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Wetland–agriculture interactions: sustaining intergenerational ecosystem services

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When I received the letter from the President of the Agricultural Economics Research Association (AERA), India, Dr P K Joshi, informing me of the decision of the association to elect me to preside over the 29th Annual Conference of the AERA, I was humbled.

I consider it a great honour and privilege to address the distinguished members of the association and am thankful to them for electing me the president for the 29th Annual Conference. I wish to place on record my appreciation to Dr P K Joshi, the past presidents of AERA, and conference presidents whose thoughts, ideas, and hard work have nurtured the AERA.

I am also aware of the contribution of the members of the executive and the editorial board, and all members, over the years adding professional values to AERA and its research journal. My sincere appreciation for the fact that not only did they contribute towards the development of the field of agricultural economics but also devised ways and means through which AERA addresses socially and contextually relevant agrarian issues at different policymaking levels.

At this auspicious moment, I wish to express my gratitude to Prof William E Phillips, University of Alberta, Edmonton, who has been my mentor since the 1970s, in helping me to understand complex natural and environmental ecosystems, including wetlands. I owe an intellectual debt to him.

Prof Daniel W Bromley, University of Wisconsin-Madison, has always been generous in encouraging me to promote natural resource economics teaching and research in the Indian context.Over the years, his scholarly writings have added value to my understanding of complex ecosystems and public policies. I am grateful to him for shaping my thoughts about institutional economics of natural and environmental ecosystems.

I have benefited greatly over the years from the joint work I did with a dear colleague and friend, Prof Brij Gopal, an internationally known wetland ecologist. He unexpectedly passed away early this year, a great personal loss to me and the community of interdisciplinary scholars. Both of us began working on natural resources and wetlands in the early 1990s. I would like to mention here a few of our joint initiatives pertaining to wetlands:

- assessment of the Ecosystem Services of River Ganga (a joint initiative of National Mission for Clean Ganga, World Wildlife Fund, and National Institute of Ecology (NIE)).
- Integrating the Economics of Wetland Biodiversity and Ecosystem Services in Management of Water Resources of River Ken, India. The Economics of Ecosystems and Biodiversity (TEEB) - India Initiative.
- Conserving the Wetland Wealth of Chhattisgarh (a joint initiative of the NIE and Chhattisgarh State Planning Commission.

Presidential address delivered at the 29th Annual Conference of the Agricultural Economics Research Association (AERA), India, held at the Odisha University of Agriculture & Technology, Bhubaneswar, 27 October 2021.

- Strategies for Water and Food Security in Bundelkhand in the Face of Climate Change (a joint initiative of the NIE, Centre for Inland Waters in South Asia, and National Bank for Agriculture and Rural Development (NABARD).
- Integrated Management of Water Resources of Lake Nainital and its Watershed: An Environmental Economics Approach (a joint initiative of World Bank; the Ministry of Environment, Forests and Climate Change (MoEFCC) of the Government of India (GoI); and Indira Gandhi Institute of Development Research (IGIDR); and
- Tanks and farm ponds versus reservoirs, a viable solution to water security

We had also jointly organized capacity-building programmes in South Asia: water science and policy for sustainable development (NIE and Chhattisgarh Council of Science and Technology-CCOST) and capacity-building for conservation of biodiversity and ecosystem services of wetlands in relation to global climate change (Asia-Pacific Network for Global Change Research, Japan).

I pay my humble tribute to my friend Brij Gopal, who had tremendous capability to work with an interdisciplinary team to address the socio-economic, cultural, and political issues of the wetland ecosystem.

I stand here at this great institute of learning to speak on wetland-agriculture interactions and ecosystem services issues, a topic that fits well within the historical, socio-economic, cultural, and wetland architectural tradition of Bhubaneswar, the holy city. Most of you may know that Odisha had the distinction of having the first internationally important wetland tag (Lake Chilika). I have chosen this topic primarily for four reasons.

The Convention on Wetlands of International Importance Especially as Waterfowl Habitat[1] ("Ramsar Convention" or "convention") adopted Resolution VIII in 2002 to enhance the interactions between agriculture, wetlands, and water resource management. Subsequently, in support of the UN International Year of Family Farming, Ramsar's theme for World Water Day 2014 was wetlands and agriculture. That is the first.

Second, in the Indian context, wetlands in general, and wetland–agriculture interactions, in particular, have not received even skimpy attention over the decades of the members of the Indian Society of Agricultural Economics, AERA, and other economics-centric societies.

Third, the economic value of the goods and ecosystem services of wetlands, including their contribution to livelihoods and rural economy, is rarely accounted for in the social- ecological cost-benefit analyses of various development projects and in designing policies. Such understanding is extremely important as wetland ecosystems in India are basically multi-use and multifunctional common pool resources.

Fourth, India has no specific policy for wetland conservation and management.

To me, an inadequate research base seems to be a major deterrent in policy problem analysis, conservation, and wise use of wetland wealth in India. I sincerely believe, based on my research on wetland–agriculture interactions, that this interaction is critical to achieve a good number of Sustainable Development Goals (SDG) if the twin issues of inadequate research base and policy problem analysis can be addressed using an appropriate institutional analytical framework. For nearly four decades now, I have been concerned with the role of institutions in the sustainable development of renewable common pools in general and wetlands in particular.

For this address, I have put together my thoughts and writings that have evolved over years of research and learning. Today, I will deal with the issue of wetland–agriculture interactions and their contribution in sustaining lives and ecosystem services. I begin my address with three caveats.

First, I have adopted the Ramsar Convention's definition and classification of wetlands, as the MoEFCC (GoI) has included and excluded certain categories of wetlands in the Wetland (Conservation and Management) Rules, 2010 and 2017, and these differences may create a confusion between the

[1]The representatives of a few international organizations and national governments signed the agreement at Ramsar, a city in Iran on the Caspian Sea, on 2 February 1971.

Convention framework and the national rules, despite the fact that India is a party to the Convention.

Second, for the purpose of this address, I restrict the scope to human-made inland rural wetlands and, most importantly, the wetland–agriculture interactions (WAIs) practiced in these wetlands.

Third, the assessment of WAIs is based on four different types of multiple-use and multifunctional village wetland, managed under common property regimes. A few are also managed under private ownership.

After having briefly mentioned the theme of my address, I now proceed to discuss some basic concepts and issues of wetlands in the context of India and the Ramsar Convention.

This discussion is followed by an account of the extent, threats, and benefits of wetlands.

I also describe briefly the institutional framework I have applied for analysing the wetland–agriculture interactions under different property rights regimes or resource regimes.

Thereafter, I discuss the performance of some important practices of the wetland–agriculture interactions in multi-use wetlands being managed under alternative resource regimes and ecosystem services derived from different types of wetlands.

Finally, I identify a few emerging issues for further research and policy interventions in sustaining wetland wetland-agriculture frontiers.

Wetlands: India and Ramsar Convention

Wetlands are places where water accumulates for sufficiently long periods of time to allow the occurrence of plants and animals specially adapted to the water-dominated environment.

Wetlands occur in all climatic zones and practically in all parts of the world. They occur along the rivers, streams, lakes, reservoirs, and sea coasts; in arid deserts (oases and saline lakes); from below the sea surface (coral reefs) to snow-clad mountains (glacial lakes); and even below the ground (caves and karst systems) (Gopal and Marothia 2017).

Wetlands drew attention in western countries during the 1950s and 1960s for their huge migratory water bird populations. The representatives of a few international organizations and national governments signed the Ramsar Convention on 2 February 1971. The convention was originally contracted by seven countries when it came into force on 21 December 1975. As of October 2019, there are 171 contracting parties and over 2,000 designated sites covering over 200 million hectares.

The Ramsar Convention aims at "the conservation and wise use of wetlands with local, national and international cooperation for overall sustainable development of the world" (Ramsar Convention Secretariat 2016, 14). The convention provides a platform for stepping up action to accomplish the aspiration of the SDGs (Ramsar Convention Secretariat 2016).

Wetlands are a distinct category of ecosystem that has its own international convention, the Ramsar Convention, for international cooperation on wetland conservation. The Ramsar Convention works and collaborates with international organizations and a network of other Convention partners. In the past 50 years the convention has introduced many resolutions for sustaining different types of wetlands in the changing socio-ecological systems. However, despite Ramsar's incredible achievements, the threat to the health and survival of many wetlands across the globe has not diminished since 1971(Bowman 2002. Marothia 2019).

The Ramsar Convention entered into force in India on 1 February 1982 and designated Keoladeo National Park (Bharatpur) and Lake Chilika (Bhubaneswar, Odisha) as internationally important wetlands. Since then, India has designated 42 sites as Wetlands of International Importance (Ramsar Sites) under the Ramsar Convention, with a surface area of 1,067,939 hectares. Despite several wetland-related programmes and activities at the central and state level, there has been, however, increasingly greater concern about the degradation and loss of wetlands in different parts of the country.

Wetlands

The Ramsar Convention has adopted a rather broad definition of wetlands to cover almost the whole range of inland and coastal aquatic ecosystems. Under the text of Ramsar Convention Article 1.1, "wetlands" are defined as "areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed six metres".

"may incorporate riparian and coastal zones adjacent to the wetlands, and islands or bodies of marine water deeper than six metres at low tide lying within the wetlands" (Ramsar Convention Secretariat 2013).

For practically the same reason, the Ramsar Convention considers lakes and rivers also as "wetlands in their entirety, regardless of their depth" (Ramsar Convention Secretariat 2013).

The Ramsar Convention (2013) recognizes five major wetland types:

- marine (coastal wetlands including coastal lagoons, rocky shores, seagrass beds and coral reefs);
- estuarine (including deltas, tidal marshes and mudflats, and mangrove swamps);
- lacustrine (wetlands associated with lakes);
- riverine (wetlands along rivers and streams); and
- palustrine (meaning "marshy" – marshes, swamps, and bogs).

In addition, there are human-made wetlands such as fish and shrimp ponds, farm ponds, irrigated agricultural land including rice paddies, salt pans, dams, reservoirs, gravel pits, wastewater treatment ponds, and canals.

The Convention has adopted a Ramsar Classification of Wetland Type, which includes 42 types, grouped into three categories: marine and coastal wetlands, inland wetlands, and human-made wetlands (Ramsar Convention 2016).

The Ramsar Convention cuddles diverse environments, spatially and temporally, but also in terms of physical size, ecology, hydrology and geomorphology in a single definition, grouping together a wide variety of landscape units whose ecosystems share the fundamental wetland characteristic of being strongly influenced by water (Davis 1994).

Although a wide variety of wetland definitions is used by different scholars[2], the fact remains that some 171 countries have adopted a common definition by signing the Ramsar Convention on Wetlands of International Importance. The Convention adopts an exceptionally broad approach in determining "wetlands" which come under its aegis (Ramsar Convention Secretariat 2018).

Wetlands: Extent, Threats, and Benefits

Extent of Wetlands

Estimates of wetlands' coverage of the earth's surface are not known precisely. According to a recent report of the Ramsar Convention (2018), global inland and coastal wetlands cover over 12.1 million square kilometre (sq km), an area almost as large as Greenland, with 54% of it permanently inundated and 46% seasonally inundated (cited from Global Wetland Outlook: State of the World's Wetlands and their Services to People. Gland, Switzerland: Ramsar Convention Secretariat 2018).

India has large physiographic diversity (from sea level to high mountains) and high average rainfall (120 cm) marked by extreme temporal and spatial variability. Therefore, India enjoys a rich diversity of wetland types. Over millennia, humans have modified and

[2]The Ramsar Convention's definition of "wetland" reflects a hydrological perspective, with water as the key factor.
Other scholars stress the link between hydrology and biology and propose "ecohydrological" definitions. Yet others suggest geomorphological definitions (Dugan 1990, for example) or agricultural (crop) definitions (for example, FAO 1998).
Wetlands are "lands transitional between terrestrial and aquatic systems where the water table is usually at or near the surface or the land and is covered by shallow water" and "must have one or more of the following three attributes: at least periodically, the land supports predominantly hydrophytes; the substrate is predominantly undrained hydric soil; and the substrate is non-soil and is saturated with water or covered by shallow water at some time during the growing season of each year" (Cowardin et al. 1979).
Pittock et al. (2015) define wetlands as "places where water is the primary factor controlling plant and animal life and the wider environment, where the water table is at or near the land surface, or where water covers the land".
See McCartney et al. (2010) for a classification of wetlands in the context of agriculture and poverty.

managed most of the natural wetlands for specific purposes, such as paddy and fish. Innumerable tanks were created in the arid and semi-arid regions of western and peninsular India. More wetlands have also been created by damming the rivers (Gopal and Marothia 2017).

Whereas several attempts had been made earlier to document the wetlands in the country, they focused only on the better known habitats. In 1998, the Space Application Centre Ahmedabad (SACA) conducted the first survey based on remote- sensing satellite images (Gopal and Marothia 2017).

Recently, SACA conducted a study to estimate wetland areas in the country (Patel 2018). The study adopted the Wetland Classification System, based on the Ramsar Convention definition of wetlands, which provides a broad framework for delineating wetlands and is acquiescent to remote-sensing data. The SACA study considered all the aspects of a water mass including its ecotonal area as wetland. In addition, in the Ramsar Convention wetland classification, fish and shrimp ponds, saltpans, and reservoirs were also included as wetlands.

Besides using the Wetland Classification System, the SACA study incorporates deepwater habitats and impoundments. It estimates 15.26 million hectares (mha) of total wetland area, which is around 4.63% of the geographic area of the country. A total of 201,503 wetlands larger than 2.25 ha have been mapped at 1:50,000 scale. In addition, 5,55,557 small wetlands (<2.25 ha) have also been identified. Inland natural wetlands account for around 43.4% of the total area, while coastal natural wetlands account for 24.3%.

The human-made inland wetlands cover about 37% of the area (3,941,832 ha) and the remaining 63% are the natural wetlands (6,623,067 ha).

It is noteworthy that paddy fields are not included as wetlands in this inventory (Patel 2018). However, paddy fields are part of the Ramsar Convention definition, as mentioned in the earlier paragraph. For wetland statutes in India see also Bassi *et al.* (2014)).

Threats to wetlands

In a comprehensive study of 189 wetland assessments, Davidson (2014) estimates that wetland losses in the 20th century were 64% to 71%, and for some regions, notably Asia, even higher. He found that

"losses of natural inland wetlands have been consistently greater, and have occurred at faster rates, than [those] of natural coastal wetlands".

His review found that the extent of inland wetlands declined 69–75% during the 20th century, while coastal wetlands declined 62–63%. Further, 64% of the wetlands have disappeared since 1900. The loss has been four times faster in the 20th century. The loss of freshwater wetlands worldwide from 1997 to 2011 is valued at USD 2.7 trillion per year (Briggs 2014). India is losing wetlands at the rate of 2–3% each year (Prasher 2018). The drivers of this decline are overfishing, agriculture, deforestation, introduced species, climate change, water drainage, land encroachment, urban development, upstream and downstream pollution, uncontrolled growth of exotic species and the absence of wetland policy (see Marothia 1995 a, 1997, 2004 a; Gopal and Marothia 2017).

The most significant factor responsible for the present state of wetlands is the absence of a clear national or state policy devoted to wetlands, natural or man-made. Wetlands receive no attention in the development plans concerned with land use changes or the development of water resources (Marothia 1995 a, 1997, 2019, Gopal and Marothia 2017; Gopal 2018).

Benefits of Wetlands

Wetlands, the most valuable ecosystem, provide services worth USD 47 trillion a year. More than a billion people rely on wetlands for income, and 40% of the world's species live and breed in wetlands. Annually, about 200 new fish species are discovered in freshwater wetlands. Aquaculture is the fastest-growing food production sector, while inland fisheries alone provided 12 million tons of fish in 2018. Rice paddies feed 3.5 billion people annually. Coral reefs are home to 25% of all species. Wetlands provide protection from floods and storms, with each acre of wetland absorbing up to 1.5 million gallons of floodwater. Wetlands help regulate the climate. For example, peat lands store twice as much carbon as forests, with salt marshes, mangroves, and seagrass beds also holding vast amounts of carbon (cited from Global Wetland Outlook: State of the World's Wetlands and their Services to People. Gland, Switzerland: Ramsar Convention Secretariat 2018).

Humans benefit in many ways from all kinds of wetlands. These benefits arise either directly from the use of the water, plants, animals, soils, and other components of the wetland ecosystem, or indirectly from their ecosystem functions. These benefits are now called ecosystem services and categorized into provisioning, regulating, supporting, and cultural services (Gopal and Marothia 2017).

Irrespective of the kinds of organisms living there, the most important function of wetlands is to regulate the hydrology of the region. The retention of water in them controls flooding (especially downstream), recharges groundwater, and provides water for various human uses including irrigation. The amount and duration of water in the soil and above it governs the diversity of biota, which mediates other ecosystem functions and determines various benefits. Indirectly, wetlands support high levels of biodiversity (fish, frogs, turtles, birds, molluscs, arthropods, and insects) by providing habitat and food Thus, various kinds of wetlands differ in their dominant biota and the ecosystem services (Gopal and Marothia 2017; for the details of ecosystem services derived from different categories of wetlands, see Marothia(*forthcoming*).

Another highly important function of wetlands benefitting the humans directly is related to their recreational (swimming, bathing, diving, boating, angling, fishing, bird watching) and social-cultural use, besides contribution to the aesthetics of the surroundings (Gopal and Marothia 2017).

Wetlands and Sustainable Development Goals (SDG)

Wetlands are implicitly or explicitly mentioned in the SDGs mentioned in the Ramsar Convention's fourth Strategic Plan 2016–2024. The sustainable use of water and wetlands, by protecting the services they provide, is critical to enable society to achieve sustainable social and economic development, adapt to climate change, and improve social cohesion and economic stability. The proposed UN SDGs offer a universal agenda that, for the first time, recognizes the need for restoration and management of water related ecosystems, including wetlands, as a basis for addressing food and water scarcity and water risks.

Wetlands are a solution for several key challenges around the world related to water, food, and climate, and key to meeting the SDGs. The multiple benefits and services provided by wetlands are essential in achieving the SDGs. Most of the SDGs are relevant in some way or another to wetlands, but the following are of particular importance in the Indian context.

SDG 1 End poverty in all its forms everywhere

SDG 2 End hunger, achieve food security, improve nutrition, and promote sustainable agriculture

SDG 5 Achieve gender equality and empower all women and girls

SDG 6 Ensure availability and sustainable management of water and sanitation for all,

SDG 8 Promote sustained, inclusive, and sustainable economic growth, full and productive employment, and decent work for all

SDG 9 Build resilient infrastructure, promote inclusive and sustainable industrialization, and foster innovation,

SDG 11 Make cities and human settlements inclusive, safe, resilient, and sustainable

SDG 13 Take urgent action to combat climate change and its impacts

SDG 14 Conserve and sustainably use the oceans, seas, and marine resources for sustainable development

SDG 15 Protect, restore, and promote the sustainable use of terrestrial ecosystems; sustainably manage forests; combat desertification; and halt and reverse land degradation and halt biodiversity loss

Institutional Framework for Analysing Multi-use Wetland Ecosystems

To assess WAIs in the selected wetlands I have borrowed the basic framework of Oakerson (1992) and subsequently developed by E Ostrom (1990) and Tang (1992) (represented through seven boxes in Figure 1). Attributes of property rights regimes (Bromely's work) and distributed governance components of Townsend and Polley are also incorporated. I have used in my earlier work different institutional approaches—developed by Oakerson (1992), Elinor Ostrom and her co-authors, Tang (1992), Townsend and Polley (1995), Bromley (1978, 1989 a, 1989b, 1991, 1992), Bromley *et al.* (1980), Gibbs and Bromley (1989), and Rawls (1971) to assess the performance of various CPR-based development programmes implemented under different governance structures or property regimes or combination of property rights regimes (Marothia 1992, 1993, 1995 a, 1995b, 1997 a, 2002, 2004 a, 2005 a, 2005b, 2012, 2017, 2019; NIE 2003).

Physical and technological attributes, decision-making arrangement, patterns of interaction and outcomes (box 1,4,6 and 7 of Fig.1) are the core attributes of Oakerson's conceptual framework to analyse common pool resources under common property regime. Each set of attributes relates to the others. For example, physical and technological attributes and decision-making arrangement jointly affect patterns of interactions. The physical and technical characteristics of the CPRs can affect the outcome directly or through patterns of interactions.

In the long run analysis, institutional changes are exogenous and their effects could be iteratively assessed on interactions and outcomes (Oakerson 1992, 41–62). Oakerson model also has dynamic application if applied iteratively.

Kiser and E Ostrom (1982) included social characteristics along with physical attributes and institutional arrangements in their institutional analysis development framework (for detailed interpretation of Kiser and E Ostrom 1982 attributes of institutional analysis development framework see Tang, 1992; Folke and Berkes, 1995; Edwards and Steins, 1996). Several researchers, in addition to four attributes of Oakerson model, added social characteristics of resource users and community (Arnold and Stewart 1991; Tang 1992; Marothia 1993, 2001, 2002 (pp 701–16), 2004 a, 2004 b, 2005, 2012; Singh 1994; Singh and Ballabh 1996).

The nature of institutional arrangements defines the extent of property regime over land, water multi-use wetlands and related resources. (Bromley 1989; Bromley and Cernea 1989; Gibbs and Bromley 1989; see also the classic work of Commons (1934) on the role of institutions, property rights, and collective action).

The basic requirement for any property rights regime (or a combination of property rights regimes) is an authority system (local governing body/Panchayat/ state/federal government) that can guarantee the security of expectations for the rights holders.

Box 3 of Figure 1 deals with resource or property rights regimes distributed or shared management of multiple-use CPRs, including multi-use wetlands.

The four categories of resource governance or property rights regimes—state, private, common, and open access regimes (Bromley 1989, 1991; Ostrom, E 1990; Gibbs and Bromley 1989; Bromley and Cernea 1989)—have been extended by Townsend and Polley (1995) to recognize that natural resources governance can be shared among states, communities and private interest groups in various ways at different decision-making levels. Distributed governance involves the external institutional arrangements[3] among government and local communities or resource users as well as internal institutional arrangements[4] within local community institutions or resource users. Government, local communities and private parties utilizing CPRs bring different interests, capabilities and understanding to the resource management and decision-making process (Townsend and Polley 1995; for an application of the Townsend and Polley framework in the Indian

[3]An external governance structure has essentially three alternatives of management systems (Townsend and Polley 1995): *rights-based management* (the government grants usufruct rights to individual resource users under well specified constraint conditions and assumes the role of monopoly over the resource base and retains all responsibility/authority for conservation decision); *co-management* (the government and the local communities share ongoing responsibility for decision-making over all or most of the resource management decisions); and *contracted management* (to transfer large part of the decision-making process to local bodies).

[4]Townsend and Polley (1995) associate with the concept of distributed governance four alternative internal institutional arrangements: *self-organizing institutions* (institutional and organizational decisions remains with local communities and the government may use the institutional building capacity to support and gain strength from self-organization); *communal management* (to reduce the existing authority of state and vest more localized interest); *cooperative management*(membership is limited with well-defined working rules for collective governance);and *corporate* (under the corporate governance the owners and shareholders of the corporation would operate under governance rules typical of private corporations).

context, see Marothia 2012). Complex multi-use wetlands can also be managed under a polycentric governance regime[5] developed by E Ostrom et al. (1994) and Andersson and E Ostrom (2008).

CPRs, including wetlands, can be managed or mismanaged under any of the four resource regimes: state property, private property, common property, and open access CPRs (Calabresi and Melamed 1972; Ciriacy-Wantrup and Bishop 1975; Bromley 1989a; Gibbs and Bromley 1989; Bromley and Cernea 1989; E Ostrom 1990; Marothia 1993, 1996b, 2002, 2004b) are also subject to degradation under distributed governance (Marothia 2001, 2002, 2005, 2012).

Alternative institutional perspectives shape the decision-making process among government and local resource users' communities and within members of local community for managing a resource by converting unorganized structures into organized ones (Marothia and Phillips 1985).

Oakerson (1992) model's decision-making institutional arrangements deal with operational rules – limits on users' behaviour, specification of relationship among co-users, if a resource has multiple-use, rules about highly subtractive behavior of co-users; – Individual share of benefits is protected by the authority system and boundary rules determine the legal domain of collective choice. Under the decision-making arrangements (Box 4, Figure 1), among other sub-attributes (Operational rules, conditions of collective choice, boundary rules of Oakerson 1992), the conditions of collective action have three levels. At the operational level, users interact with each other to use or withdraw resource units from a CPR (including multi-use wetlands). At the collective choice level, rules are established and decisions are taken by existing and potential resource users to define the operational, institutional, and technical arrangements. In constitutional situations, decisions are taken to determine who has the authority to structure rules for collective choice situations (E Ostrom 1989).

Action situation (Box 5) is the crucial point of the IAD framework (Kiser and Ostrom, E 1982; E Ostrom 1986; E Ostrom and Crawford 1995, see also Edwards and Steins, 1996; and Aligica, 2006 and Marothia 2005). Tang (1992: page 19) had added action situations, mode of individuals in terms of bounded rationality and opportunism, and incentives in the Oakerson model.

Action situation is affected by external variables (biophysical and technical condition of a resource, attributes of resource users community rules in use (E Ostrom 2005) or decision-making institutional arrangement – represented in Box 1,2, and Box 4 of Figure 1 under alternative governance structures (Box 3).

In action situations, individual resource users or groups of users adopt actions or strategies. Different outcomes may result from interactions among users, depending on number of users, choices available to users (Box 4), capability of processing information and incentives faced by users (see Tang, 1992 for detailed description of action attributes).

Sub-attributes of patterns of interaction of Oakerson model include reciprocity – individual co-users contribute to each other's welfare, and free riding behaviour – degrades reciprocity, breeds destructive competition, conflicts and ultimately leads to over-exploitation of a resource (see Box 6 of Figure 1). Edwards and Steins (1996, 1999) connected the "context- bound" factors to patterns of interaction attributes of Oakerson (1992), Tang (1992) and E Ostrom (2005).

The Oakerson (1992) outcomes attributes (box 7 of Fig.1 has two sub-attributes to analyse CPRs under the common property regime: economic outcomes, evaluated using concepts of efficiency (overall use rates of a resource) and distributive outcomes, evaluated in terms of equity (fair share to co-users on their contribution to a collective choice, effectiveness of a management system to exclude non-users' enforcement

[5]The polycentric governance regime, developed by E Ostrom et al. (1994) and Andersson and E Ostrom (2008), "is a system that seeks to unleash ingenuity and stimulates the creativity of political entrepreneurs. It is a system that is structured so that actors within the system are given opportunities for institutional innovation and adaptation through experimentation and learning" (E Ostrom et al. 1994). K Andersson and E Ostrom (2008) state: "A key aspect of all proposals for increased polycentricity (as opposed to *just* centralization or *just* decentralization) is the effort to enable institutions of multiple scales to more effectively blend local, indigenous knowledge with scientific knowledge."

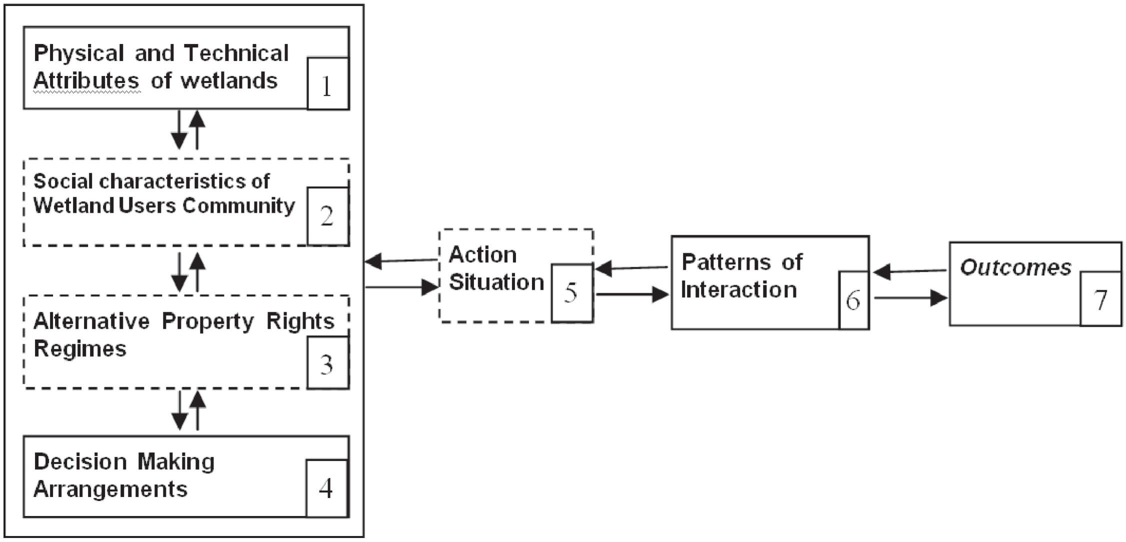

Figure 1 Institutional framework for analysing wetland ecosystems
Note Basic framework borrowed from Oakerson, Ostrom and colleagues and Tang, Berkes and Folke, Folke and Berkes added Bromley and Townsend and Pooley attributes of property rights regimes/ structures. Interpretation of boxes marked with solid and dashed lines is given in the text.

of rules. A few researchers have incorporated sustainability criteria to the outcome attribute of Oakerson framework, just after the inception of his framework (Marothia 1993; Folke and Berkes 1995).

Researchers have adequately documented the contribution of wetlands to total economic value and ecosystem services.[6] The seven boxes in Figure 1 are in dynamic interrelationship with one another. Feedback loops among the seven components are indicated with arrows (see Folke and Berkes, 1995 for details of dynamic institutional framework). To this end, I propose to analyse the wetland–agriculture interactions using the institutional framework depicted in Figure 1.

Assessing Wetland–Agriculture Interactions

In this section, I have analysed the comparative performance of the wetland–agriculture interactions in rural wetlands, being managed under different property rights regimes, through the application of institutional framework (Figure 1). All the attributes of the framework (Figure 1) are now used for assessment of different combinations of the wetland–agriculture interactions. Sub-attributes of the main seven attributes are listed in Tables 1 and 2. As mentioned in the introductory remark, the wetland–agriculture interactions analysis is confined to major rural multiple–use wetlands (community wetlands, Riverine wetlands, private ponds and paddy fields converted for lotus cultivation. Information presented in Tables 1 and 2 is extracted from the case studies, carried out by me in the Chhattisgarh state of India. I also discuss herein briefly the process by which institutional arrangements affect multi-use wetlands management, and in turn the transformation of wetland- agriculture partnership.

[6]The total economic value and ecosystem services of wetland ecosystems have been empirically estimated under different socio-ecological settings (Costanza, Farber, and Maxwell 1989; Aylward and Barbier 1992; Munasinghe 1992; Costanza et al. 1997; De Groot et al. 2002; Marothia 2001, 2004; Finlayson et al. 2005; MEA 2005; Maltby 2009; Gopal 2015; Gopal and Marothia 2015, 2016, 2017; Gopal et al. 2016; Kumar et al. 2017, 2020). Further, any change in physical and technical parameters of a CPR, including multi-use wetlands, can alter the use and non-use values and ecosystem services depending on the behaviour of users and non-users, effectiveness of institutional arrangements, and the authority system (Marothia 2001, 2004 a; Samaraweera and Marothia 2008). Several multi-use wetlands have been reported in this address; their contribution to SDGs is also assessed (see also; Pal 2018 for case studies pertaining to agriculture and ecosystem services valuation).

Table 1 Attributes of Wetlands, wetland-agricultural interactions, social structures of users, decision making arrangements, action situation and patterns of interaction

Attributes of Wetlands	Community Wetland (1)	Riverine Wetlands (2)	Private and Community Ponds for Foxnut (3)	Paddy field converted for Aquatic Crops(4)
i. Original management Regimes	Private (Zamindars)	Territorial rights over flood plain stretch	Private/ Panchayats	Private ownership
ii. Current management Regime	Panchayat of Kurra Village used by local community under common property regimes	Village Panchayats at local level, seasonal *Usufructuary* rights to fruits and vegetables growers	Private property regime, and Panchayats	Private property regime, collectively owned by group of farmers
iii. Number of wetlands included	29 (12 Perennial, and 17 Seasonal)	4 tracts of floodplains	6 private ponds, and 7 community ponds*	5 individual + 3 pooled land groups*
iv. Average water spread aera (ha)	1.87 ha	Restricted to riverbed in a village	1.60 ha private ponds and 1.25ha community ponds	1.50 ha average
v. Multiple Objectives of wetland Management	Domestic, Crops and fish production	To minimize agricultural labors distress migration during summer, production of summer season fruits and vegetables	Fox nut Production	Lotus cultivation, pulses on bunds of fields
vi. WAI Combinations	Fish + Paddy	(i) Watermelon (ii) Muskmelon (iii) Cucumber	Foxnut	Lotus
vii. Main uses	Food and nutritional security	Food and nutritional needs	Dry fruit, sweet dishes, Medicinal, starch use for silk and cotton polishing, Fox nut straw for as a poultry birds & cattle feed	Food, Socio-cultural, religious medicinal, cosmetic, leaves of lotus vital for water purification of wetlands
viii. Physical and Technical Attributes of Wetlands	In a good condition due to continued maintenance	Riverbed still in a good condition despite large scale sand mining and construction of many stop dames along riverbeds	In a good condition due to continued maintenance	Sustaining converted fields, Good water management flowing in from lower range of hills
ix. Social structures of Users and community	Heterogeneous	Homogeneous (landless, agricultural labourers and marginal farmers)	Homogeneous	Homogeneous
x. Decision Making Institutional Arrangements*	Effective coordination between internal and external decision making	Collective decision in case of group is using flood plains collectively	All decisions made by individual farmer in case of private ponds, collective decision in case of community ponds by members*	All decisions made by individual, in a group collective decision are made*
xi. Action Situation	Positive situation among users and Panchayats	Positive relation among growers and local body	Positive action situation in both regimes	Independent / group driven situation
xii. Patterns of Interaction	Conducive to collective behavior	Conducive to collective behavior	Not applicable in case of individual ponds, condusive to collective behaviour	In a group collective decisions induce collective rational behaviour

*Managed under common property regime by the members of community/group

Note Price determining mechanism and marketing of paddy is well regulated (Mandi and Minimum Support price system) in case of fish, fox nut and lotus products price mostly fixed by producers. Fox nut and lotus products have export potentiality due to value addition options.

Table 2 Outcomes of Wetland-Agriculture Interactions in different types of wetlands

Attributes of WAIs	Community Wetland (1)	Riverine Wetlands (2)	Private and Community Ponds for Fox nut (3)	Paddy field converted for Aquatic Crops (4)
i. Efficiency criteria: (a) Productivity kg/ha	554 (Fish) 38 (Paddy) 600 (Cucumber)	800 (Watermelon) 730 (Muskmelon)	275 (Fox nut)	1000 (Lotus flower) 50 (Rhizome) 500 (Pods nos.) 5 (Seeds)
(b) Return per rupee investment income levels (ratio)	1:3.99 (Fish) 1:1.26 (Paddy)	1:4.50 (Watermelon) 1:5.60(Muskmelon) 1:5.30 (Cucumber)	1:1.80 (Fox nut)	1:1.98 (Lotus)
ii. Nutritional security in terms of nutritional components	Fish- Calories: 280, Fat: 12.5g Sodium: 86mg Carbohydrates: 0g, Fiber: 0g Sugars: 0g Protein: 39.2g Paddy- Calories: 242, Fat: 0.4g, Sodium: 0mg, Carbs: 53.4g, Fiber: 0.6g Sugars: 0g Protein: 4.4g Lotus - Calories: 74, Fat: 0.1 g, Sodium: 40 mg, Potassium: 556 mg, Carbs: 17.23 g, Protein: 2.6 g Watermelon- Calories: 46, Fat: 0.23 g, Carbs: 11.48 g, Fiber: 0.6 g, Sugars: 9.42 g, Protein: 0.93 g, Calcium: 11 mg, Water content: 139 g Muskmelon- Calories: 61, Fat: 0.2g, Carbs: 15 g, Fiber: 1.5 g, Protein: 1 g Cucumber- Calories: 30, Fat: 0 g, Carbs: 6 g, Fiber: 2 g., Protein: 3 g Fox nut- Calories: 35, Fat: 0.3 g, Carbs: 7.3 g, Fiber: 0.4 g, Protein: 0.7 g			
iii. Equitable distribution of costs and benefits	Equitable distribution of cost and benefit among members of FCs, paddy gains and investment are attached with individual farmers	Equitable distribution of cost and benefit among group members	Individual investment and gains, Equitable distribution of cost and benefit among members of group	Individual investment and gains, Equitable distribution of cost and benefit among members of group

Decisions about price and marketing mechanism value addition and export potentiality of different wetland farming products (fish, lotus, fox nut, paddy)[7] are briefly explained in Table 1.

The main attributes of institutional framework related to current biophysical and technical attributes, social structures of users and non-users, and decision-making arrangements are briefly described in Table 1. All these attributes and resource regime have an important role in creating action situations among users–practically a process of transforming individual users' behaviour to collective action. This in turn affects the patterns of interaction. Assessment of the wetland–agriculture interactions was carried out using criteria related to efficiency and equity taking into consideration the wetland–agriculture interactions (Table 2).

Extent of ecosystem services derived from multi-use wetlands

Ecosystem services provided by multi-use wetlands, included for the wetland–agriculture interactions investigation, are presented in Table 3 separately. Multi-use wetlands provide a wide range of ecosystem services such as provisioning services for protective irrigation, and fish and aquatic crops (lotus and fox nut). Besides providing provisioning services, wetlands also support biodiversity, regulating the water cycle, and microclimate and water quality, promoting social, cultural, and recreational activities, and enhancing aesthetics. Often, they support subsistence and livelihoods of poor and wetland dependent local communities of the society.

[7]Scientists of KVK Dhamtari (IGKV, Raipur) have been working on agronomic aspects of fox nut at experimental level and covered case study of two field sites which have been converted from paddy fields to lotus cultivation. Refer Sahu and Chandravanshi (2017 a, b). Scientists at KVK Dhamtari and Jagdalpur are also working on other wetland crops, including lotus and chestnut. Dr. S S Chandravanshi assistance for data collection on basic economics parameters for fox nut on private and community ponds, and lotus crop on paddy converted fields for my research work is gratefully acknowledged.

