6.46
Samdrup Jongkhar	1433.58	2274.45	2637.74	2089.86	3140.79	3706.65	2115.26	2979.1	1.41	41.11	10.40	12.36	19.44	4.92	5.84
Samtse	1415.57	3226.04	3588.13	1638.81	3917.47	4982.6	2743.25	3512.96	1.28	48.48	12.26	14.58	17.67	4.47	5.31
Sarpang	734.77	1758.41	2107.14	1142.16	2132.23	3165.9	1533.44	2146.76	1.4	29.63	7.49	8.91	19.32	4.89	5.81
Thimphu	4.73	2.07	20.16	6.53	2.85	30.6	8.99	13.33	1.48	0.18	0.05	0.06	20.46	5.18	6.15
Trashigang	2092.86	2979.02	3544.99	3677.62	6595.87	8276.68	2872.29	6183.39	2.15	85.33	21.58	25.66	29.71	7.51	8.93
Trashi Yangtse	718.87	1011.9	1128.62	1611.4	2383.89	2127.72	953.13	2041	2.14	28.17	7.12	8.47	29.55	7.47	8.89
Trongsa	197.54	286.02	423.53	335.16	496.85	761.02	302.36	531.01	1.76	7.33	1.85	2.20	24.24	6.13	7.29
Tsirang	1680.74	2148.15	3143.22	2027.57	2706.84	3640.95	2324.04	2791.79	1.2	38.53	9.74	11.59	16.58	4.19	4.99
Wangdue Phodrang	61.54	105.72	221.42	108.96	192	375	129.56	225.32	1.74	3.11	0.79	0.94	24	6.07	7.22
Zhemgang	851.42	1538.57	2491.7	1228.54	2026.99	3029.07	1627.23	2094.87	1.29	28.91	7.31	8.69	17.77	4.49	5.34

Note: Nutrient output through harvested product (output). 1 MT = 10^3 kg = 10^6 g; 1 ha = 10^5 m^2. **a)** Calculation based on sample of households for different years (Year 2019 = 19831), (Year 2020 = 19820) and (Year 2021 = 19402), National Statistics Bureau of Bhutan: Agriculture Statistics Report (2019, 2020, 2021), published under https://www.nsb.gov.bt/agriculture-statistics-reports/. **b)** Maize nutrient for fresh matter (without by-products like straw etc.) according to Basic data (fertilizer advice/fertilizer rights) published by LFL (Bayerische Landesanstalt für Landwirtschaft), Stand: Januar 2019, published under Basic data (fertilizer advice/fertilizer rights) - LfL (bayern.de) (Bavarian State Institute for Agriculture, Freising, Germany). Nutrient (kg per MT of fresh matter is assumed to be 13.8 (N), 3.49 (P), and 4.15 (K).

Table 13. Total nutrient output (kg ha^{-1}) for 20 Districts.

District	Crop	Production (MT) a)	Harvested area (ha) a)	N	P	K	N	P	K
					(MT per district) b)			(kg ha^{-1})	
Bumthang	27	5472.96	875.80	39.62	6.89	29.49	45.16	7.86	33.62
Chukha	27	7831.85	1912.15	59.02	11.37	31.75	30.87	5.95	16.61
Dagana	27	7481.42	2772.67	86.87	16.91	27.27	31.33	6.10	9.83
Gasa	27	605.45	193.56	5.31	0.86	2.38	27.41	4.46	12.29
Haa	27	4112.89	765.80	22.49	4.19	18.48	29.36	5.47	24.13
Lhuentse	27	6565.69	1463.35	61.30	11.06	21.82	41.89	7.56	14.91
Mongar	27	13099.86	3854.23	123.11	29.86	55.16	31.94	7.75	14.31
Paro	27	16271.67	2319.58	100.39	11.82	54.49	43.28	5.10	23.49
Pema Gatshel	27	5305.92	1367.33	53.69	13.59	22.86	39.26	9.94	16.72
Punakha	27	12810.20	2358.06	115.59	11.18	31.08	49.02	4.74	13.18
Samdrup Jongkhar	27	7408.82	2255.64	77.68	15.22	26.91	34.44	6.75	11.93
Samtse	27	10189.26	3611.37	111.79	19.21	33.46	30.95	5.32	9.26
Sarpang	27	7466.30	2258.81	77.72	12.68	23.96	34.41	5.61	10.61
Thimphu	27	4198.85	523.93	18.56	2.85	16.32	35.42	5.44	31.14
Trashigang	27	6852.58	1271.82	57.13	10.89	25.46	46.99	9.99	21.04
Trashi Yangtse	27	15057.36	2899.09	136.24	28.97	61.02	44.92	8.57	20.02
Trongsa	27	4127.65	1077.97	34.95	5.26	13.83	32.42	4.88	12.83
Tsirang	27	7029.16	2468.20	69.42	13.83	24.39	28.12	5.60	9.88
Wangdue Phodrang	27	26928.34	3072.80	135.97	18.86	109.50	44.25	6.14	35.64
Zhemgang	27	3745.57	1293.11	44.47	9.10	13.52	34.39	7.03	10.45

Note: Nutrient output through harvested product (output). 1 MT = 10^3 kg = 10^6 g; 1 ha = 10^5 m^2. **a)** Calculation based on sample of households for different years (Year 2019 = 19831), (Year 2020 = 19820) and (Year 2021 = 19402), National Statistics Bureau of Bhutan: Agriculture Statistics Report (2019, 2020, 2021), published under https://www.nsb.gov.bt/agriculture-statistics-reports/. Values based on sum of Area (harvested area in hectares) and Production (MT) for all 27 crops calculated separately for each district. **b)** Sum of NPK (kg) output for each of 27 crops (fresh matter without by-products like straw etc.) according to Basic data (fertilizer advice/fertilizer rights) published by LFL (Bayerische Landesanstalt für Landwirtschaft), Stand: Januar 2019, published under Basic data (fertilizer advice/fertilizer rights) - LfL (bayern.de) (Bavarian State Institute for Agriculture, Freising, Germany). Nutrient output (at harvest without by-products like straw etc.) for rice grain according to Nutrients in Rice Grain and Straw at Harvest published by Agronomy Research & Information Center, University of California (Linquist, 2020) (https://agric.ucdavis.edu/sites/g/files/dgvnsk12316/files/inline-files/328497.pdf). Nutrient values for NPK (kg/MT) in each district are calculated for 25 crops based on the following values: Paddy (9.9, 0.78, 2.15); Maize (13.8, 3.49, 4.15); Wheat (21.1, 3.49, 4.56); Barley (16.5, 3.49, 4.98); Millet (23.4, 3.8, 4.15); Buckwheat (23.3, 2.83, 4.15); Quinoa (22.4, 4.10, 7.88); Mustard (50.8, 7.72, 7.72); Soybean (-9 6.54, 14.11); Lentil (-7.7, 8, 4.80, 11.62); Beans (-7.7, 5.23, 11.62); Peas (-8, 4.80, 11.62); Asparagus (2.6, 0.34, 1.99); Broccoli (4.5, 0.65, 3.81); Cabbage (1.4, 0.30, 3.73); Cauliflower (2.8, 0.43, 2.98); Tomato (3, 0.21, 3.23); Carrot (2.4, 0.39, 3.98); Radish (1.7, 0.34, 2.98); Potato (3.5, 0.61, 4.98); Turnip (2.6, 0.52, 4.31); Eggplant (2.8, 0.21, 2.49); Garlic (3, 0.74, 2.90); Chili (3, 0.26, 2.15); Onion (1.8, 0.34, 1.99); sunflower (29.1, 6.9, 19.9). * N (kg) values for nutrient output represents values after deduction of N (kg) input through legume crops (soybeans, lentils, beans, and peas).

Table 14. Total nutrient input (kg ha^{-1}) from farmyard manure (FYM) for 2021

Districts	Livestock Units (LU) a)	Manure (MT) b)	N	P (MT per district) c)	K	Arable land (ha) d)	N	P (kg ha^{-1})	K	Stocking density (LU ha^{-1})
Bumthang	7292.60	6068.04	66.02	33.01	119.66	4973.77	13.27	6.64	24.06	1.5
Chukha	13475.40	10838.56	117.92	58.96	213.74	8289.57	14.23	7.11	25.78	1.6
Dagana	15628.90	12498.74	135.99	67.99	246.48	8002.40	16.99	8.50	30.80	2.0
Gasa	479.40	404.85	4.40	2.20	7.98	400.52	11.00	5.50	19.93	1.2
Haa	4708.00	3873.75	42.15	21.07	76.39	2566.78	16.42	8.21	29.76	1.8
Lhuentse	7976.90	6511.06	70.84	35.42	128.40	2986.31	23.72	11.86	43.00	2.7
Mongar	19010.90	15755.31	171.42	85.71	310.69	8507.92	20.15	10.07	36.52	2.2
Paro	6830.50	5585.99	60.78	30.39	110.16	4369.89	13.91	6.95	25.21	1.6
Pema Gatshel	5537.90	4675.68	50.87	25.44	92.20	8289.47	6.14	3.07	11.12	0.7
Punakha	6842.00	5540.20	60.28	30.14	109.25	3549.69	16.98	8.49	30.78	1.9
Samdrup Jongkhar	10645.90	8809.83	95.85	47.93	173.73	9288.84	10.32	5.16	18.70	1.1
Samtse	31619.50	25265.38	274.89	137.44	498.23	14667.16	18.74	9.37	33.97	2.2
Sarpang	13407.20	10948.39	119.12	59.56	215.90	9390.29	12.69	6.34	22.99	1.4
Thimphu	2012.10	1659.11	18.05	9.03	32.72	1454.12	12.41	6.21	22.50	1.4
Trashigang	6798.10	5541.56	169.12	84.56	306.53	7750.30	21.82	10.91	39.55	2.4
Trashi Yangtse	18779.10	15544.15	60.29	30.15	109.28	2845.53	21.19	10.59	38.40	2.4
Trongsa	6792.60	5553.39	60.42	30.21	109.51	2986.73	20.23	10.11	36.67	2.3
Tsirang	10486.90	8599.56	93.56	46.78	169.58	6264.95	14.93	7.47	27.07	1.7
Wangdue Phodrang	16507.40	13282.38	144.51	72.26	261.93	3957.85	36.51	18.26	66.18	4.2
Zhemgang	7619.50	6265.94	68.17	34.09	123.56	6406.09	10.64	5.32	19.29	1.2

Note: Farmyard Manure (FYM) in Bhutan is based on heap-storage management system. 1 kg = 10^3 g; 1 MT = 10^3 kg; 1 ha = 10^5 m^2. * DM = Dry matter. **a)** Livestock population is taken from National Statistics Bureau of Bhutan: Agriculture Statistics Report (2021), published under https://www.nsb.gov.bt/agriculture-statistics-reports/. The unit of conversion to livestock unit is based on conversion factor from Wangchuk & Dorji (2008): Livestock used for calculating manure production include Holstein-Friesian, Brown Swiss, Jersey, Jatsha-Jatsham, Yangku-Yangkum, Doeb-Doebum, Doethra-Doethram, Nublang-Thrabum, Mithun, Buffalo under different categories (Calves 1 year or younger [livestock conversion unit = 0.5], heifer [livestock conversion unit = 0.7], milking, dry, infertile, breeding, bull and bullock [livestock conversion unit = 1]). **b)** Manure (fresh matter) is based on Samdrup et al., (2010) production of FYM in a year is estimated based on 3.2 (kg per day) * time spent on the farm (73% and 67% for improved and local livestock breed respectively) * 365 (number of days in a year). Dry matter is based on Feuerbacher et al. (2017): calculated as 68% of manure. The figure represents aggregated mature production. Refer to the detailed dataset used for this calculation. **c)** Nutrient content of FYM in Bhutan is based on long term experiments in Bhutan, published by Chettri et al., (2003) and DRDS (2001): Adjusting for dry matter, 1 MT of dry matter mature contains 1.6% N, 0.8% P, and 2.9% K. **d)** Ministry of Agriculture and Livestock: Agriculture Census Report (2018) based on microdata from 66587 agriculture holdings

Table 15. An example demonstration for the calculation of nutrient output (kg ha^{-1}) for maize in 2022.

MOV	Harvested area (ha) a)	Production (MT) a)	Yield (MT ha^{-1})	N	P (kg per MOV) b)	K	N	P (kg ha^{-1})	K
Galegthang	0.10	0.02	0.20	0.28	0.07	0.08	2.76	0.70	0.83
Khatoed	0.10	0.02	0.20	0.28	0.07	0.08	2.76	0.70	0.83
Langpa Norbugang	0.92	0.18	0.20	2.48	0.63	0.75	2.70	0.68	0.81
Ngangney	0.13	0.04	0.31	0.55	0.14	0.17	4.25	1.07	1.28
Phasuma Zamsa	0.03	0.01	0.33	0.14	0.03	0.04	4.60	1.16	1.38

Note: Nutrient output through harvested product (output). 1 MT = 10^3 kg = 10^6 g; 1 ha = 10^5 m^2. **a)** Calculation based on samples (Galegthang = 39), (Khatoed = 47), (Langpa Norbugang = 56), (Ngangney = 14) and (Phasuma Zamsa = 22). 1 MT = 10^3 kg = 10^6 g; 1 ha = 10^5 m^2. National Statistics Bureau of Bhutan: Agriculture Statistics Report (2022), published under https://www.nsb.gov.bt/agriculture-statistics-reports. **b)** Maize nutrient for fresh matter (without by-products like straw etc.) according to Basic data (fertilizer advice/fertilizer rights) published by LFL (Bayerische Landesanstalt für Landwirtschaft), Stand: Januar 2019, published under Basic data (fertilizer advice/fertilizer rights) - LfL (bayern.de) (Bavarian State Institute for Agriculture, Freising, Germany). Nutrient (kg per MT of fresh matter is assumed to be 13.8 (N), 3.49 (P), and 4.15 (K).

Table 16. Total nutrient output (kg ha^{-1}) for five organic farming sites in 2022.

District	Crop	Production (MT)	Harvested area (ha) a)	N	P (kg per MOV) b)	K	N	P (kg ha^{-1})	K
Galegthang	25	9.09	17.68	38.70	17.33	49.67	2.19	0.98	2.81
Khatoed	25	79.86	20.48	346.06	67.69	352.11	16.90	3.31	17.20
Langpa Norbugang	25	117.53	39.72	647.29	123.28	517.33	16.30	3.10	13.02
Ngangney	25	10.51	6.62	33.30	10.11	44.76	5.03	1.53	6.76
Phasuma Zamsa	25	5.97	9.02	116.17	18.29	27.08	12.88	2.03	3.00

Note: Nutrient output through harvested product (output). 1 MT = 10^3 kg = 10^6 g; 1 ha = 10^5 m^2. Calculation based on samples (Galegthang = 39, Khatoed = 47, Langpa Norbugang = 56, Ngangney = 14 and Phasuma Zamsa = 22). 1 MT = 10^3 kg = 10^6 g; 1 ha = 10^5 m^2. **a)** Calculation based on samples (Galegthang = 39), (Khatoed = 47), (Langpa Norbugang = 56), (Ngangney = 14) and (Phasuma Zamsa = 22). 1 MT = 10^3 kg = 10^6 g; 1 ha = 10^5 m^2. National Statistics Bureau of Bhutan: Agriculture Statistics Report (2022), published under https://www.nsb.gov.bt/agriculture-statistics-reports. **b)** Crop nutrient for fresh matter (without by-products like straw etc.) according to Basic data (fertilizer advice/fertilizer rights) published by LFL (Bayerische Landesanstalt für Landwirtschaft), Stand: Januar 2019, published under Basic data (fertilizer advice/fertilizer rights) - LfL (bayern.de) (Bavarian State Institute for Agriculture, Freising, Germany). Nutrient output (at harvest without by-products like straw etc.) for rice grain according to Nutrients in Rice Grain and Straw at Harvest published by Agronomy Research & Information Center, University of California (Linquist, 2020) (https://agric.ucdavis.edu/sites/g/files/dgvnsk12316/files/inline-files/328497.pdf). Nutrient values for NPK (kg/MT) in each district are calculated for 25 crops based on the following values: Paddy (9.9, 0.78, 2.15); Maize (13.8, 3.49, 4.15); Wheat (21.1, 3.49, 4.56); Barley (16.5, 3.49, 4.98); Millet (23.4, 3.8, 4.15); Buckwheat (23.3, 2.83, 4.15); Quinoa (22.4, 4.10, 7.88); Mustard (50.8, 7.72, 7.72); Soybean (-9 6.54, 14.11); Lentil (-7.7, 8, 4.80, 11.62); Beans (-7.7, 5.23, 11.62); Peas (-8, 4.80, 11.62); Asparagus (2.6, 0.34, 1.99); Broccoli (4.5, 0.65, 3.81); Cabbage (1.4, 0.30, 3.73); Cauliflower (2.8, 0.43, 2.98); Tomato (3, 0.21, 3.23); Carrot (2.4, 0.39, 3.98); Radish (1.7, 0.34, 2.98); Potato (3.5, 0.61, 4.98); Turnip (2.6, 0.52, 4.31); Eggplant (2.8, 0.21, 2.49); Garlic (3, 0.74, 2.90); Chili (3, 0.26, 2.15); Onion (1.8, 0.34, 1.99). * N (kg) values for nutrient output represents values after deduction of N (kg) input through legume crops (soybeans, lentils, beans, and peas).

Table 17. Total nutrient input (kg ha^{-1}) from Farmyard manure (FYM) for 2022

Model organic village (MOV)	Livestock Units (LU) a)	Manure (MT) b)	N	P (MT per MOV) c)	K	Arable land (ha) d)	N	P (kg ha^{-1})	K	Stocking density (LU ha^{-1})
Galegthang	204.70	160.19	1.74	0.87	3.16	61.22	28.47	14.23	51.60	3.34
Khatoed	166.00	129.90	1.41	0.71	2.56	78.31	18.05	9.02	32.71	2.12
Langpa Nobgang	210.50	164.73	1.79	0.90	3.25	104.08	17.22	8.61	31.21	2.02
Ngangney	74.10	57.99	0.63	0.32	1.14	29.47	21.41	10.70	38.80	2.51
Phasuma Zamsa	48.70	38.22	0.42	0.21	0.75	54.61	7.61	3.81	13.80	0.89

Note: Farmyard Manure (FYM) in Bhutan is based on heap-storage management system. 1 kg = 10^3 g; 1 MT = 10^3 kg; 1 ha = 10^5 m^2. * DM = Dry matter. **a)** Livestock population is taken from National Statistics Bureau of Bhutan: Agriculture Statistics Report (2021), published under https://www.nsb.gov.bt/agriculture-statistics-reports/. The unit of conversion to livestock unit is based on conversion factor from Wangchuk & Dorji (2008): Livestock used for calculating manure production include Holstein-Friesian, Brown Swiss, Jersey, Jatsha-Jatsham, Yangku-Yangkum, Doeb-Doebum, Doethra-Doethram, Nublang-Thrabum, Mithun, Buffalo under different categories (Calves 1 year or younger [livestock conversion unit = 0.5], heifer [livestock conversion unit = 0.7], milking, dry, infertile, breeding, bull and bullock [livestock conversion unit = 1]). **b)** Manure (fresh matter) is based on Samdrup et al. (2010): production of FYM in a year is estimated based on 3.2 (kg per day) * time spent on the farm (73% and 67% for improved and local livestock breed respectively) * 365 (number of days in a year). **c)** Dry matter is based on Feuerbacher et al. (2017): calculated as 68% of manure. The figure represents aggregated mature production. Refer to the detailed dataset used for this calculation. **c)** Nutrient content of FYM in Bhutan is based on long term experiments in Bhutan, published by Chettri et al., (2003) and DRDS (2001). Adjusting for dry matter, 1 MT of dry matter mature contains 1.6% N, 0.8% P, and 2.9% K. **d)** Ministry of Agriculture and Livestock: Agriculture Census Report (2018) based on microdata from 66587 agriculture holdings.

Table 18. Different aspect of agriculture in 20 Districts in 2018, in Bhutan.