Table 3 Extent of Ecosystem Services Derived from Different Categories of Wetlands

Ecosystem Services	Community Ponds (1)	Riverine Wetlands (2)	Private and Community Ponds (3)	Paddy Field converted for Aquatic Crops (4)
Provisioning Services				
Food	♦	♦♦	♦♦♦	♦♦♦
Fodder	◊	♦♦♦	◊	◊
Fuel	◊	♦♦♦	◊	◊
Fiber	◊	♦♦♦	◊	♦
Medicinal	◊	♦♦♦	◊	♦
Bio-chemicals	◊	♦♦	◊	♦
Genetic materials	◊	♦	◊	♦♦
Water storage	♦♦♦	♦♦	♦♦	♦♦
Domestic requirement of local community*	♦♦♦	♦♦	♦	◊
Regulating Services				
Sediments	♦	♦♦♦	♦	◊
Heavy metals	♦	♦♦♦	◊	◊
Toxics	♦	♦♦♦	◊	◊
C- Sequestration	◊	♦♦♦	♦	♦
GHG emission	◊	♦	◊	◊
Erosion control	◊	♦♦♦	◊	♦♦
Disease vectors	♦♦	♦♦	♦	◊
Pollination	◊	♦♦	◊	♦
Cultural and Social Services				
Recreation	♦	♦♦♦	◊	♦
Aesthetics	♦	♦♦♦	♦	♦
Spiritual	♦	♦	◊	♦♦
Religious	♦	♦	◊	♦♦
Education, R&D	♦♦♦	♦♦♦	♦♦♦	♦♦♦
Supporting Services				
Soil formation	♦	♦♦♦	◊	♦
Groundwater recharge	♦♦	♦♦♦	♦	♦♦
Nutrient cycling	♦	♦♦♦	♦	♦♦
Water cycling	♦	♦♦	♦	♦♦
Photosynthesis	♦♦♦	♦♦♦	♦♦♦	♦♦♦
Biodiversity				
Microphyte	♦♦	♦♦	♦♦♦	♦
Macrophyte	♦	♦♦	♦	♦
Fish	♦	♦♦	♦♦♦	♦
Zooplankton	♦♦	♦♦	♦♦	♦
Benthos	♦	♦♦	♦♦	♦
Birds	♦	♦♦	♦	♦♦
Herpettofauna	♦	♦	♦	♦
Lotus diversity	♦♦♦	♦	♦♦	♦♦♦
Aquatic crops diversity (Fox nut, Water Melon, Seasonal Vegetables)	♦♦	♦♦	♦♦	♦♦
Floral diversity	♦♦	♦♦	♦♦	♦♦
Screeds vegetation	♦♦♦	♦♦♦	♦♦	♦♦

Benefits: ◊ no benefits; ♦ little; ♦♦medium, ♦♦♦large

*Bathing, washing utensils, cloths, tending cattle, drinking and sanitation

Note Option value reflects future direct and indirect uses of goods and services mentioned in the above table. Non-use values include: existence, bequest and altruistic value of wetland habitats and species; Traditional/cultural knowledge and traditions.

Excessive priority on provisioning services may create an imbalance in a few cases among provisioning, regulating and supporting ecosystem services. Such imbalance may also potentially affect option values, which reflect the future direct and indirect uses of goods and services. Further, non-use values— representing the existence, bequest, and altruistic values of wetland habitats and species, and the traditional/ cultural knowledge and traditions—may have invisible implications on different ecosystem services. This needs a restructuring of the existing institutional arrangements and authority system at different decision-making levels if imbalances between different ecosystem services are observed (Table 3).

Emerging Research and Policy Issues

The wetland–agriculture interactions in multi-use wetlands in agricultural landscapes are among the least researched and feebly understood systems in India and South Asian countries. Therefore, I propose the following unexplored research areas, followed by a policy and regulation agenda, that need collective thinking and action.

Research agenda

1. Estimates for the extent of different categories of wetlands are required for the major agro-climatic zones and subzones and different types and sizes of wetlands. Using a remote-sensing database, field studies may be carried out to identify priority research areas in wetland–agriculture interactions. The inputs from such research efforts can help state wetland authorities to design actionable policies within a decentralized governance framework.

2. Article VIII.34 of Ramsar Convention Resolution VIII, adopted in 2002, called for setting guidelines to enhance interactions between agriculture, wetland, and water.[8] Resolution VIII.34 requested all the Conference of Contracting Parties (COP) to establish a framework for identifying, documenting, and disseminating good agriculture-related practices. For developing guidelines, a scoping document on agriculture–wetland interactions was produced and published (Wood and Halsema 2008; for further elaboration, see Zingstra (2009)) to explore the nature of the wetland–agriculture interactions through the application of the drivers, impacts, pressures, state changes, impacts and responses (DPSIR) framework.

   In view of the Ramsar Convention Resolution VIII, research studies on the variety of agricultural systems in different types of wetlands may be undertaken in different agro-climatic zones and subzones of the country to assess the contribution of the wetland–agriculture interactions in the conservation and wise use of wetlands, sustenance of livelihoods, provision of balanced ecosystem services, and the meeting of SDGs. Inputs from such studies can provide guidelines to work out payment for ecosystem services generated from the wetland–agriculture interactions in multi-use wetlands.

3. Very few studies are available, even globally, on good agricultural practices (GAP) to support sustainable wetland–agriculture interactions. To bridge this critical research gap, case studies need to be conducted taking into consideration the ecosystem services that are assigned to a specific wetland.

4. Wetland–agriculture interactions can happen *in situ* or *ex situ* (Zingstra 2009). To address *in situ* and *ex situ* issues, case studies are needed to understand the complexities of the wetland–agriculture interactions in multi-use wetlands.

Policy Agenda

Here, I propose the policy agenda, keeping in view the role of institutional arrangements in policymaking, in the context of inland wetland ecosystem with focus the wetland–agriculture interactions in multi-use wetlands.

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[8]The origins of the Guidelines on Agriculture and Wetlands Interactions (GAWI) initiative go back at least as far as October 2002. At that time and in two consecutive weeks, in Valencia (Spain), there were the Global Biodiversity Forum 17 (GBF17) workshop "Wetlands and agriculture" and Resolution VIII 34 at the Eighth Meeting of the Conference of the Contracting Parties to the Ramsar Convention on Wetlands of International Importance especially as Waterfowl Habitat (Ramsar COP8) titled "Agriculture, wetlands and water resource management".

1. India has no wetland-specific policy or law. The ecosystem services of wetlands are recognized in India's National Environment Policy, 2006, which also mentions the need for maintaining their ecological character. The Government of India adopted in 2010 the Wetland (Conservation and Management) Rules under the Environment Protection Act, 1986, to regulate various activities affecting the wetlands adversely. These rules were replaced by the Wetland (Conservation and Management) Rules, 2017. Frequent changes in rules may also create conflict with Ramsar Convention commitments.
2. The provision for the constitution of state wetland authorities under the 2017 Rules is a welcome step towards the decentralized governance of wetlands. A few states have recently constituted wetland authorities, but these are yet to be fully functional.
3. Floodplains and riverbeds cultivation in the summer months is very common and extensively practised by the poor and underprivileged. State wetland authorities should develop a policy to protect this cultivation system to minimize distress labour migration in summer.
4. To enhance the research and policy understanding about multiple-use commons in general and multiuse wetlands in particular, an interdisciplinary framework, for example the one used in this address, can be adopted.

I plead with this august body to collectively take up these emerging research and policy challenges so that our contribution for providing actionable research input for policymaking becomes more relevant in the changing social-economic-ecological-cultural and political environment.

Thank you all for giving me a patient hearing.

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Anionic mineral mixture prevents milk fever and improves farmer income: evidence from a randomized controlled trial

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Abstract The incidence of milk fever, a calcium deficiency disorder in dairy animals, can be prevented by supplementing their feed with anionic mineral mixture (AMM). Using data from 200 dairy farms in Haryana, a state in India, and a randomized controlled design, we find that supplementing animal feed with AMM reduces the incidence of milk fever from 21% to 2%, improves milk yield by 14%, and farmer profit by 35%. The milk yield in India, and therefore the risk of milk fever, is growing; AMM can be an affordable way to prevent milk fever and improve returns.

Keywords Milk fever; anionic mineral mixture; randomized controlled trial; impact evaluation; farmers' income; dairy farming

JEL codes Q10, Q120, Q180, C93

Nutritional deficiency disorders in high-yielding dairy animals, and the associated damages, make for avoidable depletion of scarce resources (Thirunavukkarasu et al. 2010). Nutritional deficiency disorders increase the loss of milk, decrease its availability, and increase the purchase cost to consumers—threatening the nutritional security of the nation (Hogeveen, Steeneveld, and Wolf 2019; Jodlowski et al. 2016; Nilsson et al. 2019).

One such metabolic illness is hypocalcaemia, or milk fever—the decrease in the level of blood calcium, due to the rapid drain of calcium into colostrum, after parturition, or calving (Melendez and Poock 2017; Rodríguez, Arís, and Bach 2017). High-yielding dairy animals are at greater risk of milk fever; for example, crossbred cattle are more susceptible than buffaloes.

Milk fever leads to immune suppression (Kimura, Reinhardt, and Goff 2006). Milk fever also increases the risk of other metabolic disorders, like dystocia, uterine prolapse, ketosis, and metritis. These disorders deteriorate the productive and reproductive performance of dairy animals and lead to economic loss (Goff 2008; Reinhardt et al. 2011; Melendez and Poock 2017; Oetzel and Miller 2012).

The economic literature provides evidence on the spread and persistence of bacterial and viral dairy animal diseases (Hayer et al. 2017; Sok and Fischer 2020) and on the associated losses (Govindaraj et al. 2017, 2021; Barratt et al. 2018). There is evidence in the literature on the control/prevention strategies as well (Hennessy 2007; Wang and Hennessy 2015; Schroeder et al. 2015; Weyori, Liebenehm, and Waibel 2021), but not on the economic effects of preventing nutritional deficiency disorders. And there is little data on the incidence of milk fever in India.

However, the incidence of milk fever has been documented to be 11–12% in the north-eastern states (Paul, Chandel, and Ray 2013), 13–14% in Tamil Nadu

(Thirunavukkarasu et al. 2010), and 10% in Himachal Pradesh (Thakur et al. 2017). In Tamil Nadu, between 2005 and 2008, the loss was estimated at around INR 41 crore (US$ 6 million)[1] (Thirunavukkarasu et al. 2010). In Haryana, during 2020, the loss was estimated at around INR 873 crore (US$ 118 million) (Cariappa et al. 2021a). Therefore, preventing milk fever is indispensable for the success of reproductive and productive performance of dairy animals (Melendez and Poock 2017) and from the economic point of view (Cariappa et al. 2021a).

Complex interactions between risk factors result in metabolic disorders, but these can be prevented by the right management decisions (Krieger et al. 2017), such as feeding dairy animals anionic salts—negative dietary cation–anion difference (DCAD) —before parturition (Blanc et al. 2014). Oral or intravenous calcium supplementation, instantly after calving, is another approach, but its benefits need investigation, because the evidence supporting it is not conclusive (Blanc et al. 2014). Several meta-analyses and systemic reviews of experiments conclude that feeding pre-partum dairy animals anionic feed—negative DCAD —reduces the incidence of milk fever and improves the concentration of calcium and their reproductive and productive performance (Oetzel 1991; Lean et al. 2006; Charbonneau, Pellerin, and Oetzel 2006; Santos et al. 2019; Lean et al. 2019). Only a very few studies beg to differ from these conclusions (Ramos-Nieves et al. 2009; Rajaeerad et al. 2020).

In 2016, the Indian Council of Agricultural Research–National Dairy Research Institute (ICAR-NDRI) developed and commercialized an anionic mineral mixture (AMM)—a powder that can be easily mixed with any feed or fodder and fed to dairy animals—to prevent milk fever (Kamdhenu 2020). Thakur et al. (2017) observe that the incidence of milk fever decreases from 10% among non-users of anionic diets to 2.5% among users, but the study does not quantify the improvement in yield. Except for this observational study, there is no evaluation of the effect of anionic diets on animal health or production parameters outside the controlled setting of the experimental farms of research institutes in India.

Our work is set in five villages of Haryana state, northern India, with 200 animals (100 cows and 100 buffaloes). We use a randomized controlled design to produce internally valid estimates of the effect of feeding farm dairy animals anionic diets to prevent milk fever. We include the economic effects on the incidence of milk fever, milk yield, cost of production, and farmer's net income.

This is the first study to combine an animal nutritional technology and randomized controlled trial to evaluate the economic effect of an animal nutritional technology in the field. In so doing, we complement the literature and contribute to it.

Study design

We begin by determining the sample size using statistical power calculations. No data is available on one primary outcome, the incidence of milk, and so we base our calculation of statistical power on the other primary outcome, milk yield per animal per day—as registered in the pre-analysis plan (Cariappa et al. 2021b). These calculations are designed to give an 80% power—chance to correctly detect the effect when there is an effect—at 5% level of significance.

We obtained the data on the mean of the milk yield in rural Haryana from the IndiaStat database (IndiaStat 2019). We took the standard deviation from a survey conducted in rural Haryana (Lal et al. 2020). We used these parameters and assumed an R^2 of 0.5 in the final impact regression (R^2 in the final regression was around 0.7). According to the power calculation, we required a minimum sample size of 172 animals to detect a statistically significant effect of 10% increase in milk yield between the treatment and control groups.

To account for the possibility of attrition, we selected for our sample 200 animals (100 cows and 100 buffaloes) from 200 different dairy farms: 100 animals (50 cows and 50 buffaloes) for the control group and 100 animals (50 cows and 50 buffaloes) for the treatment group. We sampled an additional 14 animals, in case of replacement.

Because the AMM is aimed at reducing milk fever in high-yielding dairy animals, we needed to work in areas where the milk yield is high and the population of high-yielding animals is large. The funding agency of the study has adopted five villages—Samora, Garhi Gujran, Churni, Kamalpur Roran, and Nagla Roran—

[1]Conversion rate (2020): US$ 1 = INR 74.10

in the Karnal district of Haryana state in India. Karnal is home to around 280,000 high-yield female bovines (110,000 exotic/crossbred cows and 180,000 buffaloes) (Government of Haryana 2020), and so these villages were ideal for our experiment.

We collected data from farmers who owned animals due for parturition in at least a month, not fed any type of anionic diet, and are at high risk of milk fever (animals in 2nd or above parity with peak milk yield of more than 10 kg per day; see the flowchart of the sampling plan in Appendix Figure 1).

We conducted a baseline survey during September 2020; between September and November, we supplemented the AMM intervention to the treatment group. The milk yield peaks 45–60 days post-parturition, and so we conducted our follow-up survey 2–3 months post-parturition, between the last week of January and the first week of February 2021.

Limitations

We purposively sampled high-yielding animals above 2nd parity at high risk of milk fever. The incidence of milk fever at the baseline may have been on the higher side, and we may have overestimated the impact of AMM. The results are true only for the population similar to our sample, not universal. Therefore, a scale-up of this pilot, or a large, cluster-level randomized design, is required to draw generalizable conclusions.

Intervention and design

The AMM is designed to reduce milk fever, and other post-partum problems, in cows and buffaloes. The technology contains Vitamin E, which is useful against oxidative stress in pregnant cows, as it makes them resistant to metabolic disorders and increases reproductive performance (Appendix Figure 2).

Dairy farmers are said to benefit economically because AMM supplementation improves the yield of milk by 10% and its fat content. The AMM also improves immunity and prevents various diseases (Kamdhenu 2020).

The AMM contains 7,640 mEq/L anionic value of sulphur; 5,080 mEq/L anionic value of chloride; 1,340 mEq/L cationic value of potassium, with a total negative DCAD of 11,380 mEq/L, and 10,000 IU/kg of Vitamin E. The recommended dosage of AMM is 50 gram each in the morning and evening three to four weeks before calving.

On the demand side, 77% of the farmers were aware of milk fever, but only around 3% (7 out of 214) knew of AMM; and only one farmer had used it earlier. Around 50% of the respondents reported taking precautionary measures against milk fever in their dairy animals post-partum, like feeding calcium solutions, jaggery, or both. But pre-partum preventive measures are not used, because AMM is not available in the villages, suburban centres nearby, or in the district headquarters (20–25 km from the village). This by default ensured that farmers cannot feed their animals an anionic diet; and that satisfies the inclusion criterion.

We separated the cows from the buffaloes. Then, we randomly assigned the animals to the treatment and control groups using the random number generator in Stata (World Bank 2018).

We gave all the farmers in the treatment group a brochure that explained the type of animal susceptible to milk fever, benefits and dosage of AMM. The brochure was in Hindi, the local language. We explained the benefits of AMM. We told the farmers how to use AMM, and the correct dosage, and the farmers supplemented the diet of all the animals in the treatment group with AMM.

Before we started the intervention, we took the control farmers into confidence and promised to give them the AMM later. This was essential, to avoid resentment against the institute. Also, because the farmers in the treatment and control groups are neighbours and the control farmers could attrite; the study is based on individual-level randomization.

We undertook the follow-up survey 60 days after the animals in the treatment group calved, and soon afterwards supplemented the control animals with AMM. We ensured that the farmers supplemented their animals with AMM properly and on time through regular field visits and telephone conversations.

Data and descriptive statistics

Dairy animals are supplemented with AMM to prevent milk fever and increase their yield.

Our primary outcomes—based on these goals, and as specified in the pre-plan—are the incidence of milk fever and milk yield.

We hypothesize that the AMM will prevent milk fever and reduce the expenditure on health enough—even above the cost of AMM—to increase revenue. Therefore, we test the impact of AMM on variable costs and net returns from dairying. These are our secondary outcomes.

Primary outcomes

Our primary outcomes are the incidence of milk fever (1/0) and average (fat-corrected) milk yield (kg per animal per day).

Incidence of milk fever

Usually, milk fever occurs within 72 hours of calving. The animals cannot stand up; they lie down, with their neck turned to one side and then laterally. In severe cases, the animal's temperature drops below normal, and it loses consciousness; if left untreated, it will succumb (NDDB 2019).

Farmers were asked if they had observed symptoms of milk fever in their animals and if they fell down after parturition at the baseline and follow-up. If the animals had clinical milk fever, we coded 1 for analytical purposes (and 0 otherwise). This is a self-reported measure; we contacted the local veterinarians who treated the animals to confirm the responses.

Milk yield (productivity)

At the baseline and follow-up, we recorded the peak milk yield, and converted it into the average daily milk yield by using the standard conversion factor.

$$\text{Average daily milk yield} = \text{peak yield} \times \frac{200}{\text{lactation length}}$$

Buffalo and cow milk differ in fat content. When analysing the whole sample, we use a 3.5% fat-corrected milk (FCM) yield; in other words, we standardize the cow and buffalo milk at 3.5% fat content when we combine both cows and buffaloes for analysis (Birthal et al. 2017).

The standardization to 3.5% fat content was done using the formula

FCM (3.5%) = (0.35 × quantity of milk in kg) + (18.57 × fat in kg) (Parekh 1986). The unit of measurement is kg per animal per day.

Secondary outcomes

Our secondary outcomes are variable costs and net returns from dairying.

Variable costs of milk production (INR per animal per lactation)

To calculate the total variable cost, we add the feed and fodder costs; veterinary costs, like expenses on artificial insemination, vaccination, and deworming; hired labour costs; and the cost of treating milk fever (veterinarian's fee and the cost of medicine).

Income/net return from dairying (INR per animal per lactation)

To calculate the net return, we subtract the variable cost from the value of milk produced (the product of price of milk (INR per kg) and total lactation milk production (kg)).

$$\begin{aligned}\text{Lactation milk production (in kg)} &= \text{average daily milk yield (in kg/day)}\\ &\times \text{lactation length (in days)}\end{aligned}$$

Sample characteristics

Dairying is the principal source of income for the sample farmers (67%). The farmers in the treatment and control groups own 6–7 acres of land and 5–6 dairy animals (Table 1).

The milk yield averages 8 kg per buffalo per day and 10–11 kg per cow per day. The incidence of milk fever at the baseline is around 15% in cows and 27% in buffaloes. All the animals in the sample are in their third parity on average.

The net income, or net returns to variable costs, is around INR 52,888 (US$ 714) per buffalo per annum, higher than the INR 42,881 (US$ 579) per cow per annum. The average variable cost is a little higher for crossbred cows than for buffaloes.

We had selected higher parity animals, with a peak milk yield of at least 10 kg per day; our inclusion criteria are reflected in the summary of baseline characteristics. We used as control variables herd size and the green fodder, dry fodder, and concentrates fed; on average, per day, dairy animals are fed 20–21 kg of green fodder, 12 kg of green fodder, and 4 kg of

Table 1 Baseline characteristics of sampling units and mean difference by treatment status

Variables	Buffalo (n=100)					Cow (n=100)					Overall (n=200)				
	Control (n=50)		Treated (n=50)		Mean Diff	Control (n=50)		Treated (n=50)		Mean Diff	Control (n=100)		Treated (n=100)		Mean Diff
	Mean	SD	Mean	SD	(C-T)	Mean	SD	Mean	SD	(C-T)	Mean	SD	Mean	SD	(C-T)
Panel A. Dependent variables															
Average milk yield (kg/animal/day)	7.80	1.94	7.86	2.82	–0.06	10.19	3.84	10.72	4.57	–0.53	8.99	2.45	9.29	4.25	–0.30
Incidence of MF (1/0)	0.18	0.37	0.12	0.26	0.06	0.28	0.44	0.26	0.35	0.02	0.23	0.32	0.19	0.40	0.04
Net income (000' ₹ /animal/lactation)	51.22	22.26	54.56	23.18	–3.34	40.85	33.72	44.91	39.23	–4.06	46.03	28.90	49.74	32.42	–3.70
Average variable cost (₹ /animal/ day)	195.32	40.79	188.20	45.22	7.12	178.54	45.65	190.20	56.29	–11.66	186.93	43.89	189.20	50.81	–2.27
Panel B. Household characteristics															
Experience in dairying (years)	13.22	9.55	14.20	10.96	–0.98	14.76	7.92	15.26	9.61	–0.50	13.99	10.26	14.73	8.79	–0.74
Education (1–7)+	4.36	1.42	4.22	1.89	0.14	4.10	1.74	4.06	1.58	0.04	4.23	1.59	4.14	1.74	0.09
Training in dairying (1/0)	0.26	0.44	0.24	0.43	0.02	0.32	0.47	0.38	0.49	–0.06	0.29	0.46	0.31	0.46	–0.02
Principal income from dairying (1/0)	0.66	0.48	0.52	0.50	0.14	0.68	0.47	0.82	0.38	–0.14	0.67	0.47	0.67	0.47	0.00
Land owned (acres)	6.39	6.61	6.41	5.63	–0.02	5.12	4.58	6.83	5.48	–1.71*	5.76	6.12	6.62	5.11	–0.86
Panel C. Animal characteristics															
Parity (nos.)	2.64	0.80	2.80	0.81	–0.16	2.80	1.03	2.80	0.90	0.00	2.72	0.81	2.80	0.97	–0.08
Peak milk yield in the previous lactation (kg/animal/ day)	11.89	2.95	11.98	4.30	–0.09	15.54	5.86	16.35	7.02	–0.81	13.72	3.74	14.17	6.51	–0.45
Herd size (nos.)	6.24	3.18	6.30	2.82	–0.06	4.60	2.95	5.10	2.56	–0.50	5.42	3.00	5.70	2.77	–0.28
Health score#	3.60	0.67	3.48	0.86	0.12	3.74	0.69	3.80	0.53	–0.06	3.67	0.77	3.64	0.62	0.03
Panel D. Feed and fodder fed															
Green fodder fed (kg/animal/ day)	21.65	6.58	20.49	6.30	1.16	20.27	6.17	17.68	4.59	2.59**	20.96	6.45	19.09	5.58	1.87**
Dry fodder fed (kg/animal/ day)	12.32	3.76	12.85	5.14	–0.53	10.71	4.11	12.03	4.90	–1.32	11.52	4.50	12.44	4.56	–0.93
Concentrate fed (kg/animal/ day)	3.90	1.52	3.47	1.36	0.42	3.56	1.64	3.59	1.54	–0.03	3.73	1.45	3.53	1.59	0.20
Milk price received (₹ /kg)	46.60	4.10	46.60	4.34	0.00	30.56	1.20	31.32	2.14	–0.76**	38.58	8.60	38.96	8.40	-0.38

Note ** and * indicates statistical significance at 5% and 10%, respectively.
+ 1 is illiterate, 2 is educated up to primary school (1–5), 3 middle school (6–8), 4 secondary school (9–10), 5 higher secondary (11–12), 6 diploma / certification, and 7 is graduate and above.
# Health score is an index computed by adding four dichotomous variables: artificial insemination (1/0), vaccination (1/0), deworming (1/0), and others (1/0).
Source Authors' calculations

concentrate. Cows in the control group are fed significantly more green fodder than those in the treatment group. Note that the baseline characteristics of treatment and control group are similar except for 2-3 variables.

Balance test

Although statistical similarities in the individual variables are achieved, sometimes the differences in characteristics between the treatment and control group might be in the same direction, indicating the inability of the random assignment to generate two statistically similar groups. A solution is to complement Table 1 with a test for joint orthogonality (Table 2) (McKenzie 2015).

The treatment status has a non–significant relationship with the control and dependent variables—except for the net income and variable costs incurred (at 10% level)— shows the linear probability estimates of the correlates of the treatment status (Table 2). The random assignment to two groups has succeeded in generating balance (p = 0.91), indicated the joint test of orthogonality (F-test).

Under pure randomization, we can expect balance in unmeasured or unobserved variables if balance is achieved in the observed variables (Bruhn and McKenzie 2009); any difference between the treatment and control groups could then be attributed to the intervention and causally interpreted.

Table 2 Balance test: linear probability estimates

Dependent variable: Treatment status (1/0)	(1) Buffalo	(2) Cow	(3) Overall
Incidence of MF (1/0)	–0.131	–0.008	–0.064
	(0.164)	(0.130)	(0.096)
Average daily milk yield (kg/animal)	0.008	–0.132	0.002
	(0.099)	(0.077)	(0.020)
Net income (000’ ₹ /animal/lactation)	0.000	0.000*	0.000
	(0.000)	(0.000)	(0.000)
Years of education of dairy farmer	0.008	–0.032	–0.021
	(0.048)	(0.040)	(0.029)
Years of experience in dairying	0.003	0.000	0.001
	(0.007)	(0.006)	(0.004)
Land holding (acres)	–0.001	0.019	0.008
	(0.010)	(0.013)	(0.008)
Herd size (nos.)	0.014	0.008	0.008
	(0.023)	(0.021)	(0.014)
Variable costs incurred (₹ /animal/day)	–0.001	0.004*	0.000
	(0.002)	(0.002)	(0.001)
Training in dairying (1/0)	0.006	0.089	0.061
	(0.143)	(0.149)	(0.095)
Health index of the animal	–0.043	0.060	0.021
	(0.082)	(0.093)	(0.062)
Extension (contact) index	0.009	–0.117	–0.057
	(0.070)	(0.071)	(0.049)
Constant term	0.604	0.458	0.427
	(0.503)	(0.394)	(0.301)
N	100	100	200
R^2	0.03	0.11	0.03
Joint test of orthogonality (F test)	0.26	1.34	0.49
p-value	0.99	0.22	0.91

Note * $p < 0.1$. Standard errors in parentheses.
Source Authors’ calculations

Estimation strategy

Following McKenzie (2012), we estimate an intent-to-treat (ITT) analysis using the randomized controlled design and the analysis of covariance (ANCOVA) specification. When evaluating the impact of interventions on outcomes that have less autocorrelations in the baseline and follow-up—such as household income, consumption expenditure, and profits—ANCOVA with lagged dependent variable achieves more power than difference-in-differences (DID) (McKenzie 2012). We estimate the multivariate model

$$Y_{it} = \beta_0 + \beta_1 \times Y_{it\text{-}1} + \beta_2 \times D_i + \varepsilon_i$$

where Y_{it} and Y_{it-1} is the outcome of interest (for instance farmer’s income) for animal *i* at the follow-up and baseline, respectively.

D indicates the treatment status of animal *i* (treatment=1 and control=0)

β_2 is the parameter of interest as it captures the impact of being in the treatment group.

We also use an extended model by simply adding baseline covariates (X_i) to the above equation as follows:

$$Y_{it} = \beta_0 + \beta_1 \times Y_{it\text{-}1} + \beta_2 \times D_i + \beta_3 \times X_i + \varepsilon_i$$

The baseline covariates (X_i) are added to increase the precision and to correct any baseline imbalances between treated and control animals.

Results and discussion

Impacts of AMM

Supplementing animal feeds with AMM reduced the incidence of milk fever, in absolute terms, in buffaloes from 15% at the baseline—the baseline value is the average of control animals and to-be-treated animals—to 2% at the follow-up (the follow-up value is from the treated animals) and, in cows, from 22% at the baseline to 2% at the follow-up (Figure 1). And the probability of milk fever incidence fell by 15 percentage points ($p < 0.01$) (Table 3, Panel A), implying that if AMM is supplemented, the incidence of milk fever will fall from 21% at the baseline to 6%.

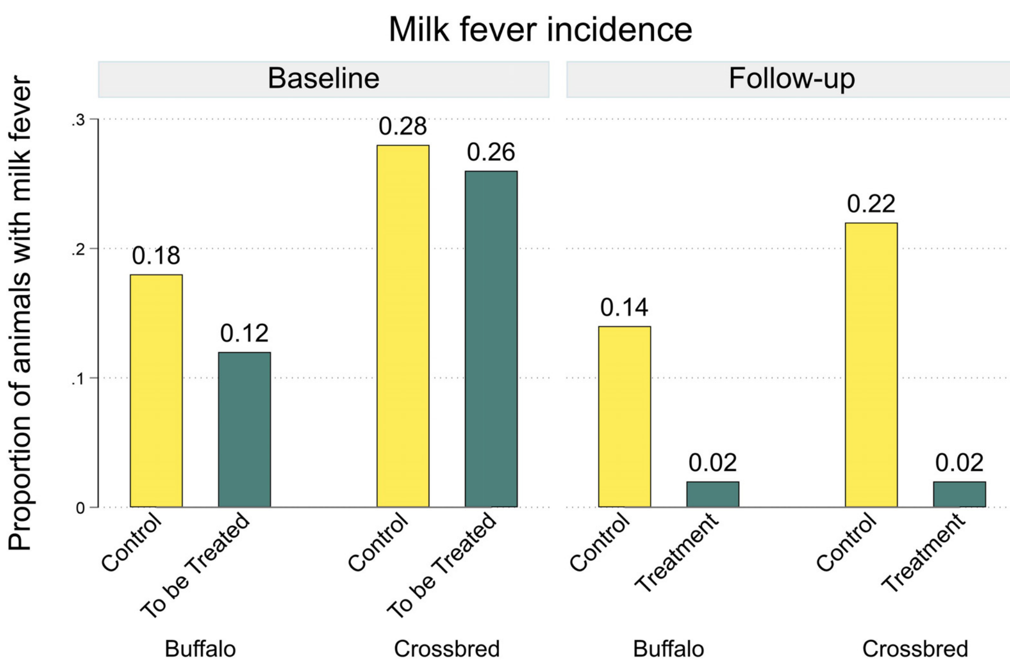
Supplementing animal feeds with AMM increases the FCM yield by 1.50 kg per animal per day ($p < 0.01$), a 14.3% increase over the baseline value, and it leads to a decline in the variable costs of milk production and an increase in farmer income. The variable costs fall by INR 1,626 (US$ 22) (2.83%, $p < 0.1$). Farmer income rises by INR 16,764 (US$ 226) (35%, $p < 0.01$).

Randomization is a process that generates two statistically identical groups by randomly assigning subjects to the treatment and comparison groups. A test of validity of randomization asks how the additions of control covariates affect the coefficient of interest (Ashraf, Berry, and Shapiro 2010). Adding covariates to the ANCOVA specification does not alter the impact estimates, we find, implying that our randomization is valid and successful in creating two identical groups. Our estimates are robust to alternative specifications, like DID, and to alternative functional forms, Appendix Tables 1 and 2.

The null hypothesis is that the distributions of the treated and control farmers are similar (Figures 2 and 3). The Kolmogorov–Smirnov test for the equality of milk yield and income distributions rejects the null hypothesis ($p < 0.01$), implying that all the farmers—not only some well-to-do farmers—contribute to the increase in the milk yield and net income, as the whole distribution of the treated group in the follow-up shifted to the right.

The incidence of milk fever decreased by 70% ($p < 0.01$) in treated cows and by 60% ($p > 0.1$) in treated buffaloes, as expected, because the incidence is higher in cows than in buffaloes (Table 3, Panel B).

The reduction in variable costs was not statistically significant, but it was higher for cows (INR 2,271, or ~ US$ 31) than for buffaloes (INR 937, or ~ US$ 13). Supplementing feeds with AMM increases the milk



Source Authors' calculations

Figure 1 Incidence of milk fever

Table 3 Impact of AMM supplementation

Model	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Dependent Variable	Probability of MF occurrence		Milk yield (kg/animal/d)		FCM yield (kg/animal/d)		Variable costs (₹ /animal/lactation)		Net returns (₹/animal/lactation)	
A. Overall sample										
AMM	–0.15***	–0.15***	1.24***	1.27***	1.51***	1.50***	–1623**	–1626*	16,775***	16,764***
	(0.04)	(0.04)	(0.25)	(0.22)	(0.25)	(0.25)	(683)	(681)	(2634)	(2616)
Baseline mean	0.21		9.14		10.47		57,360		47,891	
% change	–71.43		13.89		14.33		–2.83		35.00	
Controls	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes
N	200	200	200	200	200	200	200	200	200	200
R^2	0.25	0.26	0.78	0.82	0.69	0.70	0.91	0.91	0.71	0.73
F	15.11	6.10	284.8	95.40	205.1	59.64	661.1	780.6	247.6	40.31
B. Stratified sample										
Strata	Cow	Buffalo	Cow	Buffalo	Cow	Buffalo	Cow	Buffalo	Cow	Buffalo
AMM	–0.19***	–0.09	1.22*	1.21**	1.10*	1.77**	–2270.6	–937	14694**	18857**
	(0.052)	(0.047)	(0.36)	(0.20)	(0.32)	(0.30)	(1097.9)	(846.2)	(3966.8)	(3348.7)
Baseline mean	0.27	0.15	10.46	7.82	9.48	11.46	56233	58487	42881	52888
% change	–70.37	–60.00	11.66	15.47	11.60	15.44	–4.04	–1.60	34.27	35.65
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	100	100	100	100	100	100	100	100	100	100
R^2	0.39	0.17	0.82	0.47	0.82	0.47	0.92	0.92	0.83	0.59
F	7.18	2.60	72.8	11.7	72.8	11.7	419.1	346.1	37.8	13.7

Note Standard errors in parentheses. Romano-Wolf step-down adjusted p-values are used to correct for multiple hypothesis testing.

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Columns 1–2: Marginal effects are estimated at treated = 1 and period = 1 (i.e., treatment group at the follow-up), thus are average treatment effects on treated (ATT).

Controls used in stratified sample are milk yield and parity; in overall model, milk yield, parity, and type of animal (cow = 1 and buffalo = 0).

Columns 3–6: Control covariates in stratified sample: green fodder fed, dry fodder fed, and concentrates fed (all in kg per animal per day) and parity of animals; overall model included an additional variable, type of animal (1 for cow, 0 for buffalo).

Columns 7–10: Control covariates: parity and herd size (in numbers), green fodder fed, dry fodder fed, and concentrates fed (all in kg per animal per day in linear models and its log values in log transformed models), health score, training on dairying (1/0), experience, landholding, principal income from dairying (1/0) and extension score; and type of animal (1 for cow, 0 for buffalo) in the overall equation.

Source Authors' calculations

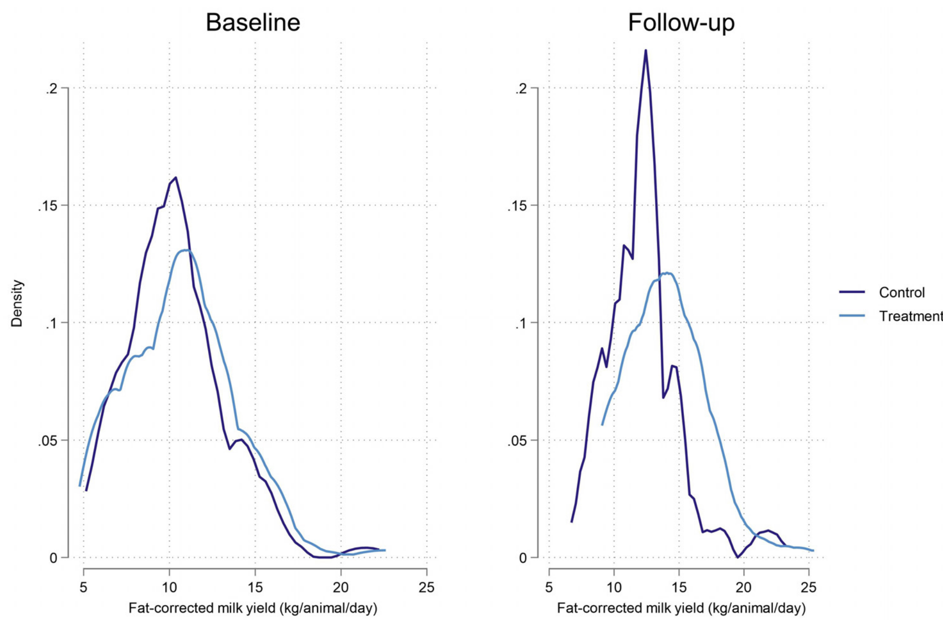
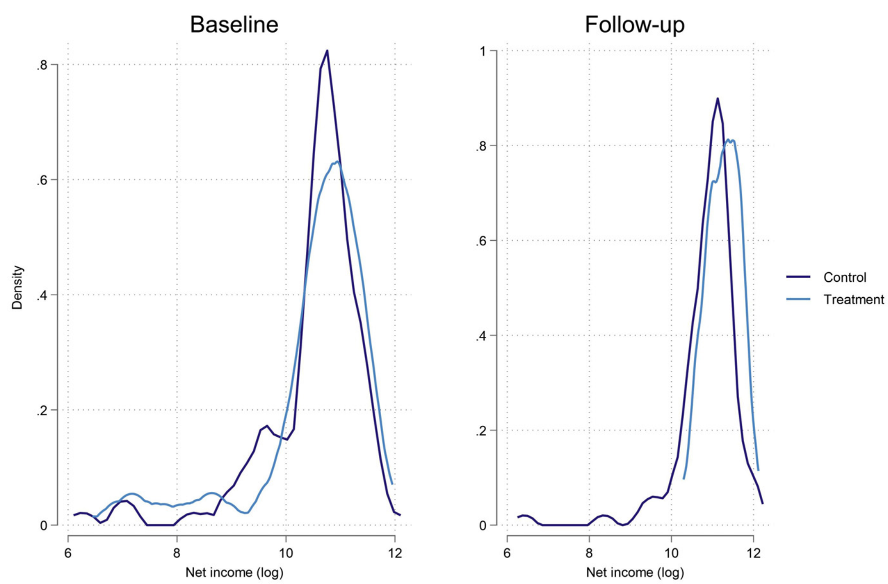


Figure 2 Distribution of 3.5% fat-corrected milk yield in control and treated groups by period



Source Authors' calculations

Figure 3 Distribution of farmer's net income from milk in control and treated groups by period

yield of cows by 12% ($p < 0.1$) and of buffaloes by 15% ($p < 0.05$); it also increases the returns to variable costs by 34% ($p < 0.05$) in cows and by 36% ($p < 0.05$) in buffaloes.

Our findings are in line with several experiments in foreign settings and in the results of meta-analyses (Lean et al. 2019; Santos et al. 2019; Melendez et al. 2019; Iwaniuk and Erdman 2015; Weich, Block, and Litherland 2013). Even the impact estimates from this study are comparable to the pooled impact estimates from meta-analysis; for instance, our estimate that milk yield increased by 1.5 kg per day, or 14%, is in line with the increase, 1.7 kg per day, reported by a meta-analysis (Lean et al. 2019).

We estimated the total economic loss (milk production loss + treatment cost + mortality loss) in the sample at INR 4,320 (USD 58.3) per animal. We simulated the total economic loss in Haryana to be around INR 873 crores (USD 137 million) (Cariappa et al. 2021a).

The finding that AMM supplementation reduces the incidence of milk fever is encouraging, and it has important implications for farmer welfare, because the population of exotic and crossbred cattle in India increased by 27% from 2012 to 2019 (PIB 2019), milk production increased around 47% (NDDB 2020), and the productivity of Indian dairy animals, too, has been increasing; therefore, the risk of milk fever is growing continually (Appendix Figure 3), and we recommend the use of AMM to prevent huge income loss due to milk fever.

Heterogeneous impact of anionic mineral mixture

The conventional wisdom is that older animals and animals at their peak of milk production are more susceptible to milk fever.

We had stratified our sample into a cow stratum and a buffalo stratum. We expect the impact to be homogeneous across the categories of animals and dairy farmers. Therefore, we test the impact on the parity of animals to check if it is homogeneous or differential.

We expect that compared to medium-size and large dairy farmers, small farmers would gain more from AMM supplementation because they were less likely to use preventive measures, like calcium solutions, against milk fever.

We expected that farmers who had undergone formal training in commercial dairying manage their herds better, and they have good breeds of animals with higher yields, and would therefore benefit from AMM supplementation more than would farmers who had not undergone formal training in commercial dairying.

Table 4 displays the coefficients of the interaction variable, treatment indicator (fed AMM or not) with covariates such as type of animal, parity, herd size, training in dairying, and the results of the F-test of equality of coefficients.

If the difference between the coefficients is statistically significant, we conclude that the impact is heterogeneous.

Table 3, Panel B displays the results of heterogeneous impacts of AMM on cows and buffaloes (see the subsection on the impact of AMM).

The F-test of equality coefficients of cows and buffaloes was not rejected ($p > 0.1$), implying that AMM is equally effective in reducing the incidence of milk fever in cows and buffaloes and in improving the welfare of dairy farmers.

Table 4, Panel B depicts the differential impact on animals of different parities. The results indicate that the effect of AMM on milk fever incidence is highest in the 5th parity (a 100% probability of reduction), and it is significantly different from the effects on the 2nd, 3rd, and 4th parity animals at $p < 0.01$ (Column 1). The increase in milk yield was highest in the 5th parity, and it was statistically higher ($p < 0.1$) than among animals in the 3rd parity. However, the effect of AMM on net returns was equal ($p > 0.1$) for animals of all parities (Column 6).

Table 4, Panel C presents the impact of AMM on small, medium-size, and large dairy farmers by herd size. Small dairy farmers experienced substantially higher positive effects in all the outcomes measured except for variable costs. Medium-size farmers experienced a higher milk yield and income gain than did large farmers ($p < 0.05$). Compared to farmers with no formal training, farmers formally trained in dairy farming had higher gains except for variable costs (Panel D).

Therefore, needy vulnerable farmers—farmers who own small herds (<6 animals) and older animals—who attend formal training programmes experience greater benefits than others from supplementing animal feeds with AMM. This finding has important implications for policy.

Conclusions

We use a randomized controlled design to evaluate the impact of AMM, a preventive health product, on milk fever in 200 dairy animals.

Supplementing animal feed with AMM prevents milk fever and improves animal health and productivity—the incidence of milk fever falls by 71%, and milk yield

Table 4 Heterogeneous impact of AMM

Model → Dependent variable	(1) Probability of MF occurrence	(2) Milk yield (kg/animal/d)	(3) FCM yield (kg/animal/d)	(5) Variable cost (₹/animal/lactation)	(6) Net returns (₹/animal/lactation)
A. Type of animal					
Cow	-0.19***	1.37***	1.28***	-2514.1**	15907.9***
	(0.052)	(0.38)	(0.36)	(1015.5)	(3613.7)
Buffalo	-0.10*	1.18***	1.73***	-742.4	17571.2***
	(0.05)	(0.247)	(0.34)	(829.38)	(3794.25)
F test of equality of coefficients					
Cow=Buffalo	1.57	0.18	0.82	1.95	0.10
B. Parity					
2nd parity	-0.11*	1.46***	1.67***	-680.9	17001.6***
	(0.057)	(0.39)	(0.35)	(503.7)	(3546.2)
3rd parity	-0.11**	0.95**	1.14***	-1468.3	13166.7***
	(0.050)	(0.39)	(0.38)	(1058.2)	(4116.1)
4th parity	-0.24**	0.60	1.40*	-5015.8*	19173.3**
	(0.11)	(0.71)	(0.81)	(2577.5)	(9257.0)
5th parity	-1.00***	3.41**	3.16***	8377.3	23560.5***
	(0.17)	(1.66)	(1.08)	(7503.5)	(8377.7)
F test of equality of coefficients					
T_2 = T_3	0.01	0.87	1.02	0.42	0.50
T_2 = T_4	1.16	1.13	0.09	2.66	0.05
T_2 = T_5	24.55***	1.30	1.73	1.45	0.52
T_3 = T_4	1.05	0.20	0.09	1.74	0.36
T_3 = T_5	24.66***	2.09	3.12*	1.71	1.23
T_4 = T_5	13.54***	2.43	1.71	2.90*	0.12
C. Herd size (number of animals)					
Small (<6)	-0.15***	1.48***	1.69***	-2234.9**	19142.0***
	(0.045)	(0.36)	(0.34)	(1089.1)	(3552.5)
Medium (6-10)	0.00	-0.53	-0.36	1092.7	-4891.2
	(0.06)	(0.45)	(0.45)	(1221.8)	(4806.3)
Large (>10)	-0.05	1.10**	0.96*	1498.1*	10619.1*
	(0.07)	(0.55)	(0.56)	(772.0)	(5665.5)
F test of equality of coefficients					
Small=Medium	2.85*	7.16***	7.99***	2.26	10.02***
Small=Large	1.31	0.31	1.14	5.69**	1.56
Medium=Large	0.94	7.05***	4.34**	0.15	5.95**
D. Training in dairying					
Training	-0.34***	2.01***	2.16***	-2100.8	24070.6***
	(0.090)	(0.50)	(0.47)	(1361.0)	(4866.7)
No training	-0.068**	0.91***	1.22***	-1440.4*	13669.4***
	(0.032)	(0.29)	(0.29)	(789.7)	(3094.7)
F test of equality of coefficients					
Training=No training	7.90***	3.73**	2.95*	0.17	3.30*

Note: Columns display OLS regressions for six outcome variables as dependent variables. Variable in each row is interacted with the treatment variable. Each cell displays the coefficient of the interaction term of control covariate (row) and the treatment indicator.

Standard errors in parentheses

* $p< 0.10$, ** $p< 0.05$, *** $p< 0.01$

rises by 14%—and reduces variable costs by 3% and improves farmer profit by 35%.

The total economic loss due to milk fever is INR 4,320 per animal (Cariappa et al. 2021a). If farmers supplement animal feed with AMM, milk yield increases by 1.5 kg per day and farmer income by INR 16,000 (USD 216) per animal per annum. Even if the market price of AMM (a maximum of INR 900 (USD 12) per animal) is subtracted, the net gain is INR 15,000 (USD 202).

The effect of AMM supplementation varies by farmer type: it is higher on small farmers (herd size < 6 animals), older animals, and who had attended formal training in dairying.

Preventing milk fever reduces economic loss and increases productivity and profit; therefore, the prevention of milk fever (+ INR 15,000, or ~ US$ 202) is better than the cure (INR 4,320, or ~US$ 58).

Farmer adoption of technology is constrained by demand-side, supply-side, and mediating factors: insufficient managerial skills; behavioural traits, such as procrastination; credit constraints; high transaction costs; non-existence of technology; lack of understanding; and unavailability (De Janvry et al. 2016).

If animal feeds are supplemented with AMM, the potential of improving farmer welfare is huge, but more farmers must adopt AMM supplementation, and there is potential for rapid adoption.

First, the demand-side constraint for technology adoption will relax in the future as the risk of milk fever rises. Farmers will adopt AMM supplementation because it reduces the incidence of milk fever and the production cost by INR 1,600 per animal, much more than the market price of AMM (maximum INR 900 per animal). Supplementing animal feeds with AMM saves on cost, and farmers rapidly adopt technologies that improve productivity and income (Ogutu et al. 2018).

Second, preventing milk fever can save the state of Haryana INR 873 crore (USD 1.5 billion) (Cariappa et al. 2021a). The government and public sector could subsidize AMM and distribute it, as the fertilizer policy does, and remove the supply-side constraints by using modern extension tools to explain to farmers that AMM is easy to use. The private sector, too, can use the evidence that AMM is a cost-saving, productivity-enhancing technology to market it.

Finally, the income gain from AMM use can overpower the influence of mediating factors.

Further research building on this successful pilot is required to corroborate the results in different settings to draw generalizable conclusions. Therefore, promoting the use of prevention strategies and training of dairy farmers is recommended by the study.

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Ethics approval

The experiment involving dairy animals were conducted under the guidelines of ICAR-NDRI Animal Ethical Committee. The research proposal was discussed and approved in the Inter Disciplinary Seminar of the Institute (a seminar of the Institutional Review Board chaired by the Joint Director (Research)). Also, farmer's consent was taken prior to the interview after explaining the length of the study and especially, the need to contact repeatedly.

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Appendix

Table 1 Robustness to alternative specification

Strata	Cow		Buffalo		Overall	
Panel A Dependent variable: milk yield						
Estimator	Difference-in-Differences (DID)					
Dependent variable in#	kg/animal/ day	Natural logarithm	kg/animal/ day	Natural logarithm	kg/animal/ day	Natural logarithm
Treatment	1.319	0.106	1.173***	0.123***	1.457**	0.115**
	(1.100)	(0.086)	(0.364)	(0.044)	(0.563)	(0.048)
Mean of milk yield in baseline	10.456	2.292	7.823	2.039	10.472	2.307
Controls?	Yes	Yes	Yes	Yes	Yes	Yes
R^2	0.19	0.22	0.40	0.38	0.30	0.33
Panel B Dependent variable: net returns from dairying						
Estimator	Difference-in-differences (DID)					
Dependent variable in	₹/animal/ lactation	Natural Logarithm	₹/animal/ lactation	Natural logarithm	₹/animal/ lactation	Natural logarithm
Treatment	14666	0.523**	17727***	0.245**	16196***	0.380**
	(9192)	(0.262)	(5732)	(0.119)	(5657)	(0.149)
Mean of income in baseline	42881	10.219	52888	10.758	47885	10.496
Controls?	Yes	Yes	Yes	Yes	Yes	Yes
R-squared	0.42	0.37	0.48	0.43	0.37	0.33
Number of observations	200	200	200	200	400	400

Note Panel A: # Dependent variable in overall sample is 3.5% fat corrected milk (FCM). FCM = (0.35 x milk in kg) + (18.57 x fat in kg)

Control covariates: green fodder fed, dry fodder fed and concentrates fed (all in kg/animal/day) and parity of animals; and of FCM included an additional variable, type of animal (1 – cow, 0 – buffalo)

Panel B: Net income = gross income – variable cost. Variable costs included are a sum total of expenses on green fodder, dry fodder, concentrates, hired labor including veterinary costs (artificial insemination, vaccination and deworming) and MF treatment costs

Control covariates: parity and herd size (in nos.), green fodder fed, dry fodder fed and concentrates fed (all in kg/animal/day in linear models and its log values in log transformed models), health score, training on dairying (1/0), experience, land holding, principal income from dairying (1/0) and extension score; and type of animal (1 – cow, 0 – buffalo) in overall equation

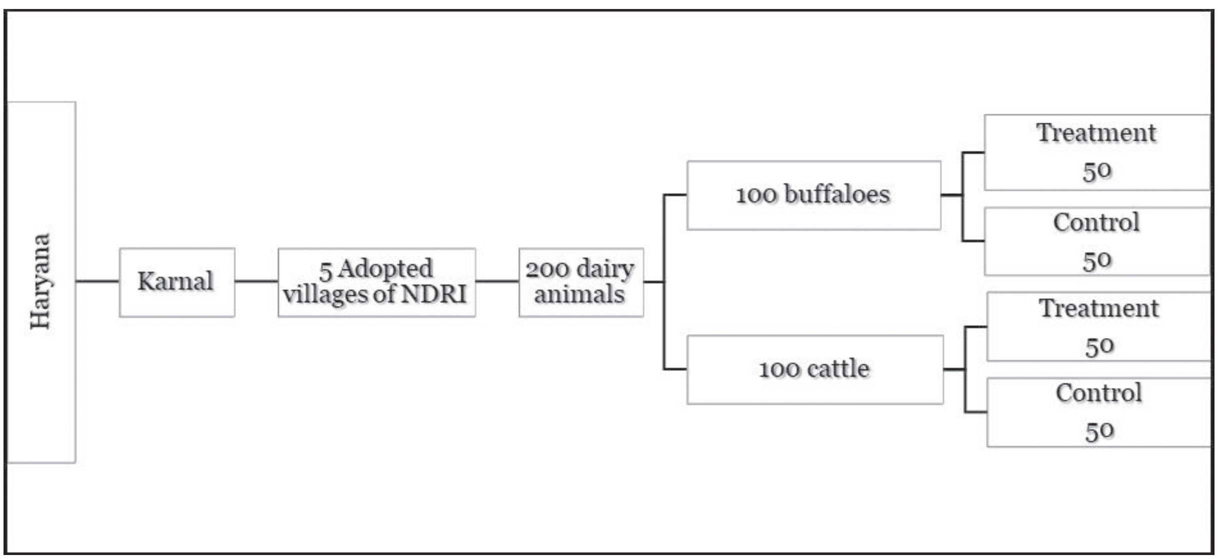
Figures in parenthesis are standard errors

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

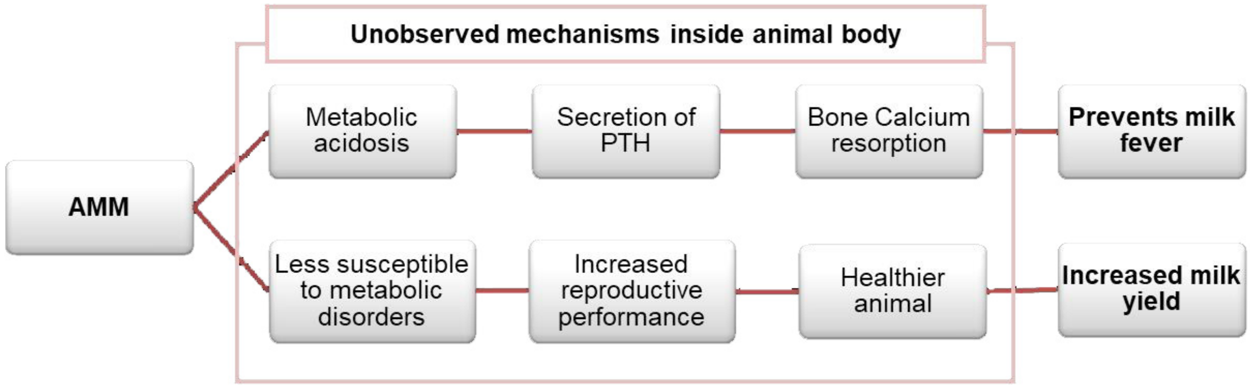
Table 2 Robustness to alternative functional forms

Dependent variable: FCM	(1)	(2)	(3)	(4)
Estimator	ANCOVA (Lagged dependent variable)			
Specification	Lin-lin	Log-lin	Lin-log	Log-log
Treated (1/0)	1.50***	0.11***	1.68***	0.13***
	(0.25)	(0.02)	(0.25)	(0.02)
Controls	Yes	Yes	Yes	Yes
N	200	200	200	200
R^2	0.699	0.702	0.673	0.698
adj. R^2	0.688	0.691	0.661	0.688
AIC	798.290	-241.540	814.580	-239.039
BIC	824.676	-215.153	840.967	-212.653
F	59.64	66.64	51.19	64.25

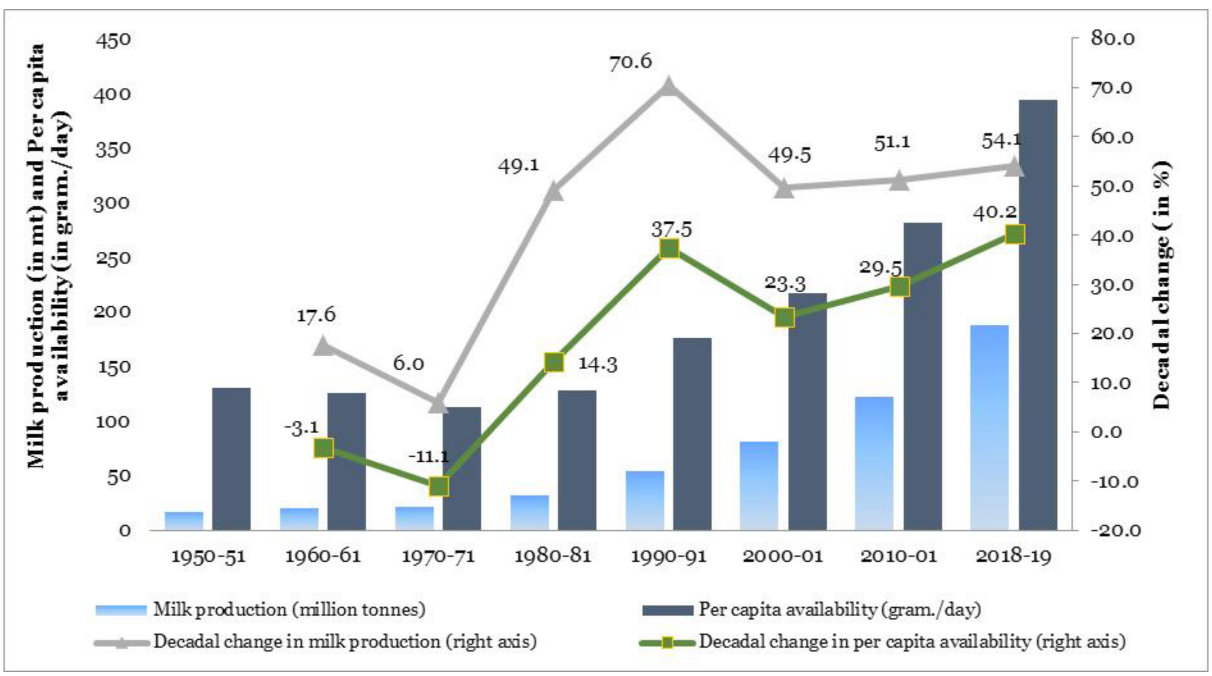
Note: Figures in parenthesis are standard errors
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.



Appendix Figure 1 Sampling plan of the study



Appendix Figure 2 Causal pathway of AMM



Appendix Figure 3 Milk production in India (1950-2018)

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The impact of downy mildew on high-value cucurbit crops in the US: an econometric analysis

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Abstract This paper describes the impact of cucurbit downy mildew (CDM) on high-value crops in the United States. The estimated logit model indicates that farmers who use plastic mulch, consider curcubits their primary crop, and utilize agricultural extension services are likely to minimize yield losses due to CDM, and farmers over 65 who use raised beds and overhead irrigation are more likely to incur higher losses. Our findings are helpful in understanding the outbreak of CDM and the on-farm strategies farmers use to mitigate the disease.

Keywords Cucurbit downy mildew (CDM), outbreak, high-value crops, farmer survey, logit model framework

JEL codes Q1, Q10, Q12

The cucurbit downy pathogen infects diverse cucurbit genera (Lebeda and Urban 2007; Palti and Cohen 1980; Savory et al. 2011). The pathogen is disseminated via windblown sporangia, and it may be transported up to 600 miles. An outbreak of the cucurbit downy mildew (CDM) disease, induced by *Pseudoperonospora cubensis*, may spread rapidly in a short period under favourable environmental conditions and present a threat to cucurbit crops and growers over a vast geographical region (Keinath 2015). Over 70 nations have reported CDM; it causes substantial yield reductions in the US, Europe, China, and Israel (Thomas 1996).

In 2004, the resurgence of CDM in the eastern US devasted production in North Carolina, Virginia, Delaware, Maryland, New Jersey, and other states, and it reduced yield by 40%. In the case of cucumber, genetic resistance was not adequate in mitigating the re-emerged pathogen (Lebeda and Widrlechner 2003); and losses that year were assessed at USD 20 million (INR 150 crore) (Holmes et al. 2006).

Since 2005, outbreaks of CDM have been reported every year in the state of Michigan, the largest supplier of pickling cucumber in the US, and the annual cost of additional fungicide applications has been estimated to exceed USD 6 million (INR 45 crore). The disease has negatively impacted cucumber production in Michigan and other regions and threatened its long-term viability (Savory et al. 2011).

Currently, fungicides are used intensively to control outbreaks of CDM in the US, but season-long fungicide programmes are expensive, and pathogens are likely to develop resistance to systemic fungicides that were once highly effective (Savory et al. 2011). In 2004, growers observed the *P. cubensis* population to be resistant to the commonly used fungicides, mefenoxam and azoxystrobin (Holmes et al. 2015). Since then, new fungicides have been registered and used for CDM control; yet, the pathogen has developed resistance to all but a few (Call et al. 2013). Growers can use disease forecasting systems (CDM ipmPIPE) (Holmes et al. 2015) and early warning monitoring systems (Bello et al. 2021) to time the application of preventative fungicides, especially in northern growing regions where the pathogen does not overwinter.

Host resistance is considered optimal to limit disease. But the CDM pathogen that re-emerged in 2004 overcame the genetic resistance once inherent in commercial cucumber cultivars. The use of fungicide has been observed to be less effective in reducing disease than genetic resistance (Call et al. 2013), which has successfully been bred into other high-value crops such as sweet basil (*Ocimum basilicum*), susceptible to a different downy mildew pathogen (*Peronospora belbahrii*) (Pyne et al. 2017; Pyne et al. 2018). Breeding efforts to develop similarly disease-resistant pickling cucumber have met mixed success; while these commercially available cultivars are more resistant than the CDM-susceptible cultivars, fungicides are still required for optimum yield (Pyne et al. 2017; Pyne et al. 2018).

Integrated research approaches and integrated pest management (IPM) strategies should consider the perceptions and preferences of farmers and the socio-economic constraints of CDM control options. As such, we conducted a survey to assess the strategies farmers used to overcome or mitigate the impact of downy mildew on high-value cucurbit crops.

Methodology

A survey of cucurbit growers was conducted—in the states of Iowa, Michigan, New York, and Ohio, in the US—to gather information on the field production of high-value cucurbit crops: pickling cucumber, slicing cucumber, squash, pumpkin, cantaloupe, and watermelon. The primary objective of the survey, conducted in 2017, was to document the extent of damage caused by CDM in cucurbits and the control measures used by producers to mitigate the damage. The survey assessed the baseline information on crop production, participation in agricultural extension activities, and farmer demographics.

The person in charge of farming activity was identified and interviewed after they consented. The consent form developed by the researchers was approved, along with the questionnaire, by the Offices of Research Protections at Michigan State University and Rutgers, The State University of New Jersey.

Data limitation

Some participants did not keep records, and it is possible that the data collected may not be accurate in certain cases; in such cases we asked the cucurbit growers probing questions to get answers that were as accurate as possible. Asking for details such as land size in acreage and then in square metre also contributed to the difficulty in acquiring accurate data. Some farmers were reluctant to share information on income and income sources, and they did not offer the exact information. Some questions were repetitive—the same information twice, for two different periods—and hence caused problems in obtaining quality data.

Logit model framework

We developed the logit model framework to estimate the factors that influence an outbreak of CDM. In addition to considering farmers' choices, production practices, and socio-economic constraints, the proposed logit model uses a random utility method (Arumugam et al. 2020; Arumugam et al. 2019; Govindasamy et al. 2018; Govindasamy et al. 2018). We used the maximum likelihood estimation (MLE) procedure as it delivers reliable parameter estimates that are asymptotically effective (Gujarati 1992; Pindyck and Rubinfeld 1991).

We explored the relationship between the level of outbreak—either low (less than 20%) or high (more than 20%)—and farmers' characteristics, choices, production practices, and socio-economic constraints by modelling the sign variable Z_i for the i^{th} farmer as a function of their choices and other independent variables:

$$Z_i = \boldsymbol{\beta}\mathbf{X}_i = \beta_0 + \beta_1 x_{i1} + \beta_2 x_{i2} + \ldots + \beta_k x_{ik} + \nu_i, \quad i = 1, 2, \ldots, n \tag{1}$$

where x_{ij} represents the j^{th} characteristics, choices, production practices, and socio-economic constraints of the i^{th} farmer;

$\boldsymbol{\beta} = (\beta_0, \beta_1, ¼, \beta_k)$ is the parameter to be estimated; and

n_i is the random error or disturbance term associated with the i^{th} farmer.

Under the logistic distributional assumption for the random term, the probability P_i is expressed as:

$$P_i = F(Z_i) = F(\beta_0 + \sum_{j=1}^{k} \beta_j x_{ij}) = F(\boldsymbol{\beta}\mathbf{X}_i) = \frac{1}{1 + \exp(-\boldsymbol{\beta}\mathbf{X}_i)} \tag{2}$$

The β-coefficients of Equation 2 do not directly denote the marginal effects of the explanatory variable on the probability of Pi. In the case of a continuous explanatory variable, the marginal effect of xj on the probability Pi is given by

$$\partial P_i / \partial x_{ij} = \left[\beta_j \exp(-\boldsymbol{\beta}\mathbf{X}_i)\right] / \left[1 + \exp(-\boldsymbol{\beta}\mathbf{X}_i)\right]^2 \tag{3}$$

However, if the explanatory variable is qualitative or discrete, $\partial P_i / \partial x_{ij}$ does not exist; the marginal effect is attained by assessing Pi at the alternative values of xij. For example, in the case of a binary explanatory variable, where x_{ij} takes the value of 1 or 0, the marginal effect is denoted as

$$\partial P_i / \partial x_{ij} = P(x_{ij} = 1) - P(x_{ij} = 0) \tag{4}$$

To capture the relationship between the level of CDM and crop production practices, producer characteristics, and socio-economic constraints, we specified the empirical model

CDM reduces yield by more than 20% =

β_0 + β_1 male + β_2 education ug + β_3 business experience + β_4 primary income + β_5 age over 65 + β_6 above 1000 acre + β_7 raised beds + β_8 direct seeded + β_9 plastic mulch + β_{10} over head irrigation + β_{11} primary crop + β_{12} disease problem + β_{13} dm more infestation + β_{14} cdm resident varieties + β_{15} crop insurance + β_{16} agrl. extension service —— —— $!_i$ (5)

The framework of the logit model and the computed results are based on STATA; the logit model response and variables are presented in Table 1.

Among the explanatory variables, business experience is a discrete variable; the others are dualistic binary (dummy) variables. The discrete variables are described in average units; the dummy variables are expressed as a percentage. Nearly 39% of the farmers reported that CDM damaged their crop severely, or they lost more than 20% of their yield; the remaining 61% reported that the damage was minimal, or they lost less than 20% of their yield.

Results and discussion

Demographics

In total, there were 98 respondents from four states: Iowa, Michigan, New York, and Ohio; 92 from Michigan (93.88%), 3 from New York (3.06%), 2 from Ohio (2.04%), and 1 from Iowa (1.02%) (Table 2).

Land ownership and use

We used the information given by the respondents to determine the sizes of land parcels and group these by acreage (Table 2). Of the 98 respondents, 32 (32.65%) owned more than 1,001 acres and 22 (22.45%) less than 50 acres; and 11 each (11.22%) owned farms of 50–100 acres and 501–1,000 acres. Ten respondents (10.22%) owned between 251–500 acres and 7 between 105–250 acres; 5 of the 98 respondents (5.10%) did not respond to this question.

Primary income from farming

Farming was the primary source of income of 55 respondents (61.10%); 35 respondents, or 38.89% of the total, indicated that farming was not their primary source of income. Eight participants did not answer this question. Farming experience averaged 27.73 years.

Crop production per season

Only 40 of 98 respondents answered the question on crop production: 13 respondents (32.5%) stated that they cultivated 3–5 crops per season, 9 respondents (22.5%) cultivated 1–2 crops, 8 respondents (20%) cultivated 6–10 crops, and 7 respondents (17.50%) cultivated 11–19 crops. Only 3 respondents (7.5%)

Table 1 Variables used to predict the impact of downy mildew on cucurbit crops

	Variable	Description	Mean / %
		Dependent variables	
	More than 20%	1 if the yield loss due to CDM is more than 20% of cucurbits, 0 otherwise	39%
		Independent variables	
1.	Male	1 if the farmer is male, 0 otherwise	89%
2.	Education UG	1 if the farmer studied up to the undergraduate level, 0 otherwise	25%
3.	Business experience	Number of years of farming experience	29.16
4.	Primary income	1 if the farmer receives their primary income through farming, 0 otherwise	65%
5.	Age over 65	1 if the farmer's age is over 65 years, 0 otherwise	12%
6.	Above 1,000 acres	1 if the farmer holds more than 1000 acres, 0 otherwise	37%
7.	Raised beds	1 if the farmer uses raised plant beds to grow cucurbits, 0 otherwise	26%
8.	Direct seeded method	1 if the farmer follows the direct-seeded method to grow cucurbits, 0 otherwise	61%
9.	Plastic mulch	1 if the farmer uses plastic mulch to grow cucurbits, 0 otherwise	16%
10.	Overhead irrigation	1 if the farmer uses overhead irrigation to grow cucurbits, 0 otherwise	40%
11.	Primary crop	1 if the farmer considers cucurbits as the primary crop, 0 otherwise	68%
12.	Disease problem	1 if the farmer considers disease in general as a major issue among the other obstacles, 0 otherwise	19%
13.	CDM outbreak	1 if the farmer is experiencing more CDM now compared to 5 years ago, 0 otherwise	33%
14.	CDM-resistant cultivars	1 if the farmer uses CDM-resistant cultivars, 0 otherwise	53%
15.	Crop insurance	1 if the farmer accesses a crop insurance service, 0 otherwise	70%
16.	Extension education	1 if the farmer received disease management and CDM mitigation training through the agricultural extension service, 0 otherwise	47%

Source Survey data, 2017

produced 20–30 crops per season. On average, 6.99 crops were produced per season.

The impact of cucurbit downy mildew (CDM)

To control CDM, growers use resistant cultivars and implement fungicide programmes; together, these form an effective IPM approach (Table 3). The primary crops include the most commonly grown and bestselling crops: pickling cucumber, squash, and pumpkins.

Thirty-seven respondents stated that they frequently grew pickling cucumber; 32 (86.49%) reported it as their primary crop. Squash was cultivated by 37 respondents, and 18 (48.65%) reported it to be their primary crop; whereas 34 respondents (91.89%) grew pumpkins and 21 (56.75%) reported it as the primary crop.

Similarly, slicing cucumber had 19 respondents, and 9 (47.37%) considered it to be their primary crop; and cantaloupe had 11 respondents, and 4 (36.36%) considered it to be their primary crop. Among the least-mentioned primary crops, watermelon had 10 respondents, of which 2 (20%) considered it to be their primary crop.

All these crops were affected by CDM, according to the respondents. Pickling cucumber was the worst affected; 35 respondents (94.59% of those who grew the crop) reported an outbreak. This was followed by cantaloupe with 7 responses (63.64%), sliced cucumber with 11 responses (57.89%), pumpkin with 19 responses (55.88%), squash with 17 responses (45.95%), and watermelon with 4 responses (40%).

Table 2 Farm business details of growers who completed the survey

	Particulars	Frequency	Percent (%)
1.	Michigan	92	93.88%
2.	New York	3	3.06%
3.	Ohio	2	2.04%
4.	Iowa	1	1.02%
	Total	98	100.00%
I.	Land ownership and use		
1.	Less than 50	22	22.45%
2.	50–100	11	11.22%
3.	105–250	7	7.14%
4.	251–500	10	10.22%
5.	501–1000	11	11.22%
6.	Above 1001	32	32.65%
7.	Not reported	5	5.10%
	Total	98	100.00%
	Primary income from farming		
1	Yes	55	61.11%
2	No	35	38.89%
	Total	90	100.00%
	Number of crops / seasons		
1.	1–2	9	22.50%
2.	3–5	13	32.50%
3.	6–10	8	20.00%
4.	11–19	7	17.50%
5.	20–30	3	7.50%
	Total	40	100.00%
	Particulars	Average	
1.	Average years of farming	27.73	-
2.	Average number of crops produced	6.99	-

Source Survey data, 2017

A fungicide programme was the most common method used to overcome CDM. All the 37 respondents who cultivated pickling cucumber reported using a fungicide programme while 18 respondents (48.65%) reported using CDM-resistant varieties.

Of the farmers who cultivated slicing cucumber, 15 (78.95%) reported using a fungicide programme, and 11 (57.89%) used resistant cultivars. Of those who grew watermelon, 7 (70%) used a fungicide programme and 4 (40%) used resistant cultivars.

Among squash cultivators, 24 (64.86%) used a fungicide programme and 16 (43.24%) used resistant cultivars. Among the respondents who grew cantaloupe, 9 (81.82%) used a fungicide programme and 6 (54.55%) used resistant cultivars.

Lastly, among pumpkin cultivators, 24 (70.59%) used a fungicide programme and 16 (47.06%) used resistant cultivars.

It is important to note that except for cucumbers, no varieties of cucurbits are resistant to CDM. This stresses the importance of grower education and training to control CDM.

Empirical results for logit model estimates

The logit model analyses the characteristics of farmers who lost more than 20% of their yield to CDM. In the total sample, the precise likelihood outcome of the response variable is 85.96% (Table 4). The χ^2 statistics rejected the null hypothesis, McFadden

Table 3 Crop preference, CDM outbreaks, and the mitigation strategies of farmers

	Crop		Primary crop	CDM outbreaks	CDM mitigation strategies*: Resistant varieties	CDM mitigation strategies*: Fungicide programme	Total respondents
1.	Pickling cucumber	Frequency	32	35	18	37	37
		%	86.49	94.59	48.65	100.00	100.00
2.	Squash	Frequency	18	17	16	24	37
		%	48.65	45.95	43.24	64.86	100.00
2.	Pumpkin	Frequency	21	19	16	24	34
		%	67.76	55.88	47.06	70.59	100.00
3.	Slicing cucumber	Frequency	9	11	11	15	19
		%	47.37	57.89	57.89	78.95	100.00
4.	Cantaloupe	Frequency	4	7	6	9	11
		%	36.36	63.64	54.55	81.81	100.00
5.	Watermelon	Frequency	2	4	4	7	10
		%	20.00	40.00	40.00	70.00	100.00

Source Survey data, 2017

Table 4 Logit model predictive accuracy

Classified	True		Total
	D	~D	
+	26 (45.61%)	5 (8.77%)	31 (54.39%)
–	3 (11.54%)	23 (88.46%)	26 (45.61%)
Total	29 (50.88%)	28 (49.12%)	57 (100.00%)

No. of observations = 57 successful predication rates: 85.96%; pseudo R^2: 0.5387; Prob > chi^2 = 0.0003

pseudo-R-squared is 0.5387, and the overall model significance is 0.0003.

The estimated logit model result indicates that farmers who use plastic mulch, cultivate cucurbits as their primary crop, and access agricultural extension services are less likely than others to lose more than 20% of their yield (Table 5). However, farmers older than 65 years and who use raised beds and overhead irrigation systems are more likely than others to incur a high yield loss.

Our results show that those who use plastic mulch are less likely to incur a high yield loss due to CDM outbreaks compared to those who use other mulches. Polyethylene / plastic mulches are commonly used for weed control (Grundy and Bond 2007; Ristaino and Thomas 1997), solar soil disinfection (Katan and DeVay 1991), and to safeguard crops from diseases spread by insect pests (Antignus 2007).

Also, compared to those who grew cucurbits as a secondary crop, those who consider cucurbits their primary crop are less likely to incur high yield losses due to a CDM outbreak. Those who grow cucurbits as a primary crop are often more knowledgeable about CDM mitigation measures and, as a result, can control the disease better compared to those who cultivate cucurbits as a secondary crop.

Further, the farmers who avail of agricultural extension services are less likely to incur a high yield loss due to CDM compared to those who do not utilize extension services as they are more likely to have access to disease management training. Also, one of the most significant obstacles to crop production according to the participants was identifying disease development. This survey shows that the use of agricultural extension services is enhancing the farmers' knowledge and skills in controlling CDM.