Districts	Land allotted for high N input crops [%] a)	Land allotted for legumes [%] a)	Cropland area of total owned land [%] b)	Meadows & pastures of total land owned [%] b)	Land allotted for cash crop production [%] b)	Households Producing for only sale [%] b) *	Households practicising livestock production only [%] b) **	Households practicing livestock and crop production [%] b) **	Households use mineral fertilizer [%] b)	N	P (kg ha^{-1}) c)	K	LU ha^{-1} a)
Pema Gatshel	81.5	3.2	34.2	2.4	10.3	3	1	45.2	13.2	0.01	0.00	0.00	0.67
Punakha	90.4	0.3	70.2	1.4	37.6	7	1.3	20.1	58.6	21.33	2.23	3.89	1.93
Bumthang	95.3	5.3	26.3	19.8	25.2	20	20.3	7	68	28.00	9.03	2.33	1.47
Paro	76.0	0.4	62.8	3.4	26.3	19	2.1	37.3	73.9	16.71	2.82	4.34	1.56
Trashi Yangtse	80.6	2	39.4	1.9	41.8	9	6.4	54.3	62.1	46.34	1.54	2.94	2.42
Samdrup Jongkhar	86.5	4.3	48.6	9.2	27.4	2	2.1	47.8	1.7				1.15
Zhemgang	92.1	3	42.3	1.3	38.1	4	3.2	10	1.5				1.19
Trashigang	81.8	2.4	40	0.8	23.7	2	0.9	7.1	58.8	24.35	2.20	3.45	2.39
Thimphu	66.1	6.9	47	4.5	22.8	24	12.1	36.1	48.8	58.00	11.22	16.43	1.38
Sarpang	90.1	2	49.4	4.3	9.7	9	4.8	43.5	2.5	0.75	0.04	0.06	1.43
Lhuentse	82.4	4.5	55.2	5.3	16.1	1	1.5	38.2	22.3	25.75	0.01	0.01	2.67
Chukha	82.2	2.8	63.5	2.9	11.7	15	5.4	22.2	11	9.81	0.76	1.38	1.63
Gasa	89.0	2.3	62.5	11.2	11.4	0.2	2.1	68.9	0.4				1.20
Dagana	89.5	3.3	62.1	2.9	65.4	4	1.6	38.4	5.6	0.88	0.12	0.23	1.95
Tsirang	83.3	1.1	64.8	3.3	10.4	7	4.2	37.6	3.5	1.99	0.14	0.24	1.67
Haa	83.2	0.7	59.2	12.8	45.7	13	5.7	68.5	36.9	4.76	0.61	1.15	1.83
Samtse	90.0	5.2	59.3	2.1	16.6	10	1.9	42.7	2.8	0.38	0.03	0.04	2.16
Trongsa	86.7	3.7	43	8.9	31.2	8	16	11.9	35.8	4.35	0.47	0.89	2.27
Mongar	82.8	1.1	56	3.2	20.1	6	0.9	48.9	17.5	13.61	0.53	1.01	2.23
Wangdue Phodrang	88.3	2.5	66.7	4.8	32.5	28	4.9	44.6	59.8	37.27	13.76	20.22	4.17

Note: Districts are arranged in the severity of Nitrogen deficiency (largest to smallest). a) statistics constructed by author using agriculture census microdata for 2018; b) figures taken from agriculture census report for 2019, published by the National Statistical Bureau (www.nsb.gov.bt); Crops for the calculation for land allotment with high nitrogen demand (top ten crops) includes millet, mustard, turnip, maize, paddy, buckwheat, potato, wheat, barley, brocolli; for allotment of land under legumes, crops include beans, lentil, peas, and soybean; and land allotment for cash crops with lower N demand includes broccoli, potato, garlic, tomato, cauliflower, eggplant, asparagus, turnip, carrot, onion, radish, cucumber, and cabbage. High nitrogen demand (kg per hectare) crops are calculated as product of yield (MT per hectare) and N need (kg per MT) c) figures are taken from data published by the National Plant Protection Center (www.nppc.gov.bt). Mineral fertilizer use is based on different mineral fertilizers includes suphala (15% N-15% P_2O_5-15% K_2O, for 100 kilograms of the fertilizer), urea (46% N), single super phosphate (16% P_2O_5), muriate of potash (60% K_2O), bone meal (14% N-15% P_2O_5), calcium ammonium nitrate (26% N), diammonium phosphate (18% N-46% P_2O_5). To convert P_2O_5 to P divide by 2.29, and to convert K_2O to K divide by 1.2). Operational arable land includes total owned land + land leased in – land leased out – fallow land (MoAL, 2019). * In this purpose of crop production category, the remaining households fall in the category for `only for own consumption’ and `mainly for own consumption with some for sale´. ** In this agricultural activity category, the remaining households fall in the category for ‘crop production´, `forestry and logging´ and ‘fishery and aquaculture`.

Table 19. Different aspect of agriculture in organic villages in 2018, in Bhutan.

Organic villages	Land allotted for high N input crops [%] a)	Land allotted for legumes [%] a)	Cropland area of total owned land [%] a)	Meadows & pastures of total land owned [%] a)	Land allotted for cash crop production [%] a)	Households producing for only sale [%] a) *	Households practicising livestock production only [%] a) **	Households practicing livestock and crop production [%] a) **	Livestock unit per hectare of total land owned a)
Phasuma Zamsa	93.4	1.3	39.4	1.9	6.2	2.1	0	87	0.89
Langpa Nobgang	79.8	3.3	34.2	2.4	46.1	3.4	8.5	45.8	2.02
Khatoed	74.2	1.5	26.3	19.8	59.9	0	0	87	2.12
Ngangney	77.7	2.7	62.8	3.4	26.1	0	0	0	2.51
Galegthang	85.5	8.4	70.2	1.4	9.9	1.9	14.8	1.9	3.34

Note: Organic villages are arranged in the severity of Nitrogen deficiency (largest to smallest). a) statistics constructed by author using agriculture census microdata for 2018. Crops for the calculation for land allotment with high nitrogen demand (top ten crops) includes millet, mustard, turnip, maize, paddy, buckwheat, potato, wheat, barley, brocolli; for allotment of land under legumes, crops include beans, peas, and soybean; and land allotment for cash crops with lower N demand includes broccoli, potato, garlic, tomato, cauliflower, eggplant, asparagus, turnip, carrot, onion, radish, and cabbage. High nitrogen demand (kg per hectare) crops are calculated as product of yield (MT per hectare) and N need (kg per MT). * In this purpose of crop production category, the remaining households fall in the category for `only for own consumption’ and `mainly for own consumption with some for sale´. ** In this agricultural activity category, the remaining households fall in the category for ‘crop production´, `forestry and logging´ and ‘fishery and aquaculture`.

Table 20**.** Organic-to-conventional yield ratio, 95% Confidence Interval, and yield (kg ha^{-1}) for 20 crops across agroecological zones (AEZ)

		Yield (kg ha^{-1}) in organic (OA) and conventional (CF) across AEZ						Organic-to-conventional yield ratio				95% Confidence Interval for yield ratio					
Descriptive statistics		CF	CF	CF	OA	OA	OA					LC	UC	LC	UC	LC	UC
	Crops	AEZ1	AEZ2	AEZ3	AEZ1	AEZ2	AEZ3	AEZ1	AEZ2	AEZ3	ALL	AEZ1		AEZ2		AEZ3	
Mean	Maize	2846.80	3492.05	3734.81	1641.48	2240.19	3136.62	0.58	0.64	0.84	0.69	0.54	0.61	0.63	0.66	0.81	0.87
Standard Deviation		1884.70	1991.63	2316.51	1391.95	1812.56	2026.23										
Mean	Paddy	3011.09	3677.29	4051.68	2057.47	2356.57	3155.86	0.68	0.64	0.78	0.70	0.66	0.71	0.63	0.66	0.76	0.80
Standard Deviation		1696.96	1706.01	1778.60	1132.13	1531.28	1686.58										
Mean	Potato	9564.65	7616.73	12572.18	3676.03	4332.36	7550.24	0.38	0.57	0.60	0.52	0.36	0.41	0.55	0.59	0.59	0.62
Standard Deviation		5929.08	4883.30	7002.15	3734.66	3928.63	5633.33										
Mean	Chili	4974.34	6094.23	7592.14	2665.42	3524.80	4961.23	0.54	0.58	0.65	0.59	0.49	0.60	0.55	0.61	0.63	0.68
Standard Deviation		4177.61	4517.09	5626.58	2646.75	3738.91	4575.00										
Mean	Beans	4056.56	4633.06	5196.04	2498.01	2436.86	2885.00	0.62	0.53	0.56	0.57	0.53	0.73	0.49	0.57	0.50	0.62
Standard Deviation		3179.29	3060.18	4870.08	2301.73	2531.47	3229.20										
Mean	Millet			2494.26			1852.04			0.74	0.74					0.63	0.89
Standard Deviation				1711.23			1943.65										
Mean	Wheat	1470.65	1416.15	1762.56	1046.03	1116.84	1451.54	0.71	0.79	0.82	0.77	0.53	1.07	0.72	0.87	0.75	0.91
Standard Deviation		1315.21	858.88	1043.64	962.81	846.17	922.74										
Mean	Buckwheat		1545.36	1450.30		1125.52	1199.57		0.73	0.83	0.78			0.55	1.08	0.75	0.91
Standard Deviation			1315.37	818.03		903.14	790.38										
Mean	Cabbage	7278.32	6159.24	12019.53	4204.13	3782.26	4820	0.58	0.61	0.40	0.53	0.51	0.67	0.55	0.70	0.38	0.43
Standard Deviation		5873.88	5172.79	9834.81	4350.06	3586.16	5808.51										
Mean	Barley			1750.95			1604.80			0.92	0.92					0.82	1.04
Standard Deviation				1003.09			1034.91										
Mean	Radish	6512.92	5223.66	11628.12	4588.84	4937.47	6562.12	0.70	0.95	0.56	0.74	0.56	0.94	0.79	1.19	0.51	0.63
Standard Deviation		6351.28	4935.06	11292.28	4342.93	5020.88	6792.71										

Note: Data source: Agricultural census for 2018, from Ministry of Agriculture and Livestock. 1 kg = 10^3 g; 1 MT = 10^3 kg; 1 ha = 10^5 m^2.

Continued from Table 20.

		Yield (kg ha^{-1}) in organic (OA) and conventional (CF) across AEZ						Organic-to-conventional yield ratio				95% Confidence Interval for yield ratio					
Descriptive statistics		CF	CF	CF	OA	OA	OA					LC	UC	LC	UC	LC	UC
	Crops	AEZ1	AEZ2	AEZ3	AEZ1	AEZ2	AEZ3	AEZ1	AEZ2	AEZ3	ALL	AEZ1		AEZ2		AEZ3	
Mean	Turnip			19388.72			11372.92			0.59	0.59					0.53	0.65
Standard Deviation				16080.63			15298.05										
Mean	Mustard		817.05	1231.79		672.77	916.56		0.82	0.74	0.78			0.68	1.03	0.51	1.25
Standard Deviation			636.43	1548.78		609.52	1042.15										
Mean	Cauliflower	4683.06	6088.68	6752.96	3264.63	3250.82	3373.86	0.70	0.53	0.50	0.58	0.59	0.85	0.46	0.63	0.46	0.54
Standard Deviation		3855.64	5600.72	5398.96	3578.07	3368.25	3576.40										
Mean	Garlic	3093.01	2842.67	3430.47	1433.90	1649.78	2237.72	0.46	0.58	0.65	0.57	0.38	0.60	0.52	0.66	0.59	0.73
Standard Deviation		2262.06	2298.44	2887.02	1271.99	1605.83	2399.94										
Mean	Broccoli	4580.82	5362.17	5749.12	2861.44	3068.28	3285.10	0.62	0.57	0.57	0.59	0.50	0.83	0.51	0.65	0.52	0.63
Standard Deviation		4631.07	4725.24	5139.10	3009.73	3316.67	3609.88										
Mean	Peas			2474.06			2330.66			0.94	0.94					0.84	1.07
Standard Deviation				2078.88			2432.89										
Mean	Carrot	6404.06		6323.02	2226.31		4464.74	0.35		0.71	0.53	0.27	0.48			0.63	0.80
Standard Deviation		4722.22		6164.01	2250.36		4846.00										
Mean	Onions	3258.55	4073.98	2496.80	2005.77	1989.71	1777.99	0.62	0.49	0.71	0.61	0.47	0.89	0.44	0.54	0.60	0.87
Standard Deviation		3136.97	2541.06	2159.66	2029.21	1845.12	1729.93										
Mean	Tomato	4819.81	4921.17	5778.02	2808.23	2875.60	3665.83	0.58	0.58	0.63	0.60	0.43	0.89	0.50	0.71	0.53	0.78
Standard Deviation		4477.35	3344.46	4567.27	2593.59	2989.63	3557.02										
Mean	All crops	3550.67	3995.61	7588.79	2556.33	3279.44	4197.98	0.72	0.82	0.55	0.70						
Standard Deviation		1685.66	2864.18	6693.50	1029.12	2750.54	5705.62										

Note: Data source: Agricultural census for 2018, from Ministry of Agriculture and Livestock. 1 kg = 10^3 g; 1 MT = 10^3 kg; 1 ha = 10^5 m^2.

Table 21. Median yield (kg ha^{-1}) for different crops between 2014 and 2022 in model organic villages (MOV)

Crops	2014	2015	2016	2018	2021	2022	Before	After
Barley	1976.00	2223.00	1979.53	1235.00	1235.00	988.00	1979.53	1235.00
Sweet buckwheat	1457.30	988.00	1512.88	2099.50	1144.43	988.00	1457.30	1144.43
Bitter buckwheat	1111.50	988.00	1482.00	617.50	4116.67	988.00	1111.50	988.00
Beans	2470.00	4940.00	1482.00	3087.50	2964.00	2470.00	2470.00	2964.00
Peas	2964.00	2470.00	2432.95	2893.77	2470.00	2346.50	2470.00	2470.00
Cabbage	2964.00	6586.67	3293.33	5804.50	4234.29	3910.83	3293.33	4234.29
Cauliflower	1235.00	2511.16	2470.00	3252.17	4281.33	3705.00	2470.00	3705.00
Carrot	1482.00	2964.00	2470.00	4651.83	4940.00	4940.00	2470.00	4940.00
Radish	3224.72	7410.00	3705.00	5557.50	3705.00	3087.50	3705.00	3705.00
Broccoli	1111.50	1482.00	2964.00	3025.75	2470.00	3087.50	1482.00	3025.75
Potato	12350.00	9731.80	8856.71	7410.00	3293.33	4116.67	11040.90	5763.33

Note: MOVs include Galeythang, Langpa Nobgang, and Khatoed. The data from 2016 includes yield from Khatoed (K) sub-district, which converted to organic since the start of organic policy in Bhutan. Years for median yield calculation include: Before (2014, 2014 and 2016), After (2018, 2021 and 2022). Authors construction based on microdata from agricultural survey and census (Surveys: 2014, 2015, 2016; Census: 2018) collected by the Ministry of Agriculture and Livestock (MoAL), and agriculture survey and census (Survey: 2021; Census: 2022) collected by the National Statistical Bureau (NSB). Samples for median calculation includes in 2014 (G =11, L =18), 2015 (G =6, L =17), 2016 (G =16, L =20, K =39), 2018 (G =54, L =59, K =54), 2021 (G =20, L =25, K =34), and 2022 (G =39, L =56, K =47). Breaks in the trend line shows no data collected for the crop. 1 kg = 10^3 g; 1 MT = 10^3 kg; 1 ha = 10^5 m^2.

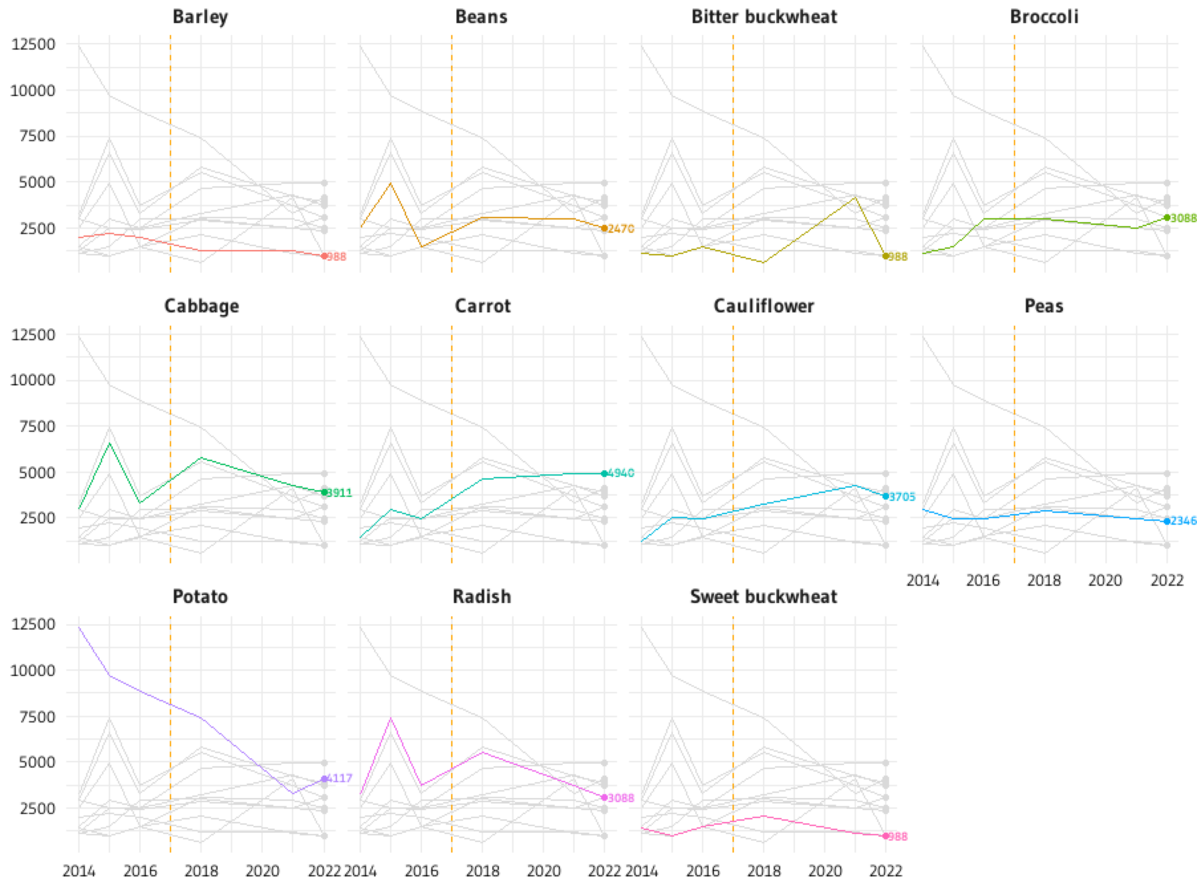


Figure 5. Median yields (kg ha^{-1}) for different crops between 2014 and 2022 in model organic villages (MOV).

Note: The colored lines show yields for the specific crop in question and the grey lines shows yields for other crops in the analysis. MOVs include Galeythang (G) and Langpa Nobgang (L), which were instituted in 2017 (vertical line in year 2017). The data from 2016 includes yield from Khatoed (K) sub-district, which converted to organic since the start of organic policy in Bhutan. While Khatoed and Langpa Nobgang are located in the temperate agro-ecological zone (AEZ), Galeythang is located in the subtropical AEZ. Authors construction based on microdata from agricultural survey and census (Surveys: 2014, 2015, 2016; Census: 2018) collected by the Ministry of Agriculture and Livestock (MoAL), and agriculture survey and census (Survey: 2021; Census: 2022) collected by the National Statistical Bureau (NSB). Samples for median calculation includes in 2014 (G =11, L =18), 2015 (G =6, L =17), 2016 (G =16, L =20, K =39), 2018 (G =54, L =59, K =54), 2021 (G =20, L =25, K =34), and 2023 (G =39, L =56, K =47). A break in the trend line shows no data collected for the crop. 1 kg = 10^3 g; 1 MT = 10^3 kg; 1 ha = 10^5 m^2.