Likewise, those who use overhead irrigation are more like to incur a high yield loss due to CDM compared to those who use other forms of irrigation (such as drip irrigation). The use of overhead irrigation promotes

Table 5 Logit model estimates of cucurbit downy mildew

	Particulars	Variables	Co-efficient	Std. Err.	Marginal effect
1.	Socio-economics characteristics	Male	2.6715	2.4118	-
		Education UG	1.0718	1.4238	-
		Business experience	–0.0498	0.0347	-
		Primary income	0.1337	1.6977	-
		Aged over 65	4.6298**	2.1623	0.7086
2.	Crop production practices	Above 1000 acre	–0.4285	1.2476	-
		Raised beds	8.9094***	3.5137	0.9403
		Direct seeded	2.0196	1.4462	-
		Plastic mulch	–4.9506**	2.5284	–0.5721
		Overhead irrigation	6.3445***	2.2055	0.9186
		Primary crop	–3.5572**	1.7543	–0.7074
3.	CDM outbreak and mitigation	Disease problem	0.5329	1.2423	-
		CDM increased outbreak	–0.1970	1.0634	-
		Resident cultivars	–0.4387	0.9580	-
4.	Other social relations	Crop insurance	–0.3666	1.1268	-
		Agricultural extension service	–2.3381*	1.3285	–0.5015

(*Note* *, **, *** significant at the 10%, 5%, and 1% levels, respectively).

long periods of leaf wetness and increases relative humidity in the canopy, creating conditions favourable for CDM development (Hansen 2009).

Further, those who are above 65 years of age are more likely to incur high yield losses due to CDM compared to younger farmers; about 12% of the respondents belonged to this category. Although older farmers may have more experience in crop production, they may not be aware of the most effective methods (e.g., resistant cultivars, effective fungicide programmes) to limit CDM. Younger farmers may be able to access the latest information regarding the control of CDM through various sources including social media and networking.

Conclusion

This paper documents the practices used by farmers to overcome the impacts of downy mildew on cucurbit crops (pickling cucumber, squash, pumpkin, slicing cucumber, cantaloupe, and watermelon). In total, 98 respondents participated in a field-level survey. According to the survey, all the included crops were affected by CDM to some degree. Pickling cucumber had the largest CDM outbreaks followed by cantaloupe, sliced cucumber, pumpkin, squash, and watermelon.

The estimated logit model result suggests that farmers who belong to one of the following three categories are less likely to incur a high yield loss due to CDM: i) those who used plastic mulch to grow cucurbits, ii) those who considered cucurbits their primary crop, and iii) farmers who availed agricultural extension services. Generally, growers who process cucurbits in Michigan do not use plastic mulch to grow cucurbits. Also, growers who use black plastic mulch mostly use drip irrigation. Farmers who use raised beds to grow cucurbits, those who use overhead irrigation, and farmers above the age of 65 years are more likely to incur high yield loss due to CDM.

There are a few growers in Michigan who use raised beds without plastic mulch and drip irrigation. However, some retailers and fresh market growers use raised beds to grow other crops. Hence, extension-based outreach should include information on CDM-resistant cultivars, effective fungicide programmes, and the need to avoid overhead irrigation to limit CDM outbreaks. This information needs to be disseminated using various methods.

In this survey, we identified that the most common method for limiting CDM was using a fungicide programme along with resistant cultivars. Extension-based outreach and IPM should be explored to further reach out to "older" farmers to help improve CDM control. The information from this survey has the potential to impact future endeavours to help mitigate CDM with an emphasis on helping the producer employ the most current resources available.

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Groundwater use and sustainability in Punjab agriculture: insights from a field survey

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Abstract Paddy is a water-intensive crop, and its cultivation is the prime cause of the depletion of groundwater resources in Punjab. We survey paddy farmers' crop choices, water use, and opinions on the causes of the depletion of groundwater resources. To make long-term groundwater use sustainable, farmers can adopt water saving technologies and practices and diversify crops. But adoption is abysmal, and diversification into alternative crops entails high production and marketing risks. To improve adoption, the government must promote water saving technologies and practices. And assured marketing at remunerative prices is a prerequisite for crop diversification.

Keywords Groundwater sustainability, water-saving technologies, crop diversification, Punjab agriculture

JEL codes Q15, Q16, Q25, Q32, Q56

India is the top user of groundwater in the world. The country consumes more than 25% of the freshwater in the world and uses 88% of it for irrigation. Much of its agricultural production depends on the excessive use of water, and productive regions are likely to experience water scarcity in the long run. Already, about 60% of the country's aquifers are under severe stress (World Bank 2012), and the water table in the Indus basin is the second-most overstressed in the world (Gorton 2017). The over-dependence and over-exploitation is particularly severe in the northwest of India, or the green revolution belt.

The term "green revolution" refers to the policies instituted since the late 1960s that transformed India from being a food-deficit country into a food self-sufficient and food-surplus country (Rena 2004). High-yielding varieties (HYV) of wheat were introduced into Punjab in the late 1960s and HYV of paddy in the early 1970s. Access to irrigation was improved; it facilitated cultivation in almost the entire state, and agricultural growth for nearly two decades (1960s–1980s), and contributed immensely to national food security.

During the 1990s, however, production and productivity fell. Profits fell because production cost rose, investment in agriculture declined, and access to credit was limited (Amanullah et al. 2020; Bera 2015; Narayanmoorthy 2017). To retain their former productivity and profitability, paddy farmers resort to unpropitious use of farm inputs and excessive irrigation.

Paddy consumes three to five times the water required by any other crop (Goud 2015). The continual increase in the area under paddy, the total cultivated area, and the cropping intensity have fuelled the demand for irrigation water. Groundwater irrigates 71% of the state; it has over 1.4 million of the 2.6 million tube-wells in India. And the over-use and over-exploitation of groundwater resources have led the water table to fall faster since the 1990s, threatening long-term

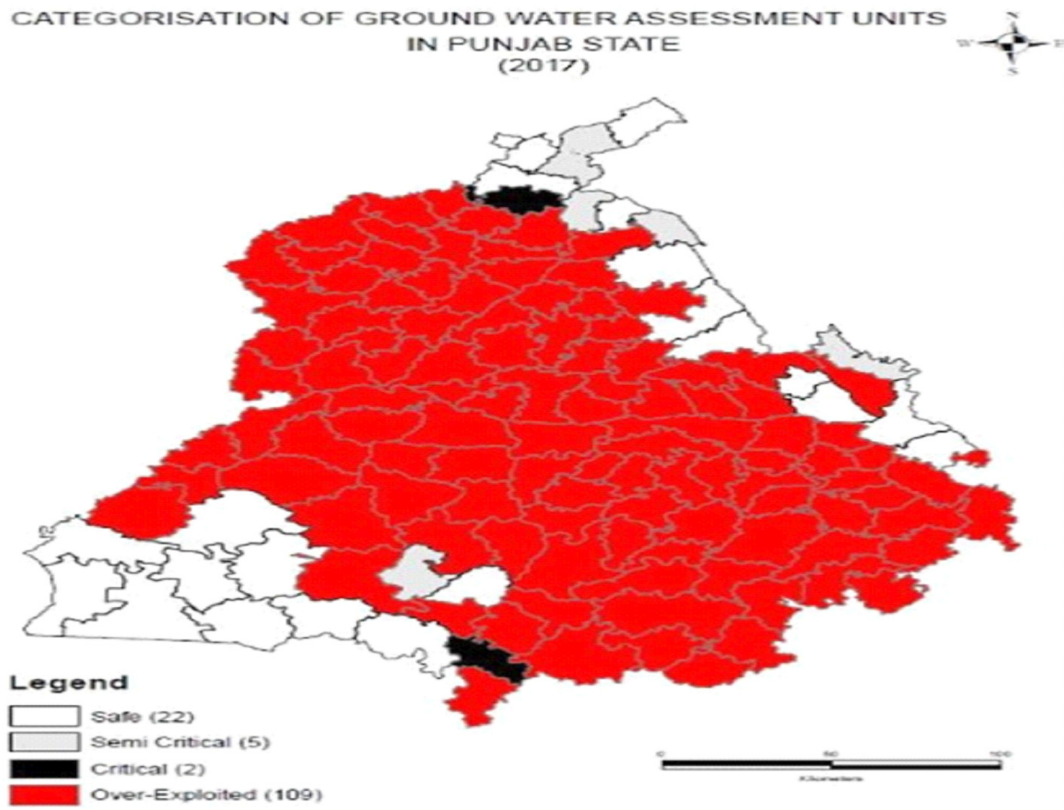

Figure 1 Groundwater use in Punjab
Source https://irrigation.punjab.gov.in as cited on 3 March 2020

sustainability (Pandey 2016; Kaur and Vatta 2015). Of the 138 blocks in Punjab, 109 blocks are termed over-exploited and two blocks critical in terms of groundwater use (Figure 1). The water table in about two-thirds of Punjab is projected to fall below 20 m by 2023 and below 30 m in the remaining (Sidhu, Vatta, and Dhaliwal 2010). The problem is worse in the central zone because most of it (3.16 million ha) is under the paddy–wheat system.

Rapid industrialization and urbanization add to the stress (Dhania and Rani 2014). And many existing policies are groundwater-unfriendly. The state provides electricity to farmers free of charge, and they use groundwater excessively and unsustainably. In the “free for all” approach that has emerged, the dwindling groundwater is mismanaged (Shah et al. 2000), and the long-term sustainability of the production system is in doubt.

We survey farmers in Punjab on their cropping choices and pattern of water use, and on their perspective on the over-exploitation of groundwater, its long-term sustainability, and the fall of the water table. This paper presents the results of the survey and attempts to chalk out pathways for making water use in Punjab agriculture sustainable.

Data

In 2019, a primary survey of 600 farmers was conducted as a part of the Flagship Project 4 (FP4) “Water Use and Management in a Changing Monsoon Climate” being carried out under the project “Transforming India’s Green Revolution by Research and Empowerment for Sustainable food Supplies” (TIGR^{2}ESS). This study is based on that survey.

The primary survey was conducted in central Punjab—where the over-exploitation of groundwater is the highest and the fall in the water table the most severe—in the districts of Amritsar, Jalandhar, and Ludhiana. Two blocks were selected from each district, and 2 villages or village clusters from each block, making a total of 12 villages/village clusters (Figure 2). From each selected village/village cluster, 50 farmers were

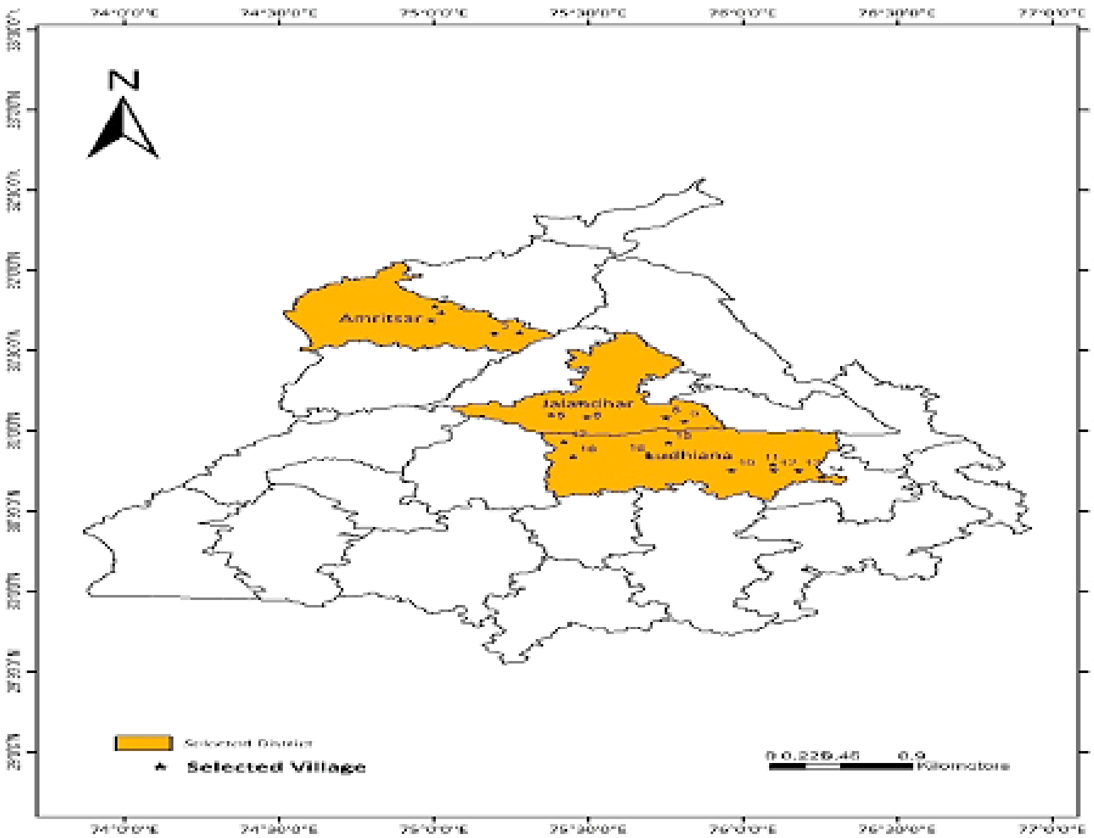

Figure 2 Districts and villages selected for the study

Table 1 Size of the operational landholdings (ha)

Particular	Amritsar	Jalandhar	Ludhiana	Overall
Owned land	2.0	2.0	2.7	2.2
	(58.9)	(29.9)	(35.1)	(37.3)
Leased-in land	1.3	4.7	5.0	3.7
	(38.2)	(70.1)	(64.9)	(62.7)
Leased-out land	0.1	0.0	0.0	0.0
	(2.9)	(0.0)	(0.0)	(0.0)
Operational land	3.4	6.7	7.7	5.9
	(100.0)	(100.0)	(100.0)	(100)

Note Figures in parentheses are % of the operational landholding

selected, making up a total sample of 600 farm households.

By landholding size, marginal farm households (up to 1 hectare (ha)) make up 18% of the sample, small farm households (1–2 ha) 20%, semi-medium farm households (2–6 ha) 35%, medium farm households (6–10 ha) 12%, and large farm households (more than 10 ha) 15%. The operational landholding size averaged 5.9 ha (Table 1).

Farmers lease in land to increase their operational holdings. About 63% (3.7 ha) of the total operational land was leased in and less than 1% leased out. In

Table 2 Source of irrigation

Source of irrigation	Amritsar (%)	Jalandhar (%)	Ludhiana (%)	Overall (%)
Canal	1.4	0.6	2.9	1.7
Tube well	84.1	95.2	85.8	88.3
Both	14.5	4.1	11.3	10.0
% farmers having access to canal water	19.5	2.0	18.5	14.7

Punjab, the land lease market is very active; and its activity is positively associated with outmigration (Singh, Garg, and Singh 2004). Most of the land is leased out by landowners living abroad or outside the village or by residents who have left farming. Ludhiana and Jalandhar have the largest number of emigrants (Jagat 2019); and about 59% of the land in Amritsar, and about 65–70% in Jalandhar and Ludhiana, is leased in.

Access to irrigation, paddy cultivation, and the fall in the groundwater table

Almost the entire cultivated area in Punjab is under assured irrigation; its primary source is groundwater pumped from tube wells. Tube wells (groundwater) irrigated 88.3% of the operational holdings and canal water only 1.69% (Table 2). In combination, tube wells and canals irrigated almost 10% of the operational holdings in the area.

Despite minor variations in the source of irrigation across the three districts, 14.7% of farmers had access to canal water for irrigation on average, 19.5% in Amritsar, 2.0% in Jalandhar, and 18.5% in Ludhiana. About 53% were situated at the head, 46% were located at the tail, and 25% noted that the canal water was insufficient for irrigation. The problem was more severe among the farmers located at the tail end of the canal.

Most tube wells are submersible (96%). On average, they have 10–15 horsepower (hp), and they are estimated to be irrigating 2.5 ha of land. Over 90% of the tube wells have 5–15 hp, 48.2% had 10–15 hp, and more than 8% had more than 15 hp. More than 40% of the landholdings reported borewell depth of 60–75 metres. About 1.3% of the landholdings had borewell depth that exceeded 120 metres. Nonetheless, almost all farmers in the region reported sufficient access to water for irrigation.

As the water table falls, farmers need to shift from using shallow centrifugal pumps to investing in and using submersible pumps (Fishman et al. 2011; Pandey 2016). The capital investment is compulsory, and it adds to the debt burden of the already debt-ridden farmers.

Water management mitigates the differential access to water that could come about through canal irrigation. Farmers in all three districts have almost equal access to water. For farmers that received insufficient canal water, access to groundwater sources met the deficit.

Assured irrigation is another critical reason for the decline in crop diversity and the increase in the dominance of the paddy-wheat cropping system in Punjab. Paddy and wheat crops, including basmati rice, occupied 75% of the total cropped area (Table 3), potato 6.9%, maize 1.5%, and sugarcane 0.6%. Fodder occupied only around 5% of the total cropped area. All other crops were grown on a negligible area.

Our survey confirms that the water table is over-exploited in most of Punjab's development blocks where the groundwater is fit for irrigation. And it fell in all three districts during the past three decades. Jalandhar witnessed the largest fall.

Farmers' opinions on the depletion of groundwater resources

About 64.7% of the farmers felt that the groundwater resources were being depleted primarily because the area under paddy cultivation was increasing (Table 4), 24% blamed the wasteful use of irrigation water in agriculture, and 11% believed that climate change and the increase in industrial activity is responsible. The perception varied by district: most farmers in Ludhiana blamed the inefficient use of water; in Amritsar and Jalandhar, most farmers blamed paddy. The opinions did not differ considerably by class. A larger proportion

Table 3 Cropping pattern (ha)

Crops	Amritsar	Jalandhar	Ludhiana
Kharif season			
Paddy	0.68 (8.63)	5.46 (40.93)	6.80 (37.20)
Basmati	2.42 (30.71)	0.13 (0.97)	0.34 (1.84)
Maize	-	0.41 (3.07)	0.18 (1.00)
Sugarcane	-	0.25 (1.87)	-
Fodder	0.21 (2.66)	0.41 (3.07)	0.33 (1.79)
Others	0.08 (1.02)	0.01 (0.07)	0.06 (0.31)
Rabi season			
Wheat	3.10 (39.34)	5.34 (40.03)	5.40 (29.54)
Potato	-	0.78 (5.85)	1.96 (10.73)
Mustard	0.04 (0.51)	-	-
Fodder	0.19 (2.41)	0.36 (2.70)	0.32 (1.77)
Others	-	0.19 (1.42)	0.02 (0.09)
Zaid season			
Fodder	0.02 (0.26)	-	0.20 (1.11)
Others	1.14 (14.46)	-	2.67 (14.63)

Note Figures in parentheses are percentages of the total cropped area

of marginal farmers than any other type blamed the depletion of groundwater resources on paddy (Table 5).

Despite all its ills, especially the depletion of groundwater, paddy is popular among farmers. The area under paddy cultivation grew from 0.3 million ha in 1970–71 to almost 3 million ha in 2018–19 (GoP 2019; Kumar and Sangeet 2019; Bhatt et al. 2016). The literature shows that the growth has occurred because the government guarantees farmers procurement at remunerative prices, assures irrigation, and provides free electricity (GoP 2019; Kumar and Sangeet 2019; Bhatt et al. 2016). But more than 95% of the respondents in this study, across all districts and farm sizes, said that the assured prices for paddy are the only dominant factor. Therefore, policy interventions and state- and national-level efforts are required to recommend crops for diversification, assure procurement at remunerative prices, and establish the processing industry.

To make groundwater use in Punjab efficient and sustainable, the literature emphasizes supply-side measures such as rainwater harvesting (Vatta et al. 2018; Taneja, Rawat, and Vatta 2018; Rahman et al. 2014) and demand-side measures such as agricultural practices like crop diversification and water management and water-efficient technologies (Menon 2007; Dixit et al. 2017; Vatta and Taneja 2018). We surveyed the farmers to identify their opinions and priorities.

Table 4 Farmers' opinions on the reasons for the decline in the water table (%)

Reasons for fall in water table	Amritsar	Jalandhar	Ludhiana	Overall
Increase in area under paddy	76.0	98.0	20.0	64.7
Wasteful use for agriculture	14.5	0.5	56.5	23.8
Others	9.5	1.5	23.5	11.5
Total	100.0	100.0	100.0	100.0

Table 5 Farmers' opinions on the reasons for the decline in the water table (by farm size, %)

Reasons for fall in water table	Marginal	Small	Semi-medium	Medium	Large
Increase in area under paddy	91.7	62.4	51.7	64.0	65.6
Wasteful use for agriculture	4.6	18.8	35.9	24.0	25.6
Others	3.7	18.8	12.4	12.0	8.9
Total	100.0	100.0	100.0	100.0	100.0

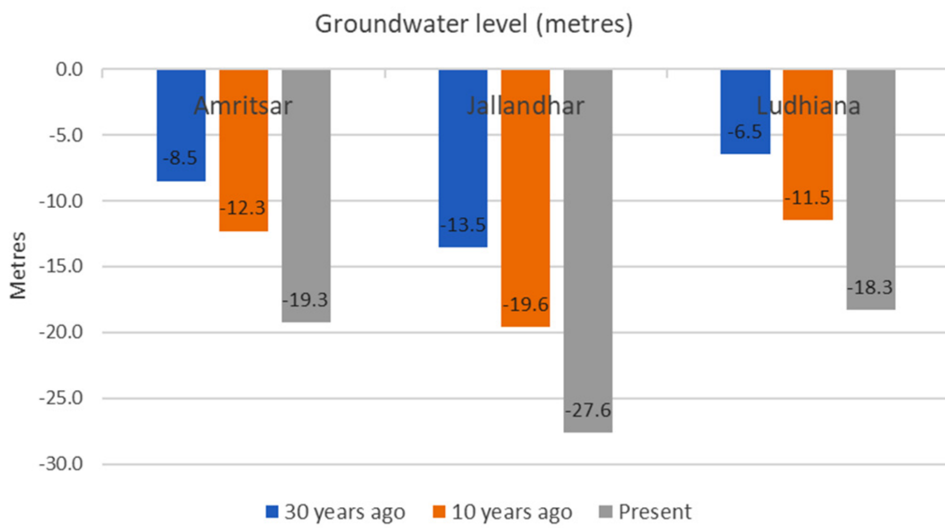

Figure 3 Decline in the water table

On the supply side, about 17% recommended the promotion of rainwater harvesting and 13.2% supported an increase in the use of canal water (Table 6). Smallholder farmers favoured rainwater harvesting, and large farmers felt that increasing the use of canal water would improve the overall supply of water for irrigation.

On the demand side, more than 27% preferred water-saving technologies and practices as the best way to ensure the sustainability of water use—provided comparable returns and efficient marketing facilities are available—and 17% chose crop diversification, or a shift to crops such as maize and vegetables.

Smallholders favoured technologies and practices and large landholders favoured crop diversification. About 6% of the farmers felt that the government should charge for electricity and 3.3% felt that the use of tube wells for agriculture should be restricted. Relative to smallholders, farmers with large landholdings were more in favour of restricting the use of tube wells.

Overall, farmers' preferences were in line with the expert views. If a long-term strategy for ensuring the sustainability of water use in Punjab agriculture were drawn up, implementation and adoption would be straightforward.

The idea of crop diversification has existed in Punjab since the mid-1980s. But although many experts and committees have recommended that over 1 million ha be shifted away from paddy to sustain the groundwater resources and enhance farmers' income (Johl 1986; Johl 2002), farmers have not shifted their cropping pattern (Chattre, Devalkar, and Seshadri 2016) because the profitability is lower for alternatives like maize, cotton, pulses, oilseeds, fruits, and vegetables and the production and marketing risk higher.

Table 6 Farmers' suggestions to improve water use efficiency (by farm size, %)

Suggestions	Marginal	Small	Semi-medium	Medium	Large	Overall
Rainwater harvesting	34.9	34.2	4.3	11.1	11.1	17.0
Increasing the use of canal water	11.9	11.1	6.7	22.2	22.2	13.2
Water-saving technologies and practices	29.4	29.9	34.9	17.8	17.8	27.2
Crop diversification	1.8	6.0	30.6	14.4	14.4	17.0
Pricing of electricity	7.3	7.7	5.3	7.8	7.8	6.0
Restricting new tube well connections	1.8	2.6	2.4	7.8	7.8	3.3
Others	12.8	8.5	15.8	18.9	18.9	16.3

Table 7 Farmers' suggestions for promoting crop diversification in Punjab (%)

Suggestion to promote crop diversification	Marginal	Small	Semi-medium	Medium	Large	Overall
Remunerative prices for alternative crops	67.0	58.1	84.7	58.7	66.7	70.3
Awareness and capacity building	20.2	19.7	8.1	26.7	-	13.7
Establishment of processing industries	-	1.7	1.0	5.3	5.6	2.2
Assured marketing	10.1	17.9	4.8	2.7	14.4	9.5
Others	2.8	2.6	1.4	6.7	13.3	4.3

This study sought suggestions from farmers on promoting crop diversification in Punjab. More than 70% suggested that the prices for alternative crops need to be as remunerative and profitable as paddy (Table 7). The prevailing market prices for these crops are much lower than the minimum support price, and procurement is not assured; that is why farmers do not diversify and farm these crops. Besides, 13.7% of farmers said that the government needs to train farmers in cultivating these crops and build their capacity to reduce production and marketing risks. Almost 10% of the farmers noted that assuring the marketing of alternative crops can make it easy to shift from paddy. Only 2.2% said that the agro-processing industry in Punjab needs to be strengthened to promote crop diversification. The suggestions were unanimous across farm sizes.

The government needs to assure markets and remunerative prices for farmers in Punjab to shift to alternative crops. Several state governments have made small-scale interventions recently, but no outcome yet can yield a clear large-scale strategy.

Awareness, adoption, and capacity-building needs for sustainable options

The use of groundwater in Punjab can be made sustainable by the adoption and use of water-efficient technologies and practices such as direct seeding of rice (DSR), drip irrigation, laser land levelling, sprinkler irrigation, rainwater harvesting, and the use of tensiometers and soil moisture sensors (Vatta and Taneja 2018; Singh, Gajri, and Arora 2001; Kukal, Hira, and Sidhu 2005; Aggarwal et al. 2009).

Almost all the farmers surveyed are aware of laser land levelling, and more than 83% have adopted it (Table 8), because of the yield advantage from levelling, which may not be the case for other options (Naresh et al. 2014; Jabran et al. 2015; Ullah and Datta 2018). But, despite considerable awareness, the adoption and use of the other technologies and practices is poor: about 17% of the farmers surveyed adopted raised bed cultivation, less than 5% adopted the other technologies and practices, and the adoption of drip irrigation was negligible.

Most of the farmers (37.7%) said that adopting the technologies and practices raises the fixed and variable costs. And 8% said that they do not know how to use these and that is why adoption reduces productivity (Table 9). The poor rate of adoption is cause for concern. The state government can ease the farmers' apprehension by making them aware of the economic and ecological benefits of adoption, build their capacity, and incentivize the adoption of these measures. And farmer-level organizations, NGOs, and gram panchayats need to supplement the efforts. However,

Table 8 Awareness and adoption of water-saving technologies and practices in Punjab (%)

Technology/practice	Awareness	Adoption
Laser land levelling	97.7	83.2
Direct seeding of rice	69.3	4.2
Drip irrigation	61.7	0.2
Sprinkler irrigation	67.7	2.0
Raised bed cultivation	45.3	17.2
Rainwater harvesting	23.0	1.5
Tensiometer/soil moisture sensor	21.0	2.5

Table 9 Why farmers do not adopt water-saving technologies (%)

Reasons	% of farmers
Rise in cost/fall in yield	37.7
Technology did not work	8.1
Lack of technical guidance	8.0
Others	46.2

Table 10 Farmers' sources of information, training, and decision-making

(%)

Source	Access
Fellow farmers/own experience	51.3
State Agricultural University*/Department of Agriculture	18.2
Primary Agricultural Cooperative Societies (PACS)	14.1
Web sources/mobile applications	5.2
Newspapers/TV/radio	5.1
Commission agents/input dealers	4.4
Other sources	1.7

Note * Includes Krishi Vigyan Kendras

the government's physical and financial support is a prerequisite.

Ongoing free electricity to agriculture is the other important reason for the poor adoption (Gulati, Roy, and Hussain 2017). We should explore the possibility of reorienting electricity subsidies for agriculture to make water saving the inevitable outcome. This study finds that low-cost water-saving options and their standardization, and capacity-building, will eliminate the production risk and the economic disadvantage of adoption. To invigorate capacity-building efforts, farmers must be encouraged to have access to more effective sources of information and training. Table 10 indicates the current access of farmers to information and training.

Most farmers (51.3%) rely on fellow farmers and their own experience for information. That might be the biggest constraint in developing the capacity to adopt and use water-efficient technologies and practices. More than 18% obtained information through Punjab Agricultural University and the State Department of Agriculture, followed by Primary Agricultural Cooperative Societies (14.1%). A tiny proportion of farmers relied on information from input dealers/commission agents for adopting water-saving options. Interestingly, more than 10% of the farmers depend on web sources, mobile applications, video and print media to enable decision-making.

Conclusions and policy suggestions

Through changes in hydrological cycles, climate change has adversely affected the availability and sustainability of freshwater (Kundzewicz et al. 2007). The effects of climate change, exemplified by the diminishing availability of water, are pervasive, intense, and extensive. Climate change and variability are particularly detrimental to agriculture because the insufficiency of water can curtail the area under cultivation by 9% by 2050 (Marshall et al. 2015; Rosa et al. 2018) and cause a water crisis that exacerbates the demand–supply gap in water for agriculture—the main reason for the agricultural crisis (Mizyed 2008; UNO 2009).

Groundwater constitutes 89% of freshwater use, of which 70% is appropriated for agriculture; the use of water in agriculture is the prime factor in the fall of the water table, and so groundwater must be used efficiently (Dumars and Minier 2004). Agriculture is water-dependent, and warm and dry regions cater to almost 50% of the world food demand. The depletion of groundwater resources worldwide is inevitable; by 2025, the depletion is projected to be six times the depletion in 1900 (Rockstrom et al. 2009; Sivakumar 2011). If not checked, the over-exploitation of water reserves will affect agricultural growth and the most impoverished strata of society, including small farmers (Marshall et al. 2015).

Groundwater fully or partially irrigates the operational holdings in Punjab. Where the canal water is not sufficient, farmers use groundwater. With a 10–15 hp tube well, it is possible to irrigate only about 2.5 ha of paddy (water-intensive but most remunerative kharif crop). The potential of water-saving technologies and practices is huge but, with the exception of the laser land leveller, awareness of these is low and adoption even lower, because the costs are higher, training is not provided, and farmers are concerned that productivity may decline. These technologies and practices need to be promoted by agricultural extension services through the Department of Agriculture and Farmers' Welfare, Department of Horticulture, state agricultural universities, and Krishi Vigyan Kendras, because most farmers rely on their fellows for information, and they may not have all the information farmers need to make a decision.

Farmers that have large landholdings believe that augmenting supply canal water can improve the supply of irrigation water. Smallholders prefer harvesting rainwater. Both crop diversification and water-saving technologies and practices can reduce the use of groundwater in agriculture. But the production and marketing risk is higher in alternative crops, and farmers, especially smallholders, prefer to farm paddy or adopt water-saving technologies and practices. Irrespective of landholding size, most farmers feel that paddy cultivation is the prime reason for the depletion of groundwater resources, but farmers cultivate it notwithstanding, because prices are remunerative and procurement is assured. Punjab has been trying to promote crop diversification for more than three decades, with little success. Most farmers want the government to assure the procurement of alternative crops at remunerative prices. Farmers need capacity building to understand the value of producing alternative crops to market requirements.

A shift from the water-intensive cropping system is called for. The shift should encourage the growth of a wide range of drought-resistant crops. Tweaking the technologies and water management practices is crucial for making the use of groundwater sustainable (Pingali and Rosegrant 1994). The demand-side interventions must be integrated carefully, the trade–food–water nexus addressed, and integrated landscaping approaches adopted (Mizyed 2008; Dankova 2016). An integrated framework—encompassing policies, strategies, and programmes to adapt agriculture to water scarcity—needs to be tailored to region-specific circumstances and requirements (Green et al. 2020).

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Impact of micro irrigation on groundwater savings, productivity, and profitability of principal crops in the Eastern Dry Zone and Central Dry Zone of Karnataka: a resource economic analysis

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Abstract This study aims at estimating the cost of irrigation and its implications on water savings, productivity, net returns, and relative profitability. The study finds that irrigation cost forms a sizeable proportion of the total cost of production in both flow irrigation and micro irrigation systems. The economic analysis indicates that the crops considered are profitable—as reflected in the net returns realized, with and without irrigation cost—but upon accounting for the irrigation cost with externalities we see a sharp fall in net returns for all the crops. Nevertheless, micro irrigation enabled water savings, and it enhanced productivity and relative profitability.

Keywords Micro irrigation impact, externalities, groundwater irrigation cost, water productivity, profitability

JEL codes Q15, Q25, Q28, Q29

Groundwater irrigation plays a critical role in agriculture in India, especially in rural areas: it provides employment opportunities and, thereby, improves food and income security and reduces poverty—leading to economic growth. Surface irrigation is uncertain in semi arid regions; and groundwater irrigation serves as a lifeline for many farmers—more than 60% of irrigated agriculture depends on groundwater. India is the largest user of groundwater for agriculture in the world. Groundwater contributed 70–80% to agricultural productivity and the value of agricultural output (Zaveri et al. 2016).

But other uses compete with irrigation to extract groundwater, and the cumulative pressure has depleted the resource, especially in hard-rock regions (Kumar 2016; Zaveri et al. 2016) and in the western, central, and southern peninsular parts of India (Saha et al. 2017). Groundwater based irrigation for agriculture is under threat; wells are being deepened, deeper wells are being drilled, and high energy pumps are being used to pump groundwater.

The state of Karnataka does not have assured sources of surface water for irrigation, and it has the highest proportion of drought prone areas, 79%, in the country. As the demand for groundwater irrigation spirals, over exploitation is diminishing its supply (Santhosh et al. 2013), but individual owners of wells are not investing in groundwater recharge, making groundwater exploitation a “tragedy of the commons”. Further, climate change poses a bigger threat.

Groundwater resources are so scarce, and the competing pressures on these are so intense, that India needs an approach to manage these resources and sustain farmer food and income security. India has regulations for rationalizing the use of water and electricity for irrigation, but the issue is so sensitive—socio economically and politically—that it is not plausible to enforce those regulations. Therefore, we must examine technological options, like micro irrigation (drip irrigation), to use groundwater efficiently.

We use the natural resource economics accounting framework in this study to estimate the costs of flow and drip irrigation, and their implications on net returns, in Karnataka. The study also analyses the impact of drip irrigation on water savings, productivity, and relative profitability. In this study "micro irrigation" refers only to drip irrigation, and "conventional irrigation" refers only to flow irrigation, and in both cases the source of irrigation is groundwater.

Methodology

Groundwater is extremely scarce in the eastern and central agroclimatic zones of Karnataka; and farmers have been practising micro irrigation not only for wide-spaced crops—like grapes, mulberry, and pomegranate—but also for narrow-spaced crops like tomatoes, capsicum, and other vegetable crops.

Sampling framework

Karnataka has 10 agroclimatic zones. Groundwater resources are the most over exploited in the Eastern Dry Zone (EDZ) and in the Central Dry Zone (CDZ); and so we chose these for this study.

Next, we identified the districts that are the most groundwater-starved: (in the EDZ) Kolar, Chikkaballapur, and Bangalore rural; and (in the CDZ) Tumkur and Chitradurga. We also identified the blocks and taluks.

At the third stage, we set up the treatment group by randomly selecting 45 farmers that practised drip irrigation. For the counterfactual, we randomly selected 20 farmers practising flow irrigation.

This is an impact study, and we need to know the demonstration effect; therefore, we selected farmers practising both flow irrigation and drip irrigation and who have similar crop patterns.

Most farmers in the study allocated a small proportion of their farm to drip-irrigating one crop or the other; hence, it was difficult to find an adequate sample size for the control group.

We used a pre-tested structured questionnaire and personal interviews to elicit the primary data for the year 2019 from the sample respondents.

Conceptual and analytical framework

Karnataka does not charge farmers for using electricity-driven irrigation pumpsets up to 10 horsepower (HP), only a flat rate of INR 300 per HP per year (up to 10 HP) is charged.

Cost of groundwater irrigation (drip and flow)

First, we consider the actual life span of all capital equipments—irrigation borewells, pumpsets, conveyance structures, drip irrigation, and water storage structures.

Next, we amortize the capital investment; it varies by the capital investment in groundwater structures, productive age of borewell, and the discount rate.

Amortized cost of groundwater irrigation = (amortized cost of borewell (BW) + amortized cost of pumpset + amortized cost of conveyance structures + amortized cost of water storage structure) + annual repairs and maintenance cost of pumpset (P) and accessories (A):

Amortized cost of BW =

$$\text{(compounded cost of BW)} \times \frac{(1+i)^{AL} \times i}{(1+i)^{AL} - 1} \tag{1}$$

where,

AL= average life of BW (5 years),

i= discount rate = 2%

compounded cost of BW = (historical investment in BW) × (1 + i) (2019 year of drilling)

amortized cost of P and A =

$$\text{(compounded cost of P and A)} \times \frac{(1+i)^{5} \times i}{(1+i)^{5} - 1} \tag{2}$$

Amortized cost of storage structure (SS) =

$$\text{(compounded cost of SS)} \times \frac{(1+i)^{5} \times i}{(1+i)^{5} - 1} \tag{3}$$

Amortized cost of micro irrigation structure (MI) =

$$\text{(compounded cost of MI)} \times \frac{(1+i)^{6} \times i}{(1+i)^{5} - 1} \tag{4}$$

Then, we add the annual amortized cost to the cost of operations and maintenance (O&M) and the labour cost of irrigation.

Finally, we apportion the total cost of groundwater irrigation to each crop by the volume of groundwater used; per acre inch, the cost of irrigation is [total annual cost of irrigation] / [volume of groundwater used for each crop in acre inch].

Rationale for compounding investments in borewells

Farmers invested in borewells and groundwater structures at different times; so, their vintages differ. To bring the historical costs on par, we compounded the investments to the present, 2019, and we used 2% as the discount rate.