Table 22. Botanical names for crops used for different analysis

Crop category	Crops	Botanical Name
Cereal	Maize	*Zea mays*
	Wheat	*Triticum aestivum*
	Barley	*Hordeum vulgare*
	Millet	*Pennisetum americanum*
	Sweet Buckwheat	*Fagopyrum esculentum Moench*
	Bitter Buckwheat	*Fagopyrum tartaricum (L.) Gaertn*
	Amaranthus	*Amaranthus caudatus*
	Rice (paddy)	*Oryza sativa; Oryza glaberrima*
	Quinoa	*Chenopodium quinoa*
Legumes	Beans	*Phaseolus vulgaris*
	Peas	*Pisum sativum*
	Broad beans	*Vicia faba*
	Chickpeas	*Cicer arietinum*
	Cowpeas	*Vigna unguiculata*
	Groundnut	*Arachis hypogaea*
	Lentil	*Lens culinaris*
	Lupin	*Lupinus spp.*
Vegetables [a)]	Cabbage	*Brassica chinensis*
	Cauliflower	*Brassica oleracea var. botrytis*
	Carrot	*Daucus carota ssp. sativa*
	Radish	*Raphanus sativus (inc. Cochlearia armoracia)*
	Tomato	*Lycopersicon esculentum*
	Eggplant	*Solanum melongena*
	Broccoli	*Brassica oleracea var. botrytis*
	Mustard	*Brassica nigra; Sinapis alba*
	Asparagus	*Asparagus officinalis*
	Coriander	*Coriandrum sativum*
	Cucumber	*Cucumis sativus*
	Chili	*Capsicum spp. (annuum)*
	Onion	*Allium cepa*
	Garlic	*Allium sativum*
	Ginger	*Zingiber officinale*
	Okra	*Abelmoschus esculentus*
	Pumpkins	*Cucurbita spp.*
	Spinaches	*Spinacia oleracea*
	Turmeric	*Curcuma longa*
	Potato	*Solamum tuberosum*
	Turnip	*Brassica rapa*
	Sunflower	*Helianthus annuus*

Note: a) Vegetables are considered as cash crops for Table 18 and 19. Botanical names of crops are based on Alphabetical list of crops with botanical names and crop code, published by FAO available at appendix4_r7.pdf (fao.org)

Chapter 3

3 Organic agriculture, labour exchange, and social networks: a case study of smallholder farming in Bhutan

3.1 Abstract

We examine the informal exchange of labour in farming villages with the successful adoption of labour-intensive farming practices. Previous studies have characterised the network pattern of labour exchange to relate such cooperative behaviour to the community's social structure. We use network patterns from the literature and recreate the internal network structure of the labour exchange in selected Bhutanese villages to determine the type of social enforcement mechanisms used. Results show that labour exchange networks in these villages are characterised by a high prevalence of triad closure as an underlying social structure. These are completely connected structures within the labour exchange network in which any two farmers exchanging labour have a common farmer with whom both share labour. The results from our random graph modelling imply that villages with well-functioning labour exchange institutions may be most suitable for being promoted as "organic villages" as they can adapt to the high labour requirement that comes with organic farming. Future research should analyse how villages with different network structures produce different farm outcomes and how the village and farm-specific attributes affect their social enforcement mechanisms.

Keywords: Organic farming, Labour intensive farming, Labour exchange, Social enforcement, Network analysis

3.2 Introduction

In most farming societies in low-income countries, the majority of day-to-day farming activities are still predominantly performed manually. The absence of formal labour markets and scarce labour supply means farmers cannot rely upon the use of contract labour; instead, family farms depend on labour exchange arrangements (Erasmus 1956; Jackson et al. 2012; Gilligan 2004). In such an agricultural context, farmers agree to engage in joint action by participating in labour exchange among themselves, because this type of cooperative behaviour produces mutually beneficial outcomes for all involved parties (Dasgupta 2005; Gilligan 2004; Kirinya et al. 2013).

In low-income countries, it is a burden for labour-intensive farming systems when communities fail to organize labour exchange. Evidence shows that the promotion of labour-intensive farming systems in smallholder farming has failed in farming communities where labour exchange has disappeared (Natcher et al. 2018). Without well-functioning labour exchange institutions, communities also resort to herbicides and farm inputs that have devastating effects on the environment (ICIMOD and MoAF 2018; Bajgai and Yeshey 2014). In mountainous regions, subsistence farmers vulnerable to climate change are encouraged to transition to sustainable farming practices and abandon the use of mineral fertilizers and herbicides (ICIMOD and MoAF 2018; RGoB 2021). However, the transition can be challenging due to its implications on labour to replace external inputs. But, for progressive communities with well-functioning labour exchange institutions, the transition would be easier (Kinga 2010). Although labour exchange was predicted to disappear from peasant societies by early studies (Erasmus 1956; Moore 1975), Kranton (1996) shows that it can persist alongside formal labour markets and does not show signs of disappearance. The persistence of labour exchange arrangements implies that farming societies are still benefiting from it, making labour exchange still an important institution.

Labour cost plays an important role in the production and profitability of organic farming. Crowder and Reganold (2015) compared conventional and organic farms and found that the global average cost of organic farming exceeds the corresponding cost of conventional farming by 7–13%. Such discrepancies arise mainly from more labour used to control pests, manage weeds, apply manure, and perform a wide diversity of work (Crowder and Reganold 2015; Lampkin and Padel 1994; Pattanapant and Shivakoti 2013; Suwanmaneepong et al. 2020; Tashi and Wangchuk 2016). Labour exchange institutions can help organic smallholders to cope with the burden of labour and keep the cost of labour uniform across households and constant across time.

Many scholars have been intrigued to study communities with well-functioning labour exchange and to investigate how they foster cooperative behaviours through social networks (Dasgupta 2005; Jackson et al. 2012). They have studied the use of different forms of social norms and culture to informally enforce cooperation. Some have even formulated models providing a theoretical foundation of informal enforcement mechanisms in labour-sharing arrangements (Gilligan 2004; Jackson et al. 2012; Krishnan and Sciubba 2009). They have argued that labour-sharing networks carry network patterns that characterize the network structure generated by the informal enforcement of cooperation (Gilligan 2004; Jackson et al. 2012; Krishnan and Sciubba 2009). They further argue that the network structure explains the type of social enforcement used by the community (Gilligan 2004; Jackson et al. 2012; Krishnan and Sciubba 2009).

Our objective in this article is to examine whether these social structures reported in the literature are also prevalent in the labour exchange network data from our study sites and whether they can characterize the social mechanisms for enforcing cooperative behaviour. In examining this, our aim is to illustrate how labour relationships in a society must be organized to cope and adapt to labour-intensive farming systems (Jackson et al. 2012). Specifically, we first want to analyse how a farmer’s decision to engage in labour exchange is influenced by the network pattern of behaviour of other actors in the community. Secondly, using the social structures found in the selected villages, we aim to identify a set of properties that illustrate the social enforcement mechanisms in the studied Bhutanese villages. In this way, we show that tools from social network analyses can be used to identify appropriate villages in which labour-intensive farming is feasible. This also implies that the functioning and preservation of such networks are a prerequisite for a successful conversion to labour-intensive organic farming. Our network formation analysis combines economics and graph theory and offers a unified framework to understand the *why* and *how* of labour exchange network formation.

While the European organic farming movement has been a bottom-up initiative, farmers receive substantial support under the Common Agricultural Policy (CAP) (Jaime et al. 2016; Buitenhuis et al. 2020; Runowski 2021; Feuerbacher et al. 2018). On the contrary, organic farming in Bhutan is a top-down initiative (ICIMOD and MoAF 2018), and providing large subsidies is not possible because of budgetary constraints. Thus, the issue of whether a society like the Bhutanese one, which primarily relies upon the farming sector, can adapt to a more labour-intensive farming system is important to address. Although 66% of farmers in Bhutan use labour exchange arrangements (MoAF 2019), it has not yet been analyzed how this informal sector is used and benefits smallholders. Besides our understanding of labour arrangement as a culture and social norm in the country, no study provides a careful examination of this institution. In this respect, considering that certified organic farming is relatively new in Bhutan, and only a few traditional farming villages have converted to this comparatively more labour-intensive farming system, our analysis can serve as an example on how smallholder farming can adopt farming systems that can provide a sustainable future even with a relatively high labour burden.

This article is structured as follows: "The role of social networks in labour exchange" section presents the theoretical foundations and concepts from social network analyses along with a brief literature review. Next, a description of our data and of the methods used is given in the section "Data and methods". Finally, the "Results" section is followed by a "Discussion" and a "Conclusion" section.

3.3 The role of social networks in labour exchange

3.3.1 Theory of network formation

A simple network formation theory guides our social network analysis of labour exchange. The network formation theory postulates that individuals can choose with whom to form labour relationships and make efforts to maintain them if they perceive them as beneficial and dissolve those labour ties that are not considered useful (Jackson et al. 2020; Jackson 2006; Krishnan and Sciubba 2009). The choice of labour links among farmers then results in patterns of interactions between them, leading to social networks (Barnes 1954). The network formation theory predicts that some distinctive network patterns will emerge, forming the underlying micro-configuration of the social network under study (Jackson et al. 2020; Jackson 2006). They are considered the building blocks or mechanisms through which society fosters cooperation among the farmers (Jackson et al. 2012; Jackson 2006). Different processes can result in varying network patterns for dissimilar communities, characterising the form of the specific social enforcement mechanism used to informally enforce cooperation.

While we do not formulate new network patterns that emerge from our labour exchange networks, we use two specific social structures described in the literature that capture strategic network formation theory. According to this theory, forming and dissolving labour-sharing relations involves strategic decision-making and communities capable of fostering cooperation in informal labour exchanges show the prevalence of certain social structures (Jackson 2006; Krishnan and Sciubba 2009). The social structures emerging from this strategic decision-making can be characterised in one of two ways. They are either homophilious, wherein labour exchange ties are more common among homogenous farmers with similar characteristics (Krishnan and Sciubba 2009). Or they show a triad closure, in which labour exchange ties between two farmers are always supported by a common farmer with whom they both share a labour tie (Jackson et al. 2012).

Further, a theory outlining the effects of endowment (with land and machinery) on the formation of labour exchange ties between farmers is also used in our analysis to capture the effects of farmers' attributes (Gilligan 2004). We use these theoretically founded social structures to identify which micro-configurations of the labour network are (most) important in our study villages. This helps to disentangle the *why* behind the network formation and gain insights into the incentives or costs and benefits of the links formed (Jackson 2006).

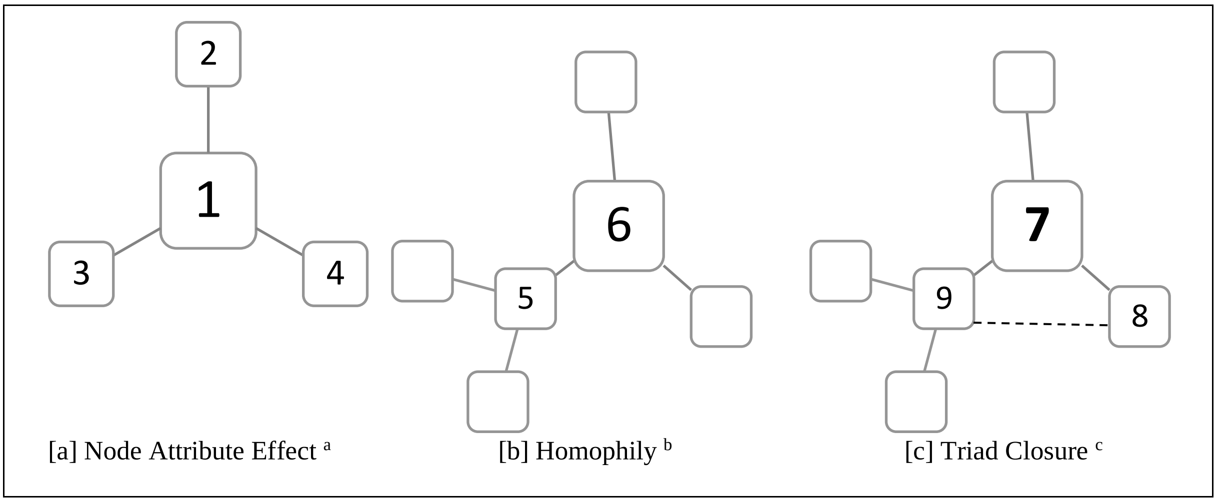
We use random graph theory to disentangle the *how* behind the network formation (Jackson 2006). Social network analysis for network formation is now possible with the graph theory developments, specifically the exponential random graph model (Robins et al. 2007). This technique makes it possible to model the formation and dissolving of ties as a stochastic process (Robins et al. 2007). This helps to trace the overall labour network to the social structures used to informally enforce cooperation and enables us to understand the underlying network formation process (Jackson 2006). In the following sections, we present the relevant empirical evidence on the above-mentioned social structures in the literature.

3.3.2 Node attribute (endowment) effect

While there are studies that predict that labour exchange will disappear under conditions of out-migration of surplus labour from agriculture (Lewis 1954), low population density (Boserup 1965) and certain social and economic conditions (Erasmus 1956; Moore 1975), recent evidence shows otherwise (Gilligan 2004; Jackson et al. 2012; Kranton 1996; Krishnan and Sciubba 2009). Gilligan (2004) shows that a farmer's decision to engage in labour exchange decreases with improvement in his endowment level measured in terms of bigger farm size, household size, and asset holding. Other researchers analyzed the relation between formal labour market imperfections and the prevalence of an informal labour market (Carter and Zimmerman 2000; Eswaran and Kotwal 1986; Feder 1985). Gilligan (2004) used plot-level data from Indonesia to show that better-endowed households are autarkic and that the probability that they will participate in labour exchange is low.

In network terms, the effect of a farmer's endowment on labour exchange is called the node attribute effect (Fig. 6a). In our study, we use ownership of a power tiller and area under cultivation as measures of the endowment to test the effect of the endowment on enforcing labour exchange. We hypothesize the following:

- Hypothesis 1: Farmers are less likely to engage in labour exchange when they own a power tiller.
- Hypothesis 2: Farmers are less likely to engage in labour exchange with an increasing size of their cultivated area.



[a] Node Attribute Effect [a] [b] Homophily [b] [c] Triad Closure [c]

Figure 6. The different social structures to enforce cooperation in labour exchanges (Source: Authors' elaboration)
Notes: Nodes represent farmers. Edges represent labour exchange links. [a] Example for Node Attribute Effect: nodes 2, 3 and 4 own machines and have few labour links, but node 1 has more links since it does not own a machine. [b] Example for Homophily: nodes 5 and 6 share a link because they have the same number of labour links with other farmers. [c] Example for Triad Closure: nodes 8 and 9 share labour when they are connected to node 7 with whom they both share a labour link. Node 7 cooperates and exchanges labour with nodes 8 and 9 because when not participating in the group node 7 would lose two links.

3.3.3 Node attribute (endowment) effect

Some literature has shown how similar farmers prefer to form links in informal labour-sharing relations (Krishnan and Sciubba 2009; Udry and Conley 2005), referring to the common social phenomenon of "birds of a similar feather flock together" (Glueck and

Glueck 1950). In network terms, this social structure that can informally enforce cooperation in labour-sharing is called the homophily effect (Fig. 6b). It also received interest in the studies of informal enforcement mechanisms (Galeotti et al. 2006; Johnson and Gilles 2003; Haller and Sarangi 2005).

Homophily indices are constructed using different farm-level characteristics to study how homophily can explain participation in labour exchange. Udry and Conley (2005) used both binary (similar religion, matrilineage, gender, soil type, generation, origin from the same region) and continuous (absolute difference of age, wealth, plot distance) categories of farm and household level characteristics. Based on labour exchange data from four villages in Ghana, Udry and Conley (2005) showed that homophily defined as ‘farmer’s origin from a similar region’ has a high odds ratio of 9.73 in enforcing labour exchange, with similarly high effects from the same religion, matrilineage, and gender.

Krishnan and Sciubba (2009) constructed a simple homophily index using the number of labour exchange links. They used labour exchange data from 15 villages in rural Ethiopia to show that farmers with a similar number of links are more important in enforcing labour exchange cooperation and contribute highly to labour network formation.

We construct an index similar to Krishnan and Sciubba (2009) to test the informal enforcement of labour exchange from homophily, which leads to our third hypothesis:

- Hypothesis 3: Farmers are less likely to engage in labour exchange when the difference in the number of labour exchange ties increases.

3.3.4 Triad closure

One social structure that has received much attention in enforcing cooperation in labour exchange is clustering (Coleman 1988; Dasgupta 2005; Krackhardt 1996; Simmel 1950). It measures “the number of pairs of friends that have some friends in common” (Jackson et al. 2012). In the context of labour exchange, it counts the number of pairs of farmers which overlap when exchanging labour. In network terms, this network structure is called triad closure (Fig. 6c).

The common farmer to whom a pair of farmers is connected has different terms throughout the literature: *support* (Jackson et al. 2012), *mutual enforcement* (Dasgupta 2005), and *closure* (Coleman 1988). Jackson et al. (2012) show that 80% of all pairs of labour exchange ties between two farmers have a common farmer with whom they have exchanged labour. To test the effect of triad closure on labour exchange network formation, we specify our final hypothesis as:

- Hypothesis 4: Two farmers are more likely to engage in labour exchange when they have a common farmer with whom they share labour exchange.

3.4 Data and methods

3.4.1 Context, study location, and data collection

Although organic farming faced minimal support in the past, the current Bhutanese government invested a relatively high budget in the 12th Five-Year Plan.[Footnote2] The organic support provides farmers with seeds, training, electric fencing, machinery, and in a few cases, the construction of farm roads and access to water. Development partners also aid Bhutan in building resilient communities against climate change by helping communities with the transition to organic farming[Footnote3]. The National Organic Programme (NOP) provides training in certification procedures and access to the local certification system (LOAS) without administrative cost to improve the market access to organic produce in the local market. The LOAS also ensures the credibility of organic production within Bhutan and is supposed to incentivize organic ‘mass conversion’ (NOP 2019a). It ensures that food production follows the Bhutan Organic Standard (BOS) (NOP 2019b). BOS is adapted to the traditional agricultural system and is not in conflict with the norms of IFOAM-Organics International and Codex Alimentarius Guidelines. It is characterised by promoting traditional farming practices that are still practiced by farmers and do not contradict the core organic principles. For instance, farmers are obliged to continue using farm-yard-manure in place of mineral fertilizers and to apply only manual weeding instead of herbicides to control weeds. Bhutanese farmers also cultivate a wide diversity of crops, which is also encouraged under the BOS. In addition to the traditional farming practices still allowed under BOS, the NOP introduces new farm management practices such as organic pest management, new improved organic seeds, crop protection, etc. Although LOAS requires the whole land of farmers to be certified and to grow diverse crops, the government identifies each village with specific crops to increase production under the ‘One Gewog One Product (OGOP)’ policy.

Our study sites are based on the list of registered and certified organic producers provided by NOP. Hence, the organic villages selected were comprised of households that were certified organic. Khatoed gewog (a subdistrict administrative block consisting of five villages) and Berti village fulfilled this criterion and were selected for the survey. Khatoed focuses on potato and garlic, and Berti on watermelon and paddy. Our network analysis uses nine villages situated in different agroecological zones under different farming systems (Table 23). Besides Khatoed and Berti, our village list includes three traditional farming villages, which are "villages that use no or minimal external inputs" (NOP 2019a).

Table 23. Study locations and their characteristics (Source: Authors' elaboration)

No	Study sites	Status [c]	AEZ [d]	No. of villages	No. of households	Cultivated area [e]	Power tiller ownership[f]	Average labour links[g]	Network density[h]
1	Khatoed	OFV	CT	5	50	39.49	0.52	6.84	0.14
2	Berti (W) [a]	OFV	HST	1	23	64.08	0.17	7.33	0.32
2	Berti (P) [b]	OFV	HST	1	23	105.65	0.17	18.70	0.85
3	Lingmukha	TFV	DST	1	19	228.42	0.84	7.05	0.39
4	Drachukha	TFV	WT	1	19	206.58	0.79	8.32	0.46
5	Hebisa	TFV	DST	1	22	137.73	0.55	11.18	0.53

Notes: [a] In Berti (W): W stands for watermelon, [b] In Berti (P): P stands for paddy: The data was collected from the same village but for different crop seasons. [c] Status: [OFV: Organic Farming Village, TFV: Traditional Farming Village]. [d] AEZ: Agroecological Zone [CT: Cool Temperate (2600-3600 masl), HST: Humid Subtropical (600-1200 masl), DST: Dry Subtropical (1200-1800 masl), WT: Warm Temperate (1800-2600 masl)]. [e] Cultivated area measured in decimal [1 decimal = 0.00404686 hectare or 435.56 square feet (sqft)]. [f] % of households who owns power tiller. [g] Average number of labour exchange links in the village. [h] share of actual labour exchanges in theoretically possible exchanges.

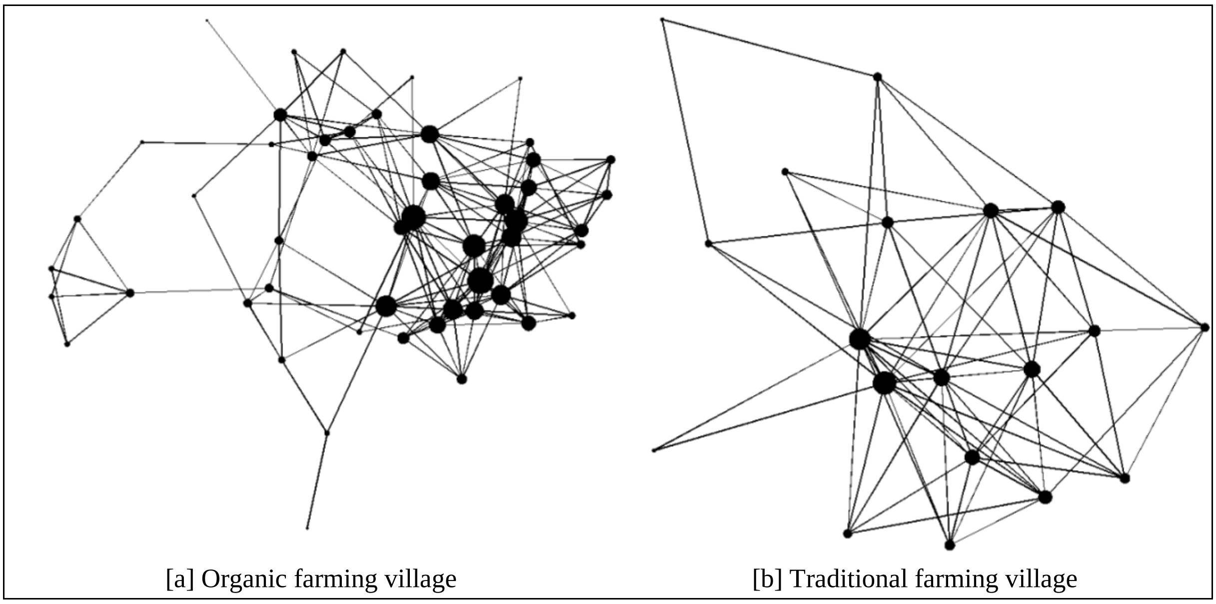
Our study site consists of different villages from diverse AEZ with a large diversity of farming systems (NEC 2022). A farming system in the humid subtropical zone (600–1200 m above sea level (masl)) receives more rainfall and is characterised by higher temperatures. The wetlands are used for main crops like wheat and paddy, while hilly cropland is cultivated with commercial crops like vegetables, legumes, citrus, etc. In the dry subtropical zone (1200–1600 masl), farmers receive moderate rain, and the temperatures are warm. Farmers grow diverse baskets of crops like paddy, maize, mustard, legumes, and vegetables. A moderately warm climate with winter frost is characteristic of the warm temperate zone (1800–2600 masl). Farmers use wet and dry land to grow crops like paddy, wheat, potato, fodder, and vegetables. Farmers in the cool temperate zone (2600–3600 masl) engage in livestock rearing as a common activity and also partake in dryland farming. They grow potatoes, buckwheat, mustard, and barley.

Paddy is grown as a subsistence crop for livelihood in all the selected villages except for Khatoed, where only a few farmers have access to wetland for growing paddy. Farmers depend on monsoon rain to irrigate their fields. In Khatoed, farmers grow garlic and carrot, while potatoes are cultivated as cash crops in both Khatoed and Lingmukha. Only in Berti, do farmers grow watermelon as a cash crop. Chili is a common vegetable grown in all the study villages after the harvest of major crops. While, in Berti, the harvest of watermelon is followed by plantations of paddy, in Lingmukha, potato harvest is followed by paddy. In Khatoed, garlic harvest is followed by the harvest of potatoes. Farmyard manure is used as the main source of soil fertilization in all the villages.

For smallholder farming, during a typical crop season, work in the field begins with land preparation, followed by plantation. For a few months of the crop calendar, farmers are engaged with weeding, which is usually conducted two-to-three times, separated by 4 to 5 weeks apart, and is ultimately followed by the harvest. In all these field activities, farmers depend on labour exchange. In traditional villages, weeding is often replaced by herbicides, especially for paddy and potatoes. Weeding is a major field activity in organic villages, even during land preparation. In both the organic and traditional villages, farmers use power tillers only during land preparation to plough the field, and almost all remaining work on the field is completed manually.

The complete list of the households was requested from the Gewog office. In each village, the enumerator asked: “With whom among them [names of the village members read out to the respondent] did you engage in labour exchange during the specific crop [name of the crop coinciding with the data collection period] season?” This method enables a complete enumeration of names associated with labour exchange instead of asking half of the village farmers to nominate a few with whom they exchange labour (Jackson et al. 2012; Krishnan and Sciubba 2009; Udry and Conley 2005). Additional information on social, economic, and agricultural variables was gathered. The villages given in Table 23 consist of smallholdings with very small areas under cultivation, and with satisfactory use of machinery, like power tillers. The average area under cultivation for paddy (Berti (P), Lingmukha, Drachukha, Hebisa) is higher than for cash crops like watermelon (Berti (W)) and potato (Khatoed). In all the studied villages, more than half of the village population owned a power tiller except for Berti.

Network data of labour exchange were collected for the crop season in which the survey was administered to enable high recollection of the names with whom the surveyed households were engaged in labour exchange. The data collection time coincided with paddy cultivation for most of the villages (Berti, Lingmukha, Drachukha, Hebisa), potato (Khatoed), and watermelon (Berti). The data collected is a binary-directed network, where each household indicated in a list the names of the households with whom labour exchange was performed. All the networks are one-mode in that only information related to labour exchange between households was used in the adjacency matrix. The adjacency matrix is a social matrix that records the labour exchange tie between households. We represent this data in network form (Fig 7).



[a] Organic farming village

[b] Traditional farming village

Figure 7. Labour exchange network (Source: Authors' elaboration). Notes: Nodes represent farmers and edges represent labour exchange links. Size of the nodes: Bigger nodes represent more labour exchange. [a] shows labour exchange from five villages in Khatoed during potato season, and [b] shows labour exchange from the village of Lingmukha during the paddy season.

Labour exchange networks were plotted, and descriptive statistics for average ties (average number of farm households with whom a farmer exchanged labour) and network densities (ratio of actual ties over potential ties) were estimated for organic farming villages. In Khatoed, the average number of labour exchange ties was 6.84 with a density of 13.95% (Table 23); in Berti, the average tie was 7.33 with a density of 31.88% during watermelon season, and 18.70 with a density of 84.98% during paddy season (Table 23). The procedure was repeated for traditional farming villages. In Lingmukha, the average number of labour exchange ties was 7.05 with a network density of 39.18%; in Drachukha the average tie was

8.32 with a network density of 46.19%; in Hebisa the average tie was 11.18, and the network density amounted to 53.24% (Table 23).

3.4.2 Graph modelling and conditional dependence

Graph theory is used to model labour exchange network formation as the result of the given social structure measured using different network structures. These social structures are the micro-configuration of the underlying network that explains the formation of the network under study. One of the advantages of using graph modelling is its ability to account for dependency in nodes connected by edges (Fig. 3.1). When two farmers exchange labour, they create a dependency between them conditional on the rest of the network. This feature of network modelling is called conditional dependence. Our analysis accounts for dependency between nodes and, unlike previous studies (Gilligan 2004; Jackson et al. 2012; Krishnan and Sciubba 2009; Udry and Conley 2005), uses endogenous network formation modelling. It is unrealistic to model network formation under assumptions of conditional independence. An Exponential Random Graph (ERG) model, belonging to a class of random graphs, was designed to analyse the dependent data (Lusher et al. 2013; Frank and Strauss 1986; Wasserman and Pattison 1996).

The ERG model estimates a set of parameters for each of the micro-configurations (chosen by the researcher) to show their effect on the formation of the network. The magnitude (high or low) of the parameters should be interpreted as whether the micro-configurations could have occurred more or less likely by chance. The parameters are estimated using an iterative procedure called Markov Chain Monte Carlo (MCMC) maximum likelihood estimation (MLE). This model first estimates a provisional parameter. Next, using this parameter as a basis, many networks (graphs) are simulated for which network statistics for each configuration in the sampled networks are compared with the statistics of the observed network. The parameters in the simulated network are then adjusted to get the means of the network statistics closer to the observed network statistics. When this happens, the model is said to have achieved convergence. In addition to convergence, ERG needs to achieve significant goodness of fit. In this procedure, after thousands of networks are simulated using the estimated parameters, a random sample of statistics of the micro-configurations (social structures) is compared with those of the observed network. When the ratio of the difference between the simulated and the observed data and the standard deviation of the simulated network is less than 0.1, the model is treated as a good representation of the observed data.

3.4.3 ERG model specification

The Exponential Random Graph (ERG) models allow for treating a labour exchange network as a dependent variable (Lusher et al. 2013; Frank and Strauss 1986; Wasserman and Pattison 1996). The dependent variable is a variable N_{ij}, which shows the potential ties between individual farmers *i* and *j* that take a value of 1 if a labour exchange tie exists and 0 in the case it does not. The matrix ***N*** of these random variables will represent all the potential ties in the network. This type of modelling is however based on several assumptions of which randomness and dependencies of ties are primal. ERG models for any social network assume that networks are the result of -micro-level processes (Lusher et al. 2013). The network n_{ij} is one such observed network among many potential labour exchange networks and matrices $\boldsymbol{n}$ the observed labour exchange network. The observed network n_{ij} could be a result of certain dominant micro features like the prevalence of closed triads, and it would look completely different in another form if closed triads were not prevalent. Under the influence of different micro-level structures, different configurations of n_{ij} can exist within the population of possible networks represented by N_{ij}. In the most general sense, ERG models estimate the probability of observing the observed network of labour exchange as a function of its underlying micro network structure, which is represented by the network statistics $\gamma_S(n)$ that describe our network n concerning micro level features such as nodal attribute effects, homophily, and triad closure. The network statistics are simply the count of those micro features. For example, an observed network might have 10 edges, 4 homophily ties, and 20 triad closures. The corresponding coefficients β_S are the parameters to be estimated for each network statistics according to equation (1):

$$prob(N_{ij} = n_{ij}) = \left[\frac{exp(\sum_S \beta_S \gamma_S(n))}{C}\right] \quad (1)$$

This probability is expressed as a sum over all the network possibilities *C*, which is difficult to estimate. As such the ERG can be reformulated using logistic regressions, which will represent the likelihood ratio between two hypothetical networks. They differ only by a single dyad value in which a hypothetical network *A* will have the relation N_{ij} = 1 and the network *B* has $N_{ij} = 0$. The estimated probability will be the probability that farmers *i* and *j* have a labour exchange tie with each other conditional on the rest of the network N_{ij}^c.

$$logit\left[prob\left(N_{ij} = 1 | N_{ij}^{c}\right)\right] = \sum_S \beta_S \delta\gamma_S(n) \qquad (2)$$

The network statistics $\delta\gamma_S(n)$ measures the amount by which a potential tie between i and j will change the underlying network statistics (the considered tie for instance may change the homophily cases by a certain number), which are modelled as the independent variables. The coefficient β_S is to be interpreted as the change in the log-odds when the particular labour exchange tie existed and if the formation of this tie changed the corresponding network statistics by one unit (Goodreau et al. 2009). The coefficients are to be interpreted exactly like in logistic regression.

3.4.4 Independent variables

The goal of ERG modelling is to describe the global network of labour exchange we observe with a set of local structures or micro configurations as shown in Table 24 (column 1). These social structures enter our ERG model similar to how we specify independent variables in logistic regression. For Nodeofactor, ERG estimates the effect of outgoing ties of a farmer who owns a power tiller (Fig. 3.1a); for Nodeocov, ERG estimates the effect of outgoing ties of a farmer for different levels of cultivated area (Fig. 3.1a). For Absdiff, ERG estimates the effect of the absolute difference of tie numbers between two farmers (Fig. 3.1b). The ERG model term uses a geometrically weighted edgewise shared partner (GWESP) to estimate the effect of triad closure (Goodreau 2007; Hunter et al. 2008; Robins et al. 2007). Two farmers are said to have edgewise-shared partners if they are connected simultaneously, and each one is connected to a third farmer (Hypothesis 4). This term counts the number of triangles in which all the farmers in the network are connected to everyone in the triangle (Fig. 3.1c).

Table 24. Independent variables in the ERG model

Social structure	ERG model terms	Hypothesis	Expected effect	Source
Endowment	Nodeofactor (power tiller)	Hypothesis 1	Negative	Gilligan 2004
	Nodeocov (area cultivated)	Hypothesis 2	Negative	Gilligan 2004
Homophily	Absdiff (number of links)	Hypothesis 3	Negative	Krishnan and Sciubba 2009
Triad closure	GWESP	Hypothesis 4	Positive	Jackson et al. 2012

3.5 Results

We examined labour exchange networks and analysed which distinctive social structures emerge as micro-configurations out of the network formation process to explain how the surveyed Bhutanese communities informally enforce cooperation in the organic and traditional farming systems. The social structures that are statistically significant in the model hint at the properties of the labour exchange network that emerged as effective in enforcing cooperation. They should be interpreted as the relevant key features of the informal mechanism that drives the cooperative behaviour observed in our study sites. These results highlight the role of social network structures in fostering cooperation to pool labour inputs and cope with the burden of labour.

The results from the ERG model estimation are presented in Table 25. To show that the surveyed communities are suitable, we check for social structures that informally enforce cooperation in labour exchange. As outlined above, we formulated four hypotheses based on previous literature and tested them together but separately for different villages. While the results from organic farming villages allow us to understand how farmers adapt to labour-intensive farming, results from traditional farming villages enable us to understand similar behaviour for comparable labour-intensive traditional farming. The *edge* term can be interpreted as how the probability of a labour exchange tie between two farmers is affected by existing ties in the network. This term is similar to an intercept in regression.

Table 25. ERG Model Results

	Organic Farming Village			Traditional Farming Village		
	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Edges	-4.44***	-2.75***	-36.09***	-10.17***	-2.43***	-36.27***
	(0.25)	(0.57)	(10.28)	(2.85)	(0.71)	(0.94)
Endowment (Powertiller)	0.33***	0.41	0.29	-0.32	-0.64*	0.21
	(0.09)	(0.25)	(0.39)	(0.34)	(0.30)	(0.25)
Endowment (Cultivated Area)	-0.00	0.01***	-0.00	0.00	0.00	-0.00
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Homophily (Ties)	-0.06***	-0.11***	-0.06	-0.07	0.04	-0.25***
	(0.02)	(0.02)	(0.04)	(0.03)	(0.04)	(0.03)
Triad Closure (GWESP [a])	2.07***	1.20**	20.97***	7.07***	0.92***	32.07***
	(0.19)	(0.40)	(5.64)	(2.07)	(0.27)	(0.81)

Notes: Significance of estimated results evaluated at (***p < 0.001; **p < 0.01; *p < 0.05). [a] For GWESP estimation decay parameter [α] was varied for different models to attain convergence of MCMC-MLE: Organic Farming Villages [Model 1 = 0.15, Model 2 = 0.15, Model 3 = 0.6]; Traditional Farming Villages [Model 4 = 0.25, Model 5 = 0.6, Model 6 = 0.15].

The estimates regarding the *endowment effect* (Hypotheses 1 and 2) failed to show any conclusive result for the predictions made by the endowment theory. We found only one village (Model 5) with the predicted sign and significance for power tiller endowment, and none of the villages showed a significant expected effect on the cultivated area.

For the *homophily effect* (Hypothesis 3), we found that five out of six models have the expected sign, but only three show a significant effect. The homophily effect is more pronounced than the endowment effect, which is not supported by our data.

We found the most conclusive result for *triad closure* as the social structure feature that can explain best how farmers informally enforce cooperation in labour exchange. A non-ERGM analysis of labour exchange formation would not detect this effect. We found the expected sign and significant results for Hypothesis 4: the tendency for two farmers to form a labour exchange when they have a common farmer with whom they exchange labour. The odds are very high, especially for networks with a high density of labour exchange (Models 3 and 6). We found this effect for all villages studied, indicating its power in explaining how farmers informally enforce cooperation.

An important element in ERG analyses is to assess the goodness of fit. Table 26 shows *p*-values for differences in network statistics (columns) between observed and a sample of simulated networks for different models (rows) for the ERG estimates in Table 25.
Table 26 shows that all the model specifications are good fits for the data generated in different farming villages. Figure 8 shows an example of the goodness of fit plots for one of the models estimated. The boxplots show statistics for simulated networks, which are compared with observed network statistics illustrated by the solid line. The figures show that the observed network statistics are within the simulated confidence intervals and do not deviate too much.

Table 26. Goodness-of-fit Assessment

Farming system	Villages	Edges	Endowment (Power tiller)	Endowment (Area cultivated)	Homophily (Ties)	Triad Closure
Organic	Model 1	0.84	0.88	0.84	0.86	0.82
	Model 2	0.90	0.84	0.88	0.84	0.82
	Model 3	0.74	1.00	0.62	0.70	0.70
Traditional	Model 1	0.28	0.24	0.38	0.34	0.24
	Model 2	0.92	0.96	0.90	0.94	0.86
	Model 3	1.00	1.00	0.94	0.94	0.98

Notes: Calculated approximate p-values for the differences between your observed graph statistics and those from the simulated networks based on the fitted parameters of our model. A high p-value suggests that there is no problem with the fit for that graph statistic.

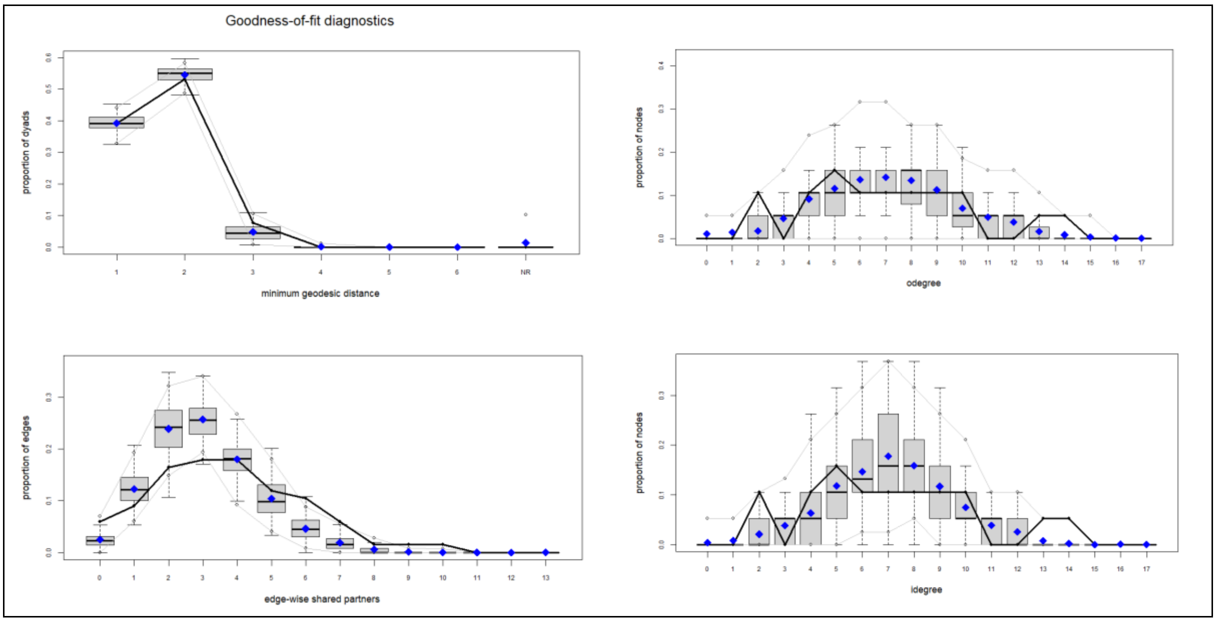


Figure 8. Example of Goodness-of-fit assessment for Model 5. Notes: Box plots of the simulated counts for network structures. Our observed statistics fall within the range of the simulated values. A model fit looks solid associated with high p values in Table 26.

3.6 Discussion

We studied labour-intensive farming villages in Bhutan, intrigued by their ability to enforce cooperation in forming labour exchange to reduce the burden of labour on their farm. We examined the micro-configurations of these labour exchanges that emerge out of the network formation process to explain the mechanisms used by farmers to enforce cooperation in these villages informally. We used social structures identified in prior literature to interpret *why* farmers may decide to form certain links. We then used an exponential random graph model to show *how* the network formation process generates the labour network we have observed. Our objective was to characterize the informal enforcement mechanism of cooperative behaviour in a labour-intensive farming system of a low-income country.