Kiran Kumar et al. (2016) compare the investment in the earliest well (IEW) to the investment in the latest well (ILW) using the formula IEW (1+i) n= ILW, and find that the interest rate, i, was approximately 2%; and the commercial bank interest rate for agriculture loans cannot be used. Other studies in the hard rock areas of Karnataka also consider an interest rate of 2% (Diwakara and Chandrakanth 2007; Kiran Kumar et al. 2016; Anitha 2018). We, too, chose 2% as the discount rate, therefore.

Estimating the cost of negative externality in groundwater irrigation

If no borewell fails, there is no externality. But farmers in hard rock areas deepen their borewells, and drill deeper borewells, and so the probability that borewells will fail is very high.

Also, groundwater extraction is interdependent and involves reciprocal externality. One farmer's extraction from his borewell depends on the extraction by neighbouring wells at a time, and over time. And all the users of groundwater impose external costs on each other simultaneously and over time. Therefore, the cumulative interference of wells, and the magnitude of externality, increases (Nagaraj et al. 1994; Kiran Kumar et al. 2016).

We hypothesize that wells fail due to reciprocal negative externality; hence, the difference between the amortized cost per well and the amortized cost per functioning well will reflect the magnitude of negative externality.

The amortized cost per well is the total amortized cost divided by all the wells on the farm. The amortized cost per functioning well is the total amortized cost divided by the number of functioning wells on the farm. Subtracting the amortized cost per well from the amortized cost per functioning well gives us an empirical measure of the externality per farm borewell.

Cost of on farm improved groundwater storage structures

In hard-rock areas, the supply of electricity to agricultural pumpsets is irregular, especially during the summer. And the discharge of water from borewells is low. So, farmers cannot irrigate their land continuously, especially if they practise drip irrigation.

To cope, farmers build improved groundwater storage structures, pump groundwater whenever electricity is available—in the day and night—and store it to irrigate during the day.

Typically, the structures measure 18 m × 18 m × 3.5 m. To prevent seepage and loss, farmers line the structures with HDPE plastic. Depending on the quality of the material, the investment is huge—INR 60,000–90,000. Banks lend farmers the sum at an interest rate of 5% per annum.

The lifespan of the storage structure averages six years. We compute the annual cost of improved storage by amortizing the total investment over the lifespan.

Estimating the water used in micro-irrigation

The volume of groundwater used per crop (acre-inches) in the conventional system is estimated as

[(area irrigated per crop) × (frequency or number of irrigations per month) × (duration of irrigation given to crop in months) × (number of hours given to each irrigation) × (average yield of borewell in gallons per hour)] / 22611.

Under drip irrigation it is

(number of emitters per cropped area × water discharged per emitter (litres/hour) × number of hours irrigated the cropped area for one irrigation × duration of crop irrigated in months × frequency of irrigation per month (in number) × crop duration in months)] / 4.54/22611,

where,

4.54 is the factor to convert litres per hour to gallon per hour.

We analyse the physical (agronomic) productivity of irrigation (output per acre-inch of water applied) and its economic productivity (net returns per acre-inch of water applied).

The impact, or the change that occurred due to the adoption of micro-irrigation, is measured as the average change in the outcome considering treatment and control. The difference between the water applied through drip irrigation and flow irrigation method for each crop is considered as water saving.

The costs and returns are computed considering the actual input costs incurred and the price received by the farmer at the farm gate. This comprises all the material input cost, machinery and labour cost, groundwater irrigation cost, and marketing expenses.

Simpson Diversity Index

Simpson's Index = $1 - \Sigma_{t=1}^{n} P_i^2$

where, Pi is the proportion of area under each crop in acres to the total gross cropped area.

The index ranges from 0 to 1. If the index is closer to 1, it indicates high diversification; if the index is closer to 0, it implies low diversification.

Results and discussion

Groundwater is the main source of irrigation in the study area. The conventional method of flow irrigation is widely practised. However, of late, in response to the scarcity of groundwater, there has been a marked shift towards drip irrigation.

Key profile of sample respondents

The respondents in both groups are middle aged, on average, mature in their profession, and capable of making the right farm management decisions (Table 1). In both groups, the average family size is seven.

Table 1 Key profile of respondents in Eastern and Central Dry Zone of Karnataka

Particulars	Farmers with micro irrigation (MI)	Farmers with flow irrigation (FI)
Sample size (number)	45	20
Average age of the respondent (Years)	45	49
Average size of family (Number)	7	7
Literacy (%)	100	90
Average level of education (No of years studied)	12	9
Proportion of respondents studied up to 10th standard (%)	60	75
PUC (%)	28	20
Graduation (%)	12	5
Proportion of general category (%)	17	20
Proportion of OBC (%)	74	75
Proportion of SC and ST (%)	9	5
Proportion of small farmers < 5 acres (%)	50	40
Proportion of medium 5–10 acres (%)	40	30
Proportion of large farmers > 10 acres (%)	10	15
Average size of landholding (acres)Range	5.76 (1.0 to 19)	5.15 (2.0 to 11)
Gross cultivated area (acres)	7.69	7.77
Net cultivated area (acres)	4.8	5.6
Gross irrigated area (acres)	5.45	4.25
Net irrigated area (acres)	2.55	2.1
Net area under rainfed (acres)	2.24	3.5
Proportion of irrigated area (%)	53.5	37.5
Proportion of rainfed area (%)	46.5	62.5

The literacy rate of farmers practising micro irrigation, 100%, is higher than that of farmers practising flow irrigation, 90%. About 60% of the micro-irrigation respondents and 75% of the flow irrigation respondents had schooled up to the 10th standard on average, followed by PUC and graduation. Most farmers in both groups are small and medium-size farmers; the proportion of large farmers is very low. Most farmers in both groups are members of Other Backward Castes.

Gross and net cultivated area

On average, the landholding size is 5.76 acres for micro-irrigation farmers and 5.15 acres for flow irrigation farmers. The gross cultivated areas is about the same for both cases, but the gross irrigated area formed about 70.8% of the gross cultivated area in the case of micro-irrigation farms but 55.0% in the case of flow irrigation farms (Table 1). The proportion of area irrigated is 53.0% for micro irrigation farms but 37.0% for flow irrigation farms, mainly because micro irrigation facilitated the efficient use of water and water savings. The saved water is used to irrigate a larger area. Flow irrigation farms cannot minimize water use and expand the area under irrigation, and that is why they have a larger proportion of rainfed areas than micro irrigation farms.

Cropping pattern under micro-irrigation

Micro-irrigation farmers cultivated kharif crops on more than 41% of their gross cropped area, rabi crops on 19%, and summer crops on 18% of their gross cropped area (Table 2). The perennial crops occupied around 22% of the total gross cropped area. Around 21% of the gross cropped area is devoted to finger millet, which is grown under rainfed conditions and is a main staple food crop in the area.

Around 53% of the total gross cropped area was allocated to cash crops, mainly vegetables. Among vegetables, tomato is the most popular; farmers cultivate it on 53% of their gross cropped area. Beans, cabbage, and carrots are also grown. Among perennial crops, mango, areca nut, coconut, grapes, and pomegranate are prominent.

The cropping diversity is high, as micro-irrigation farms grow several crops on a small scale; their diversity score on the Simpson's Index is 0.92. Compared to flow irrigated farms, the cropping intensity and irrigation intensity of micro-irrigation farms is high, mainly because micro-irrigation enables farmers to not only use groundwater more efficiently but also to expand the cultivable area under saved water. These results are in conformity with the results of other studies (Kiran Kumar et al. 2014; Anitha 2018).

Thus, the cropping pattern is highly diversified, and a combination of annual and perennial crops ensures regular cash flow. None of the respondents grew rice, sugarcane, or banana, which are all water guzzling crops, showing that farmers are prudently using groundwater and diversifying crop patterns to minimize risk.

Cropping pattern of respondents practising flow irrigation

Around 44% of the gross cropped area of flow irrigation farms is devoted to kharif crops, 16% to rabi crops, and 11.5% to summer crops. Over 28% of the gross cropped area is under perennial enterprises like mulberry, coconut, and mango (Table 3). In rain fed conditions, the cropping system based on finger millet and mixed crops occupy almost 13% of the gross cropped area, as does the cropping system based on groundnut with mixed crops.

The cash crops, mainly vegetables, occupied about 45% of the total gross cropped area; tomato occupied 42%. The other crops grown are beans, cabbage, beetroot, carrot, and potato. Flow irrigation farms score 0.70 on the Simpson Diversity Index; and their cropping intensity, irrigation intensity, and cropping diversity is lower than in micro-irrigation farms.

Our cropping pattern analysis shows that the crops cultivated are not only input intensive but also water intensive; in both cases the diversification towards horticultural crops was high.

Resource economics approach to costing groundwater irrigation

We use the resource economics approach to cost groundwater irrigation and estimate the return on investment. In hard rock areas, the probability of borewell failure is high, the well density is high, and the extraction rate exceeds the recharge rate; hence, wells fail frequently. Of late, due to the rapid and intensive over-exploitation of groundwater, the depth of borewells has increased massively, by 1,000–

Table 2 Cropping pattern of sample respondents with micro irrigation

Season	Crops	Area (acres)	Gross cropped area (%)
Kharif Rainfed	Finger millet (Ragi) + Dolichus	73	0.21
	Pigeon pea	5	0.01
	Horsegram	4	0.01
Major irrigated crops	Maize	6	0.012
	Tomato	25	0.072
	Cabbage	8	0.023
	Beans	10	0.029
Other vegetables	Capsicum, ridge guard, carrot, brinjal, cucumber, ladies finger	12	0.035
Sub total		143 (0.42)	0.413
Rabi-Major irrigated crops	Tomato	28.5	0.08
	Cabbage	8	0.023
	Beans	6	0.014
	carrot	5	0.014
	Potato	3.5	0.010
	Flowers	3.5	0.010
Other vegetables	Brinjal, cucumber, cauliflower, ladies finger, bottle guard,	10.75	0.031
Sub total	onion &other leafy vegetables	65.25 (0.18)	0.19
Summer	Tomato	46.5	0.13
	Beans	4.5	0.01
	Cucumber	4.5	0.01
	Other vegetables	9.5	0.027
Sub total		65 (0.18)	0.18
Perennials	Mango (Rainfed)	19	0.054
	Coconut	8	0.023
	Grapes	8	0.023
	Pomegranate	6	0.01
	Arecanut	15	0.04
	Guava	4	0.011
	Mulberry	6	0.014
	Sapota (Chikko)	4	0.01
	Papaya	3	0.008
Sub total		73 (0.22)	0.22
Total GCA		346.23	
NCA		216	
GIA		247	
NIA		**115**	
Irrigation intensity		**214**	
Cropping intensity		**194.0**	
Simpson's Index		0.92	

Note Figures in the parenthesis indicates proportion of Gross Cropped Area (GCA) to the total

Table 3 Cropping pattern of sample respondents with flow irrigation

Crops/season	Area (acres)	GCA (%)
Kharif		
Finger millet based mixed cropping (rainfed)	21.5	0.138
Groundnut based intercropping	20	0.128
Tomatoes	10	0.064
Beans	6	0.038
Beet root	5	0.032
Other vegetables	6	0.038
Total	**68.5**	0.4405
Rabi		
Tomatoes	10	0.064
Potatoes	5	0.032
cabbage	6.5	0.042
Carrot	3.5	0.022
Sub total	**25**	0.161
Summer		
Tomatoes	9	0.058
French beans	5.0	0.032
Water melon	4.0	0.026
Sub total	**18**	0.115
Perennial		
Mulberry irrigated	10	0.064
Mango rainfed	29	0.186
Coconut semi irrigated	5	0.032
Sub total	44	0.283
Total GCA	155.5	
NCA	112.5	
GIA	85	
NIA	42	
Cropping intensity	177	
Irrigation intensity	188	
Simpson's Index	0.70	

1,700 ft, and the well failure rate has risen and the average productive lifespan of the wells has decreased drastically. Based on the well inventory in the study area, borewells turned out to be unproductive approximately in five years with micro irrigation and four years without micro-irrigation. We consider that the average life of a borewell and we amortize the capital investment on the well structures over five years for micro irrigation farms and four years for flow irrigation farms at the discount rate of 2%.

The variable cost on operations and maintenance (O&M) includes electricity (at the subsidized flat rate) and repairs and replacements. The cost of O&M is high because the electricity voltage fluctuates wildly during the day and farmers need to run their motor frequently and spend more on repairs. The annual cost of irrigation is the sum of annual amortized cost plus the variable cost.

The investment in well irrigation depends mainly on the number of failed and functional wells, depth of borewell, horsepower of the irrigation pumpsets, the number of stages of the pump, improved conveyance, and storage structures. Accordingly, the cost of irrigation differs.

The investments in wells and other components at historical prices are not directly comparable with the net returns estimated by considering the current year prices. Hence, we compounded the historical investments from the year of the cost incurred to the present period at an interest rate of 2%, as it represented the rate of inflation in the cost of well components (Chandrakanth 2015; Kiran Kumar et al. 2016; Nagaraj et al. 2003).

On average, the compounded investment per functioning well is around INR 470,000 in the case of micro-irrigation farms, about 39% higher than the INR 289,000 for flow irrigation farms (Table 4). This difference is mainly due to high capital investment in failed and functional deep borewells, micro irrigation (drip), and improved storage structures. In the case of micro-irrigation farms, the total annual amortized cost of groundwater irrigation amounts to INR 114,733 per functioning well, 38% higher than the INR 71,161 for flow irrigation farms. Adding O&M costs raises the total cost of irrigation per borewell per year to INR 139,000 in the case of micro-irrigation farms, 32% higher than the INR 93,911 for flow irrigation farms.

Around 65 acre-inches of water was extracted from the borewells on micro-irrigation farms but 69 acre-inches from flow irrigation farms, indicating that flow irrigation farms extracted around 6% more water. The externality cost was around 45% of the total irrigated cost on micro-irrigation farms but 32% on flow irrigation farms (Table 4).

The implicit cost of irrigation in hard-rock areas is increasing because the probability of initial and

Table 4 Cost of irrigation with externality cost under micro-irrigation and flow irrigation

Particulars	MI	Fl
Total borewells	170	68
Functioning borewells	48	22
Total of all investments/ functioning well (INR)	472,753	289,500
Amortized cost of borewell (INR)	27,790	24,695
Amortized cost of I P set & conveyance (INR)	19,793	13,925
Amortized cost of micro-irrigation (INR)	26778	
Amortized cost of failed borewells and deepening (INR)	33,944	23,337
Amortized cost of improved storage (INR)	5,090	7,955
Other sundry items	1,338	1,249
Total amortized cost/functioning well (INR)	114,733	71,161
Operation and maintenance cost (INR)	21,200	19,750
Electricity charges @ INR 300/HP	3,000	3,000
Total	139,033	93,911
Gross area irrigated/well (acres)	5.45	4.25
Water extracted per acre of GCA (Acre inches)	12.26	16.1
Water extracted /well (Acre inches)	65	69
Annual Irrigation cost/well (INR)	139,033	93,911
Cost per acre inch of water	2,138	1,364
Cost per acre of Gross irrigated area (GIA)	25,510.6	22,096.7
Externality cost particulars		
Amortized cost/borewell	51,321	41,158
Amortized cost/functioning well	114,733	71,161
Annual negative externality /well (INR)	63,412	30,003
Proportion of externality out of total irrigated cost (%)	45	32

premature borewell failure is high, forcing farmers to invest in additional borewells, high capacity irrigation pumpsets, improved storage structures, and micro irrigation to remain on the original production possibility curve. Therefore, the overall irrigation cost per acre and per acre-inch is higher, as layers of investments are needed to cope with groundwater scarcity. This high irrigation cost prompts farmers to cultivate commercial crops to recover their investments at the earliest. If adequate efforts are not made now to recharge the groundwater, groundwater irrigation in hard-rock areas will become prohibitive in the future.

Cost of failed borewell

The recharge of groundwater is low in hard rock areas, and the over extraction of groundwater and overcrowding of borewells raises the extraction rate above the recharge rate; hence, the probability of well failure is high (Nagaraj et al. 1995; Anitha 2019). On average, every farmer in the study area has lost their investment in at least three or four failed wells (Table 4).

The investment must include the investment in functioning and failed borewells since a farmer invests in the hope that the borewell will serve at least up to the payback period while knowing that it may fail initially or prematurely since in hard-rock areas the probability of well failure is very high.

There is no effort to recharge the groundwater. The indiscriminate drilling of borewells and over-extraction of groundwater violates the isolation distance (the distance between borewells). Thus, the investment on borewells is increasing due to reciprocal negative externality.

Negative externalities in well irrigation

To compute the negative externalities, we consider all forced investments in deepening wells, drilling deeper wells consequent to the failure of existing wells, and the costs incurred in adopting other mechanisms to cope with the decline in the discharge of water.

We estimate the annual externality cost of irrigation as the difference between the amortized cost per functioning well and the amortized cost per well. The externality cost is the cost of well failure due to the cumulative interference of irrigation wells. The negative externality cost computed per borewell in micro-irrigation farms is about INR 63,421, almost 52% more than the INR 30,003 for flow irrigation farms. Thus, every acre inch of water pumped imposes a reciprocal external cost of INR 976 on micro-irrigation farms and INR 435 on flow irrigation farms.

Estimating the cost of production by incorporating the cost of groundwater irrigation

In estimating the production cost of crops, the cost of water is ignored; it is assumed that water is free. But farmers make massive investments in drilling deeper wells to access groundwater in hard rock areas, installing mechanisms to extract water like higher horsepower pumpsets, and in improving storage and conveyance structures. Thus, it is crucial to include the cost of groundwater in the production cost and assess its implications on net returns.

The Commission for Agricultural Costs and Prices (CACP) uses a method to calculate the cost of irrigation, but the method has a few limitations. One is that they do not include the full cost of groundwater irrigation or the cost of negative externalities—owing to the mushrooming of irrigation borewells that do not maintain the isolation distance—and so they underestimate the cost of cultivation. The CACP does not have adequate information on the volume of water used for crops in the Record Type forms.

In computing depreciation, the CACP considers that the lifespan of the borewells averages 10 years, which is subjective and a myth. Wells have failed initially and prematurely for many farmers in the study area; in those cases, the depreciation is zero and the cost is infinity. Also, the failure of wells in hard-rock areas raises the cost of groundwater irrigation, but their method ignores this.

Relative profitability of groundwater-irrigated crops under micro irrigation

The diversity of groundwater-irrigated crops is high, and we consider only the crops that occupy a significant proportion of the gross cropped area. We compute the cost of production for all the crops considered and compare its relative profitability with and without the cost of irrigation in both micro-irrigation and flow irrigation farms (Tables 5 and 6).

We find that on micro irrigation farms the irrigation cost forms 18–33% of the total cost of production of seasonal crops and 20–49% of the total cost of production of perennial crops. All the crops are profitable, as reflected in the net returns realized—with

Table 5 Cost and returns for the principal crops grown under micro irrigation (INR per acre)

Particulars/crops	Tomato	Cabbage	Carrot	Beans	Potato	Onion	Capsicum
Cost of inputs	80,100	31,816	16,500	21,500	38,000	17,620	42,730
Labour & Machinery cost	35,165	49,300	24,000	27,500	18,500	13,550	29,850
Marketing cost	32,745	10,150	13,500	13,500	17,530	12,330	19,550
Total cost without irrigation cost	148,010	91,266	54,000	62,500	74,030	43,500	92,130
Irrigation cost (IC)	33,077	29,449	26,675	26,675	25,608	18,139	26,675
Total with IC	181,087	120,715	80,675	89,175	99,638	61,639	181,087
Irrigation cost as% of the total cost	18.3	24.3	33.0	29.9	25.7	29.4	22.4
Output/ac (Qtl/acre)	185	215	80.0	61.50	101.50	62.50	126.5
Gross returns	305,250	182,000	135,000	131,250	126,700	90,675	169,625
Net returns without IC	158,250	90,734	81,000	68,750	52,670	47,175	77,495
Net return after accounting IC	125,173	61,285	54,325	42,075	27,062	29,036	50,820
% fall in NR	21	32.4	33	38.8	48.6	38.4	34.4
Cost to Return ratio without IC	2.07	1.99	2.5	2.1	1.7	2.08	1.84
Cost to Return ratio with IC	1.70	1.51	1.74	1.52	1.31	1.52	1.48

Table 6 Per-acre cost and returns for the principal crops under micro irrigation

Particulars/crops	Coconut	Pomegranate	Areca nut	Grapes	Mulberry	Chrysanthemum
Cost of inputs	18,350	52,350	18,500	27,450	12,530	23,480
Labour & Machinery cost	11,550	39,530	33,250	15,330	12,300	34,600
Marketing cost	3500	12,350	3,700	31,500	0	32,800
Total cost without Irrigation cost (IC)	33,400	104,230	55,450	74,280	24,830	90,880
Irrigation cost	32,692	26,995	39,479	37,345	24,541	38,412
Total with IC	66,092	131,225	94,929	111,625	49,371	129,292
Irrigation cost as% of the total cost	49.40	20.5	41.5	33.4	49.7	29.7
Output/ac (nuts/acre)	3900	38.0	8.75	89.5	130.0	58.0
Gross returns (INR/Acre)	116,000	181,716	197,000	179,000	91,000	286,000
Net returns without (IC)	82,600	77,486	141,550	104,720	66,170	195,120
Net return with IC	49,907	50,490	102,071	67,375	41,629	156,708
% fall in NR	39.60	53.00	28.00	35.60	37.00	19.70
Cost to Return ratio without IC	3.47	1.74	3.55	2.4	3.66	3.14
Cost to Return ratio with IC	1.75	1.38	2.07	1.60	1.84	2.21

and without irrigation cost per acre—but their relative profitability varies depending on the degree of net returns. Accounting for the irrigation cost reduces the net returns on micro irrigation farms for seasonal crops from 21% to 48.6% and for perennials from 19.7 % to 53.0%. After accounting for irrigation cost in the cost of production on flow irrigation farms, the net returns for perennials fell from 29.8% to 53.2% and for annual crops from 24.5–57.5%.

If the cost of irrigation is not accounted for, the gross returns per acre on vegetable crops ranged from INR 300,000 to INR 130,000 and the net returns from INR 150,000 to INR 47,000. Tomato turned out to be the most profitable vegetable crop; after accounting for all costs, including the irrigation cost, its net return was INR 94,000 per acre. The other profitable vegetable crops were chrysanthemum, carrot, and capsicum. Grapes, areca nut, and pomegranate turned out to be most profitable perennial crops (Table 5–6). The results clearly indicate that in ignoring the cost of groundwater irrigation in estimating the cost of production, the net returns for crops are being overestimated.

Even after accounting for the cost of irrigation in the total cost of production, however, the net returns-to-cost ratio exceeds 1 for all the crops, indicating that the investment on these crops generated adequate returns due to access to groundwater irrigation. A similar trend was evident for flow irrigation farms. The gross returns of annual crops varied from INR 268,000 to INR 96,000 and for perennials from INR 175,000 to INR 78,000 (Tables 7–8).

Water savings and the physical and economic productivity of water

We analyse the irrigation water productivity (output per unit of water) and economic water productivity (net returns per unit of water applied) for all the 13 crops in both micro-irrigation farms and flow irrigation farms (Tables 9–11). Compared to flow irrigation farms, micro-irrigation saved 21.5–32% of the groundwater applied per acre, and the productivity per acre is 11–26% higher. The productivity per acre-inch of water is 31–48% higher on micro-irrigation farms than on flow irrigation farms (Table 10). The highest productivity per unit of water was observed in crops like chrysanthemum, tomato, capsicum, and pomegranate. The net returns realized per acre-inch of water are 33–63% higher on micro-irrigation farms than on flow irrigation farms (Table 11). The highest returns per unit of water were observed for chrysanthemum, tomato, capsicum, mulberry, onion, pomegranate, and coconut.

Thus, micro irrigation enhances both irrigation water use efficiency and economic water use efficiency for the principal crops considered in the study. In micro-irrigation, the quantity of water required is delivered continuously to each plant at its root zone through micro-tubes, avoiding water stress and ensuring the availability of water where it is most needed (Nagaraj

Table 7 Cost and returns for the principal crops grown under flow irrigation (INR per acre)

Particulars/crops	Coconut	Pomegranate	Arecanut	Grapes	Mulberry	Chrysanthemum
Total inputs cost without Irrigation cost (IC)	32,944	107,560	57,500	75,600	27,103	94,565
Irrigation cost	28,234	23,870	32,054	31,099	22,506	35,191
Total cost with IC	61,178	131,430	89,554	106,699	49,609	129,756
Irrigation cost as% of the total cost	46.1	18.4	35.7	29.1	44.4	27.1
Output/ac (nuts/acre)	3,200	31.5	6.5	80.5	110.5	43
Gross returns (INR/Acre)	86,050	175,570	146,950	169,050	78,455	212,650
Net returns without IC	53,106	70,010	89,450	93,450	51,352	118,085
Net return after accounting IC	24,872	46,140	57,396	62,351	28,846	82,894
% fall in NR	53.2	34	35.8	33.3	43.8	29.8
Cost to Return ratio without IC	2.61	1.66	2.55	2.23	2.89	2.29
Cost to Return ratio with IC	1.40	1.35	1.64	1.58	1.58	1.64

Table 8 Costs and returns for principal crops (flow irrigation, INR per acre)

Particulars/crops	Tomato	Cabbage	Carrot	Beans	Potato	Onion	Capsicum
Total cost without Irrigation cost	143,513	95,320	58,540	71,500	82,430	53,750	110,550
Irrigation cost	30,690	24,824	22,506	23,051	23,188	17,050	23,870
Total cost with IC	174,203	120,144	81,046	94,551	105,618	70,800	174,203
Irrigation cost as% of the total cost	17.6	20.6	27.7	24.3	22.0	24.0	17.7
Output/ac (nuts/acre)	141	151	70.0	52.5	90.5	55.5	102.5
Gross returns (INR/Acre)	268,550	156,100	129,000	129,625	131,525	96,575	161,812
Net returns without irrigation cost (IC)	125,037	60,780	70,460	58,125	69,552	42,825	62,650
Net return with IC	94,347	35,956	47,954	35,704	29,507	25,775	38,780
% fall in NR	24.5	40.8	32	38.5	57.5	39.8	38.1
Cost to Return ratio without IC	1.87	1.6	2.20	1.81	1.63	1.79	1.57
Cost to Return ratio with IC	1.54	1.3	1.6	1.4	1.3	1.40	1.29

Table 9 Water savings due to micro-irrigation over flow irrigation

Particulars/crops	Water used in micro-irrigation (Acre inches)	Yield/ac (Qtls)	Water used in FI	Yield/Ac (Qtls)	Saving water (%)	Increased productivity over flow (%)
Coconut (nuts/Acre	15.32	3900	20.7	3,200	25.9	18.0
Arecanut	18.5	8.75	23.5	7.50	21.25	14.2
Grapes	17.5	89.5	22.8	80.5	23. 24	10.0
Pomegranate	12.65	38.0	17.5	31.5	27.71	18.4
Mulberry	11.5	130	16.5	110.5	31.25	15.0
Tomato	15.5	185	22.5	145	31.11	21.6
Cabbage	13.8	215	18.2	185	13.95	13.0
Carrot	12.5	80	16.5	65.5	24.24	18.2
Beans	12.5	61.5	16.9	51.0	26.03	17.1
Potato	12.0	101.5	17.0	90.5	29.4	10.9
Onion	8.5	62.5	12.5	55.5	32.0	11.20
Capsicum	12.5	126.5	17.5	102.5	28.5	18.9
Chrysanthemum	18.0	58	25.8	43.0	30.2	25.8

Table 10 Physical and economic productivity per acre-inch of water

Crops	Water productivity in MI (Qtls/ac. inch)	Water productivity in flow irrigation (Qtls/ac. inch)	% difference in increased productivity/ ac inch of water over flow
Coconut (nuts/Acre	254.5	154.6	39.3
Arecanut	0.47	0.3	32.2
Grapes	5.1	3.5	31.0
Pomegranate	3.0	1.8	40.1
Mulberry	11.3	6.7	40.7
Tomato	11.9	6.4	46.0
Cabbage	15.5	10.1	34.7
Carrot	6.4	3.9	37.9
Beans	4.9	3.0	38.6
Potato	8.4	5.3	37.0
Onion	7.3	4.4	39.6
Capsicum	10.1	5.8	42.1
Chrysanthemum	3.2	1.6	48.3

Table 11 Net returns per acre and per acre-inch of water (micro-irrigation and flow irrigation)

Crop	NR/Acre **MI**	NR/Acre **FI**	NR/acre inch of water **MI**	NR/acre inch of water **FI**	Difference in net returns per acre inch of water over Flow (%)
Coconut	49,907	24,872	3,257	1201	63.1
Arecanut	102,071	57,396	5,517	2,442	55.7
Grapes	67,375	62,351	3,850	2,735	28.9
Pomegranate	50,490	46,140	3,991	2,636	33.9
Mulberry	41,625	28,846	3,619	1,748	51.7
Tomato	125,173	94,347	8,075	4,193	48.1
Cabbage	61,284	35,956	4,441	1975	55.5
Carrot	54,325	47,954	4,346	2,906	33.1
Beans	42,075	35,074	3,366	2075	38.3
Potato	47,062	29,507	3,922	1,735	55.7
Onion	29,036	25,775	3,416	2,062	39.6
Capsicum	50,820	38,780	4,065	2,216	45.4
Chrysanthemum	156,708	82,894	8,706	3,213	63.1

2020). The precision makes micro-irrigation more efficient than flow irrigation; it also reduces the water loss through evaporation and run-off (Kabbur et al. 2020).

Thus, to promote efficiency in water use, more economic incentives need to be provided for micro-irrigation, along with technical advice, so that more farmers switch from flow irrigation to micro irrigation.

Conclusion and policy interventions

Given the economic scarcity of groundwater in the study area, massive investments have been made in extracting and using it; and the over-extraction of groundwater resources, deepening of the existing borewells, and the drilling of deeper borewells is fast exhausting the resource. The cost of groundwater irrigation has increased, and the use of groundwater has become unsustainable, affecting the income and livelihood security of the farmers in rural areas that use groundwater for irrigation. The demand–supply gap of groundwater in the study areas of Karnataka is widening.

The recharge and discharge components need to be balanced with demand- and supply-side management tools and solutions. Arresting the further depletion of groundwater, and promoting judicious and sustainable use, need sound technological, institutional, and policy measures. Groundwater is a state subject; and both the central and state governments should initiate appropriate measures to arrest groundwater depletion and find alternative sources of water for conjunctive irrigation.

Micro irrigation enhances water productivity and relative profitability; it needs to be incentivized and scaled up. But outreach has so far been left to vendors selling micro irrigation equipment, whereas outreach plays the central role in sharing the knowledge of micro-irrigation technologies and facilitating its adoption. The follow-up services to the adopters of micro-irrigation need to be strengthened. Krishi Vigyan Kendras and agricultural universities and institutes need to research groundwater irrigation, train farmers in water accounting procedures, and deliver the appropriate technical services to them. And the CACP needs to include the cost of groundwater irrigation in the cost of production.

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Decomposing productivity growth in the Indian sugar industry

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Abstract We measure the growth in the total factor productivity (TFP) of the Indian sugar industry from 2002–03 to 2017–18 using the stochastic frontier production approach. The TFP grew at –10% per annum on average during the study period. The growth was negative because the allocative change and scale effect declined. To arrest the negative growth, the technical change must be improved urgently, modern processing technology must be adopted on a large scale, and the pricing policy of inputs, especially production factors, must be rationalized.

Keywords Total factor productivity (TFP), growth, sugar, manufacturing industry

JEL codes L11, L25, L60, O13, O33

Sugarcane is a widely grown crop in India. The country produced 348.448 million metric tons of sugarcane in 2015–16; 67.87% of the produce was used to make white sugar, 11.62% for seed and feed, and 20.51% to make gur and khandsari, a local type of sugar (NFCS 2017).

India produced 33.8 million metric tonnes of sugar: 560,000 metric tons of khandsari and 33.3 million metric tonnes of raw sugar in 2017–18 (Aradhey 2018). India ranks second in sugar production in the world, after Brazil, though its share in the global market is only 20%. In 2016–17, India exported 2,542.676 thousand metric tonnes of sugar worth INR 8,639.83 crore (NFCS 2017).

Recent policy changes have affected the sugar industry's performance (Singh 2016). The Government of India (GoI) removed the export duty on sugar with effect from 20 March 2018; earlier, it was 20%. A transport subsidy to sugar millers raised their cash flow; and it raised the export revenue by more than 46% (ISMA 2019).

At the World Trade Organization (WTO), Brazil and Australia claimed that the Indian subsidy programme distorts world sugar trade. The WTO has been exerting pressure on the sugar industry to become efficient and meet the challenges of global competition.

The sugar industry induces economic development because of the high returns that are increasing at a high rate, the incidence of technological change and innovations, and the synergies and linkages arising from the division of labour (Reinert 2009).

The trends in gur and khandsari production are envisaged to decrease over the base year of 1976 and the demand for sugar to increase to 33 million metric tons by 2030 (IISR 2011). To meet the increased demand, the productivity of sugarcane needs to be improved (Suresh and Mathur 2016).

Most of the assessments of total factor productivity (TFP) use a non-parametric approach (Arora and Kumar 2013; Kumar et al. 2011; Singh 2006; Singh 2016). Aggregate analyses mask the variation in productivity growth, though the variation is greater at the lower levels of aggregation of spatial units.

This study uses panel data aggregated by state to measure the state-specific TFP growth of the Indian sugar industry. The study also computes the spatial and temporal variation in TFP growth. The study quantifies TFP and its components—technical progress, technical efficiency, and scale efficiency.

Data

The study is based on panel data pertaining to the period from 2002 to 2018. We accessed the data from the Microdata Archive, an offshoot of the Ministry of Statistics and Programme Implementation, Government of India. We extracted the unit-level data from the Annual Survey of Industries (ASI), compiled it, and aggregated it at the state level.

First, we extracted the firm-level data on sugar mills for the years 2002 to 2018 from the ASI database. We used the National Identification Code (NIC) at different time level mills specific identification; we used the five-digit industrial classifications used from the year 2002 to 2004 NIC 2004 (code 15421) and NIC 2008 (code 10721) for the years 2002 to 2018 from the ASI database. Second, we aggregated the data by state by applying the multiplier presented in the dataset. Last, to normalize the data, we used deflators to deflate the inputs and output at constant prices.

We deflated the gross total outputs of industries by their respective Wholesale Price Index (WPI) of sugar products manufacturing. Likewise, we deflated the costs of the material inputs by the weighted average WPI of raw materials, fuel, power, light, and lubricants. We considered wages—including provident funds and other employee benefits—labour input and deflated it by the Consumer Price Index (CPI) for industrial workers. We deflated the total fixed capital input by an implicit price deflator for the gross fixed capital formation (GFCF) obtained from the National Accounts Statistics, Government of India. We normalized all the output and input variables before the log transformation.

Output and inputs

The ASI provides information on the outputs of manufacturing firms, or the value of output[1] (Mukherjee 2008; Mukherjee 1 2004; Deb and Ray 2014; Ali, Singh, and Ekanem 2009; Abdulla and Ahmad 2017; Khan and Abdulla 2019; Kumar et al. 2020). The ASI also provides information on the net value added (the difference between the (1) total intermediate inputs and depreciation and (2) the total value of output (Dholakia and Pateria 2015; Kumar and Arora 2009).

We followed the ASI tabulation programme to calculate the input and output variables. We consider the value of output an appropriate outcome variable. To assess the productivity of the Indian sugar industry, we take as input variables the number of employees[2] (wages and salaries), fixed capital,[3] and fuel consumed.[4] Before the analysis, we divide all the input and output variables by the number of factories in the respective states to remove the heterogeneity in the data.

Decomposing the total factor productivity (TFP)

We use stochastic frontier analysis (SFA) to measure productivity and technical efficiency. We apply the SFA to obtain an estimator for the degree of technical efficiency. Technical change is captured (as usual) by a time trend and the interactions of the explanatory variable with time. Thus, we estimate technical efficiency and technical change.

Changes in TFP may occur due to technical change or changes in the efficiency of input use, scale of production, or input and output price. We can introduce in the production function a decomposition of TFP into these components. Aigner et al. (1977) and van den Broeck et al. (1994) independently proposed the stochastic frontier production function. A single-output production function, with panel data and output-oriented technical inefficiency, can be defined as

$$y_{it} = f(x_{it}, t)\, exp(-u_{it}) \tag{1}$$

where, y_{it} is the maximum possible output produced by i^{th} firm (i = 1, 2, … …, N) in the t^{th} time period (t = 1, … … …, T);

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[1]The value of output, or the value of products and by-products, is the sum of the ex factory value of output, the variation in the stock of semi-finished goods, and the value of own construction.

[2]Wages and salaries provided to all workers.

[3]It is the sum of net value of closing (land, building, plant and machinery, transport equipment, computer equipment including software, others and capital work in progress).

[4]It is the sum of value of electricity purchased and consumed, petrol, diesel, oil, lubricants consumed, coal consumed, and other fuel consumed.

f (.) is a production function,

x_{it} is the input vector,

t is the time trend and serves as a proxy for technical change, and

$u_{it} \geq 0$ is the output-oriented technical inefficiency.

Following Coelli et al. (2005) and Kumbhakar et al. (2015), we take the logarithm of *y* and totally differentiate Equation 1 with respect to t:

$$\dot{y} = \frac{d \ln f(x_{it},t)}{dt} - \frac{\partial u}{\partial t} = \frac{\partial \ln f(x_{it},t)}{\partial t} + \frac{\partial \ln f(x_{it},t)}{\partial x_j}\frac{\partial x_j}{\partial t} - \frac{\partial u}{\partial t} \quad (2)$$

In Equation 2, on the right-hand side, the first term provides the change in frontier output caused by technical progress and the second term provides the change in frontier output caused by input use.

Using the output elasticity of input j, $\varepsilon_j = \frac{\partial f(x_{it},t)}{\partial \ln X_j}$, the second term can be expressed as $\sum_j \varepsilon_j \dot{x}_j$.

The dot (.) indicates the rate of change. The overall productivity change is influenced not only by technical progress (TP) and change in input use but also by changes in technical efficiency. The exogenous technical change shifts the production frontier upward (downward) for a given level of input if the technical progress (TP) is positive (negative). If the technical efficiency improves (deteriorates), then $\frac{\partial u}{\partial t}$ is negative (positive). The rate at which inefficient producers catch up with production frontier is interpreted as $-\frac{\partial u}{\partial t}$.