Previous work on the role of social structures in fostering cooperation in informal exchanges has suggested that certain network patterns emerge in these networks that can be used to characterize and predict consistency within data (Coleman 1988; Dasgupta 2005; Gilligan 2004; Jackson et al. 2012; Krishnan and Sciubba 2009). However, with few exceptions, empirical evidence has remained largely scant in the informal labour exchange still prevalent in low-income countries (Gilligan 2004; Jackson et al. 2012; Krishnan and Sciubba 2009). Our research contributes to the literature by providing empirical evidence for the consistency of the network patterns of labour network formation theory. We use multiple theoretical foundations from this research to characterize the social network of labour-sharing arrangements in our labour-intensive farming villages.

When modelling different structures of informal enforcement mechanisms used in the selected villages, both organic and traditional farming villages show significant effects of triad closure in enforcing cooperation (Coleman 1988; Jackson et al. 2012). Jackson et al. (2012, page 1857) use social ostracism as an argument to explain why this structure emerges in most labour-sharing arrangements: “any two individuals interact too infrequently to sustain exchange, but such that the social pressure of the possible loss of multiple relationships can sustain exchange”. They further argue that this social ostracism leads to “tree-like unions of completely connected subnetworks (in which) any two individuals exchanging favors have a common friend” (Jackson et al. 2012). Coleman (1988) uses closure within a similar network structure, arguing that groups of farmers can easily monitor and exert pressure on other farmers to behave in the interest of the group.

The literature has focused only on explaining *why* farmers engage in cooperative labour-sharing behaviour and has remained short in explaining *how* the labour network formation process results in the network patterns. Our work combines both approaches used for explaining the network formation theory to provide a unified approach and explain the *why* and *how* of labour exchange networks. We use a recent development in the random graph theory called ERG modelling and test multiple social structures from the literature to determine which network patterns emerge among the Bhutanese farmers. Past studies do not consider this feature and assume only one structure underlying the social enforcement mechanism. Our analysis assumes that multiple social structures can exist. One social structure could lead to the formation of another structure through an endogenous process. This kind of modelling is still a novelty in the literature on labour network formation. The evidence for other network patterns we tested is mixed in our analysis. Two explanations come to mind. One, villages have differing underlying social structures, and some network patterns are relevant only in a certain context. This feature could be useful in differentiating labour exchange institutions in future work. Two, farmers tend to work in more constellations than in groups of two. However, the predictions made by some theories make sense only for dyad relationships between farmers. For instance, the first three hypotheses are only based on dyad-level network structures. But in the field, we found that group dynamics are often more prevalent, which might have provided consistent predictions for triad closure as a network pattern in all the villages.

In drawing our recommendations, we emphasize that projects and policies should consider villages with well-functioning labour exchange to promote organic farming.
When smallholders adopt organic farming practices this can have huge implications on labour. This holds especially true in low-income countries, where farm infrastructure is weak, and where labour exchange can play a critical role in meeting increasing labour demands. While labour exchange may play an important role in mitigating labour problems in organic farming, it will face limitations if problems of out-migration from villages are not considered a policy priority in Bhutan. In general, the farming systems in Bhutan are highly labour-intensive (Feuerbacher et al. 2020), and a decrease in the pool of available labour could have an impact on the labour exchange system, with further implications for the promotion of organic farming. Although our research did not analyse such issues, network structures are susceptible to changes in the underlying conditions (Jackson et al. 2012). Further research in this area could help policymakers intervene with necessary measures to ensure well-functioning labour exchange systems.

While our data from ‘organic’ and ‘traditional farming’ villages are from Bhutan, caution is necessary for generalizing the results beyond Bhutan’s country context. However, it must be reiterated here that the network patterns used in predicting the consistency were test-based in other low-income countries. One finds relevance across the board, implying that some social enforcement mechanisms may be common across different contexts. Our analytical approach can serve as a tool for policymakers and project partners to identify suitable villages to promote organic farming. As governments in low-income countries usually face serious budgetary constraints, choosing suitable villages when implementing organic farming to promote policies and projects matters. For instance, over 66% of the farmers in Bhutan use labour exchange (MoAF 2019). Our analysis can be used to characterize which villages are most suitable for implementing labour-intensive farming practices. Although our argument of a suitable farming community for promoting organic or other labour-intensive farming is based on the existence of a well-functioning labour exchange system, a similar network analysis using ERG could be performed to describe and explain other informal institutions like the ones that govern the exchange and use of credit, seed, machinery, water, etc., which constitute other forms of resource sharing mechanisms in low-income countries. A report by ICIMOD and MoAF (2018) showed that over 98% of Bhutanese farmers use seed networks to meet seed demand. Surprisingly, the Bhutanese government does not currently take advantage of such networks.

Although our work is focused on examining informal labour-sharing systems, it will be valuable in future work when analyzing the association between networks and economic outcomes. Past work has emphasized that not only the number of labour exchange links but also the structure of the network matters when estimating the effects of labour exchange on farm productivity (Krishnan and Sciubba 2009). It has shown that high-ability farmers tend to form links with similar high-ability farmers and that these farmers are unavailable to low-ability farmers. It has further been shown that this structural behaviour leads to productivity differences on the farm. Our analysis shows that other social structures are also relevant (and partly statistically significant) in addition to triad closure as a common social structure. A careful observation of our analysis shows that all the surveyed villages are structurally different. This implies that economic outcomes from these villages should also be different, which could be explored in future work.

In our view, labour exchange has always been seen as an old-age custom passed down from generation to generation. We think this view is somewhat misleading because this resource gap-filling institution is assumed being available to everyone in the village and makes the adoption of labour-intensive farming systems easy for farmers. Together with previous researchers, we highlight the existence of strategic decision-making, leading to network structures with specific characteristics. This implies that labour exchange is not a norm where a labour contribution from all members of the community is expected. Instead, it involves careful decision-making concerning with whom to form links. Farmers engage in labour exchange not because they want to contribute to the community's well-being but, according to the triad closure hypothesis, for fear of losing other links if they do not exchange with farmers in the connected links (Jackson et al. 2012). Alternatively, it could be that another farmer has machinery that can be useful (Gilligan 2004) or that the other is of high ability compared to the farmer close to his house (Krishnan and Sciubba 2009). In short, although labour exchange is common in most villages in Bhutan, its specific 'micro-configurations’ might differ, implying that the social mechanisms used for enforcing cooperation are different.

Although smallholder subsistence farmers are among the most vulnerable groups concerning climate change, they also display the ingenuity and capacity to adapt to climate change through their community dynamics (Nazir and Das Lohano 2022; Tshotsho 2022). Because smallholder farming produces relatively high yields and engages in a high diversity of crops, it is also enshrined in future sustainable agriculture development policies (Ricciardi et al. 2021). Policymakers should recognize the role of communities in building resilient farming systems. However, smallholders also need the state and external support to improve the outcomes of resilient communities (Ahmed 2022; Shafeeqa and Abeyrathne 2022).

3.7 Conclusion

We presented the case of labour-intensive farming villages that are capable of coping with the burden of labour through the use of labour exchange institutions. While examining these informal institutions, we found that farmers engage in joint action of sharing labour, which seems to provide a mutually beneficial outcome to managing the burden of labour. We modelled our social network data using an exponential random graph model to characterize the underlying social structure. We identified one major network pattern that emerges from the network formation process: triad closure. This social structure seems to be a labour exchange arrangement that can help to identify other communities that may be suitable for further promotion of labour-intensive (organic) farming systems in Bhutan and other low-income countries. Our network formation analysis combines economics and graph theory and offers a unified framework to understand the *why* and *how* of labour exchange network formation.

Our analysis has relevance for organic development policies for three reasons: first, a society like the Bhutanese one that, to a large extent, relies upon the farming sector, can thus better adapt to a more labour-intensive farming system; second, the functioning and preservation of labour exchange is even to be seen as a prerequisite for successful conversion to labour-intensive organic farming; third, public spending in suitable communities assures successful implementation justifying public funding for providing seeds, training, machinery support, electric fencing, road and water connectivity, and market support. This article provides insight into whether the transition from one agricultural system to another may be possible without major difficulties for the farmers studied here and in the broader context of the country.

The analysis of organic farming villages provides a starting point in recognizing the role of labour exchange in managing labour requirements in organic farming. As more farm households convert to organic farming, future research should focus on collecting network data from more villages before and after conversion to organic farming. It should study if labour exchange institutions are successfully carried over as the farming system undergoes conversion and whether communities can still informally enforce cooperation. Future research should also extend beyond labour and look at other important informal exchanges for farm inputs like seed, credit, machinery, advice, water use, etc. Future work on the role of labour exchange systems may conduct comparative analyses investigating to what extent labour exchange systems with different enforcement mechanisms increase the uptake of labour-intensive farming practices. Future studies can also use the specific properties of labour exchange to investigate the economic outcomes of the farms under different farming systems. For instance, one could study the yield gap in different farming systems with different mechanisms used for enforcing cooperation in labour exchange.

Notes:

1. The traditional farming villages are organic-by-default with no or very minimal dependence on external inputs.
2. Gross National Happiness Commission: https://flagship.gnhc.gov.bt/organic/
3. ICIMOD: https://www.icimod.org/initiative/rms/ UNDP: https://reliefweb.int/report/bhutan/launch-undp-gef-ldcf-project-enhancing-sustainability-and-climate-resilience-forest

3.8 Reference

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Chapter 4

4 Contagion or structural equivalence? Social network mechanisms in the adoption of improved seed varieties among smallholder farmers in Bhutan

4.1 Abstract

Farmers can learn from each other through direct relationships of communication and advice sharing. They can also be inspired to imitate the behavior of others because they are in similar social positions to themselves even if they do not directly exchange information with each other. The latter mechanism is typically not explicitly considered in research on the role of networks in agricultural technology adoption and only diffusion through direct ties is mostly implied. This is likely inaccurate and unfortunate because the different potential network mechanisms at play in a given context would have different implications for targeting effective interventions towards adoption of recommended practices. We use field data on retrospective adoption of improved seed varieties among farmers in five remote villages of Bhutan to explicitly explore these two mechanisms. Our results suggest that both mechanisms, diffusion by social contagion and structural equivalence can explain behavior change among farmers. Interventionists should not only preferentially target farmers with numerous connections in the hope that their behavior will influence their abundant network partners but also farmers in diverse social positions, including peripheral network positions, who can inspire less-connected others towards adoption.

Keywords: Technology diffusion, Social network, Social contagion, Structural equivalence, Improved seeds

4.2 Introduction

For over five decades, we have seen sustained interest in the role of social networks in shaping the process of technology diffusion in agrarian areas. Evidence accumulates that farmers do not make their decisions in isolation even if coordination on separate fields is not explicitly required (Cheng, 2022; DeDecker et al., 2022; Higgins et al., 2023). Technology diffusion models that account for networks within the social context provide improved explanations and policy guidance (Driscoll & Holden, 2014; Pauschinger and Klauser, 2022). Network ties can potentially shape individual behavior as direct conduits of peer-to-peer information and influence (Medina et al., 2022; Ryan & Gross, 1943; Ward & Pede, 2014). Position in the network topology is also an indicator of an individual’s standing in their community and self-awareness of this position vis-a-vis their frame of reference may also influence one’s behavior (Medina et al., 2022).

The distinction between these two network mechanisms matters for the effectiveness of policies and programs aiming to scale the impacts of interventions through spontaneous local social processes. If a particular behavior in a certain context is susceptible to diffusion through social relationships, resembling the metaphor of a flow of water through a network, or an epidemic spread through direct contact, this may support the case for common programs preferentially targeting “key” or “model” farmers with a high number of social links in their community (Geleta et al., 2023). When adoption is also shaped by social comparison to others in similar social positions, marginalized community members may be more inspired by behaviors of other members on the community periphery, even if they do not directly communicate with one another (Gao et al., 2022). This mechanism would support a case for a higher inclusion of peripheral community members in intervention targeting, which then is not only motivated by social justice, but also by effectiveness.

Conceptually, in the case of “simple contagion” through peer-to-peer networks, the analytical frame of reference is at the dyad level (Burt & Doreian, 1982). In the structural equivalence case, the frame of reference is the entire social system (Burt & Doreian, 1982). Empirical research of the role of social networks in farmers’ adoption of technology typically tends to assume contagion mechanisms, often neglecting the possible role of structural equivalence. While numerous studies of personal network characteristics of “early adopters” bear a resemblance to structural equivalence thinking (Bursztyn et al., 2014; Maertens, 2017) these usually do not explicitly examine whether actors who have topologically similar chains of connections in the same fully-measured social network tend to adopt similar practices. Common studies of early adopters usually contribute only less nuanced generic statistical regularities, for example, that farmers with more links may adopt innovations sooner, without considering how the structure of these links in the community may influence structurally equivalent, although disconnected, actors to adopt certain roles and patterns of behavior.

Our objective is to test how structural equivalence and contagion fit the observed reality of improved seed adoption in six remote villages in Bhutan. We estimate three types of models, one that represents each network mechanism (contagion or structural equivalence) in isolation and a third that combines both mechanisms. In the present case, structural equivalence proved to be as good a predictor of behavior as the contagion mechanisms. The remainder of this article is organized as follows: In Section 4.2, we refer to selected aspects of social network theory, from which we derive three hypotheses and describe a general theory for testing the latter. Section 4.3 describes the study sites, data collection, and our analytical approach. The analytical approach outlines the specifications for the logistic regression method used to test the general theory and describes its estimation procedures. The best-fitting models involving a combination of the two network adoption norms considered are presented in Section 4.4 and discussed in Section 4.5. We conclude by suggesting how these results highlight the need for more nuanced strategies to promote improved agricultural practices (Section 4.6).

4.3 Theoretical Framework

4.3.1 Social structure and agricultural technology adoption

Extension programs typically do not have the capacity to work directly with all smallholder farmers and therefore these tend to focus only on a smaller number of “model” farmers when promoting new technologies. If the model farmers adopt the new technology, the hope is that others will imitate them and spread the new practice. This approach rests on the evidence that farmers do not make economic decisions in isolation (Cheng, 2022; DeDecker et al., 2022; Higgins et al., 2023). The practical question is, under limited resources, which farmers to choose as the target of technology promoting government interventions to maximize their impact? The answer depends on which network mechanisms are expected to drive other farmers’ change in behavior. When behavioral *contagion* through network links is (implicitly) expected as the dominant driver of behavioral change (Cliff, 1981; Bayley, 1976; Emerick, 2018; White et al., 1981), “opinion leaders”, with many network links seem like the best choice for intervention targeting (Oldmeadow et al., 2003). However, this might not always be the best approach.

Another possible mechanism is based on *structural equivalence*, when two individuals (“ego” and “alter” in network terminology) in similar social positions may compete or inspire each other, even without direct communication (Burt, 1987; Lorrain & White, 1971). This can be exemplified by two physicians who are trying to keep up with medical innovations and maintain the image of good medical practitioners in the medical community. Burt (1987) argues that “the more similar ego’s and alter’s relations with other persons are-that is, the more that alter could substitute for ego in ego’s role relations, and so the more intense that ego’s feelings of competition with alter are-the more likely it is that ego will quickly adopt any innovation perceived to make alter more attractive as the object or source of relation” (p.1291). According to Burt (1987), alters who are status apart from the ego do not matter irrespective of the frequency and empathy of communication between them. For example, among the physicians in the medical innovation study by Burt (1987), early adopters who prescribe new drugs were often young, often contacted by similar drug companies, subscribed to similar professional journals and emphasized keeping up with the recent scientific developments. Analogically, structurally equivalent farmers are subjected to similar general social pressures (Maertens, 2017). In related fields, structural equivalence has been found to play a role in the spread of climate change policies (Kammerer & Namhata, 2018) and food sovereignty movements (Shawki, 2015), as well as international conflict resolution (Maoz et al., 2006). For example, Cao and Prakash (2011) provide evidence of mimicking competing actors in the international trade arena. Structural equivalence provides a general understanding that network effects are heterogeneous because they are influenced by background attributes and require contextual targeting of different social positions.

To test the relevance of specific social network mechanisms in farm technology adoption, we examine the following alternative hypotheses. *Hypothesis 1*: Ego and alter have a strong relation but they do not have a similar relation pattern with the rest of the network. Only social *contagion* predicts similarity in technology adoption. *Hypothesis 2*: Ego and alter have an identical relation pattern with others in the network but they are not strongly related to each other. Only *structural equivalence* predicts similarity in technology adoption. *Hypothesis*

3: Ego and alter have a strong relation and also have identical relation patterns with others in the network. Both *structural equivalence* and social *contagion* jointly matter.

4.3.2 Formal conceptualization

To formulate and test the predictions of technology adoption by personal background, *contagion*, and *structural equivalence*, we use the simple general theory of Burt (1987) illustrated by the following equation, with a slight modification in the presentation:

$$y_j = b_p p_j + b_s^c y_j^* + b_s^{se} y_j^{**} + e_j \qquad (1)$$

In equation (1), y_j quantifies ego's (*j*) response to an innovation (measured as a binary variable with, 1 if the seed variety is adopted, and 0 if not) subject to the influence of p_j, a variable that indicates ego's personal background and can change his response. The variables y_j^* and y_j^{**} quantify the adoption norm for ego, and e_j is the residual term. The betas show the importance of personal background and social network mechanisms in explaining the ego's behavioral response. A comprehensive explanation of how p_j, y_j^* and y_j^{**} are related to y_j can be found in Burt's (1987) publication, while a more detailed theoretical treatment can be found in Burt and Doreian's (1982) publication. We retain the original equation but separate the social mechanism into contagion and structural equivalence.

The adoption norm variables $y_j^*$and y_j^{**} are expressed as a weighted average of the adoption behaviors of the alters *i (*Eq.2*)*.

$$y_j^* = \sum_i w_{ji}^c y_j \;\; \& \;\; y_j^{**} = \sum_i w_{ji}^{se} y_j \quad (2)$$

In equation (2), w_{ji}^c and w_{ji}^{se}quantifies the extent to which alters *i* are used as a social reference for ego's response to the innovation. This weighting factors w_{ji}^c and w_{ji}^{se} for defining the social norm of adoption can be expressed in general as follows (Burt, 1987):

$$w_{ji} = \frac{(\text{proximity of } j \text{ to } i)^v}{\sum_k (\text{proximity of } j \text{ to } k)^v}\ , k \neq j \qquad (3)$$

Given the social network data, w_{ji} can be used to define both contagion and structural equivalence. If one measures proximity by the frequency and empathy of *j*'s communication with *i*, w_{ji} is operationalized as contagion (w_{ji}^c), in which case y_j^* reflects the adoption behavior of the people with whom j talks about the innovation. When measuring proximity based on the similarity of each person's relationships with j and i, w_{ji} is operationalized by structural equivalence w_{ji}^{se}. However, since the two weighting factors are conceptually different, they are calculated differently. We clarify that the weighting factor w_{ji}^{c} is based on only "i" alters who are connected to ego "j", but w_{ji}^{se} is based all alters "i" in the network whether they connected or not to ego "j". The adoption norm y_j^{**} then reflects the adoption behavior of individuals who share the ego's status in the study population. To normalize w_{ji}, summation is performed over all members of the study population except the ego, which results in weight values between 0 and 1. The proportion w_{ji} indicates the extent to which person i serves as a social reference for evaluating the ego's response or how ego's expected response based on decisions made by individuals who form the frame of reference for the two mechanisms. The degree of conservatism exhibited by the ego in relying on others is determined by the exponent υ. A high value of υ indicates that only ego's "closest confidants" (contagion) or those who are typically his "closest rivals" or sources of inspiration (structural equivalence) have an influence on his evaluation of innovation (Burt, 1987).

4.4 Materials and methods

4.4.1 Analytical approach: Estimation

The following logistic regression model (Allison, 1984) with linear regression coefficients b_p and b_s is used to estimate the adoption model shown in equation (1).

$$\log \frac{\Pr(y_j = 1)}{\left(1 - \Pr(y_j = 1)\right)} = \alpha + \sum b_p p_j + b_s^c y_j^* + b_s^{se} y_j^{**} + e \qquad (4)$$

The outcome variable of the logistic regression is ego's response to the innovation, measured by y_j ($y_j = 1$ in the case the new seed variety has been adopted and $y_j = 0$ in the case of non-adoption). α is the intercept and p_j represents a vector of personal background variables such as age, education, and gender of the household head. y_j^* represents ego's adoption norm under contagion and y_j^{**} represents ego's adoption norm under structural equivalence. e is the residual. The betas to be estimated are b_p, b_s^c, and b_s^{se}. We used a special statistical package [netdiffuseR] developed to create network-based technology diffusion data (Valente, 2010; Vega Yon & Valente, 2020). Once the data is set up, generating the ego's adoption and adoption norm variables is straightforward. The adoption norm variable, represented by y_j^* and expressed in Equation (1), is generated using the exposure function from the package.

We use the following formulae to calculate the weight w_{ji} introduced in equations (2) and (3) above (refer to Burt (1982) for a more detailed discussion):

$$w_{ji}^{c} = \frac{(Z_{ji})^{v}}{\sum_k (Z_{jk})^{v}}\ , k \neq j \qquad (5)$$

The value of w_{ji}^{c} for contagion is based on the raw choice data of communication between "ego" and "alter" (expressed in 0 and 1). The term Z_{ji} is the path distance (geodesic) between ego "j" and alter "i". The term Z_{jk} is the path distance (geodesic) between ego "j" and alters "k". For structural equivalence, w_{ji}^{se} will be calculated in two steps:

$$\textit{Step 1}: d_{ij} = \left[(Z_{ij} - Z_{ji})^2 + \textstyle\sum_k (Z_{ik} - Z_{jk})^2 + \sum_k (Z_{ki} - Z_{kj})^2 \right]^2 \qquad (6)$$

$$\textit{Step 2}:\ w_{ji}^{se} = \frac{(dmax_j - d_{ij})^{v}}{\sum_k (dmax_j - d_{kj})^{v}} \qquad (7)$$

In the first step, we calculate the Euclidean distance between ego "j" and alter "I". The term d_{ij} is the Euclidean distance between the positions of ego "j" and alter "i". Euclidean distance is calculated using path distances in the social network: Z_{ij} and Z_{ji} are the path distance (geodesic) between ego "j" and alter "i", and Z_{ik} and Z_{ki} are the path distance (geodesic) between alter "i" and actors (nodes) "k" in the social network, Z_{jk} and Z_{kj} are the path distance (geodesic) between ego "j" and other actors "k" in the social network. Then using the Euclidean distance d_{ij} , the weight for structural equivalence w_{ji}^{se} is calculated in the second step. The term $dmax_j$ is the largest distance between ego "j" and any actor in the network, and d_{kj} is the Euclidean distance between ego "j" and other "k" actors in the network. The weight w_{ji}^{se} will vary between 0 (high structural similarity) and 1 (low structural similarity) between ego "j" and alter "i".

The adoption norm can calculate values for contagion and structural equivalence at different values of υ [1, 2, and 15 in our study], following closely with Burt's strategy in his publication (Burt, 1987). Different values of υ resulted in changes in the adoption norm only for structural equivalence and not for contagion [hence contagion is assigned $\upsilon = 1$ throughout the paper] and for different specifications of the model in equation 3.

We specify the model in equation 4 in five different ways to test our hypotheses. To test Hypothesis 1 [Model 1], we specify Equation 4 with only the adoption norm for contagion and assume that "ego" and "alter have a strong relationship but not a similar relationship pattern with the rest of the network. To test Hypothesis 2 [Model 2], we specify Equation 4 with the adoption norm for structural equivalence and assume that ego and alter have the same relationship pattern with others in the network but are not closely related. In testing Hypothesis 3 [Model 3], we specify Equation 4 with both the adoption norm for contagion and structural equivalence and personal background. We start with $\upsilon = 1$ in model 3, and to explore higher values of υ (2 and 15), equation 4 is re-estimated in models 4 and 5.

4.4.2 Context, study sites and data collection

Bhutan is predominantly covered by forests and only around 3% (112,550 hectares) of its land is available for agricultural production (CIAT & World Bank, 2017). Bhutan relies on food imports to meet most of its food needs, and achieving food security and food self-sufficiency remains an important policy goal for the country (Feuerbacher et al., 2018). This policy goal faces two major challenges. First, agriculture in Bhutan has typical characteristics of subsistence agriculture with small landholdings, a widely dispersed population, and limited farmer access to markets. Second, Bhutan's agricultural sector is highly vulnerable to climate change, has low productivity, and faces numerous constraints (CIAT & World Bank, 2017).

Farmers engage in both crop and livestock production. The government is advocating for the commercialization of the agricultural sector, as the contribution of smallholders to agriculture is minimal and the number of households making a living from agriculture is declining (CIAT & World Bank, 2017). With several agricultural research centers throughout the country, most of the policy strategy in the past has focused on research (Christensen et al., 2012). Crop diversification has gained momentum with policy revisions and the research centers' new research and outreach program directly involves farmers in development programs (Christensen et al., 2012). The crop diversification strategy depends on the research centers to introduce new and improved crop varieties and disseminate them to a larger group of farmers.

Distribution of improved seeds, including quinoa, potatoes, watermelons, and vegetables, is a recent development with limited implementation in some villages in Bhutan. We conducted telephone interviews with extension officers and community members to gain insight into this progress. Information on the type of seed introduced and where it is being used also comes from Sanam Drupdrey, an annual publication of the Ministry of Agriculture and Livestock (MoAL). The villages in Table 27 have received improved seed and were selected as study sites because of their high adoption rates. The specific seed introduced in these villages, chiwog or gewog, has been in circulation for some time and is therefore well suited for studying diffusion of seeds.

The study villages included in our study are located in two of the three agroecological zones (AEZs). The subtropical AEZ is located at an elevation of 150 to 1800 meters, receives annual rainfall between 850 and 5500 millimeters, and has temperatures between 3.1 and 34.6 degrees Celsius. The main agricultural practices in this AEZ include the cultivation of irrigated rice, mustard, wheat, pulses, vegetables, tropical fruits, maize, millet, and lemongrass, as well as livestock raising with cattle, pigs, and poultry. The temperate AEZ ranges in elevations from 1800 to 3600 meters, has an annual rainfall of 650-850 millimeters and temperatures of 0.1-26.3 degrees Celsius. Agriculture in this region includes the cultivation of irrigated rice, wheat, mustard, barley, potatoes, buckwheat, vegetables and temperate fruits. In addition, livestock is also raised. Crops are grown in a single field each year and farmers usually practice multi-cropping.

The primary analysis includes only three study sites. Sergithang Maed gewog (a gewog is a sub-district) is located in the humid subtropical agroecological zone (HST-AEZ, 600-1200 meters above sea level (masl)). In this chiwog, a drought-resistant, nutrient-rich, high-value cereal crop, quinoa, was introduced in 2015. The chiwog is registered with the National Center for Organic Agriculture (NCOA) in Bhutan for organic farming. There are 58 farmers [interviewed] and two farmer groups in the chiwog. Lobnekha chiwog is located in the warm temperate AEZ (WT-AEZ, 1800-2600 masl). Here, a high-yielding, blight-resistant, and nutrient-rich seed for potatoes (called Yuesi Marp) was introduced in 2017. There are 64 [respondent] farmers and one farmer group, but only 5 farmers are members of the group, all of whom are women. The farmers practice conventional (not organic) agriculture. Berti village is located in the humid subtropical AEZ (WST, 150-600 masl). In this village, a drought-resistant and heat-tolerant watermelon seed was introduced in 2017. There are 24 [interviewed] farmers and one farmer group with only 11 women as members. The members are certified as organic farmers by NCOA. The above seeds are procured, produced and distributed by the National Seed Center (NSC) in Bhutan, which is also registered with NCOA. NCOA also conducts field trials of new seeds and distributes them to both organic and conventional farmers in the country.

Table 27. Description of the study sites

Study sites	Berti	Lobnekha	Sergithang Maed	Goongring	Khar
Adopters interviewed	24	64	58	36	32
Number of adopters each year					
2015			3	7	6
2016			3	9	10
2017	10	10	8	19	8
2018	3	3	7	1	4
2019	3	3	5		3
2020	6	4	3		1
2021	2	29	1		6
2022		4			
Non-adopters		11	28		
Female household head [in %]	62.5	54.7	13.8	11.1	46.9
Age	51.8	46	52.1	41.2	55.3
Education	1.4	2.4	2	5	1.9
Group member [in %]	45.8	14.1	41.4	97.2	18.8
Number of Villages	1	4	1	5	4
Diffusion period	2017-21	2017-22	2015-21	2015-18	2015-20
Farming system	Organic	Conventional	Mixed	Organic	Conventional
Agro-Ecological Zone	Sub-tropical	Temperate	Sub-tropical	Sub-tropical	Sub-tropical

Note. Gender, Age and Education attainment is reported for head of the household who makes the decision. Female household head [in %], Age (Number of years), Educational attainment (Years of educational levels attained). Organic refers to farms operating under certified organic system. Mix farming system consists of both conventional and certified organic farm. Group member is percentage of adopters who are members of farmer's group in the study site. In Sergithang those farmers who were members of a farmer's group also belong to organic farming system. Berti is a village. Lobnekha, Goongring, and Khar are chiwogs. In Bhutan, chiwog is a collection of villages. Sergithang Maed is a gewog. Gewog is a collection of chiwogs.

Data for this study were collected in 2022 through in-person surveys with sociometric interviews (Pachoud et al., 2019). Data were collected by trained extension officers in Goongring, Sergithang Maed, and Khar. They provided valuable information on farmers' adoption of seeds and willingly participated in the data collection. Trained students from the College of Natural Resources (where the corresponding author is stationed) in Bhutan collected data in Berti and Lobnekha. The enumerators' place of work and residence proved helpful for producing reliable network data because they knew the residents of the study sites well.

At each site, we collected data on the timing of adoption of improved seed varieties, social networks in the villages, and user characteristics such as age, education level, and gender. Despite our goal to survey all members of the villages in the study sites, it was not possible to fully capture social networks in two of the five study sites (Goongring and Khar). The time period for potential adoption of the improved seed varieties was since their introduction in 2015 and 2022. Following Rogers (1983), we asked farmers to recall when the crops were introduced.

We used a social relationship name generator to collect information about respondents' network partners (Marsden & Friedkin, 1993). Farmers were asked to name three farmers in their village for each name-generating question: (1) from whom they "seek advice", whom they (2) "consider best friends", (3) "close relatives", (4) "influential farmers", and (5) "influential in agricultural technology" (Caeiro, 2019; Saint Ville et al., 2016; Unay Gailhard et al., 2015). Respondents could name any partners from the study sites where they reside and were allowed to name the same person for multiple roles.

In Figure 9, the farmers to whom the improved seed variety was distributed are located in Berti village, and they also have varying degrees of social connections, as indicated by the size of the node. For example, farmer-4 has a high number of social connections but was not selected as a model farmer in 2017, while farmer-2 appears to be less connected but was selected as a seed in 2017. Farmers-2, 7, 5, 10, 16, 18, 20 and 24 were selected as seed or model farmers. Unlike in previous studies, in which one found strategically selected "seed" farmers introducing new technologies into their communities (Matouš, 2023), there were no indications that farmers were strategically selected in our study. There is no evidence of long-term experiments in which research centers implement this strategy. This is also evident in

Figure 9, where early adopters were selected from farmers with different social connections (e.g., farmer 2 versus farmer 17). In general, however, farmers who are part of a Farmer's Group (FG) are more likely to experiment first, although membership changes over time.

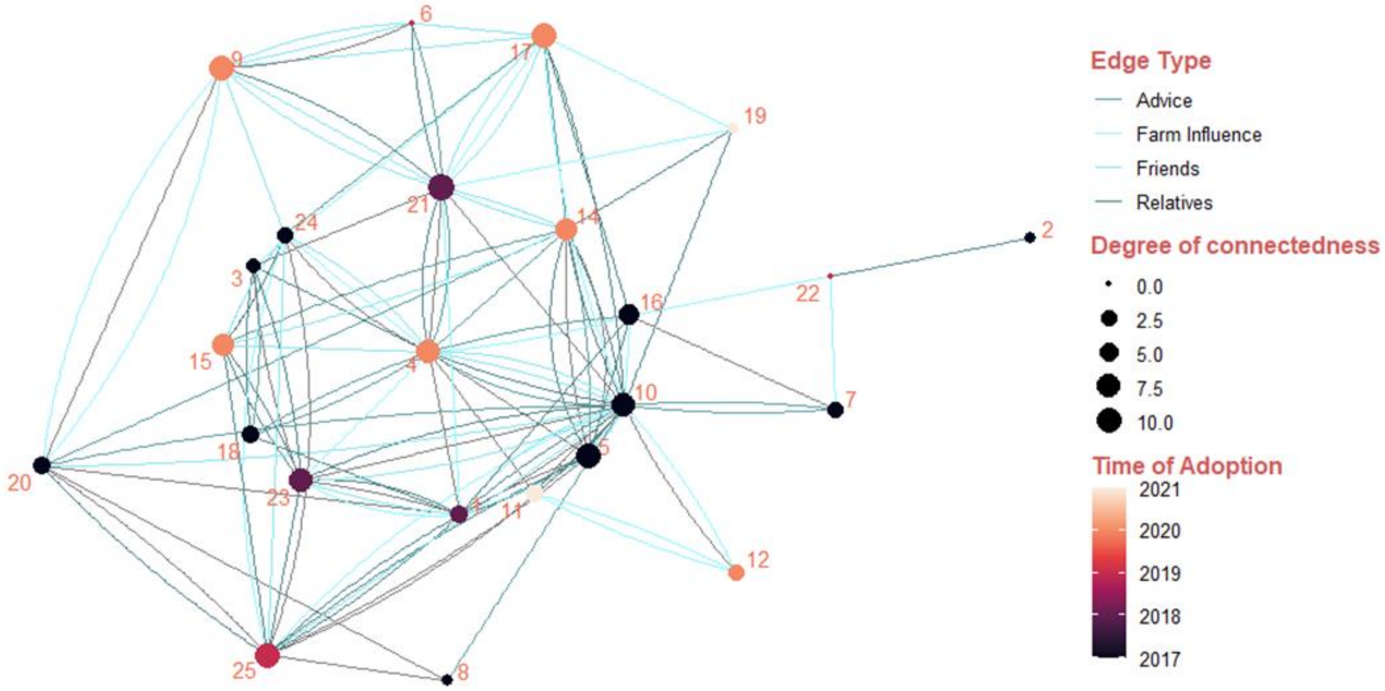

Figure 9. Farmers' network from one study site (Berti). The nodes show farmers who represent the "alter" and "ego", and the edges represent the network for describing the advice, friendship, close relatives, and influential farmers ties between farmers. The size of the node indicates high connectivity (degree) among the farmers. The graph shows adoption behavior (whether the farmer adopted or did not adopt the improved seed variety) in the selected site. Edge type shows the type of social network used for constructing social mechanism. Time of adoption shows the year in which farmers adopted the seed. Size of the node shows the degree of connectedness among the farmers.

Our strategy was to collect complete data on the village network. The study site was limited by the boundary of the targeted village. In Berti, for example, the question of the boundary is not problematic because of its isolated location. In the case of Lobnekha Chiwog, which consists of four villages, the boundary was set to include all farms of the chiwog, not just those in individual villages. Respondents were allowed to name network connections from each of the four villages in Lobnekha Chiwog. A similar method of data collection was used for Goongring and Khar. For Sergithang Maed (Gewog), we limited participants to mentioning connections exclusively within the designated Gewog and not from the adjacent Gewog (Sergithang Toed). We removed network connections that were outside the study site boundaries, although few appeared. Full network data are generally reliable, as then all existing network connections are included.

Our methodology aims to determine which specific model provides a better fit to our data. To build and evaluate our models, we use the machine learning package tidymodels in R (Kuhn & Silge, 2022). We use an 80:20 data split and a k-fold (k=10) resampling validation method to test our classification models. First, we build and test our model on 80% of the data and reserve the remaining 20% for the final performance test. We use ROC-AUC (Receiver Operating Characteristics-Area Under the Curve, ratio of true-positive to false-positive), supported by prediction accuracy where appropriate, as the performance metric for our models. We also report sensitivity (true positive) and specificity (true negative).

The analysis is performed using data from three study sites, as a complete village network is available. However, in two sites [Goongring and Khar], we were not able to collect a complete village network because some farmers were not available [due to the long distances they had to travel]. For this reason, we focused on three villages for the main text: Lobnekha, Berti, and Sergithang Maed. In netdiffuseR, adoption data from 146 farmers yield 534 observations after field data are transformed into data in diffusion format. This method of data transformation is described in Valente (1996; 2010). This data transformation captures the change in the adoption norm variable in equation 4, resulting in more observations than were actually collected in the sample. In addition, we repeated the analysis using data from all five study sites and presented the results in Tables 31- 33 of the Supplementary Material. Using a similar data transformation, 707 observations from 214 farmers from five study sites were used for analysis. We note that the inclusion of sites without a complete village network in the analysis does not change the results presented in the main analysis. The results of the estimated coefficients for personal background, contagion, and structural equivalence, as well as the predictive accuracy and ROC-AUC metrics, agree well with the results of the main analysis.

In netdiffuseR, the influence of degree (number of connections) can be included to control for the effects of other network attributes. However, to rule out multicollinearity, this variable was excluded from the analysis due to its correlation with the contagion variable. Potential future updates to the package could control for network attributes such as clustering and size.

4.4.3 Data construction for ego's adoption norm using event history analysis

Event history analysis is used to calculate the adoption status of an ego in each year (Allison, 1984). Following closely with Valente (2010), the data construction using this method can be explained as follows: In our case of seed variety adoption, we analyze for each farmer (ego) whether he or she has adopted the seed variety and how many of his or her network partners have adopted it. The data is not measured at every point in the study. Rather, the existing data is reshaped to reflect events over time (pooled). For example, suppose that at the end of the year, data is collected on whether each farmer in a village grows a seed variety and in what year they adopted it. Since we want to show that the diffusion of seed has taken place through farmers network, we collect data on the farmers social network. The diffusion of seeds using the network of farmers can be modeled by reshaping the data and constructing the adoption norm for both contagion and structural equivalence. Such network-based diffusion requires multiple measures of the network (advice seeking, friends, relatives, influence, etc.) to determine the network structure and how it has changed (although we assumed it has remained constant) over the year. To create the adoption data, the information in which year each farmer adopted the seed variety would be converted into a series of vectors (columns) with a 0 for not adopted and a 1 for adopted in each period (year). The network weight (in the form of a matrix) is multiplied by each of these vectors and divided by the number of friends with whom each person claims to have a network relationship. This gives a measure of the percentage of each person’s personal network that has adopted in each year. So, if there are 40 farmers and 5 years, the new database has 200 cases (observations), 40 farmers in each year, and we know in each year how many of a farmer’s friends have adopted the seed. There will also be adoption behaviour of 200 cases for the ego.

4.5 Results

The results presented here are from a sample of 534 observations at three research sites [i.e., 6 remote villages] in Bhutan. The mean age, education level, and gender of the adopting household are shown in Table 27. In the study sites of Berti, Lobnekha, and Sergithang Maed, 62.5%, 54.7%, and 13.8% of the household heads were female, respectively. The average education level in all sites is below the 5th standard (primary education) and the average age is above 40 years. The duration of the diffusion period ranges from 5-8 years and is relatively recent (2015-2022). The study sites represent different cropping systems consisting of “certified” organic, conventional, and a mix of both.

Table 28 summarizes the relationships between the adoption norm and the decision to adopt the improved seed variety in the study region. With respect to the three hypotheses, we used Model 1 to examine how the ego responds when the adoption norm is presented exclusively as contagion (Hypothesis 1). With Model 2, we examined the ego's response to the adoption norm represented by structural equivalence (Hypothesis 2). In Models 3-5, we examined the effects of an adoption norm represented by both contagion and structural equivalence on the ego's response (Hypothesis 3). Model 1 showed that the log odds of adoption for the ego increased by 4.26 when the number of members in the ego's network increased and adoption was modeled as an effect of social contagion. When adoption was modeled as an effect of structural equivalence in Model 2, the log odds of adoption increased by 4.25 for an increase in "alters" who are structurally similar to the ego. In model 3, the log odds increased by 2.60 and 2.65, respectively. The effects were statistically significant at the 1% level in all three models.

Table 28. Estimated coefficients for contagion, structural equivalence and personal background

	Model 1	Model 2	Model 3	Model 4	Model 5
Contagion	4.26***		2.60***	3.60***	3.76***
	(0.35)		(0.42)	(0.38)	(0.38)
Structural equivalence		4.25***	2.65***	0.96***	0.70***
		(0.36)	(0.42)	(0.30)	(0.26)
Age [in years]	0.01	0.00	0.01	0.01	0.01
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
Education [in educational level]	0.02	-0.02	0.01	0.01	0.01
	(0.03	(0.03)	(0.03)	(0.03)	(0.03)
Female household head [in %]	0.25	0.35	0.35	0.44**	0.37
	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)

Note: Significance level evaluated at *** 1%, ** 5% and * 10%. Standard errors are reported in parentheses. Different values of υ are used for evaluating the models: Model 2 [υ = 1], Model 3 [υ=1], Model 4 [υ=2], and Model 5 [υ=15]. With higher values of υ, more structurally similar network ties are used for estimating the effect of structural equivalence. All models [1-5] were estimated using farmers from Lobnekha, Berti and Sergithang Maed. Model 1 is specified to test the relevance of only contagion; Model 2 for only structural equivalence; Model 3, 4 and 5 for both contagion and structural equivalence. The estimated results are from the testing dataset of 427 [80% of 534].