Thus, Equation 2 can be rewritten as

$$\dot{y} = \frac{d \ln f(x_{it},t)}{dt} - \frac{\partial u}{\partial t} = TP + \sum_j \varepsilon_j \dot{x}_j - \frac{\partial u}{\partial t} \quad (3)$$

The classical definition of TFP growth is defined as output growth unexplained by input growth:

$$T\dot{F}P = \dot{y} - \sum S_j \dot{x}_j \quad (4)$$

where, S_j is input j's share in production cost.

Substituting Equation 3 in Equation 4, we get

$$T\dot{F}P = TP - \frac{\partial u}{\partial t} + \sum_j \varepsilon_j \dot{x}_j - \sum S_j \dot{x}_j = TP - \frac{\partial u}{\partial t} + \sum_j \left(\varepsilon_j - S_j\right) \dot{x}_j \quad (5)$$

$$= TP - \frac{\partial u}{\partial t} + (RTS - 1) \sum_j \lambda_j \dot{x}_j + \sum (\lambda_j - S_j)\dot{x}_j \quad (6)$$

where, $RTS = \left\{\sum_j \varepsilon_j\right\}$ denotes the returns to scale,

$\lambda_j = \frac{f_j x_j}{\sum_j f_i x_i} = \frac{\varepsilon_j}{\sum_i \varepsilon_i} = \frac{\varepsilon_j}{RTS}$ where f_j is the marginal product of input x_j, and

ε_j are input elasticities defined at the production frontier.

The decomposition formula in Equation 6 follows from Kumbhakar et al. (2015). The last component in Equation 6, $(\sum (\lambda_j - S_j)\dot{x}_j)$, measures the inefficiency in resource allocation resulting from the deviation of input prices from the value of their marginal product. Thus, in Equation 6, TFP growth can be decomposed into technical progress, the technical efficiency change (TEC)$\left\{-\frac{\partial u}{\partial t}\right\}$, scale change = (RTS – 1) $\sum_j \lambda_j \dot{x}_j$, and the allocative efficiency change denoted by $\sum(\lambda_j - S_j)\, \dot{x}_j$.

Model specification

To estimate the model and TFP decomposition, we used the book by Kumbhakar et al. (2015). We consider a single-output production function with panel data and output-oriented technical inefficiency

$$Y_{it} = \beta_0 + \beta_l\, ll_{it} + \beta_k\, lk_{it} + \beta_m lm_{it} + .5 * \beta_{ll}\, (ll_{it})^2 + .5 * \beta_{kk}\, (lk_{it})^2 + .5 * \beta_{mm}\, (lm_{it})^2 + \beta_{lk}\, (ll_{it} * lk_{it}) + \beta_{lm}\, (ll_{it} * lm_{it}) + \beta_{km}\, (lk_{it} * lm_{it}) + \beta_t\, t_{it} + .5 * \beta_{tt}\, (t_{it})^2 + \beta_{tl}\, (t*ll_{it}) + \beta_{tk}\, (t*lk_{it}) + \beta_{tm}\, (t*lm_{it}) + v_{it} - u_{it} \quad (7)$$

where,

Y_{it} is the output measure in rupees of i^{th} firm at t^{th} time,

t is the time variable of i^{th} firm at t^{th} time,

ll_{it} is the wage input measure in rupees of i^{th} firm at t^{th} time,

lk_{it} is the total fixed capital input measure in rupees of i^{th} firm at t^{th} time,

lm_{it} is the total fuel input measure in rupees of i^{th} firm at t^{th} time,

v_{it} is assumed to be independently and identically distributed as $N\sim(0, \sigma_v^2)$, and

u_{it} represents the production loss due to firm-specific technical inefficiency.

The technical efficiency i^{th} of firm at t^{th} time (TE_{it}) is computed as $TE_{it} = exp(-u_{it})$.

The technical efficiency change (TEC) over time is $TEC = -\frac{du}{dt}$

The technical progress or frontier shift is defined as $TC_{it} = \frac{\partial f(xt,\beta)}{\partial t} = \beta_t + \beta_{tt} + \beta_{tl}(ll_{it}) + \beta_{tk}(lk_{it}) + \beta_{tm}(lm_{it})$

The elasticity of output with respect to the j^{th} input is defined by $\varepsilon_j = \frac{\partial lnf(x,t)}{\partial lnx_j}$, is calculated as the sum of labour elasticity

$$\varepsilon_l = \frac{\partial lf(x,t)}{\partial lx_l} = \beta_l + \beta_{tl}t + \beta_{ll}(ll_{it}) + \beta_{lk}(lk_{it}) + \beta_{lm}(lm_{it}),$$

The elasticity of capital is computed by

$$\varepsilon_k = \frac{\partial lf(x,t)}{\partial lx_k} = \beta_k + \beta_{tk}t + \beta_{kk}(lk_{it}) + \beta_{kl}(ll_{it}) + \beta_{km}(lm_{it})$$

and

The elasticity of fuel is computed by

$$\varepsilon_m = \frac{\partial lf(x,t)}{\partial lx_m} = \beta_m + \beta_{tm}t + \beta_{lm}(lm_{it}) + \beta_{lk}(ll_{it}) + \beta_{km}(lk_{it})$$

The returns to scale (RTS) is computed by

$RTS = \Sigma_j \varepsilon_j$ and $S = \varepsilon_l + \varepsilon_k + \varepsilon_m$.

Using Equations 5 and 6, TFP is defined as

$$T\dot{F}P = TC - \frac{\partial u}{\partial t} + \sum_j \varepsilon_j \dot{x}_j - \sum S_j \dot{x}_j = TC - \frac{\partial u}{\partial t} + \sum_j (\varepsilon_j - S_j)\,\dot{x}_j$$

$$= TC - \frac{\partial u}{\partial t} + (RTS - 1)\sum_j \lambda_j \dot{x}_j + \sum (\lambda_j - S_j)\dot{x}_j$$

where,

S_j is the share of inputs, and

the dot (.) indicates the rate of change of the variable.

Results and discussion

The study is limited to sugar manufacturers producing homogenous products (manufacturing of sugar). The literature uses three inputs (labour, capital, and fuel) and output as the total production of sugar. The national output of the sugar industry averaged INR 3,740 crore per annum for the period from 2002 to 2018.

Wages and salaries average INR 186 crore, and the average fixed capital is INR 2,660 crore; on average, fixed capital exceeds labour (wages and salaries) (Table 1). The expenditure on fuel averages INR 933 crore. On average, the industry uses INR 4,420 crore of fixed capital and INR 2,690 crore of fuel.

We applied several alternative restrictions on the specification of the translog production function. We used likelihood ratio tests to check whether the restrictions are appropriate (Table 1 in the Appendix). The likelihood ratio statistics favour the translog functional form (Table 2). The first order parameters, labour and fuel, are insignificant; the capital elasticity of output is statistically significant at the 5% level. All other things being equal, an increment in capital of 1% would increase the sugar output by 88%.

The second-order parameter labour and fuel (β_{lm}) is negative, revealing the possibility of substitution between the factors of production. The parameter labour and capital (β_{lk}) is also negative and statistically insignificant, revealing the tendency towards the substitution of labour and capital. The parameter capital and fuel (β_{km}) is positive, revealing that there is no substitution between capital and fuel. The coefficients of time*labour (β_{tl}), time*capital (β_{tk}), and time*fuel

Table 1 Input and output variables (constant prices, 2002–18)

Variable	Mean	Std. Dev.	Min	Max
Sugar (INR in crore)	3,740.00	5,950.00	0.02	27,200.00
Labour (INR in crore)	186.00	346.00	0.43	2,060.00
Capital (INR in crore)	2,660.00	4,420.00	1.87	23,200.00
Fuel (INR in crore)	933.00	2,690.00	0.18	18,200.00

Source Authors' calculations

Table 2 Estimates of half-normal stochastic production frontier model

Variables	Parameters	Coefficients	t- statistics
Labour	β_l	0.117	(1.08)
Capital	β_k	0.879***	(10.84)
Fuel	β_m	–0.098	(–1.53)
Labour*Capital	β_{lk}	–0.064	(–0.61)
Labour*Fuel	β_{lm}	–0.275**	(–2.89)
Capital*Fuel	β_{km}	0.261**	(3.27)
time	β_t	0.031	(1.72)
Time*Labour	β_{tl}	–0.032	(–0.69)
Time*Capital	β_{tk}	0.038	(1.11)
Time*Fuel	β_{tm}	–0.036	(–1.84)
time*time	β_{tt}	–0.008	(–1.64)
Labour*Labour	β_{ll}	0.135	(1.86)
Capital*Capital	β_{kk}	–0.087	(–1.50)
Fuel*Fuel	β_{mm}	–0.019	(–0.34)
constant	β_0	0.641***	(6.93)
usigmas	σ_u		
time		0.054	(1.74)
constant		–0.760*	(–2.17)
vsigmas	σ_v		
constant		–2.639***	(–10.86)
N		273	

Source Authors' calculations

Note *** significantly different from zero at the 1% level. ** Significantly different from zero at the 5% level.* Significantly different from zero at the 10% level.

(β_{tm}) are statistically insignificant or Hicks-neutral.[5] Thus, the Hicks-neutrality test of technical change in the sugar industry is fulfilled. The coefficients of time and labour (β_{tl}) and time and fuel (β_{tm}) are negative, showing labour- and fuel-saving technical change. The coefficient of time and capital (β_{tk}) is positive, showing the capital using technical change in the industry. One possible explanation is that most sugar firms invested more in plant and machinery, apparent from the calculation of capital input in monetary terms (in descriptive statistics, Table 1).

The Government of India and the state government of Maharashtra have exempted new sugar plants from the entry tax on sugar and the trade tax on molasses. They have undertaken to reimburse the administrative charge on molasses and the expenditure on the transfer of sugarcane. Sugar is exempt from purchase tax; it will be reimbursed. The industry is exempt from the society commission; it will be repaid. These incentives, to be offered for 5–10 years from the date of fulfilling the eligibility standards, would encourage entrepreneurs not merely to boost production capacity but also to increase economies of scale.

We compute the values of TFP growth and its components (Figures 1 and 2). The average scale change was –3%, technical change 3%, technical efficiency change 2%, price change was –12%, and the average TFP was –10%. Despite the technical progress (TC is positive), the TFP has been declining (TFP is negative)—driven primarily by a negative allocative and scale component. The scale change improved, and it is attributed mainly to the sugar policy in 2004 (Tuteja 2004). The change in scale has a positive contribution over the time span.

The sugar committee made certain recommendations in 2006, but these did not effect an increase in scale; it deteriorated, because the drought in 2008 reduced the availability of raw material for some states (ISMA 2016). The trade liberalization policies expose developing country farmers to the risks of price fluctuations in the global market (Shah 2010). The average growth in technical change improved over the period. The results confirm that Indian sugar mills improved technologically, due mainly to technical progress, and the TFP of the industry grew because of technical progress (innovations) rather than technical efficiency change. These results are in line with previous studies (Singh and Agarwal 2006; Kumar S et. al 2020).

The allocation of inputs in the industry was optimal, and so the average technical efficiency change (TEC) improved continually, in turn improving the TFP. The difference in allocative efficiency indicates that the market distortion among firms varied by state (Liu and Huang 2009; Kim 2010). The average allocative change (AEC) fluctuates because droughts, and changes in the regulatory and policy regimes, make the supply of sugarcane erratic. The rhythm of the growth in TFP matches the price change, indicating that price change drives the growth in TFP. The movement of scale

[5]Hicks neutrality occurs if the input coefficients of an industry fall in the same proportion (Batra 1970).

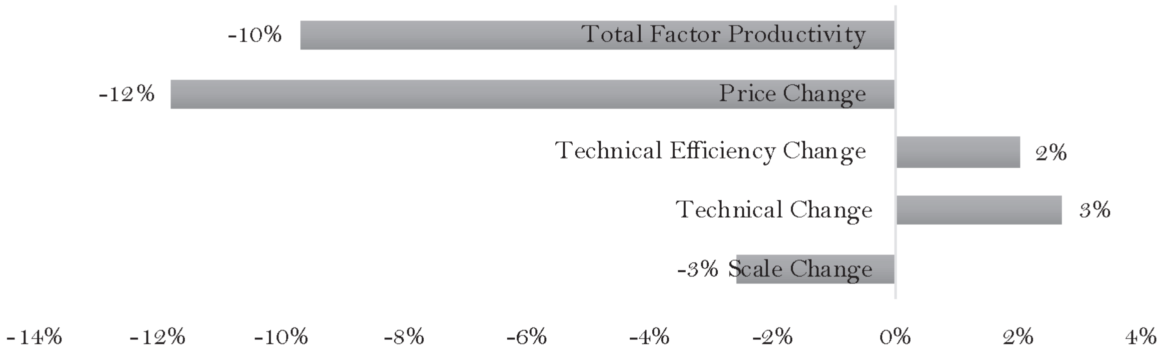

Figure 1 Temporal variations in technical change, technical efficiency change, scale change, allocative change, and TFP growth in the Indian sugar industry (2002–2018)

Source Authors' calculation

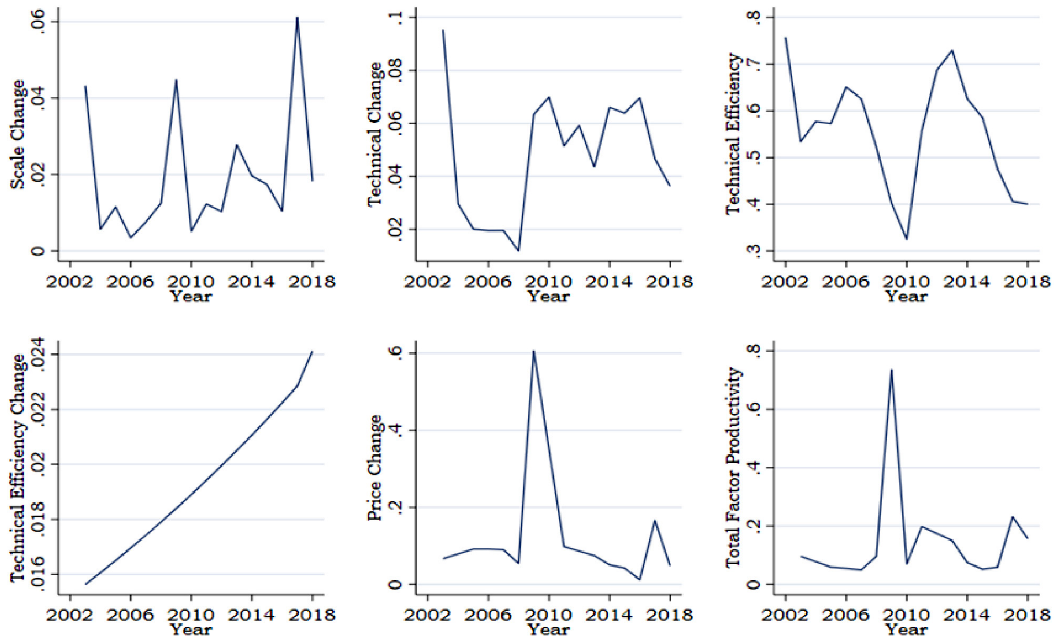

Figure 2 Trend of temporal scale change, technical change, technical efficiency, technical efficiency change, allocative change and TFP growth of sugar manufacturing industry (2002–2018)

Source Authors' calculation

efficiency shows that the global recession impacted the input prices and led the TFP growth to decline. The scale efficiency began improving after 2012 and supported the growth in TFP. These results are in line with Singh (2016) on the temporal variation in TFP growth.

The TC averaged 3.00%; it was highest in West Bengal (15.00%) and Chhattisgarh (14.90%) (Figure 3). The technical change was the least in Uttar Pradesh (–3.40%) and Maharashtra (3.00%). The scale change averaged –3.00%. The allocative change was negative for all states except Haryana and Telangana. The scale change was positive in Karnataka and Maharashtra, indicating that the sugar policy reform positively impacted the industry in the two states. Uttar Pradesh and Maharashtra produce the most sugarcane among the states in India. The pricing policy differs by state. Tamil Nadu and Uttar Pradesh have adopted the state advisory price (SAP). Karnataka and Maharashtra have adopted the fair and remunerative price (FRP) fixed by the central government (ISMA-Grant Thornton 2014). The SAP is substantially higher than the FRP.

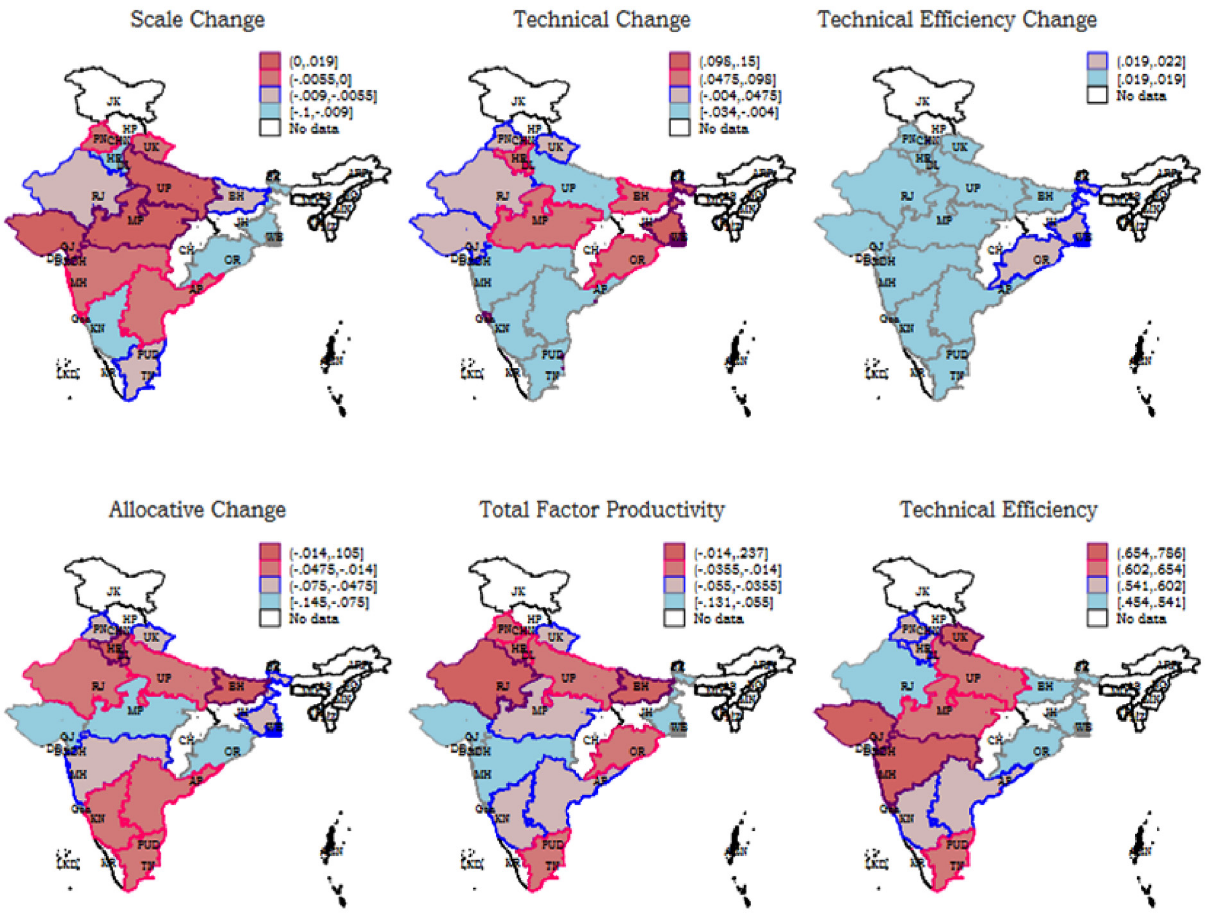

Figure 3 Spatial variation of the TFP (and components) of the Indian sugar industry (2002–2018)
Source Authors' calculations

Tamil Nadu and Uttar Pradesh are the least impacted by the price change compared to Karnataka and Maharashtra. The average price change in Uttar Pradesh has the least effect on the price change in the states. The TFP was highest in Chhattisgarh and lowest in Maharashtra, probably because Maharashtra has more sugar mills.

Conclusion and policy implications

The Indian sugar industry competes directly with the global sugar industry. The average value of capital use was higher than the other inputs. To stay competitive, the industry needs capital to adopt modern technology and adjust to the dynamic business environment. To help it do so, the government has liberalized policies and set up institutions.

The findings of the stochastic frontier approach explain the dynamic behaviour of the components of the industry's TFP. The economic shocks from the domestic economy and global markets impact the factors of production and TFP growth. The TFP grew at –10% on average during the study period. The growth varied widely by state. The average TFP growth regressed in all the states except Rajasthan, Bihar, Chhattisgarh, and Telangana.

The rhythm of the country-level TFP growth matched the rhythmic change in allocative efficiency (price effect). The fluctuations in allocative efficiency reduced technical efficiency. The industry's technical efficiency is poor—its technical inefficiency increased over time and it was around 42% during the study period. The industry did not use input resources efficiently and its technical efficiency fell as the business scenario changed.

The growth in TFP was driven temporarily by technical change and technical efficiency change and it was adversely affected by allocative efficiency. The government must institute a mechanism to improve technical efficiency and the industry needs to learn to use inputs optimally. To improve allocative efficiency, the government must implement price policy reforms.

The industry's technical progress increased continually during the study period but it declined in the last two years. To boost technical progress, old and obsolete technology needs to be replaced with modern processing and preservation technology and the labour force needs to learn to use the machinery.

A few states have not adopted the fair remunerative price for cane. Nevertheless, the government must rationalize the pricing policy of the factors of production to make the industry more sustainable.

This paper quantifies TFP and its components—technical progress, technical efficiency, and scale efficiency—and adds to the literature. The in-depth analysis would provide feedback to researchers, industry management, and policymakers and help them to design and refine policy and target their investment.

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Appendix

Table 1 Likelihood ratio test

Null Hypothesis	Degree of freedom	Statistic test	Critical Value at 5%	Decision
Cobb-Douglas vs Translog 1	4	407.60	8.76	Reject H0
Translog 1 vs Translog 2	3	107.14	7.04	Reject H0
Translog 2 vs Translog 3	4	1,050.18	8.76	Reject H0
Time invariant vs Time varying	1	346.02	2.70	Reject H0

Source Table 1, Econometrica, Kodde and Palm (1986)

Table 2 Share of labour, capital, and fuel (2002–2018)

Year	Labour Share	Capital Share	Fuel Share	RTS
2002	0.14	0.83	0.04	1.19
2003	0.14	0.83	0.03	1.17
2004	0.07	0.47	0.47	1.01
2005	0.09	0.47	0.44	1.02
2006	0.08	0.46	0.46	1.00
2007	0.08	0.45	0.47	0.97
2008	0.07	0.43	0.50	0.94
2009	0.19	0.76	0.05	1.04
2010	0.15	0.80	0.06	1.10
2011	0.16	0.79	0.06	1.05
2012	0.07	0.87	0.06	1.28
2013	0.05	0.89	0.07	1.27
2014	0.05	0.89	0.07	1.26
2015	0.04	0.91	0.05	1.24
2016	0.03	0.91	0.06	1.27
2017	0.06	0.83	0.11	1.01
2018	0.05	0.83	0.12	0.97

Table 3 Spatial variation in technical change, technical efficiency change, scale change, allocative change, and TFP growth (2002–2018)

State	SC	TC	TEC	AEC	TFP	TE	No. of Mills
Punjab	–0.10%	–0.10%	1.90%	–5.20%	–3.40%	59.80%	301
Uttaranchal	0.00%	3.30%	1.90%	–4.90%	–4.80%	66.00%	175
Haryana	–1.10%	6.20%	1.90%	2.10%	–1.90%	56.90%	147
Rajasthan	–0.70%	2.50%	1.90%	–4.60%	0.80%	47.90%	25
Uttar Pradesh	0.50%	–3.40%	1.90%	–1.40%	–1.40%	64.60%	2035
Bihar	–0.70%	6.60%	1.90%	–1.00%	4.60%	50.80%	187
West Bengal	–10.00%	15.00%	2.10%	–5.30%	–5.70%	45.40%	13
Orissa	–4.40%	9.10%	2.00%	–10.80%	–2.20%	49.70%	62
Chhattisgarh	–0.60%	14.90%	2.10%	10.50%	23.70%	63.90%	15
Madhya Pradesh	1.90%	9.80%	1.90%	–7.50%	–4.80%	62.20%	159
Gujarat	0.40%	1.90%	1.90%	–9.30%	–6.30%	78.60%	278
Maharashtra	0.00%	–3.10%	1.90%	–5.20%	–13.10%	68.80%	2,563
Andhra Pradesh	–0.30%	–0.40%	1.90%	–2.00%	–3.70%	58.10%	517
Karnataka	–0.90%	–1.40%	1.90%	–1.50%	–4.30%	56.50%	780
Goa	–0.50%	11.60%	1.90%	–14.50%	–11.70%	65.70%	18
Tamil Nadu	–0.80%	–2.60%	1.90%	–2.70%	–3.10%	65.40%	679
Pondicherry	–3.70%	11.10%	1.90%	–13.30%	–5.50%	60.60%	25
Telangana	0.00%	6.40%	2.20%	7.00%	14.30%	54.10%	50

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What drives the profitability of dairy processing firms in India? The results of decomposition analysis

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Abstract We study the profitability growth in the organized dairy processing sector in India from 1993 to 2017. Using a parametric approach, we decompose the change in profitability into price and non-price factors. The total factor productivity (TFP) grew, driven mainly by improvements in technical efficiency and technical change. The output grew, too. The growth in TFP and output increased profitability at 5.90% per annum. The study also analyses performance by firm size and finds that large firms performed better in terms of profitability growth, mainly due to the growth in output and efficiency in use of inputs.

Keywords Dairy industry, decomposition analysis, efficiency, profitability

JEL codes C33, L25

Many studies have analysed the growth in profitability, productivity, and efficiency of the organized dairy sector in India over the years to understand its trajectory and realize its potential. Mondal (2014) studies the profit margin and cost. Several researchers study total factor productivity[1] (TFP) and technical efficiency (Singh 2004; Elumalai and Birthal 2010; Mondal 2014; Ohlan 2013). Bhandari and Vipin (2016) study food processing companies in India from 2000 to 2015 and find that the technical efficiency of units producing dairy products and sugar is lower than in other sub-sectors but higher in those producing vegetable oil and related products. Globalization and liberalization affected the manufacturing industry in India in the 1990s (Goldar and Agarwal 2004; Kambhampati and Parikh 2003; Kalirajan and Bhinde 2005), and the profit margin fell for many firms, but some improved it by adopting new technologies and products (Siggel and Agarwal 2009). Competition—domestic and foreign—has increased, and the profit margin has fallen but, we argue, firms in the organized dairy industry, too, can improve efficiency and offset the fall.

Has the profitability of the dairy processing sector improved over the years? What factors contributed positively to profitability growth? How did the contributing factors change during different periods? Does firm size affect performance? We study large and medium-size firms in the organized dairy processing sector in India during the period from 1993 to 2017 in our attempt to answer these questions.

Database

The Centre for Monitoring Indian Economy (CMIE) manages Prowess, a query-based database that contains calendar-year firm-level financial data of active business entities, including registered companies. We make use of secondary data from Prowess.

The unit in this study is a dairy processing firm. We collected data on 138 dairy processing firms for 27

[1]Total factor productivity (TFP) is constituted of technical change, scale change, and technical efficiency change.

years (1991–2017). Observations were not available for all the firms for all the years; therefore, the panel data is unbalanced.

We use the three-digit-level data of the Annual Survey of Industries (ASI) on firms' total income, expenses, assets, sales by product, production volumes, unit prices, and profits. Some observations were missing, and the data on all the intended variables was not available. Information on "the number of employees" was available, for example, but the observations were not sufficient for the analysis.

We approximated the value of some variables. The information on the number of employees was available for only a few firms; so, we constructed the "efficient units of labour" measure, as in Balakrishnan, Pushpangadan, and Babu (2000), by dividing the total expense on salaries by the average wage rate of the Indian dairy industry from the three-digit-level ASI data for each year.

The database classifies firms by decile. We arranged the firms in descending order of the 2018 triennium ending (TE) average of total incomes and assets. And we grouped the firms—into small, medium-size, and large—to compare performance by firm size.

Large firms made up 31.88% of the firms in the database, medium-size firms 44.93%, and small firms made up 23.19%. The firms in the sample were located in 19 states: 44 (31.40%) in Maharashtra, 22 (15.70%) in Delhi, 11 (7.80%) in Gujarat, and 63 (45.00%) in the other 16 states. The firms produce 1–15 types of dairy product; the average is 4.

Methodology

Kumbhakar, Wang, and Horncastle (2015) developed a parametric approach. Using this method lets us decompose the change in profitability over a period into the three components of TFP—technical change,[2] scale change,[3] and technical efficiency change[4]—and the changes due to input prices, output prices, and output growth. We use this approach to decompose the change in profitability of the organized dairy processing industry in India.

We use econometric methods to estimate technical change, scale change, and technical efficiency change. We calculate the change due to input prices, output prices, and output growth components from the observed data. We follow the cost function approach to econometrically estimate the components. The cost function approach explicitly assumes cost minimization, implying that firms try to minimize their production cost.

The dual cost function of a production technology (Kumbhakar, Wang, and Horncastle 2015) can be specified as

$$C = C\,(w,y,t)\, e^{\eta} \tag{1}$$

where w is the vector of input prices,

y is the output,

t is the time period, and

$\eta \geq 0$ is the input-oriented technical inefficiency.

Differentiating Equation 1 totally with respect to time gives

$$\dot{C}a = \sum_j \frac{\partial lnC}{\partial lnw_j}\dot{w}_j + \frac{\partial lnC}{\partial lny}\dot{y} + \frac{\partial lnC}{\partial t} + \frac{\partial \eta}{\partial t} \tag{2}$$

where

$\dot{C}a$ is the rate of change in actual cost and

j is the inputs used ($j = 1,2,\ldots,J$).

Using Shepherd's lemma, the first term in Equation 2 can be rewritten as

$\frac{\partial lnC}{\partial lnw_j} = \frac{w_j}{C}x_j = S_j^a$ showing the cost share of j^{th} input on total cost

[2]Technological progress, organizational management, and other such factors change production technologies and shift frontiers. Such shifts are indicated by *technical change*. Any technical change that reduces production cost will improve profits.

[3]Economies or diseconomies of scale change profitability; the *scale component* indicates the extent of profitability. Profitability improves if the returns to scale (RTS) increase (RTS > 1) and if the aggregate input growth rate is positive.

[4]For any given level of output, firms try to use inputs efficiently to minimize costs and improve profits; in other words, firms aim for positive input-oriented *technical efficiency change*.

Hence, Equation 2 becomes

$$\dot{C}a = \sum S_j^a \dot{w}_j + \frac{1}{RTS}\dot{y} - TC - TEC \tag{3}$$

where,

$\frac{1}{RTS} = \frac{\partial lnC}{\partial lny}$, *technical change* $(TC) = -\frac{\partial lnC}{\partial t}$, and

technical efficiency change $(TEC) = -\frac{\partial \eta}{\partial t}$.

Differentiating $Ca = w'x$ gives

$$\dot{C}a = \sum_j S_j^a(\dot{w}_j + \dot{x}_j) \tag{4}$$

Equating Equations 3 and 4 gives

$$S_j^a \dot{x}_j = \frac{1}{RTS}\dot{y} - TC - TEC \tag{5}$$

Using the Divisia Index, we can write

$$T\dot{F}P = \dot{y} - \sum_j S_j^a \dot{x}_j \tag{6}$$

Substituting Equation 4 in Equation 5 yields

$$T\dot{F}P = \dot{y}(1 - RTS^{-1}) + TC + TEC \tag{7}$$

where,

$\dot{y}(1 - RTS^{-1})$ is scale efficiency,

$-\frac{\partial lnC}{\partial t}$ – is technical change, and

$\frac{\partial \eta}{\partial t}$ is the TEC component.

We can use the cost function to estimate the technical change, scale change, and technical efficiency change, but we cannot correctly infer firm profitability from the cost function, because a positive change in TFP does not confirm that profit increases over the period.

The percentage change in profit will be negative if the profit is negative even if there is an improvement over the previous year. This can be solved by expressing profitability change as a change in cost or revenue. We can relate the change in profitability and in TFP by differentiating profit with respect to time totally, $\pi = py - w.x$ and then dividing both sides by C

$$\tfrac{1}{C}\frac{d\pi}{dt} = \frac{py}{C}\left\{\dot{P} + \dot{Y}\right\} - \left\{\sum_J S_j^a \dot{W}_J + \sum_J S_j^a \dot{X}_J\right\} \tag{8}$$

From Equations 5 and 8, after some algebraic manipulations, we get

$$\tfrac{1}{C}\frac{d\pi}{dt} = \frac{R}{C}\dot{P} + \left\{\frac{R}{C} - 1\right\}\dot{y} - \sum_j S_j^a \dot{w}_J + T\dot{F}P \tag{9}$$

Equation 9 decomposes the change in profitability into output, output price changes, and input prices.

Substituting Equation 6 in Equation 9 yields all seven components of profitability change

$$\tfrac{1}{C}\frac{d\pi}{dt} = \frac{R}{C}\dot{P} + \left\{\frac{R}{C} - 1\right\}\dot{y} - \sum_j S_j^a \dot{w}_J + \dot{y}(1 - RTS^{-1}) + TC + TEC \tag{10}$$

The additional components in Equation 10 are output price change $\left(\frac{R}{C}\dot{P}\right)$; output change $\left(\left\{\frac{R}{C} - 1\right\}\dot{y}\right)$; and input price change $\left(\sum_j S_j^a \dot{w}_j\right)$.

Improvements in all components over the time period increase profit, except for growth in input prices (Kumbhakar, Wang, and Horncastle 2015). We analyse large and medium-size firms, but the data for some variables is missing, and so the period varies.

For our analysis, we use a translog cost function with three inputs—capital (K), labour (L), and raw materials (R)—and one output. We include in our model only three input variables—raw material, labour, and capital.

Other inputs, too, may affect firm profitability, but raw material, labour, and capital constitute most of the cost of dairy processing firms, and we assume that the changes in profitability and the other contributing components accurately represent the actual trend.

To make the function linear and homogeneous with respect to input prices, we normalize the total cost and input prices using the price of raw materials. The price of capital (w_k), price of labour (w_l), and total cost (tc) were normalized with the price of raw materials (w_r) as $lwkd = \ln(w_k/w_r)$, $lwld = \ln(w_l/w_r)$, and $ltcd = \ln(tc/w_r)$, respectively.

The translog cost function for the estimation was specified as

$$\begin{aligned} Itcd &= \propto_i + \beta_y lny_{it} + \beta_{yy} lny_{it}^{\,2} + \beta_k lwkd_{it} + \beta_l lwld_{it} + \beta_t t \\ &+ \frac{1}{2}\beta_{kk} lwkd_{it}^2 + \frac{1}{2}\beta_{ll} lwld_{it}^2 + \frac{1}{2}\beta_{tt} t^2 + \beta_{kl} lwkld_{it} \\ &+ \beta_{yl} lny_{it} lwld_{it} + \beta_{yk} lny_{it} lwkd_{it} + \beta_{yt} tlny_{it} \\ &+ \beta_{tk} tlwkd_{it} + \beta_{tl} tlwld_{it} + v_{it} - u_{it} \end{aligned}$$

where,

$v_{it} \sim iid\ N\ (0,\ \sigma_v^2)$ was the random-noise error component,

$u_{it} \geq 0$ was the technical inefficiency error component, and it was assumed to follow half-normal distribution $u_{it} \sim iid\ N^+\ (0,\ \sigma_u^2)$.

Variables in decomposition: a description

Output

A firm produces more than one product. Therefore, we averaged the price of all the products and divided the total sales value by the average product price per kilogram to obtain the output in kilogram.

Capital

The Prowess database provides data on gross fixed assets (rupees in million). We used this data as the capital variable. We deflated the data using an implicit deflator at 2004–05 prices. We derived the deflator using a gross fixed capital formation series at constant and current prices from the National Account Statistics.

Labour

We used efficient units of labour. We obtained these by dividing the total employee compensation (in the Prowess database) by the average compensation per worker (from the ASI data).

Raw material

Milk is the primary input in dairy processing. We obtained the quantity of raw material (in kilogram) by dividing the total raw material expenditure by the milk price. Some firms had not provided the price information; so, we averaged the milk price for firms in a particular year.

Price of output (INR per kg)

We averaged the prices of different products to obtain the output price; we deflated it with the Wholesale Price Index (WPI) of dairy products at 2004–05 prices.

Price of capital (%)

Sugathan et al. (2013) obtained the expense on capital by summing the interest share of capital and depreciation; and they calculated the interest share of capital as (annual interest on long-term debt) × (fixed assets) ÷ (long-term debt). We, too, consider the ratio of the expense on capital to gross fixed assets as the price of capital, but we assume that a large percentage of long-term debt is incurred to create fixed assets, and we sum the interest rate and depreciation.

Price of labour (INR per worker per year)

Only a few firms make the information on their number of employees available. We obtained the compensation per worker from the ASI. We deflated the price series by the Consumer Price Index (CPI) for industrial workers at 2001–02 prices. Finally, we divided the total compensation by the number of employees to obtain the price of labour.

Price of raw material (INR per kg)

No information was available on prices for some firms, but the database lists the unit prices of raw materials, and we plugged the average price of milk in a particular year across different firms into the series as price information. To obtain the deflated price series, we divided the price series by the WPI of milk at 2004–05 prices.

We calculated the total revenue (in INR) by multiplying the price with the quantity. We obtained the total cost (in INR) by summing the cost of all three inputs.

Results and discussion

Decomposing profitability change in the dairy industry

To understand the dynamics of growth in the TFP of the dairy industry, we split the 24-year period (1993–2017) under study ad hoc into 1993–99,[5] 2000–08, and

[5]The second sub-period (2000–08) is nine years long, as is the third sub-period (2009–17), but the first sub-period (1993–99) is only seven years long, because the data for the years 1991 and 1992 was available for so few firms—too few for our analysis—that we had to exclude the data for those years.