In Model 4-5, we assessed the degree of conservatism exhibited by the ego in relying on others using the exponent υ of 2 and 15. This value was used only for structural equivalence, and the changes in υ for contagion do not change the value for which all values of υ were assigned 1. Although the results in models 4 and 5 were statistically significant, the magnitude of the effect of the adoption norm decreased for structural equivalence but increased for contagion. In Models 4 and 5, the log odds ratios increased by only 0.96 and 0.70, respectively, for structural equivalence, compared with 2.65 in Model 3. The estimates showed that the adoption norm of the combined representation of contagion and structural equivalence is statistically significant even when we model ego behavior as conservative, in which it is assumed to rely only on structurally very similar alters to change its behavior. We found no consistent and statistically significant effect of personal background variables such as age, education, and gender of the household head. Except in model 4, where the "female head of household" variable was statistically significant and showed that the log odds of adoption increased by 0.44.

Table 29 presents statistics to evaluate model performance for the model presented in Table 28. Table 29 shows the metrics of accuracy, ROC-AUC (ratio of true-positive predictions to false-positive predictions), sensitivity (true-positive), and specificity (true-negative) to evaluate the performance of our classification models. We use ROC-AUC, to select the best model (adoption norm) because it contains information about sensitivity and specificity, which are important in a classification model. Model 3 performed the best, followed by Model 4 with the highest ROC-AUC value of .78 and .76, respectively. All models had a high predictive accuracy of over 70%. We could argue that Model 2 also performed better in most metrics, but we are less satisfied with the range of specificity values. In this regard, given the high ROC-AUC and accuracy metrics, we can conclude that the adoption norm of representing the network of farmers with both contagion and structural equivalence is preferable.

Table 29. Performance metrics for training estimated models

Performance metric	Model 1	Model 2	Model 3	Model 4	Model 5
Accuracy	0.71	0.76	0.74	0.71	0.70
ROC_AUC	0.75	0.75	0.78	0.76	0.75
Sensitivity	0.72	0.79	0.77	0.74	0.72
Specificity	0.65	0.59	0.64	0.60	0.62

Note: The different models differ in terms of social mechanism used. Model 1 (only contagion); Model 2 (only structural equivalence at v =1); Model 3 (both contagion and structural equivalence at v = 1); Model 4 (both contagion and structural equivalence at v = 2); Model 5 (both contagion and structural equivalence at v = 15. The estimated results are from the testing dataset of 107 [20% of 707].

Table 30 shows the final model performance using the test data set. We found that models 4 and 5, representing the adoption norm with both contagion and structural equivalence, performed better than models 1 and 2. The ROC-AUC for Models 4 and 5 were .84 and .85, respectively. Model 3 performed better than Model 2 with a ROC-AUC value of .83 compared to .80. Although Model 1 and Model 3 had the same value of ROC-AUC at .83, we found a high accuracy value for Model 3.

Table 30. Performance metrics for final estimated models

Performance metric	Model 1	Model 2	Model 3	Model 4	Model 5
Accuracy	0.71	0.79	0.75	0.74	0.73
ROC_AUC	0.83	0.80	0.83	0.84	0.85

Note: The different models differ in terms of social mechanism used. Model 1 (only contagion); Model 2 (only structural equivalence at v =1); Model 3 (both contagion and structural equivalence at v = 1); Model 4 (both contagion and structural equivalence at v = 2); Model 5 (both contagion and structural equivalence at v = 15. The estimated results are from the training dataset [107 observations].

The performance of the model on the full data set, which includes all five study sites with 707 observations of 214 farmers' adoption behavior, is presented in Tables S4.1-S4.3 in the Supplementary Material section. The results in Tables S4.1-S4.3 show that both contagion and structural equivalence are significant predictors of adoption of improved seed varieties. We found that models where adoption norms are represented by both contagion and structural equivalence have the best results with the highest ROC-AUC metrics.

The results shown above also indicate the importance of social reinforcement in technology adoption (Banerjee et al., 2013). Social reinforcement or exposure refers to farmers adopting the technology only when a growing number of other farmers have also adopted the technology in question. This is illustrated in Figure 10. More adoption occurs at higher values of structural equivalence and contagion (Figure 10).

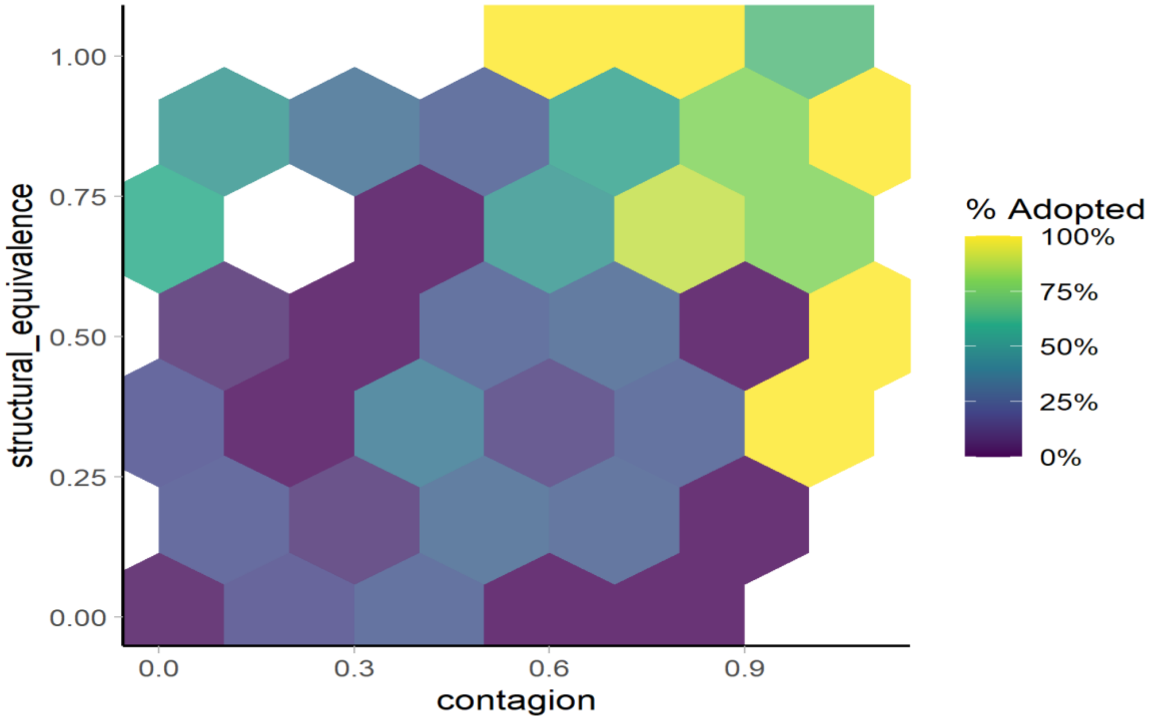

Figure 10. Relationship between the adoption of improved seed and the adoption norm (Contagion and Structural Equivalence). The x and y-axis represent the proportion of farmers who adopted the technology under the two mechanisms (expressed in Equation 4). As the number of "alters" adopting the technology increases within the two adoption norms, the probability of the "ego" adopting the technology also increases.

4.6 Discussion

Farmers can learn from each other through direct communication and advice (Conley & Udry, 2001; 2010; Geleta et al.,2023; Mamiit et al., 2021; Warriner and Moul, 1992), for which contagion is a mechanism. They can also imitate the behavior of others in similar social positions, even if they do not have a direct relationship with each other (Gao et al., 2022, Medina et al., 2023), for which structural equivalence is a mechanism. The latter social mechanism has received less attention in the context of agricultural technology adoption. This article studied both network mechanisms and attempted to determine whether contagion through direct peer-to-peer communication and the structural equivalence of farmers' social positions in the network topology contradict each other or have similar predictions for the adoption of agricultural technology. Our results suggest that structural equivalence and contagion are both significant predictor of the adoption of improved seed varieties, which has policy implications for targeting interventions to promote recommended agricultural practices (Jokisaari and Vuori, 2010). It appears that social comparison by structural equivalence can strengthen the effects of simple additive influence from direct network partners, which resonates with literature on complex contagion that considers extra-dyadic effects in contagion (Centola and Macy, 2007; Guilbeault et al., 2018; Jokisaari and Vuori, 2010).

While simple contagion models have been explicitly or implicitly used to justify the predominant policy focus on socially central and progressive “model” farmers (Taylor and Bhasme, 2018), structural equivalence presents a case for the inclusion of socially peripheral and marginalized farmers in demonstration programs to potentially inspire numerous less-connected others in similarly peripheral positions (Medina et al., 2023). The present results and the confirmed importance of the structural equivalence network mechanism highlight the limitations of exclusively relying on the contagion model alone and remind us of the importance of targeting actors in diverse social positions. More diverse representation in intervention programs may be necessary not only on social justice grounds but also to effectively achieve change at larger scale through networks. These findings add to the body of critique that highly central, and typically male (Matouš, 2023), “model” farmers are often not pro-active in spreading the benefits of interventions targeted at them (BenYishay and Mobarak, 2019; Cheng, 2022). Alternative recommended strategies include targeting female farmers (Kondylis et al., 2016) or innovators (Brown & Roper, 2017), through technology mediums like smartphone (Ma & Zheng, 2022), through farmers in broker positions (Zhang et al., 2020) even if they have fewer direct links in their villages.

Structural equivalence has a long tradition of research among white-collar professions in industrialized settings (Burt and Doreian, 1982; Cao and Prakash, 2011; Kammerer and Namhata, 2018; Shawki, 2015). Less is known about structural equivalence in low-income remote villages. Despite the current neglect of structural equivalence mechanisms in the current research on agricultural technology adoption and in extension practice, the present findings echo Burt’s words from almost four decades ago that the “evidence of contagion and social pressure that has in the past been attributed to cohesion (contagion) is probably evidence of structural equivalence obtained in social structural circumstances where the two models make identical predictions” (Burt 1987) (p. 1328). Burt (1987) also argued that “adoption by people in other status- people above, below, and apart from ego- do not matter in ego’s evaluation of innovation adoption, regardless of the frequency and empathy of ego’s communication with them. The ego can enjoy the luxury of paying little attention to information about the innovation until diffusion reaches his status (p. 1294)”. Similar arguments in the context of complex contagion is provided by Guilbeault et al., (2018): “The value of a communication technology such as a fax machine rests heavily on the number of people who use it. When only one person has a fax machine, it holds no value (…) After exposure to a sufficient number of reinforcing contacts, a person with no inherent interest in fax machines can be convinced that it is a necessary investment" (p.5). In the context of agrarian villages, marginalized farmers' hearts and minds might not get moved by what high-status model farmers do even if they have a direct (and inevitably hierarchical) communication relationship. Adoption is not only about access to information, superficial awareness of new technologies is often abundant in villages for the technology is already present, it is also about believing that something will work for someone like you (Gao et al., 2022; Kammerer and Namhata, 2018). This aspect of adoption is lacking in simple models of contagion.

The two mechanisms quantified in our work should not be interpreted as an option that intervention organizers can choose to diffuse new innovations. They are inherent in the system and are influenced by sociopsychological trends, market pressures, network density, and other factors. Understanding which mechanism is prevalent in the system, or how the two reinforce each other, can help interventionists figure out which individuals to target with their interventions. The results suggest that both mechanisms are equally important whether they are used together or separately. Considering the adoption norm separately through contagion (Hypothesis 1 and Model 1) and structural equivalence (Hypothesis 2 and Model 2) implies that both mechanisms have an impact. However, when both mechanisms (Hypothesis 3, Model 3) are modeled as coexisting, as is the case in our study sites, they offer valuable insights to interventionists. We found that adoption norms were effective for both contagion and structural equivalence at high exposure levels, as shown in Figure 10. This suggests that they are not necessarily complementary, contrary to the claims of others (Jokisaari and Vuori, 2010). Jokisaari and Vuori (2010) found that the effects of structural equivalence come into play only in the later stages of adoption. We found evidence of both structural equivalence and contagion, suggesting that adoption norms are relevant and that social networks can host multiple norms simultaneously. Empirical analyzes of how multiple mechanisms, such as contagion and structural equivalence, can simultaneously describe the adoption norm are rare in technology and policy diffusion research (Medina et al., 2022).

Our study was conducted among farmers practicing conventional agriculture, organic agriculture, or a mixture of both farming systems. The results confirmed old assumptions from quite different contexts that structural equivalence should not be neglected. Confirmation in the present context may be directly relevant to policy makers seeking to improve the productivity and incomes of farmers in Bhutan and other agricultural regions of the Global South. However, as with any study, we must acknowledge some limitations. The use of self-report and retrospective adoption data has both advantages and disadvantages. Although the time period we studied includes only seven years during which adoption occurred, this can be improved by using extension data to improve the accuracy of the adoption period data. Another limitation is the lack of dynamic network data. We know that social networks are not static, but collecting longitudinal data is time and resource intensive and was not possible in the current study. Finally, the study focused on a limited number of personal backgrounds to highlight the theoretical contribution of the two mechanisms, particularly structural equivalence. Future studies should collect comprehensive data on non-network factors including personal backgrounds and assess their influence on outcomes (Schmidt and Wagner, 2023). This may require more heterogeneous villages, which are lacking in our study. Because cross-sectional data were used, this study should be interpreted as a proof-of-concept case analysis in which a mixture of innovation diffusion-related adoption norms can be tested simultaneously. Longitudinal or experimental data that can address endogeneity concerns must be used to determine causality.

4.7 Conclusion

In this article, we presented two conceptually different social mechanisms in the context of agricultural research and policy efforts focusing on technology adoption and social network linkages. Contagion mechanisms capture how farmers can learn from each other through direct relationships of communication and advice. Structural equivalence, which is a less studied mechanism in the agricultural adoption, captures how farmers can also be inspired to imitate the behavior of others that are in similar social positions even if they do not directly exchange information. Simple contagion operates at the dyad level via frequent communication and socialization. Structural equivalence operates at the collective level via comparisons among farmers in similar positions within the community.

Using field data on retrospective adoption of improved seed varieties among farmers in remote villages of Bhutan, we showed that both mechanisms in combination, diffusion by social contagion and structural equivalence can better explain behavior change among farmers. We suggest that interventionists should not only preferentially target farmers with numerous connections hoping that their behavior will influence their abundant network partners but also focus on those farmers in diverse social positions, including peripheral network positions, who can inspire others in comparable parts of the social spectrum towards adoption that might otherwise be missed. More nuanced understanding of social network mechanisms behind agricultural technology adoption can inform interventions to promote better practices.

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4.9 Supplementary materials

Table 31. Estimated coefficients for contagion, structural equivalence and personal background

	Model 6	Model 7	Model 8	Model 9	Model 10
Contagion	3.68***		2.16***	2.71***	2.91***
	(0.28)		(0.34)	(0.31)	(0.31)
Structural equivalence		3.66***	2.31***	1.27***	1.09***
		(0.28)	(0.35)	(0.26)	(0.22)
Age [in years]	0.01*	0.00	0.01	0.01	0.01
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
Education [in educational level]	0.04*	0.03	0.03	0.04	0.03
	(0.02)	(0.02)	(0.02)	(0.02)	(0.03)
Female household head [in %]	0.20	0.06	0.18	0.06	0.03
	(0.17)	(0.17)	(0.18)	(0.17)	(0.17)

Significance level evaluated at *** 1%, ** 5% and * 10%. Standard errors are reported in parentheses. Different values of υ are used for evaluating the models: Model 7 [υ=1], Model 8 [υ=1], Model 9 [υ=2], and Model 10 [υ=15]. With higher values of υ, more structurally similar network ties are used for estimating the effect of structural equivalence. All models [6-10] were estimated using 214 farmers from five study sites consisting of 15 villages. Model 6 is specified to test the relevance of only contagion; Model 7 for only structural equivalence; Model 8, 9 and 10 for both contagion and structural equivalence. The estimated results are from the testing dataset of 566 observations [80% of 707].

Table 32. Performance metrics for training estimated models with all study sites

Performance metric	Model 6	Model 7	Model 8	Model 9	Model 10
Accuracy	0.70	0.73	0.73	0.71	0.73
ROC_AUC	0.76	0.77	0.79	0.78	0.77
Sensitivity	0.72	0.78	0.76	0.74	0.76
Specificity	0.65	0.60	0.64	0.62	0.61

Note: The different models differ in terms of social mechanism used. Model 6 (only contagion); Model 7 (only structural equivalence at v =1); Model 8 (both contagion and structural equivalence at v = 1); Model 9 (both contagion and structural equivalence at v = 2, and Model 10 (both contagion and structural equivalence at v = 15). Analysis based on training data set of 566 observations [80 % of 707] observations from five study sites consisting of 15 villages (214 farmers).

Table 33. Performance metrics for final estimated models with all study sites

Performance metric	Model 6	Model 7	Model 8	Model 9	Model 10
Accuracy	0.74	0.77	0.73	0.71	0.72
ROC_AUC	0.82	0.81	0.83	0.82	0.82

Note: The different models differ in terms of social mechanism used. Model 6 (only contagion); Model 7 (only structural equivalence at v =1); Model 8 (both contagion and structural equivalence at v = 1); Model 9 (both contagion and structural equivalence at v = 2, and Model 10 (both contagion and structural equivalence at v = 15). Analysis based on testing data set of 141 observations [20 % of 707] from five study sites consisting of 15 villages (214 farmers).

Chapter 5

5 General conclusion

This thesis aimed to improve our understanding of the potential of farmers' social networks in addressing the challenges organic farmers face in Bhutan. The objective was framed against the background that farmers in low-income countries face numerous challenges when opting for sustainable farming systems such as OA. The rationale behind exploring the role of social networks was that farmers in low-income countries and specifically in Bhutan rely on informal network relationships of various kinds as a substitute for the missing or inadequate formal institutions. Social networks are also important, because, farmers are part of a community and embedded in the social structure. A change at the community level can have a huge impact on individual members. The actions of each individual can also have an impact on others, which in turn can affect the overall outcome for the community. To assess the potential of farmers' social networks in addressing the challenges of OA in Bhutan, this thesis identified specific social networks that are characteristic of the farming community and relevant to addressing the challenges of OA for smallholder farmers. The organic sector in Bhutan is described to understand the important aspects of organic agriculture in such countries. The thesis then identified and suggested social networks in the village community that have the potential to address some of the challenges of organic farming. This concluding chapter summarizes some of the key case analyzes, empirical findings and contributions of this thesis as presented in the three papers and provides a summary of these contributions in Section 5.1. The chapter also discusses the limitations of studying OA in low-income settings and the empirical and methodological approaches adopted in Section 5.2 and suggests ways to overcome these limitations. The chapter discusses some general policy implications in Section 5.3. The chapter concludes in Section 5.4.

5.1 Contributions to the literature

The aim of this sub-chapter is to discuss the contributions that this thesis makes to the general understanding of OA, the associated challenges and the potential of social networks. In particular, this chapter discusses the findings of the three papers presented and how they contribute to the existing literature on OA.

5.1.1 The contribution from the case-analysis of OA in Bhutan

Chapter two of the thesis contributes to our understanding of the implementation of organic agriculture (OA) in low-income countries, particularly in the context of large-scale conversion to OA. In writing the chapter, it was recognized that organic agriculture in low-income countries is often promoted with a top-down approach, which can neglect the challenges faced by many organic farmers. Furthermore, the chapter aims to assess the possibility of large-scale conversion of OA, which is hampered by the lack of data in low-income countries.

Compared to previous attempts that mainly focused on agronomic aspects (Neuhoff et al., 2014) or policy-oriented approaches (ICIMOD & MoAF, 2018), it provides a more in-depth analysis of large-scale organic agriculture in Bhutan. This contribution is made possible primarily through the accumulation of data from the agricultural sector over time. This advantage is unique to Bhutan and makes it possible to examine important aspects of OA and provide transferable results for many contexts characterized by smallholder farming systems. The chapter contributes to the literature by describing the necessary management and farming practices under an organic standard, the institutional framework of organic farming and the level of certification achieved. The analyzes provide a clear picture of the yield gaps and nutrient balances in a situation of large-scale organic conversion.