Table 1 Summary statistics of variables overall

Variables (per firm)	Mean			
	1993–99 (SD)	2000–08 (SD)	2010–17 (SD)	Overall (SD)
Output (000' tonnes per year)	10.90	22.10	43.80	34.10
	(32.50)	(54.60)	(91.10)	(78.10)
Raw material (000' tonnes per year)	41.70	70.80	164.00	124.00
	(55.3)	(102.00)	(314.00)	(251.00)
Labour (efficiency units per year)	205.19	915.88	1,451.18	1,194.03
	(261.00)	(2,694)	(3,872.79)	(3,396.37)
Capital (INR million per year)	353.06	511.41	997.52	787.77
	(434.68)	(888.53)	(1,596.23)	(1,359.83)
Price of output (INR per kg)	123.25	93.64	83.97	89.43
	(12.03)	(8.37)	(20.05)	(18.63)
Price of capital (ratio)	0.15	0.12	0.14	0.13
	(0.07)	(0.08)	(0.12)	(0.10)
Price of raw material (INR per kg)	29.76	20.92	15.30	18.07
	(24.18)	(21.52)	(5.49)	(15.14)
Price of labour (INR per worker per year)	93400.47	52,645.46	56,377.19	56,814.00
	(48,496.80)	(1,035.82)	(4,062.39)	(13,943)

Note Figures in parentheses are the standard deviations of the respective value in the given sub-period.
Source Authors' calculation

2009–17 (Table 1; see the coefficients of the cost frontier model in Table 1 in the Appendix).

The increase in population, urbanization, and per capita income led demand to surge during the study period; in response, output grew at 4.20% per annum, improving profitability by 5.90% and the TFP by 2.80% (Table 2).

The main contributor to the TFP growth rate was technical efficiency change, which grew at 2.50%, or close to the TFP growth rate, driven probably by improvements in knowledge, experience, and investment in research and development (R&D). The scale change was the second contributor to the TFP growth rate.

The dairy industry accrued economies of scale at 0.60% during the study period (1993–2017). The technical change component fell; technological regress led profitability to fall at 0.30%, due probably to the adoption of obsolete technologies. The output price fell at 3.70%; the real prices of products fell over the years, due potentially to an increase in competition—which forced firms to sell their products at competitive prices—but the 2.60% fall in input prices contributed positively to the change in profitability. Any growth in output improves profitability, and any increase in output price increases profit; similarly, any increase in input price reduces profits and profitability. Thus, all the components of TFP except output price and technical change contributed positively to the change in profitability.

From 1993 to 1999, profitability grew at only 0.80%, but the TFP grew at a high 8.40%, driven mainly by high growth in technical efficiency (12.80%) and scale change (3.10%), and despite the 7.60% fall in technical change. The output grew at 3.60%, input prices increased by 4.50%, despite the 6.60% fall in output prices; both the changes, in input and output prices, negatively affected profitability.

The profitability growth rate improved in the second sub-period, 2000–08, mainly because output grew at 3.50%, almost the same rate as in 1993–99, the previous period. Price factors contributed— output prices fell, but at a lower rate (1.70%), and input prices increased (by 4.50%), resulting in a net price effect of 2.80%.

Table 2 Changes in profitability of dairy industry and its components (1993–2017)

Variables	Sub-period			Overall
	1993–99	2000–08	2009–17	
Total factor productivity (+)	0.084	0.013	0.034	0.028
Scale (+)	0.031	0.007	0.004	0.006
Technical change (+)	–0.076	–0.036	0.020	–0.003
Technical efficiency change (+)	0.128	0.042	0.010	0.025
Output change (+)	0.036	0.035	0.046	0.042
Output price change (+)	–0.066	–0.017	–0.047	–0.037
Input price change (–)	0.045	–0.045	–0.018	–0.026
Profitability change	0.008	0.076	0.050	0.059

Source Authors' estimates

Technical efficiency improved, although at a lower rate (4.20%) than earlier, in 1993–99 (12.80%)—as did the scale change (0.70%, compared to 3.10%)—and reduced the growth in TFP to 1.30%. The technical change fell—but at 3.60%, less than the 7.60% in 1993–99, the first sub-period—indicating that better technologies were adopted between 2000 and 2008, the second sub-period.

Between 2009 and 2017, the third sub-period, price factors changed and reduced the profitability growth to 5.00%. The output price fell (by 4.70%), as did input prices (1.80%), instead of growing as in the second sub-period, 2000–08. Output growth improved (4.60%); and TFP growth (3.40%) increased mainly because technological processes improved (2.00%), despite a fall in the growth rate of technical efficiency to 1.00% and of the scale component to 0.40%.

Throughout the study period (1993–2017), therefore, output growth contributed consistently to the dairy industry's growth in profitability, as did the fluctuations in the growth rate of output prices and input prices. The TFP of the organized food and beverages segment was low during the 1980s and early 1990s; it improved in the late 1990s but decelerated in 2014–15 (Bathla and Kannan 2020). The growth in the dairy industry's TFP fluctuated, but was positive, throughout the study period (1993–2017). In the first sub-period (1993–99) and in the second (2000–08), the TFP grew because technical efficiency improved, but in the third sub-period (2009–17) the TFP grew due to the improvement in technical change.

The scale component fluctuated wildly over the years; it grew during the late 1990s but hovered around 0 (Figure 1). The growth in technical change was negative until 2008, but although its mean value was –0.30%, it improved steadily, though marginally. The rate of decrease in technical efficiency change increased initially but slowed down gradually; it tended towards 0 over the last few years. Therefore, input-oriented efficiency grew over the study period (1993–2017) but at a decreasing rate/extent of growth, indicating an increase in the overuse of inputs and a resulting increase in production cost.

Until the early 2000s, the TFP exhibited a decreasing trend, mainly because the scale component decreased and the technical efficiency change declined at an increasing rate. Later, the rate of decline in technical efficiency change decreased, and the scale component and technical change improved; as a result, the TFP improved. The study period (1993–2017) was marked by high variability in profitability and in the change in output price and in output and input prices, but no trends were noticeable.

Decomposing change in profitability by firm size

We analysed the firms by size to determine the variation in profitability growth by component (Table 3; see the coefficients of the cost frontier model in Table 1 in the Appendix). During the maximum likelihood estimation, convergence could not be achieved for small firms; so, we excluded small firms from our analysis.

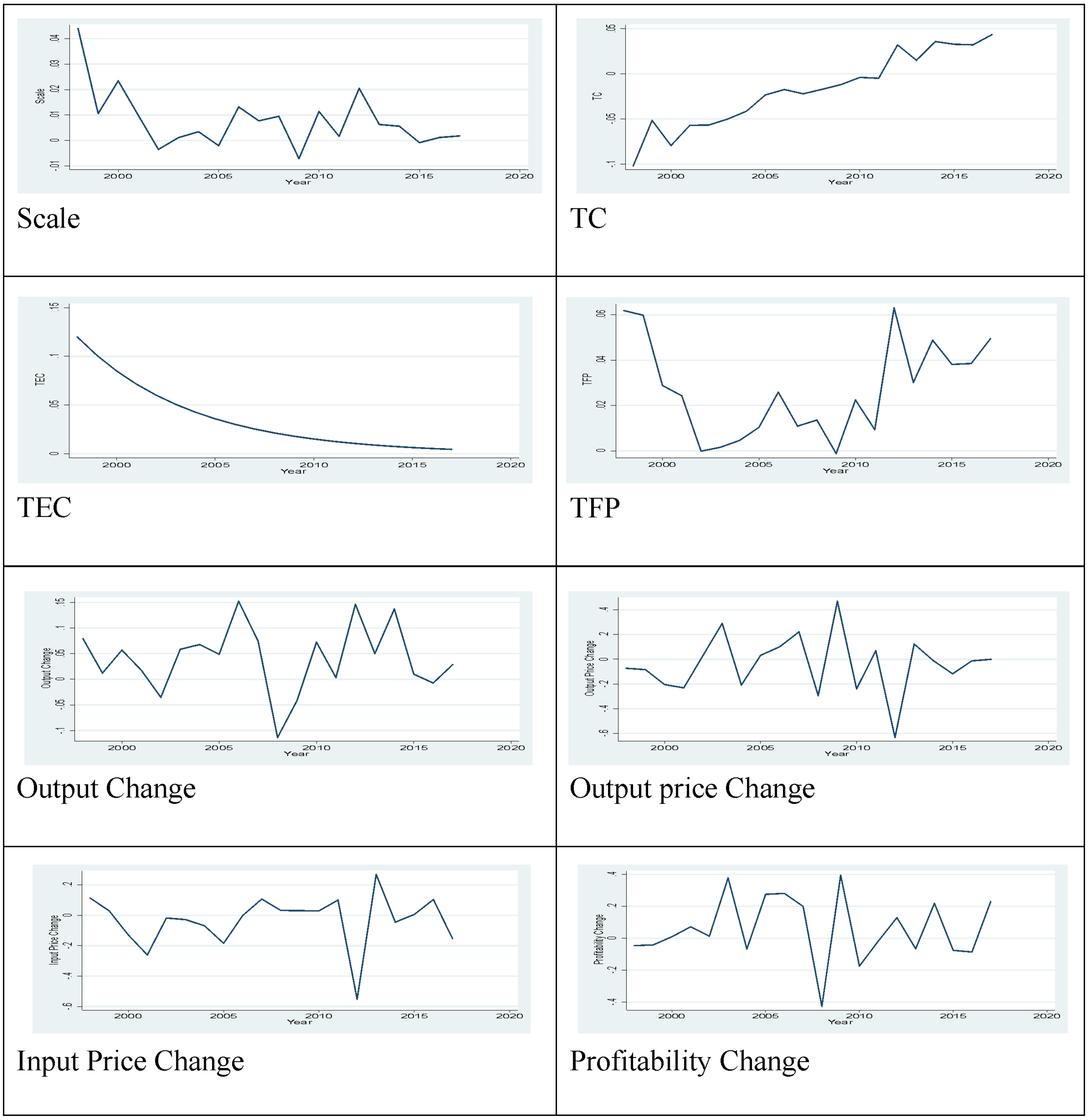

Figure 1 Annual variation in the change in profitability of the dairy industry (1993–2017)
Source Authors' calculations

During the study period (1993–2017), the profitability of large firms increased at 6.10% per annum, primarily because of the 4.20% growth in output (Table 4). The profitability of medium-size firms increased, too, though at a lower 4.90%, and also primarily because output grew (at 3.70%). The output growth and profitability may have been higher for large firms because these can produce larger volumes and sell higher quantities. The second-largest contributor to profitability was TFP; it grew at 3.00% for large firms and at 2.40% for medium-size firms.

The technical efficiency change grew at 3.20% for large firms and at 1.50% for medium-size firms. Large firms

Table 3 Summary statistics of variables by firm size (1993–2017)

Variables (per firm)	Large	Medium
Output (000' tons per year)	67.60	6.13
	(105.00)	(7.35)
Raw material (000' tons per year)	238.00	28.80
	(334.00)	(39.20)
Labour (efficient unit per year)	2321.92	246.01
	(4737.07)	(315.42)
Capital (INR in million per year)	1465.69	224.35
	(1753.70)	(240.31)
Price of output (INR per kg)	89.56	89.58
	(19.05)	(18.42)
Price of capital (ratio)	0.14	0.13
	(0.12)	(0.09)
Price of raw material (INR per kg)	18.87	17.56
	(17.41)	(13.74)
Price of labour (INR per worker per year)	56916.01	56609.53
	(14428.01)	(13363.95)

Note Figures in parentheses are the standard deviations of the respective value in the given sub-period
Source Authors' calculations

Table 4 Change in profitability and components by firm size

Component	Large	Medium
TFP (+)	0.030	0.024
Scale (+)	0.018	–0.009
TC (+)	–0.019	0.018
TEC (+)	0.032	0.015
Output change (+)	0.042	0.037
Output price change (+)	–0.032	–0.045
Input price change (–)	–0.020	–0.034
Profitability change	0.061	0.049

Source Authors' estimates

have economy of scale and can use resources efficiently; that is why their growth in technical efficiency was so high. Technical change, on average, reduced the profitability of large firms (at 1.90%) and improved it for medium-size firms (at 1.80%). The scale component of large firms grew at 1.80% but fell at 0.09% for medium-size firms; growth due to economies of scale was higher for large firms.

Output prices fell 3.20% for large firms but by 4.50% for medium-size firms because the product mix differed. Input prices fell 2.00% for large firms but by 3.40% for medium-size firms and improved profit.

Throughout the study period (1993–2017), the changes in profitability, output, and input and output prices fluctuated wildly for large firms (Figure 2) and medium-size firms (Figure 3). The TFP increased for large and medium-size firms from 2008 to 2017, driven mainly by technological change, and technical efficiency fell continually.

Conclusions

The growth of an industry depends on the availability of resources, policies and regulations, competition between firms, and the adoption of modern technologies. Profitability is affected by location parameters, like access to input and output markets, the number of firms in an area, and fiscal policy (Asiseh et al. 2010); any change in these factors over a period may affect firm productivity, efficiency, and profitability. And industry competitiveness is hindered by large inefficiencies in resource use; high cost of production and packaging; safety and quality issues; irregular access to finance; and inadequate investment in the marketing, transport, and cold chain infrastructure for perishables (Bathla and Kannan 2020).

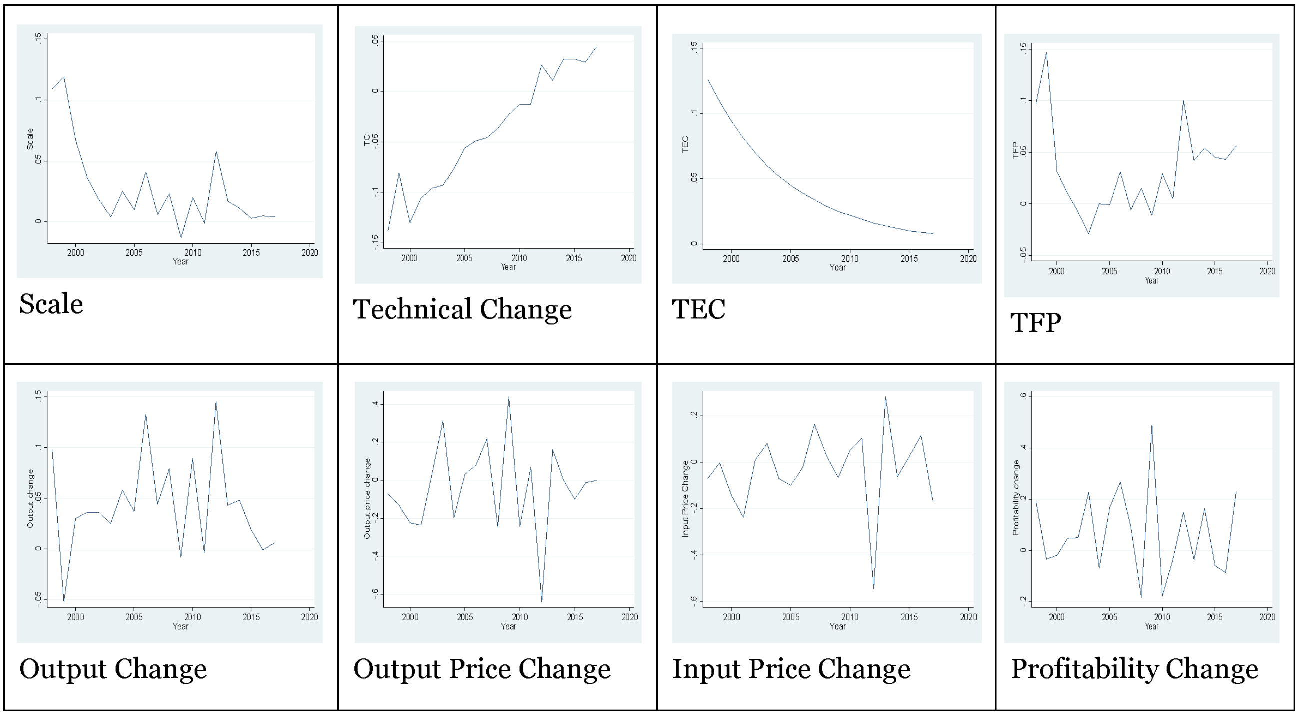

Figure 2 Large firms' profitability change (annual variation, 1998[1]–2017)

Note [1]When we divided the total sample into categories, we were getting convergence only with data from 1998 to 2017, because the number of observations prior to 1998 is insufficient. However, for the industry overall, we clubbed the observations of all firm categories together, and we could get convergence with the data from 1993 to 2017 because the number of observations is sufficient.

Source Authors' estimates

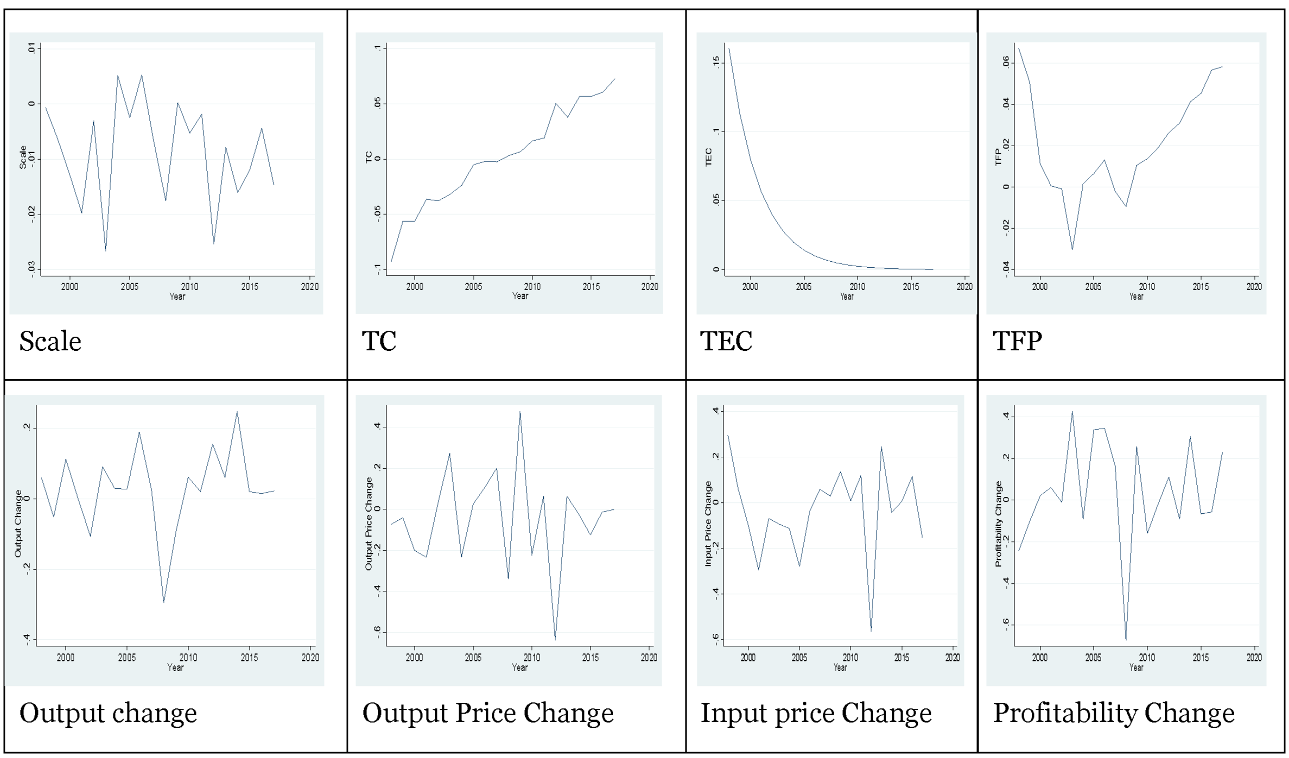

Figure 3 Medium-size firms' profitability change (annual variation, 1998–2017)

Source Authors' estimates

The population is increasing, as are urbanization and per capita income, and the demand for milk and milk products is growing in response. Therefore, there is enormous potential for the organized sector to process milk and add value. That is important particularly because value addition can help farmers access remunerative pricing and markets; and the dairy industry provides food, nutrition, and livelihoods to millions of people and plays a pivotal role in socio-economic development.

At the individual producer level, a firm aims to maximise profit, but profitability can be maximized even with suboptimal productivity; therefore, the profitability measure alone may not indicate an industry's productivity and efficiency. Besides, firm profitability may be affected not only by firm-level factors but also by exogenous factors like price factors (input prices, output prices, and mark-up) and non-price factors (efficiency, technical change, returns to scale, and output growth (Kumbhakar and Lien 2009). And firms may be inefficient (overuse inputs for a given level of output and incur additional costs) or efficient (use inputs efficiently, reduce cost, and improve profit). The technical efficiency change is positive for efficient firms and negative for inefficient firms. In addition, output change indicates the growth in the quantity of output.

From 1993 to 2017, the dairy industry's profitability grew at 5.90% per annum, driven largely by the growth in output and TFP, the growth in TFP driven mainly by increases in technical efficiency and technical change. The rate of growth in technical change increased for large and medium-size firms and growth in technical efficiency declined. Firms should use inputs efficiently and improve input-oriented technical efficiency to raise profitability.

The change in input and output prices was negative for most categories. The fall in input prices improved profitability. The trends for the sub-periods show that during the 1990s, TFP and technical efficiency change contributed to the change in profitability, and both these indicators registered a decrease over the time period.

Dairy firms, whether large or medium-size, cannot use modern technologies and resources. That may be why, over time, technical inefficiencies increase and the TFP falls. Firms need to scale investment to adopt modern technologies and improve their input-oriented technical efficiency to reduce costs and improve profitability and growth. A stable price environment would incentivize firms to scale investment and production.

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Appendix

Table A1 Coefficients of cost frontier model for dairy industry (overall and by firm size)

Variables	Overall		Large		Medium	
ltcd	Coefficients	Standard Error	Coefficients	Standard Error	Coefficients	Standard Error
ly	1.67***	0.27	3.79***	0.49	0.55	0.59
ly^2	–0.01***	0.01	–0.10***	0.01	0.09***	0.02
lwkd	–0.87	0.76	–2.27**	1.05	0.43	0.99
lwld	3.13***	1.46	4.90**	2.07	3.56*	2.08
$lwkd^2$	–0.02	0.04	–0.13***	0.05	0.08*	0.05
$lwld^2$	–0.08	0.13	–0.12	0.18	0.08	0.16
lwkld	0.09	0.07	0.08	0.09	0.06	0.09
lylwkd	0.04***	0.01	0.09***	0.02	0.00	0.03
lylwld	–0.05**	0.03	–0.14***	0.04	0.11*	0.06
t	0.17*	0.09	0.00	0.12	0.14	0.13
tt	–0.01***	0.00	–0.01***	0.00	0.01***	0.00
tly	0.01***	0.00	0.02***	0.00	0.00	0.00
tlwkd	–0.02***	0.00	–0.03***	0.01	0.02***	0.01
tlwld	–0.03***	0.01	–0.04***	0.01	0.02*	0.01
Constant	–21.99***	8.55	–49.13***	12.73	11.79	12.74
N	1025		475		471	
Model significance	Wald Chi2 = 23391.84, Log likelihood = –435.60, Prob > chi2 = 0.000		Wald Chi2 = –8479.71, Log likelihood = –74.8, Prob > chi2 = 0.000		Wald Chi2 = –6091.2, Log likelihood = –166.905, Prob > chi2 = 0.000	

Source Authors' estimates

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Spatio-temporal distribution of subsidy on major livestock inputs and services in India

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Abstract We estimate the subsidies on the major inputs and services to the livestock sector in India. The livestock subsidy increased at 7% per annum from 2006 to 2017. Of the total livestock subsidy, veterinary and health services accounted for 75%, and livestock insurance the least, although it grew at a high rate. We also construct an agricultural development index. The rank correlation between the livestock subsidy and the index shows that the allocation of subsidy is higher to states that rank low on the index, as it should be, because less developed regions need more support for growth and development.

Keywords Livestock, subsidy, spatio-temporal analysis, agricultural development index, development

JEL codes Q12, C22, C23, C82, O11

Livestock is one of the fastest-growing sub-sectors of agriculture in developing countries (Thornton 2010). The world's production of milk grew by 13% per annum from 2002 to 2007, predominantly through smallholder dairy production in China, India, and Pakistan (FAO 2010).

The livestock sector in India provides a livelihood to 20.5 million people and employment to about 8.8% of the population. The sector contributes around 4% of the gross domestic product (GDP) and 25.6% of the agricultural GDP (GoI 2019). The income elasticities of demand for livestock products are higher; every 1% increase in income raises expenditure by 1% (Ghandi and Zhou 2010). Therefore, the demand for livestock products is increasing; and the sector is evolving rapidly in response (Steinfeld and Mäki-Hokkonen 1995).

Livestock is the mainstay of small and marginal farmers, who make up almost 85% of agricultural households. Individually, most farmers are resource-poor; subsidies on livestock inputs and services make smallholder production systems sustainable, and the government has instituted many schemes to help farmers make livestock farming a primary occupation rather than a secondary one. The marketable surplus of livestock farmers is small, but they produce about 73% of the milk in the country. Collectively, therefore, they represent an opportunity for aggregation.

The livestock sector's share in agricultural GDP has been growing at 4% per annum, and the growth in yield is often linked to poverty reduction (Bathla, Joshi, and Kumar 2019). And structural changes in livestock production are supported by institutional reforms (Chandel, Lal, and Kumari 2019). But the livestock sector receives fewer resources and less institutional support than commensurate with its contribution to the economy (Qureshi et al. 2015).

Yet, few researchers have studied the livestock sector, and livestock subsidies have not been quantified because these were implicit or disbursed through development programmes and agricultural subsidies were estimated under subsidies on irrigation, fertilizer, power, and credit. The literature on livestock subsidies is sparse, therefore, and this study attempts to fill the gap by determining whether the subsidy to the livestock sector is commensurate with its contribution to the economy.

Forms of subsidy to the livestock sector

Subsidies are disbursed in many ways, and a wide range of methodologies is used to estimate subsidies. The methodologies are described in the Global Subsidies Initiative manual (Jones and Steenblik 2010). We use the FAO (2003) guide for identifying, assessing, and reporting on subsidies in the fishery sector.

Subsidies to the livestock sector may be direct, or these may take the form of subsidies on veterinary and health services, credit or interest, or livestock insurance.

Direct subsidy

The financial accounts of the centre and the states have a head called "subsidy". The direct subsidy is the expenditure mentioned directly under the subsidy head; it is the financial allocation made for subsidies under the schemes and components and routed mainly through the state departments of agriculture and allied sectors. But subsidies are not presented in the same pattern in the finance account documents of all the states.

From the state financial accounts, we collected the data on livestock subsidies on cattle and buffalo development, feed and fodder development, dairy development projects and milk federations, veterinary services and institutions, livestock insurance, and other livestock development schemes.

Subsidy on veterinary and health services

Artificial insemination centres and veterinary hospitals provide veterinary and health services (such as vaccination). The expenditure accounts for 25% of the total public expenditure (Birthal and Taneja 2012) but the services are provided free or at a nominal fee. The difference between the expenditure and receipts, or the unrecovered cost, is a form of subsidy to the livestock sector.

We follow the unrecovered cost approach (Mundle and Rao 1991; Srivastava et al. 2003) to estimate the subsidy on veterinary and health services. We collected the data on public expenditure and receipts from the state finance accounts and aggregate it to generate country-level estimates.

Credit/interest subsidy

We cannot calculate the credit/interest subsidy directly, because the central and state financial documents club the agriculture and livestock sectors' loans outstanding into the "agriculture and allied sectors" head. Therefore, we followed a multi-step procedure to estimate the credit/interest subsidy to the livestock sector.

First, we selected a few states and banks, and their major loan-disbursing branches, and determined the amount of loans disbursed to the livestock sector. Drucker et al. (2006) used this so-called survey method to determine the main subsidy types to the piggery sector.

Then, we calculated the state-level loans outstanding to the livestock sector by segregating its average share in the loans outstanding at these branches to the agriculture and allied sector.

We collected our primary data from commercial nationalized banks. We found that they disbursed credit at a concessional rate to animal husbandry for the purchase of animals; setting up mini dairies, milking parlours, and cold chain facilities; and the purchase of bulk milk cooling units and dairy processing infrastructure.

We obtained the outstanding credit in agriculture and allied sector from secondary sources: cooperatives, regional rural banks, and commercial banks.

To segregate the outstanding country- and state-level credit to the livestock sector from that to the agriculture and allied sector, we used the percentage share of the outstanding livestock credit in the total agricultural credit.

Banks charge the agricultural and livestock sectors a lower credit/interest rate than the other sectors of the economy. To estimate the credit subsidy to the livestock sector, we multiplied the outstanding credit with the difference between the interest rate to agriculture and to the other sectors of the economy.

Livestock insurance subsidies

The difference between the premium paid by farmers and the premium fixed by insurance companies is the livestock insurance subsidy. The subsidy data was directly available for most states. In the cases where data was not available, we estimated the livestock insurance subsidy on the basis of the number of animals insured and the subsidy sharing pattern between the state and central governments (50:50).

We quantified the livestock subsidy for the period from 2006 to 2017. Then, to remove the impact of inflation, we deflated the values using a GDP deflator with 2011–12 as the base year.

We computed the compound annual growth rate (CAGR) and conducted a tabular analysis to estimate the real growth in subsidies, and we compared the real growth in the zones. We conducted a spatio-temporal analysis and estimated the subsidy allocated per unit to remove the effect of the size.

Agriculture development and the state agriculture development index

How are subsidies related to a state's agricultural development? We conducted correlation analysis and rank correlation analysis to answer this question.

We constructed an agricultural development index using 10 indicators—irrigation percentage, cropping intensity, share of area under cereals to total area, share of small and marginal holdings to total holdings, animal density, number of animals served per cooperative society, milk production, per capita milk availability, percentage of crossbred animals, and farmer's income—and scored the major states on the index.

We collected the data on the indicators for the triennium ending (TE) 2016–17 from a variety of secondary sources. We collected the data on irrigation percentage, cropping intensity, area under cereals, and small and marginal holdings were collected from the Handbook of Statistics on Indian States, the Economic Survey reports of states, and the websites.

We collected the data on livestock data related to animal density, number of animals served per cooperative societies, milk production, per capita milk availability, and the number of crossbred animals from reports of Basic Animal Husbandry and Fishery Statistics and the 19th Livestock Census.

We collected the data on farmers' income from the National Sample Survey (NSS) 70th round report on Income, Expenditure, Productive Assets and Indebtedness of Agricultural Households in India.

We normalized the data to make it unit-free, or bring them into a comparable range, by subtracting the minimum value from the observed value and dividing the range of the corresponding indicator (Mahida et al. 2018; Feroze and Chauhan 2010; Ayyoob, Krishnadas, and Kaeel 2013; Ponnusamy, Sendhil, and Krishnan 2016). Then, using E-views to conduct principal component analysis, we assigned weights to each indicator:

$$W_i = \Sigma\, |L_{ij}|\, E_j \qquad \ldots(1)$$

where,

W_i is the weight of the i^{th} indicator

E_j is the eigenvalue of the j^{th} factor

L_{ij} is the loading value of the i^{th} state on j^{th} factor.

We summed the product of weights and value of indicator and divided the sum by the aggregate value of weights to calculate the index:

$$I_{State} = \frac{\Sigma_{i=1} X_i W_i}{\Sigma_i W_i} \qquad \ldots(2)$$

Where,

$$W_i = \Sigma\, |L_{ij}|\, E_j \qquad \ldots(3)$$

I_{state} is the index value of each state

X_i is the normalized value of i^{th} indicator.

We calculate each state's score on the index, rank them by score, and categorize the states by type of development into low, medium, and high. We also rank the states by total subsidies allocated per unit and determine if the allocation of subsidy was disproportionate. We estimated a rank correlation coefficient (ρ) to determine whether a state's rank on the agricultural development index was the same as the total subsidy per unit.

$$\rho = 1 - \frac{6\Sigma d_i^2}{n\,(n^2-1)} \qquad \ldots(4)$$

where

ρ is a rank correlation coefficient, and

D is the rank difference between two variates of the ith state, and 'i' varies from 1 to n.

Results and discussion

Researchers have estimated the subsidy to the livestock sector by component and state in aggregate and per unit. We calculate the rank correlation between the livestock subsidy per unit and a state's agricultural development index to determine whether and how much the allocation of livestock subsidy to a state depends on its development status.

Subsidy by component

We computed the proportion and quantum of subsidy allocated to the livestock sector by component (direct subsidy, veterinary and health services, credit, and insurance) from 2006 to 2017 (Table 1). We also calculated the CAGR.

Around 80% of the subsidy to the livestock sector takes the form of veterinary and health services; the allocation, INR 1,791.47 crore (USD 223.93 million) in TE 2008–09, grew at 5.97% per annum to INR 2,870.39 crore (USD 358.75 million) in TE 2016–17. But the percentage share decreased during the study period, implying that the subsidy to other components increased faster.

The rest of the subsidy to the livestock sector, around 20%, takes the form of direct subsidies and subsidies on credit and insurance (1–3%). The subsidy on livestock credit, INR 174.62 crore (USD 21.83 million) in TE 2008–09, increased at 6.62% per annum to INR 283.57 crore (USD 35.45 million) in TE 2016–17.

The third highest allocation was to direct subsidy, the subsidy provided to purchase animals and small equipment for dairying. The subsidy to livestock insurance was the least.

The subsidy on insurance and the direct subsidy are increasing at a higher rate, indicating the success of several schemes implemented to uplift the sector.

The intensity of allocation as depicted by subsidy per milch animal reveals that the allocation to veterinary and health services was the highest, and it increased from INR 162 (USD 2.03) to INR 235 (USD 2.94) over the period, at a CAGR of 4.64%.

The veterinary and health services subsidy per animal grew at a lower rate than the total subsidy, implying that the subsidy on veterinary and health services has not risen commensurate with the increase in the population of milch animals.

The Government of India initiated a subsidized livestock insurance scheme in 2006. But the scheme could cover only 900,000 dairy animals by 2010–11 and only 300 districts and 6% of the animal heads

Table 1 Livestock subsidy by component (constant prices, base year 2011–12)

Components	Triennium average						CAGR (%)	
	TE 2008–09		TE 2012–13		TE 2016–17		Total	Per milch animal
	Total (INR crore/ USD million)	Per milch animal (INR / USD)	Total (INR crore/ USD million)	Per milch animal (INR / USD)	Total (INR crore/ USD million)	Per milch animal (INR / USD)		
Direct subsidy	78.53 / 9.82 (3.79%)	7.00 / 0.09	245.11 / 30.64 (8.16%)	21.00 / 0.26	33.13 / 265.04 (7.51%)	22.00 / 0.23	24.32%	22.76%
Veterinary and health services	1791.47 / 223.93 (86.44%)	162.00 / 2.03	2440.39 / 305.05 (81.23%)	206.00 / 2.60	2870.02 / 358.75 (81.33%)	235.00 / 2.94	5.97%	4.64%
Livestock insurance subsidy	27.83 / 3.50 (1.34%)	3.00 / 0.04	59.23 / 7.40 (1.97%)	5.00 / 0.06	110.38 / 13.80 (3.13%)	9.00 / 0.11	19.57%	15.68%
Livestock credit subsidy	174.62 / 21.83 (8.43%)	16.00 / 0.20	259.55 / 32.44 (8.64%)	22.00 / 0.28	283.57 / 35.45 (8.04%)	23.00 / 0.29	6.62%	5.28%
Total	2072.45 / 259.06 (100.00%)	187.16 / 2.34	3004.28 / 375.54 (100.00%)	253.85 / 3.17	3529.01 / 441.126 (100.00%)	288.56 / 3.61	7.00%	6.65%

Source Estimation based on data from secondary sources
Note Figures in parentheses are percentages of column total

excluding poultry by 2013 (Birthal and Taneja 2012). Farmers do not subscribe to livestock insurance schemes despite the subsidy mainly because of technical or implementation reasons. Therefore, the government needs to raise awareness, increase the number of delivery channels to doorstep, and devise a mechanism for settling claims immediately. That will encourage farmers to subscribe to insurance schemes and also increase the livestock insurance subsidy.

Subsidy by state

We analysed the allocation of subsidy by state and milch animal (Figure 1). The allocation was the highest in Maharashtra, Rajasthan, Haryana, and Tamil Nadu in all the triennium averages.

We plotted the subsidy per animal against the total allocation in each state. We found that higher the allocation, less the subsidy per animal—or the allocation intensity was disproportionate to the animal population—and exceptionally so in Kerala and Himachal Pradesh (for the subsidy by components, see Tables 1 to 4 in the Appendix).

The subsidy allocated per animal improved in TE 2016–17 in Haryana and Tamil Nadu. The subsidy per animal on veterinary and health services was higher in these states, and its effect is evident in the higher milk productivity and share of crossbred animals.

The livestock subsidy is allocated disproportionately among the states, overall; the total allocation to the topmost states is high but the allocation per animal is low. The variation in the subsidy allocated per animal between the states has increased.

There were improvements in some states; for instance, the livestock subsidy per animal almost doubled in Haryana because veterinary and animal health services improved. Dairy farming is advanced in Gujarat and Punjab. Their marketing networks are strong, and they provide many services to dairy farmers without needing recourse to subsidy. That is why the allocation of livestock subsidy (total and per animal) was lower in both states. Punjab spent more than Gujarat on livestock credit and insurance but less on veterinary and health services.

Growth rate by state

The livestock subsidy grew at 5.65% CAGR and the subsidy per animal grew at 7.00% CAGR (Table 2). Kerala received the highest subsidy per milch animal.

Figure 1 State-wise total livestock subsidy and per milch animal subsidy for three time intervals

Table 2 Distribution of states by growth rate in livestock subsidy and in subsidy per animal (2006–07 to 2016–17)

CAGR (%)	Total subsidy (overall growth rate 7.00%)	Per milch animal (overall growth rate 5.65%)
Lower decrease (–5–0%)	Kerala, Punjab, West Bengal	Kerala, Punjab, Sikkim, West Bengal
Lower increase (0–5%)	Manipur, Sikkim, Tripura, Uttarakhand	Assam, Bihar, Gujarat, Jharkhand, Odisha, Tripura, Uttar Pradesh
Moderate increase (5–10%)	Andhra Pradesh, Arunachal Pradesh, Assam, Bihar, Gujarat, Haryana, Himachal Pradesh, Jharkhand, Madhya Pradesh, Meghalaya, Odisha, Tamil Nadu, Uttar Pradesh	Arunachal Pradesh, Chhattisgarh, Haryana, Himachal Pradesh, Madhya Pradesh, Tamil Nadu, Uttarakhand
Higher increase (>10%)	Chhattisgarh, Jammu and Kashmir, Karnataka, Mizoram, Nagaland	Andhra Pradesh, Jammu and Kashmir, Karnataka, Manipur, Meghalaya, Mizoram, Nagaland

Source Estimation based on data from secondary sources

Kerala, Punjab, West Bengal, and Sikkim had a negative growth rate.