Previous studies have attempted to describe the opportunities and challenges of OA for smallholder farmers (Jouzi et al., 2017). However, these analyzes lack in-depth research and are based on evidence collected in different countries. Deeper analyzes of OA in low-income countries focus on yield gaps (Badgley et al., 2007), implementation (Schader et al., 2021), institutional frameworks (Bendjebbar & Fouilleux, 2022), nutrient balance (Surekha & Satishkumar, 2014) and management practices (Seufert et al., 2017). The second chapter contributes to the literature by examining these important aspects of OA in a specific country context.

In-depth analyzes of different aspects of OA can make a valuable contribution to the literature for several reasons. First, it provides a holistic understanding of how the OA movement is progressing in a country. For example, the steady increase in certified OA can be understood in the context of NCOA, which focuses on local certification. However, farmers do not receive export premiums because local certifications do not meet the standards of importing countries in high-income countries. Secondly, policy makers can develop a variety of instruments to develop the OA sector. For example, direct payments, agricultural subsidies and capacity building for farmers are needed to reduce the burden of income loss due to yield losses. Thirdly, policymakers can design an effective policy strategy, such as improving the supply of nutrients, especially nitrogen, to reduce yield gaps.

5.1.2 The empirical contribution of labour exchange networks

The third chapter of the thesis deepens our understanding of the function of labor exchange networks in meeting labor needs in OA. Labor shortages are a major problem for smallholder farmers due to the lack of capital in low-income countries, which makes it difficult to invest in machinery (Feuerbacher & Luckmann, 2023). In addition, the hilly and mountainous terrain makes the use of machinery virtually impossible, even for those who can afford it (Neuhoff et al., 2014). Farmers use herbicides to replace labor, which is prohibited in OA (Daum et al., 2023). In addition, internal migration from rural areas has made labor a scarce resource (Feuerbacher & Luckmann, 2023). Research has shown that informal sharing of labor is still a relevant and valuable social network arrangement (Gilligan, 2004).

The third chapter makes an empirical contribution to the literature on labor exchange networks and shows how they can be a valuable resource for smallholder farmers who opt for labor-intensive farming systems such as OA. The main contribution to the literature relates to the empirical study of the formation of labor exchange networks using graph theory (Jackson et al., 2012). This approach provides a detailed understanding of farmers' cooperative behavior, which is critical for organizing the village economy and promoting successful OA programs. The study of labor exchange networks allows policy makers to identify effective policies by recognizing the network structures described in Chapter Three.

Identifying a cooperative community can be useful in identifying villages or communities with well-functioning local institutions. For example, this can be done through the identification of labor exchange networks. The correct identification of such communities can reduce the risk of project failure in low-income areas. In addition, the implementation of OA programs with traditional knowledge guarantees a more democratic approach to OA development in low-income countries (Canwat & Onakuse, 2023).

In addition to addressing labor shortages in OA, labor exchange networks have the potential to promote social learning among farmers. For example, OA tends to be knowledge-oriented, and labor-sharing arrangements can facilitate learning about various aspects of OA, such as new seeds, crop protection measures, soil fertility, etc. (Padel, 2001). Although many trainings related to OA are organized by governments and NGOs, these frequent collaborative arrangements can help farmers learn practically from each other and consolidate and repeat what they have learned, which can be challenging for farmers with low literacy skills (Gilligan, 2004). Working in groups can strengthen group dynamics within the farming community, e.g. by building trust and mutual verification of compliance with organic farming standards through group certification and internal monitoring systems (Bhatt & John, 2023).

5.1.3 The contribution of social networks in technology adoption

The fourth chapter of this thesis contributes to our understanding of the role of social networks in technology adoption (Cheng, 2021). Organic farming is a knowledge-intensive system that requires a shift to a completely different farming technology (Padel, 2001). Research on organic farming with smallholder farmers often highlights their lack of skills, opportunities and inputs (Bottazzi et al., 2023). Research has also shown that access to new technologies helps smallholder farmers to improve their production, consumption and marketing (Tabe-Ojong & Geffersa, 2024).

The fourth chapter is an important part of the thesis. It deals with a predominant policy instrument used in the early stages of OA development in Bhutan. Under this OA strategy, the research centers along with NCOA used the concept of a Research Development and Outreach Program to develop and test improved seeds, soil fertility and crop protection practices at the center before introducing them to farmers. In the literature on farmer behavior, it is important to note that farmers do not make their decisions in isolation, even if coordination in separate fields is not explicitly required (Cheng, 2022). This understanding opens the scope for social networks. For more than five decades, there has been an ongoing interest in the role of social networks in shaping the process of technology diffusion in agricultural fields (Cheng, 2023).

In the fourth chapter, we examine two seemingly widespread but conceptually distinct farmer networks. The chapter exploits the fact that farmers can learn from each other through direct communication relationships and advice-sharing networks (Ryan & Gross, 1943). The chapter also suggests that farmers can be encouraged to imitate the behavior of others because they are in a similar social position as themselves, even if they do not directly exchange information with each other (Burt, 1987). The fourth chapter makes a contribution to the literature by noting that the latter mechanism is not explicitly considered in the research on the role of networks in the adoption of agricultural technologies, and mostly only diffusion through direct links is implied. The chapter argues that this is likely to be inaccurate and unfortunate because the different potential network mechanisms at play in a given context would have different implications for targeting effective interventions for adoption of recommended practices in OA system.

The context for OA in low-income countries differs from the original bottom-up OA in high-income countries. In low-income countries, OA is enforced in a top-down approach, with few 'progressive farmers' benefiting from limited government interventions during the process of organic development (Meek & Anderson, 2020) or few farmers presenting themselves as 'model farmers' to benefit from organic agriculture development projects (Flachs, 2017). This has an unintended consequence; only a few farmers benefit, while the rest of the farmers in the community remains marginalized. As in the few successful cases, OA should promote the integration of traditional knowledge, community and women's participation, and market integration (Canwat & Onakuse, 2023). In thinking about technology diffusion, we argue that structural equivalence provides an argument for including socially peripheral and marginalized farmers in demonstration programs to potentially inspire numerous less connected others in similarly peripheral positions (Medina et al., 2023). We illustrate this with the example of the diffusion of improved seed varieties among smallholder farmers, emphasizing the role of networks that consider community-level actors. This contribution adds to the critique of the fact that very central and typically male (Matouš, 2023) 'model farmers' are often not proactive in disseminating the benefits of interventions targeted at them (BenYishay and Mobarak, 2019; Cheng, 2022).

Social networks operating at the periphery are highly relevant to the study of OA in low-income countries for several reasons. First, the adoption of OA can differ with respect to economic status. Secondly, the diffusion of technology in such a diversified farmer group using traditional peer-to-peer communication will not be effective as there will clearly be information problems between the different groups (Cheng, 2022). Thirdly, the social status or position of the different groups will not be enough to increase competitiveness or inspire the others.

The main advantage of proposing structural equivalence as a suitable network approach to technology adoption is that these networks are inherent in the system. Competition and inspiration between social statuses are common network features of human society that interventionists can utilize to design effective policy interventions (Burt & Doreian, 1982). This can help promote a democratic approach to agriculture, where instead of highly networked 'model farmers', farmers at the periphery will play an increasing role in disseminating technologies to people in their social class. This approach has the potential to address the “autocratic implementation” of OA in low-income countries (Das, 2023) and the welfare of smallholder farmers (Bhatt & John, 2023), and to promote democracy in the agri-food system for the provision of public goods (Canwat & Onakuse, 2023). As in the case of previously analyzed labor exchange networks, the contribution helps to understand the mechanisms of interactions between farmers with or without direct contact.

5.2 Limitations and remedies

This thesis uses both primary and secondary data to answer the research questions posed in the three separate chapters (Chapters 2, 3 and 4). Although the study attempted to use or generate reliable data and appropriate analytical tools, there are still limitations that can be addressed in future endeavors. These limitations are summarized and presented in four main groups: lack of validation, extrapolation, missing information, small and cross-sectional data.

5.2.1 Lack of validation

In Chapter 2, the calculation of yield gaps and nutrient balances is based entirely on secondary data collected by MoAL and NSB. These two institutions use the World Bank (WB) Survey Solutions and collect data using mobile devices. They perform a number of consistency and data validation checks during data collection, but they do not check for outliers. A useful approach would be to match farmer-reported yields with yield data from field trails, but as this is not readily accessible or available, this can be included in future research.

In Chapters 3 and 4, after collecting the social network data, we checked the consistency of the data. For example, when we asked farmers to name their labor exchange relationships, we found that there were some inconsistencies. For example, farmer A claims to have shared labor with farmer B, but farmer B does not list farmer A as his network partner. We treated such network links as a shared relationship as we assumed that farmers may have recollection difficulties. Such inconsistencies need to be addressed with better data collection methods, like using pictures. One approach we adopted to generate reliable data, was by conducting repeated trials on collecting social network data and adapting it based on experience. But despite these efforts, we felt that repeated collection of data over time would be the best approach to capture the true relationships between farmers, as network relationships are dynamic and change from season to season. This could be considered in future studies.

5.2.2 Extrapolation

In Chapters 3 and 4, we approached the social network data by collecting data from the entire network, i.e. all households living in a defined administrative area (village, chiwog or gewog) were surveyed. This was very difficult given the dispersed location of farmers; so, we were only able to collect data from very few study sites. Restrictions during the COVID-19 pandemic have also limited our access to most villages. This limits our ability to extrapolate to the general population. Even for analyzes with the complete village network, such as advice sharing network in Chapter 4, it is highly recommended to collect data from many villages or study sites.

5.2.3 Missing information

In Chapter 2, the results on yield gaps and nutrient balances provide only a basic understanding of the challenges in low-income countries. The yield gap analysis is a simple mean analysis between the organic and conventional farming systems. This is due to a lack of information from secondary data on agricultural inputs such as fertilizers and pesticides in different survey years, amount of labor available, rainfall, type of seeds etc. Most agricultural surveys and censuses focus on production and ignore important questions about agronomic practices. For example, only the 2012 and 2018 agricultural surveys provide information on the use of synthetic inputs. The most recent 2022 Integrated Census of Agriculture and Livestock omits important aspects of farming such as fertilizer and pesticide use, labor shortages, water availability and credit. Lack of information limits the use of better econometric tools to generate more reliable results. Future agricultural censuses and surveys need to communicate with scientists and jointly generate realistic data for thorough analysis.

In Chapter 2, nutrient balance represents a very simplified understanding. Capturing a realistic nutrient balance is limited by a lack of information on many important variables. For example, it is difficult to determine the true value of nitrogen available to crops without information on volatilization, leaching and loss through erosion. Data on all these aspects will need to be collected in the future. Other missing information on the amount of synthetic inputs used, the amount of organic fertilizers used and the prices of the different inputs need to be filled in.

In chapter 4, we have mainly focused on the variables measuring social network mechanisms. However, to obtain realistic results and to test the actual impact of the social network on technology adoption, data from other aspects of farming such as agronomic, risk and socio-economic characteristics of farmers as well as other relevant confounding variables must be collected.

5.2.4 Limitations from cross-sectional data

This limitation applies to Chapter 4, which examines the introduction of technologies and social networks. Although the adoption of technologies takes place over a longer period of time, we were able to apply a retrospective process of data collection. To improve the reliability of the results presented in Chapter 4, data collected over time would be more realistic for such studies. In the future, researchers can address this issue by collecting more data on technology use over time. Similar limitations related to social networks are also noted in Chapter 4. The chapter assumes that village networks are static. This assumption needs to be tested by collecting more data. Panel data should be collected and the applicability of the proposed model needs to be tested in the future.

This also applies to our analysis of yields and nutrient balances in Chapter 2. The chapter presents a cross-sectional study for districts and some MOVs. However, how the yield gap changes over the course of conversion to organic farming would in fact provide a much deeper and more realistic insight into the evolution of farms under the organic system. In Chapter 2, analyzing the nutrient balance over time would not only show the feasibility of organic farming in low-income countries, but also the sustainability. Future efforts could easily address this through studies conducted over a long period of time.

5.3 Policy implications

Bhutan wants to improve the sustainability of its agricultural sector and has identified organic agriculture as one promising strategy. However, the policy of converting to 100% organic can be characterized as a top-down policy with little regard of what knowledge, technology and other prerequisites such as market access are necessary for a successful implementation. This thesis has identified the many challenges which farmers face for a successful adoption of organic farming. The government should urgently tackle the foundations necessary for a successful transition towards organic agriculture. Otherwise, policies that just support the expansion of organic farming are likely to lead to trade-offs with other policy objectives like food self-sufficiency and general agricultural development. There are various interventions and policies that the government and lawmakers in Bhutan could consider: increasing farmers’ knowledge about organic farming principles, which include improved soil fertility management (e.g. green manure, composting, etc.), adapting crop rotations to the location and farm system specific conditions, promoting organic seed varieties that are suitable for the Bhutanese context, fostering organic markets through necessary legislation and market development, monetary compensation for the provision of public goods that are by-products of organic farming and strengthening of rural livelihoods. The thesis has demonstrated the relevance of social networks which are key for the implementation of organic support measures and for tackling challenges such as labor scarcity amid the situation of increased labor demand when converting to organic agriculture. In the context of labour shortage, Bhutan should also intensify its efforts to introduce new technologies into the agricultural sector that help to reduce the labor intensity in farm operations like weeding or farmyard manure application.

Large-scale conversion to OA in Bhutan is a new policy that has been heavily promoted after 2012 (Neuhoff et al., 2014). This policy is the epitome of top-down policies in many agricultural policies promoted in Bhutan. It lacks a sustainable and stable funding mechanism. There is a severe shortage of extension workers specifically for OA. Most of the existing organic farms are managed by the same extension workers who advise and manage farming villages that use inputs that are banned in organic farming. Organic farmers have problems with nutrient management, low yields and lack of price premiums. These are important considerations for successful transition to OA and policy to provide premiums for products produced in organic systems must be established, and how the nutrient requirements of organic farmers will be met for improving the yield must be a top priority.

Other alternative modalities for the development of the agricultural sector in Bhutan could be proposed, implemented and adapted based on experience. For example, farmers need to be supported to make them more competitive instead of the government setting up state-owned enterprises (SOEs) in the agriculture sector to compete with local farmers. Many farming communities in Bhutan are praised for their communitarian vitality, but there are no policies in place to strengthen these communitarian institutions. This work has shown, for example, that the social network of labor exchange plays an important role in reducing workloads when labor-intensive farming systems that protect biodiversity are introduced. Bhutan’s biodiversity conservation efforts are internationally recognized and the promotion of organic farming is part of the strategy. But the challenges of organic farming are not getting the attention they deserve.

In Bhutan, there are also concerns about the feminization of agriculture, where the burden on women to practice agriculture is increasing as male household members seek alternative sources of income outside agriculture. In recent years, agricultural interventions have always targeted women to improve gender equality, but the promotion of OA by women's groups may also bring new challenges for women. In this thesis, the gender aspect of OA has been completely ignored, but the impact of biodiversity-smart agriculture, which is mostly labor-intensive, needs to be further explored.

The good thing about the development of OA in Bhutan is that NCOA has focused on supporting remote villages that are vulnerable and have not benefitted from state programs. Although the approach is inclusive, it remains a challenge for the Bhutanese government as to how this can be extended to many similar farming communities. The lack of financial resources will remain a major obstacle. As part of its contribution to the Paris Agreement, Bhutan plans to reduce its dependence on synthetic fertilizers by 5% annually, so policy makers will need to design compensation schemes depending on farmers' willingness. Although dependence on synthetic fertilizers is low, it is commendable that a complete ban on import of mineral fertilizers and synthetic pesticides has not been imposed as in Sikkim and Sri Lanka. The process of OA development is slow and restrictions should not be hastily imposed without understanding the full implications. This thesis shows that there are challenges that need to be addressed for a successful transition to OA. There are many other aspects that could not be examined in this work. A carefully designed compensation scheme, based on government capacity and donor willingness and acceptable to organic farmers, is necessary to incentivize farmers to provide ecosystem services from their agricultural practices that contribute to the provision of general public goods.

Is OA the Cinderella of agricultural policy for Bhutan, waiting to realize its potential? Are communities with well-functioning social networks the Cinderella for the Bhutanese government waiting for its potential to be realized? These are just some of the many important research questions that need to be explored further in the future.

5.4 Concluding remarks

This study sought to provide a general understanding of OA in low-income countries. The thesis emphasized the importance of data in low-income countries to better understand the challenges of OA for smallholder farmers. The thesis also emphasized the potential of social networks in addressing the challenges of the OA movement.

Chapter 2 was written against the backdrop that in many low-income countries, the promotion of OA is often top-down and entails risk of neglecting the challenges faced by organic farmers. The chapter argues that there are serious problems with the lack of data in low-income countries, which hinders a deeper analysis of the feasibility of such ambitious OA policy initiatives and their challenges. To provide some understanding of the challenges, a large-scale conversion of OA in Bhutan is analyzed and described, related to management and farming practices, yield gaps between OA and conventional agriculture, nutrient balances, and the institutional setting of OA.

Chapter 3 presented the case of labor-intensive farming villages that are able to manage the burden of labor through the use of informal labor exchange institutions. In exploring the potential of social networks to address labor shortages the chapter showed that farmers act collectively and share labor, which appears to be mutually beneficial in managing the burden of labor. The chapter then argues that the existence of such labor exchange can help identify other communities that may be suitable for further promotion of labor-intensive (organic) farming systems in Bhutan and other low-income countries. The chapter makes an empirical contribution to the literature on the combination of economics and graph theory and provides a unifying framework for future work on understanding and investigating the why and how of labor exchange network formation.

In turn, in Chapter 4, this thesis presents two conceptually distinct social mechanisms in the context of agricultural research and policy efforts that focus on technology adoption and social network connections. The chapter examines two social network mechanisms and demonstrates their potential for understanding the diffusion of new technologies in village settings of low-income countries. The study introduces the concept of structural equivalence to agricultural sciences, which is a less studied mechanism in the adoption of agricultural technologies. The results show that farmers can be inspired to imitate the behavior of others when they are in a similar social position, even if they do not directly exchange information.

Overall, this thesis suggests that there are challenges that many organic farmers face after adopting organic farming, and that the informal communitarian institutions represented by village social networks have the potential to overcome these challenges.

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SUPPLEMENTARY DATA

[This material can be found on the CD-ROM submitted along with the dissertation]

Excel file name	Sheet name	Description
Chapter 2	1. district_nutrient_input	1. Data for nutrient input in districts
	2. district_nutrient_output	2. Data for nutrient output in districts
	3. mov_nutrient_input	3. Data for nutrient input in MOV
	4. mov_nutrient_output	4. Data for nutrient output in MOV
	5. district_yield_analysis	5. Data for yield analysis for Bhutan
	6. yield_figure_data	6. Data for yield gap figure
	7. yield_before & after	7. Data for before and after yield analysis for MOV
Chapter 3	1. net_dra	1. Network data for Drachukha village
	2. att_dra	2. Attribute data for Drachukha village
	3. net_heb	3. Network data for Hebisa village
	4. att_heb	4. Attribute data for Hebisa village
	5. net_lim	5. Network data for Lingmukha village
	6. att_lim	6. Attribute data for Lingmukha village
	7. net_berw	7. Network data for Berti village
	8. att_berw	8. Attribute data for Berti village
	9. net_berp	9. Network data for Berti village
	10. att_berp	10. Attribute data for Berti village
	11. net_kha	11. Network data for Khatoed sub-district
	12. att_kha	12. Attribute data for Khatoed sub-district
Chapter 4	1. data_main	1. Adoption and network data for only three study sites with complete network data
	2. data_extra	2. Adoption and network data for all five study sites
	3. attributes	3. Data for Descriptive statistics

ANNEX 3

Declaration in lieu of an oath on independent work

according to Sec. 18(3) sentence 5 of the University of Hohenheim's Doctoral Regulations for the Faculties of Agricultural Sciences, Natural Sciences, and Business, Economics and Social Sciences

8. The dissertation submitted on the topic

Social and Economic Analysis of the Organic Sector in Bhutan

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is work done independently by me. 2. I only used the sources and aids listed and did not make use of any impermissible assistance from third parties. In particular, I marked all content taken word-for-word or paraphrased from other works. 3. I did not use the assistance of a commercial doctoral placement or advising agency. 4. I am aware of the importance of the declaration in lieu of oath and the criminal consequences of false or incomplete declarations in lieu of oath. I confirm that the declaration above is correct. I declare in lieu of oath that I have declared only the truth to the best of my knowledge and have not omitted anything.

Place, Date

Signature

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Employment

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Education

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Dzongkha (Excellent, mother tongue)

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