The subsidy per animal increased at 5–10% in most states and at more than 10% in Andhra Pradesh, Chhattisgarh, Jammu and Kashmir, and some north-eastern states.

The total subsidy grew at a lower rate in Andhra Pradesh and Uttarakhand but the subsidy per animal grew at a higher rate because the number of milch animals decreased. In Gujarat and Chhattisgarh, however, the total subsidy grew at a higher rate but the subsidy per animal grew at a lower rate because the number of milch animals increased.

States that had a larger share of the subsidy grew at a higher rate (Figure 2). The subsidy to Kerala and West Bengal increased marginally. The subsidy per animal was highest in Kerala. The share of subsidy was lower in Andhra Pradesh, Uttar Pradesh, Assam, Karnataka, and Jharkhand, but it had grown at a high rate in the past.

States that had a high subsidy per animal grew at a lower rate than did states that had a lower subsidy per animal (Figure 4). The subsidy per animal grew at more than 15% in Jammu and Kashmir, Andhra Pradesh, and Karnataka.

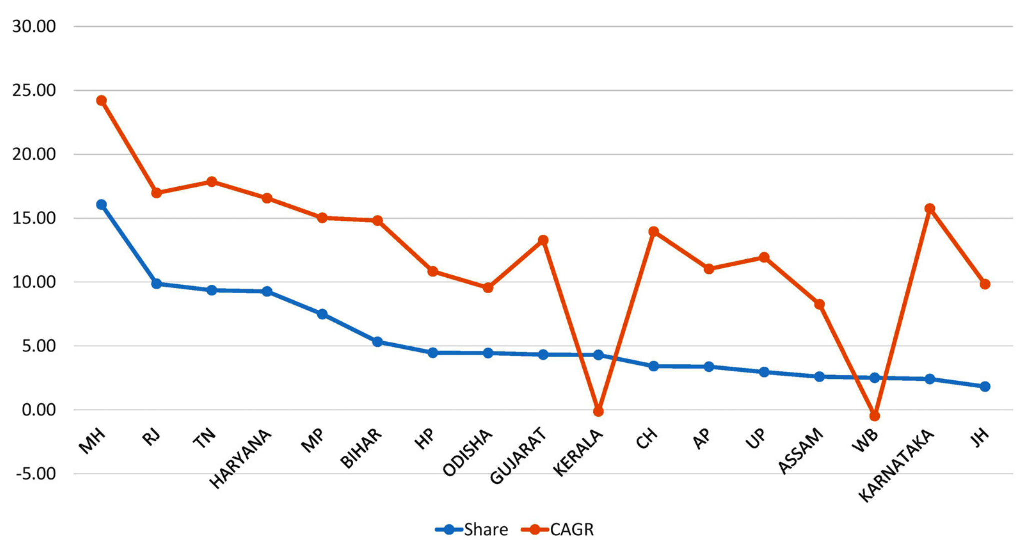

Figure 2 Trend in CAGR and share of total livestock subsidy in major states
Source Estimation based on data from secondary sources

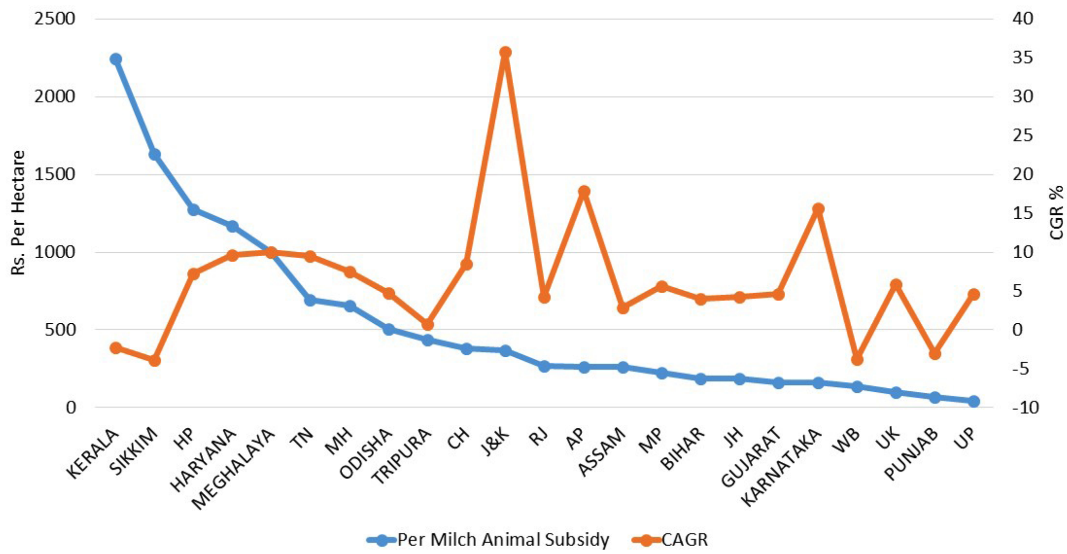

Figure 3 Trends in CAGR and subsidy per animal
Source Estimation based on data from secondary sources

The subsidy per animal on veterinary and health services increased substantially in Jammu and Kashmir, and livestock insurance improved in Andhra Pradesh and Karnataka (for the livestock subsidy by state and animal, see Table 2 in the Appendix).

Relationship of subsidy with agricultural development

To calculate the rank correlation, we correlated the states' rank on the index with their rank in the total subsidy. The rank correlation coefficient between the livestock subsidy and the agricultural development index was –0.3725, and it was –0.3376 between the livestock subsidy and the value of output from the livestock sector. The coefficient is negative, implying that the livestock subsidy was higher to the states where the value of output from the livestock sector was low or the states that ranked low on the index.

The subsidy per animal was low in the states that ranked high on the index (like Punjab, Uttar Pradesh, and Rajasthan) and high in the states that ranked low on the index (Figure 4). That is needed, as the less

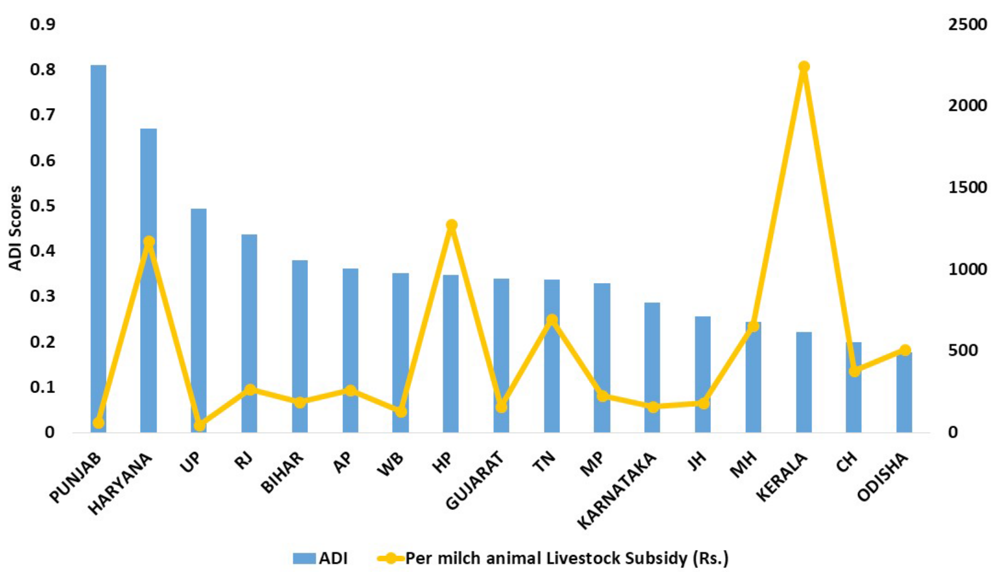

Figure 4 Agricultural development index and livestock subsidy per milch animal
Source Estimation based on data from secondary sources

developed regions require more support in the form of subsidies than the less developed regions.

Conclusions

The green revolution subsidies increased input use and, in turn, productivity (Buringh and Dudal 1987; Gordon 2000; Hazell et al. 2007; Ajah and Nmadu 2012). Agricultural development is the combination of the primary outcomes of subsidies (production and income) and the secondary outcomes (welfare effects, level of input use, farm labour employment); and it is positively correlated with subsidies (Deshpande and Reddy 1992).

Government documents cite some budgetary subsidies; for example, a report (GoI 2006) indicates that in the 11th Five Year Plan, the interest subsidy on the purchase of milk processing equipment was INR 550 crore (USD 8.75 million) and the capital subsidy in the 12th Five Year Plan was INR 4,000 crore (USD 500 million). The total subsidy in the central budget on crop husbandry was INR 4,672 crore (USD 584 million) in 1998–99; the subsidy in terms of unrecovered costs on the economic services of animal husbandry and dairy development was INR 138 crore (USD 17.25 million), or 2.95% of the total central budget subsidy on crop husbandry (Srivastava et al. 2003).

Both subsidies and investment increase the use of fixed inputs and improve agricultural income, and the government must keep subsidies and investment at equilibrium. But subsidies, now constituting about 2.5% of India's GDP, also impose negative externalities on both the exchequer and the environment. As agricultural growth stagnates, and because the resources for expenditure are limited, policymakers must shift the expenditure from subsidies to investment to boost growth (Jha 2011; Qureshi et al. 2015). The government is planning to support farmers by direct benefit transfer, phase out the subsidies, and replace these with additional production and sales subsidies; these measures would raise real farm income by about 4% and improve welfare overall (Dixon et al. 2020).

We attempt to quantify the subsidy to the livestock sector and analyse whether it is commensurate with the sector's contribution to the economy. To do so, we consider the range of indicators of agricultural development and construct a comprehensive agricultural development index that includes the components of the livestock subsidy.

The livestock subsidy, INR 2,072.45 crore (USD 259.06 million) in TE 2008–09, grew at 7% per annum to INR 3,529.01 crore (USD 441.13 million) in TE 2016–17. In comparison to the livestock sector's share in the economy (4.9% of gross value added in 2017–18), the subsidy was disproportionately low; and the subsidy per milch animal, which grew at a low 5.65% CAGR, was still not commensurate with the animal population. About 75% of the subsidy was allocated to veterinary and health services. The insurance subsidy had the least of the allocation, but it grew at a high rate.

The livestock subsidy allocated to poorly developed regions was greater than to well-developed regions. That indicates that the allocation of the subsidy was rational. The subsidy per animal was high in states where the allocation was high, in all the three TE averages, with a few exceptions.

There were improvements in some states; for instance, the livestock subsidy per animal almost doubled in Haryana because veterinary and animal health services improved. Dairy farming is advanced in Gujarat and Punjab. Their marketing networks are strong, and they provide many services to dairy farmers without needing recourse to subsidy. That is why the allocation of livestock subsidy (total and per animal) was lower in both states.

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Valuing pollination services in the apple orchards of Kashmir valley

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Abstract In the Kashmir valley, managed pollination orchards yield 35.22 tons per hectare of apples on average, 19.43% more than the non-managed orchards' yield of 29.49 tons, and the quality of fruit is also better. Pollination services improved the income of managed apple orchards, and its value for apple in the Kashmir valley is estimated at INR 126.56 billion per annum. If managed pollination services are extended to the entire area under the apple crop, an additional pollination welfare implication to the tune of INR 29.71 billion (almost INR 300 crore) will be realized per annum.

Keywords Ecosystem, valuation, pollination, apple, payment for pollination services, social welfare, bio-centric approach

JEL codes Q57

Food production depends directly or indirectly on pollinated plants (Aizen et al. 2009a, b; Kremen et al. 2007). About a third of all food crops are insect-pollinated (Kevan and Phillips 2001; Nabhan and Buchmann 1997). Therefore, crop pollination is essential for the supply of human food resources (Daily 1997) and an ecosystem service of enormous economic value.

Pollination makes a significant difference to the yield and quality of fruit crops and, ultimately, translates into farm revenue. In economies based on horticulture and, particularly, fruit crops, such as Jammu and Kashmir (J&K), the role of pollinators is even more important. Pollinators enhance the quality of fruit and, consequently, the economic value of crop production (Klatt et al. 2013).

Honeybees are considered the most efficient pollinators of cultivated crops because of their potential for long working hours. The other reasons are the presence of pollen baskets, floral fidelity, micromanipulation of flowers, maintainability of high population, and adaptability to different climatic conditions (Verma 1990). Honeybees can be domesticated, marketed, and transported from place to place (Crane 1990). Using honeybees to pollinate crops and exploit their yield potential can generate an income that is 15–20 times their value as honey and other bee products (Verma 2003). The apple orchards of Kashmir valley have 20 species of insect pollinators apart from honeybees (Ganie et al. 2014), such as moths and butterflies, bumblebee, syrphid fly, and soil-dwelling beetles. Honeybees play a vital role in pollinating many cultivated crops, but this role is often underestimated in developing countries.

The populations of pollinators have declined, due mainly to habitat loss and climate change, and to the excessive application of pesticides. The diminishing

Note First two authors are equal authors
The research is part of Master's Thesis of first author under the guidance of second author.

of pollination services in agricultural environments has received considerable scientific attention, particularly because the failure of pollination has reduced crop yield. Climate change is likely to reduce agricultural productivity, and population growth will demand an increase of agricultural production by at least 70% by 2050 (FAO 2009). Achieving food security is a great challenge because agriculture has to enhance yields and produce more food while protecting biodiversity and ecosystem services, without further harm to the environment. The loss of pollination services has, to date, been confined to local cases (Needham and Bowman 1988). But we need to improve our understanding of pollination and plant–pollinator interactions and, therefore, pollination services (Balmford et al. 2002).

Apple (*Malus* x *domestica* Borkh.) is one of the most important fruit crops in the world at global level and the fourth most widely produced fruit (Mittal 2007). Apple cultivars are self-incompatible to varying extents, requiring pollen transfer from another pollenizer cultivar to set fruit in marketable quantities. Insects such as bees and hoverflies are the predominant pollination vector for apples. Thus, their activity in apple orchards worldwide is essential for production (Free 1964).

Apple is cultivated over 5.29 million hectares worldwide; the production is 89.33 million tons and productivity 16.87 tons per ha. In India, apple was cultivated over 310,000 ha in 2019–20; the production was 2.32 million tons (NHB 2020) and productivity 8.08 tons per ha. In the state of Jammu and Kashmir (J&K), apple is grown over only 160,000 ha, and in 2019–20 the production was 1.88 million tons and productivity 12.25 tons per ha (DOH-Kashmir 2020).

The population of pollinators are declining steadily in J&K, and particularly in the apple orchards of Kashmir valley, because habitats are being destroyed by the unrestrained use of agrochemicals, pesticides, and other antifungal sprays (Bajiya and Abrol 2017; Rather et al. 2017; Muzafar et al. 2018). To assess the potential loss of economic value, it is imperative to assess the true value of the pollination service to apple production.

In apple orchards, adequate pollination is important. It is important also to create markets for bee rentals so that both apple farmers and pollination service providers alike may profit.

We undertook the study to

- quantify the influence of honeybee pollination on the yield and quality of commercially important apple cultivars,
- estimate the economic value of honeybees to apple production, and
- provide policy recommendations.

Methodology

We conducted the study in four districts of Kashmir valley: Shopian and Pulwama, from south Kashmir; Baramulla, from north Kashmir; and Srinagar, from central Kashmir. We purposively selected these districts, and the tehsils and villages, because very few farmers used honeybee colonies at their orchards for pollination services during the flowering season, and we surveyed a total of 100 such farmers. From each selected village, we surveyed as control, for comparative analysis, 30 orchardists who did not use honeybee colonies for supplemental pollination.

We collected the data by administering a pre-tested and well-structured questionnaire to the respondents. We selected the managed and control orchard groups so that the orchard age, tree density, and canopy, as well as the natural resource factors and input use, are similar enough to attribute the difference to the managed pollination service.

The market value of apple produce depends on several factors, some of which are directly influenced by pollination services. A higher fruit set and greater weight result in greater overall output; and quality parameters, such as size and shape, affect the price of apple. In terms of the added market output in a given year, the market value of pollination services is a product of the added quality and quantity of apples:

$$PVc = (Vc_{OPEN} - Vci)\,Ac$$

where,

PVc is the output added by insect pollination services in cultivar c across the sampled farmers,

Vc_{OPEN} and Vci are the total economic output per hectare of apple under open pollination and managed pollination treatments (when considering deficits), and

Ac is the total area cultivated with apple in 2018 (from the Directorate of Horticulture, J&K).

Garrat et al. (2014a, b) adopted a similar approach. We used, apart from tabular analysis, various statistical tools to analyse the data. To estimate the contribution of factors determining the resource use efficiency, and the farm gate value output (FGVO) of the sampled apple orchards, we used the multiple regression model:

$Y = \alpha + \beta_1 X_1 + \beta_2 X_2 + \dots \dots + \beta_P X_P + E$

where,

α = intercept,

$\beta_1, \beta_2, \dots \dots \beta_P$ = estimated regression coefficients,

$X_1, X_2, \dots \dots X_P$= independent variables, and

E= error term.

We used this functional form to quantify the determinants for the payment for pollination services. We used the partial budgeting technique to arrive at the comparative economics of managed and non-managed apple orchards and estimate the returns on investment in managed pollination services in the apple orchards of Kashmir valley. To quantify the economic value of pollination service provided by honeybees in case of apple, we employed two empirical models:

Pollination service value = V × D × P

where,

V = Annual value of the crop

D = Dependency of the crop on insect pollinators

P = Proportion of (effective) insect pollinators (honey bees in case of apple).

Pollination welfare implications (W) = S. Δq

Where,

W = welfare implication (Rs.)

S= area under apple production (ha)

Δq = increase in net returns (Rs./ha) as a consequence of pollination service

Δq = added returns from pollination service – added costs of pollination service.

The formulae for pollination service value and pollination welfare implication have been used earlier (Lars Hein 2009; Partap et al. 2012, 2017; Garrat et al. 2014a, b).

Results and discussion

The scientific fraternity is aware that managed pollination services are important in offsetting the pollination deficits. Their awareness has led the apple growers of Kashmir valley to use honeybee hives during the flowering season. We present and discuss the findings on the various dimensions of the study in the following sections.

Improvement in apple productivity

Pollination as an ecosystem service is vital for the yield and quality of apple. Honeybees are the major pollinators.

The yield averaged 35.22 MT per hectare in managed pollination orchards and 29.49 MT in non-managed orchards (Table 1). Supplementary pollination by honeybees enhanced the apple yield by 19.43%. The findings are in accordance with previous studies (Partap et al. 2017; Dar 2016; Mattu and Raj 2015; Bhagat and Mattu 2013).

Partap et al. (2017) found that honeybee pollination in the Chitral district of Pakistan increased apple yield by 41.9% in 2014 and 47.9% in 2015. Dar (2016) found that in the Srinagar and Budgam districts of Kashmir valley, the yield from controlled pollination with *Apis mellifera* was 205% of natural pollination. Mattu and Raj (2015) and Bhagat and Mattu (2013) reported that

Table 1 Impact of honeybee pollination on apple yield

Apple yield (MT/ha)		Difference (T_y– C_y)	Increase in yield due to managed honeybee pollination (%)	Value of ‘z’ (calculated)	p – value
Managed pollination orchards (T_y)	Non-managed orchards (C_y)				
35.22	29.49	5.73 MT	19.43	4.51	0.032*

*at 5% level of significance, z (tabulated) = 1.96
Source Output results from surveyed data of Master’s thesis

Table 2 Comparison between managed and control orchards

Inputs	Managed orchards	Non-managed orchards	Value of 'z'	p – value
Farm size (ha)	0.82	0.58	1.37	0.130*
Tree density (No.)	192	133	1.49	0.104*
Age of orchard (years)	23	19	1.84	0.071*

*at 5% level of significance, z (tabulated) = 1.96
Source Output results from surveyed data of Master's thesis

pollination by honeybees increased the fruit set and reduced the fruit drop in Royal Delicious variety of apple in the Kullu valley and Shimla hills of Himachal Pradesh, India.

To find out whether pollination causes the difference in yield, we employed a z-test to compare managed and non-managed orchards with respect to different inputs. All the input averages—farm size, tree density, and age of orchards—were found to be statistically non-significant ($p>0.05$), implying that the difference in output is attributed to managed pollination (Table 2).

To obtain the production coefficients of potential variables, we estimated a production function in which the explained variable (dependent variable) was the output per hectare, and explanatory/independent variables were age of the orchard, farm size, tree density, and pollination as a dummy variable (1 for managed orchards and 0 for non-managed orchards).

The input variables explain 80.6% of the variation in output per hectare (Table 3). The estimated coefficients were found to be statistically non-significant for the age of the orchard, farm size, and tree density. But pollination showed a positive and statistically significant ($p<0.05$) impact on output per hectare, suggesting that managed pollination influences output.

Table 3 Estimated production coefficients of sampled apple orchards

Independent variables	Estimated coefficients	p-value
Intercept	7.95 (0.205)*	0.041
Age of orchard	0.11(0.073)	0.845
Farm size	0.08(0.002)	0.354
Tree density	0.001(0.025)	0.138
Pollination	0.67(0.091)*	0.025
R^2	0.806	
Adj. R^2	0.801	

Source Output results from surveyed data of Master's thesis

Improvement in the FGVO of apple

In terms of the added market output in a given year, the farm gate value of pollination services is a product of the added quality and quantity of apples. The data shows that the FGVO was higher for managed pollination orchards than for non-managed orchards. The FGVO per hectare averaged INR 971,000 for managed pollination orchards, INR 278,000 more than the INR 693,000 for non managed orchards (Table 4). Supplementary pollination by honeybees enhanced the FGVO by 40.11%. Our findings are in line with Majewski (2012): the difference in economic value output between pollinated and non-pollinated apple orchards in Poland was estimated at EUR 3,997 per hectare in 2012.

Impact of honeybee pollination on apple quality

In managed pollination orchards, Grade A apples made up 58.68% of the total produce, Grade B 30.27%, and Grade C 11.05% (Table 5). In non-managed pollination orchards, Grade B apples made up 43.70% of the total produce, Grade A 30.28%, and Grade C 26.02%.

In managed pollination orchards, Grade A apples constituted 71.72% of the FGVO, Grade B 23.91%, and Grade C 4.37%. In non-managed pollination orchards, Grade B apples contributed 44.74% of the FGVO, Grade A 42.10%, and Grade C 13.16%.

Farmers using managed pollination services end up with more of Grade A apples and less of grade C than farmers who do not; and the better yield and quality lead to higher farm revenues. Quality is the strongest determinant of farm revenues (Figure 1).

Table 4 Impact of honeybee pollination on farm gate value output (FGVO) in apple

FGVO (lakhs/ha)		Difference (T_{fv}– C_{fv})	Increase in FGVO due to managed honeybee pollination (%)	Value of ‘z’	p - value
Managed pollination orchards (T_{fv})	Non-managed orchards (C_{fv})				
9.71	6.93	2.78	40.11	6.63	0.025*

*at 5% level of significance, z (tabulated) = 1.96
Source Output results from surveyed data of Master’s thesis

Table 5. Impact of honeybee pollination on production and FGVO

Apple Grades	Managed pollination orchards(N = 100)		Non-managed orchards(N = 30)	
	Production (MT)	FGVO (Rs. Lakh)	Production (MT)	FGVO (Rs. Lakh)
Grade - A	1609 (58.68%)	558 (71.72%)	149 (30.28%)	48 (42.10%)
Grade - B	830 (30.27%)	186 (23.91%)	215 (43.70%)	51 (44.74%)
Grade - C	303 (11.05%)	34 (4.37%)	128 (26.02%)	15 (13.16%)
Total	2742 (100%)	778 (100%)	492 (100%)	114 (100%)

Note The figures in parentheses represent percentage contribution to the total
Source Output results from surveyed data of Master’s thesis

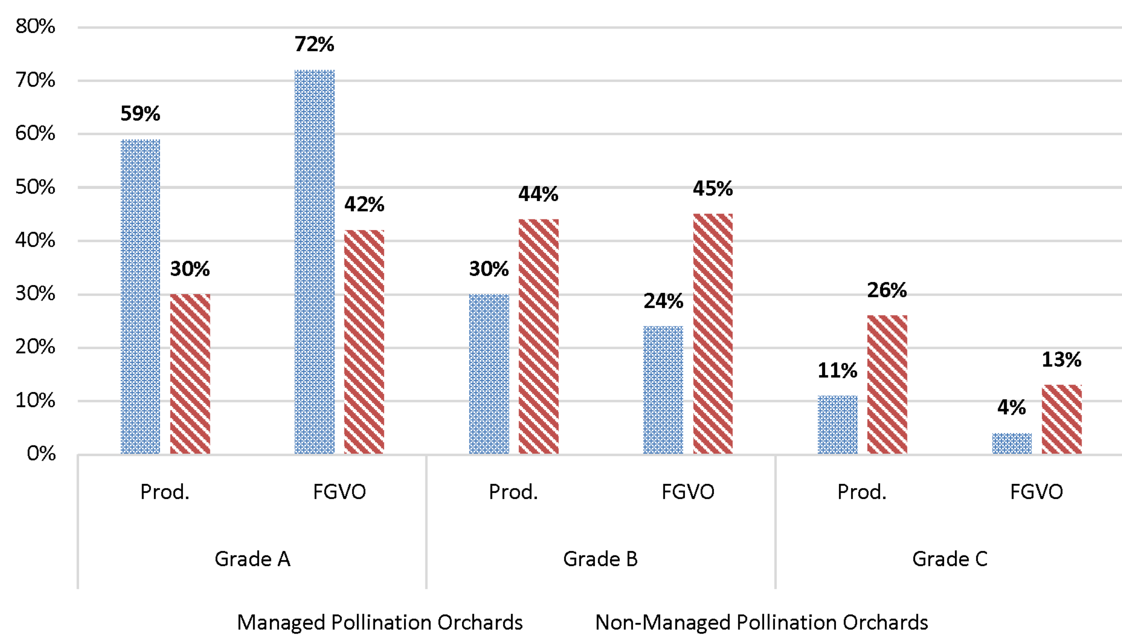

Figure 1 Effect of managed pollination service on quality and farm revenues
Source Output results from surveyed data of Master’s Thesis

In both orchard groups, Grade A apples make up a large proportion of the corresponding FGVO, and Grade C apples constitute a smaller proportion of the corresponding FGVO, indicating that the pollination service contributes significantly to quality and revenue. The deficit pollination in non-managed apple orchards results in a lower fruit set and, hence, yield, besides poor quality. The number of pollinators is insufficient; therefore, the pollination of flowers is inadequate, and fruit drop increases in non-managed apple orchards (McGregor 1976; Free 1993).

These findings are supported by Dar (2016), which finds that controlled pollination by *Apis mellifera*, in comparison to natural pollination, improved quality in the Red Delicious variety—in the Srinagar and Budgam districts of Kashmir valley—in terms of apple weight (+29.95%), length (+20.05%), diameter (+13.19%), volume (+10.49%), and number of seeds (+69.15%).

The findings are supported also by Partap et al. (2017): in the Chitral valley of Pakistan, compared to natural pollination, pollination by *Apis mellifera* improved apple weight (+35%), shape (+19.9%), colour, and brightness (+17.5%).

Partial budgeting of pollination services

When contemplating the adoption of a new technology or service, partial budgeting serves to analyse its costs and benefits. Partial budgeting is a statement of anticipated changes in costs, returns, and profits. The technique considers only the factors that are changed; it ignores the farm resources not changed. A partial budget analysis evaluates the incremental effects of the change being considered.

This study compares the costs and benefits of pollination services in managed apple orchards with non-managed orchards. The market value of apple production per hectare depends on several factors, some of which are directly influenced by pollination services. A higher fruit set and greater weight result in greater overall output. Quality parameters such as size and shape affect the price paid per kilogram. In terms of added market output in a given year, the market value of pollination services is a product of the added quality and quantity of apples, as estimated in this study, plus the cost of the pollination service.

The net income per hectare of managed pollination orchards was INR 714,904, 60% higher than of non-managed orchards (INR 466,078). In managed pollination orchards, the added costs were INR 29,688 and the added returns INR 278,514 (Table 6). Pollination input contributed to the added returns, as did the higher use of inputs like fertilizers and pesticides.

Figure 2 shows the returns contributed by the pollination service alone by graphically representing the contribution of each cost component—cost of pollination input, cost of added inputs except pollination input, and total cost without added cost—to the FGVO. If pollination services are not employed, the output-input ratio of non-managed orchards and managed orchards (3.05 in this study) could be almost the same.

We estimate the contribution of added inputs (except pollination) to the added returns by multiplying the output-input ratio to the cost of the other added inputs. In managed orchards, the other added inputs contribute INR 64,898 to the FGVO. When we subtract this value from the total added returns, we find that the remainder (INR 213,616) is contributed by the pollination service (employed at the cost of only INR 8,410).

Dividing the pollination service part of FGVO (INR 213,616) by the total pollination service cost

Table 6 Partial budgeting for managed pollination service

Particulars	Managed pollination orchard	Non-managed orchard
FGVO (Rs/ha)	971836	693322
Operational cost (Rs/ha)	256932	227244
Net income (Rs/ha)	714904	466078
Added costs (Rs)	29688	-
Added returns (Rs)	278514	-

Source Output results from surveyed data of Master's thesis

Box 1 Calculation method for factoring out the impact of pollination service cost to added returns

Total cost without added cost	= 227244
Total returns without added returns	= 693322
Output-input ratio	$= \dfrac{\text{Total returns without added returns}}{\text{Total cost without added cost}} = \dfrac{693322}{227244} = 3.05$
Added cost	= 29688
Added returns	= 278514
Pollination input cost	= 8410
Added cost for other added inputs	= 29688 – 8410 =21278
Contribution of added returns by other added inputs	= 21278 × 3.05 = 64898
Contribution to added returns by pollination	= 278514 – 64898 = 213616
Output-Input ratio of pollination service	$= \dfrac{\text{Contributions to added returns by pollination}}{\text{Pollinations inputs cost}}$
	$= \dfrac{213616}{8410} = 25.4$

(INR 8,410) gives us 25.4, the output-input ratio of the pollination service. This proves that employing a pollination service improves the overall returns. A rupee invested in the inputs alone yields a return of INR 3.05; if it is invested in pollination services, however, the return is INR 25.4.

Box 1 shows how to factor out the impact of the cost of pollination services on the added returns. The results show that pollination services constitute an important input and orchardists should consider it in farm management decisions. To reap higher returns, farmer investment in pollination services should be in proportion to the area and tree density of apple orchards. Figure 2 graphically represents the contribution of pollination services to the added returns. The investment in pollination services in the corresponding cost bar leads to much higher returns corresponding to the returns (FGVO) bar.

Determinants of farm revenue

The FGVO of a farm unit depends upon many variables. We consider the strongest determinants to estimate their contribution to the production process, and the resource use efficiency, to understand the use and management of inputs.

The key independent variables are fertilizers, chemical sprays, labour, mechanization, and pollination. The dependent variable is the FGVO. We regress the independent variables on the dependent variable (Table 7). The results indicate that the independent variables accounted for 90.12% of the variation in the model.

The regression analysis revealed that fertilizers and chemical sprays have a positive and significant impact on the FGVO. Apples are prone to several disease and pest problems. Using chemical sprays maintains their quality and yield and keeps orchards in good health.

Labour and mechanization have negative, though statistically non significant, coefficients, due probably

Table 7 Regression results explaining determinants on FGVO

Independent variables	Coefficient	P-value
Intercept	5.034	0.012
Fertilizers	26.17	0.036*
Chemical sprays	7.98	0.005*
Labour	-0.76	0.413
Mechanization	-2.93	0.648
Pollination	2.71	0.041*
R^2 (%)	90.12	
Adjusted R^2 (%)	89.80	

*at 95% confidence level of significance

Source Output results from surveyed data of Master's thesis

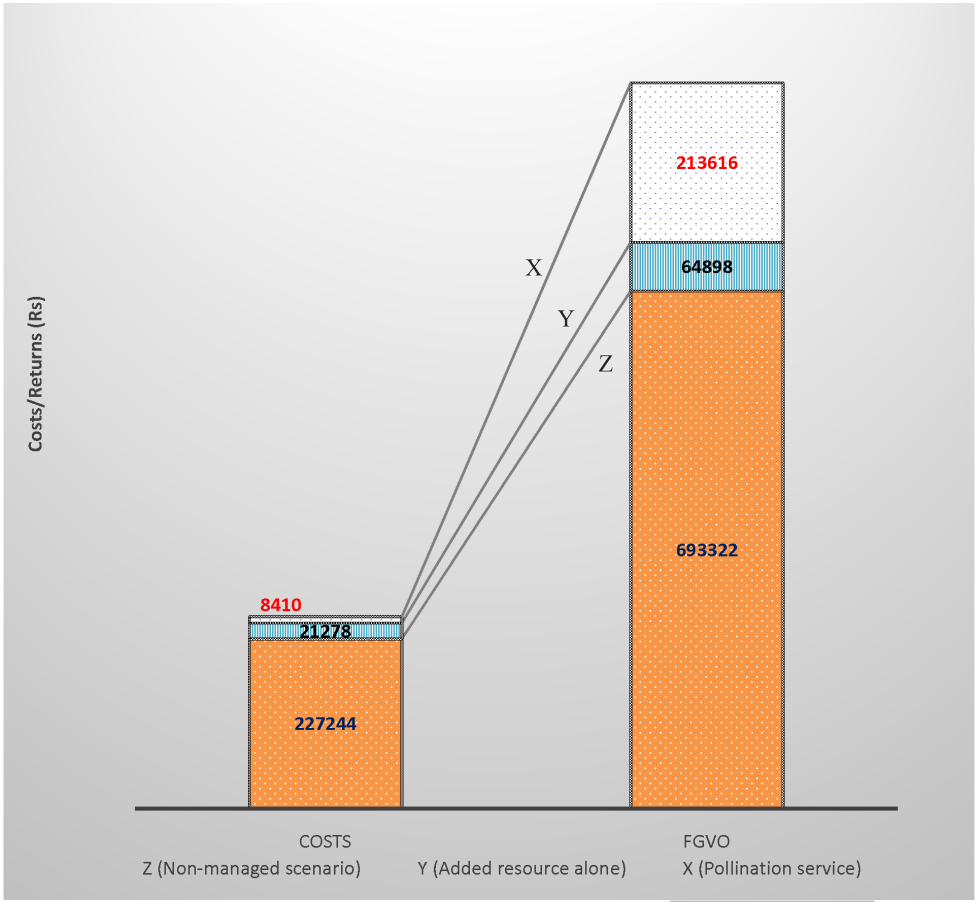

Figure 2 Contribution of pollination service investment to added returns
Source Output results from surveyed data of Master's thesis

to overuse. Optimal usage would not impact the net returns.

In managed pollination apple orchards, pollination services significantly raise the FGVO revenue.

Payment for pollination services

Beehive owners provide pollination services to orchardists, who make payments for pollination services to beekeepers. Payments are governed by the ecosystem services mechanism. In this mechanism, apple orchardists make a series of payments to beekeepers, the natural resource owners, in return for pollination, or a guaranteed flow of ecosystem services or actions likely to enhance their provision over and above what would be provided in the absence of payment. The payment is INR 700–1600 per hive. The sample farmers employed a minimum of 3 hives to a maximum of 15 hives depending upon the orchard area, tree density, canopy size of trees, and topography.

Increasing attention is being paid to the idea of ecosystems as natural capital or assets. If ecosystems generate services that can be valued in economic and financial terms, the payments for ecosystem services mechanism can support their conservation and expansion. Ecosystem assets depreciate over time if the value of service flows declines, but society can choose to invest in such assets (such as by restoring habitats) and by incentivising the pro environment and bio-centric based production systems. There is scope for start-ups in ecosystem provision services in the agricultural sector.

Economic value of honeybees and potential welfare implications

Apple orchards in the Kashmir valley have only recently begun to use managed pollination services during the flowering stage. To examine the potential benefits of employing supplemental pollination services for the apple crop for all the 10 districts in the entire Kashmir valley, we adopt an ex ante approach based on the findings of this study and using secondary data on the area and production. The potential was calculated using Equation 1, as used by Morse and Calderone (2000), and estimated at INR 126.56 billion.

Equation 2 helps us to estimate the benefits at INR 29.71 billion. Deficit pollination in the Kashmir valley causes a loss of almost INR 30 billion rupees every year. The loss can be stemmed by formulating and implementing policies to increase the use of pollination services. Creating awareness and capacity-building programmes for farmers and beekeepers on pollenizers and pollination management would help. Incentives may be offered to develop entrepreneurship in the pollination services market.

The results are in line with previous studies (Southwick and Southwick 1992; Morse and Calderone 2000).

Pollination service value = V × D × P …(1)

= 140.62 billion × 1×0.9
= 126.56 billion INR

Where,

V= Annual value of the crop = total apple area under Kashmir × average FGVO of managed orchards =Rs.140.62 billion

D=Dependency of the apple crop on insect pollinators = 1

P=Proportion of (effective) insect pollinators (honey bees in case of apple) = 0.9

D and P values are taken from Morse and Calderone (2000).

Pollination welfare implications (W) = S × Δq …(2)

= 144825 ×205206
= 29.71 billion INR

Where,

S = Area under apple production (ha) = 1,44,825

Δq = Increase in net returns (INR/ha) because of pollination service (added returns of pollination service – added costs of pollination service) = 2,05,206

Conclusions

Climate change, excessive and ill-conceived pesticide use, and anthropogenic pressure cause the number and diversity of pollinators to decline continually. The pollination deficit seriously threatens agricultural production—particularly for crops and fruits that depend on pollinators—and the livelihood security of farmers.

It is hoped that the findings of this study will help in formulating policies to conserve pollinators and integrate pollination as an input essential to agriculture and, in turn, promote the use of honeybees for pollination in the Himalayan mountain ecosystems, in general, and in the Kashmir valley, in particular.

More research is needed on pollinators and their value to

- improve our understanding of the economic value of insect pollinators, and the vulnerability of agricultural economies to the loss of pollinators;
- raise awareness among farmers, land managers, academic institutions, policymakers, and governments of the need to include crop pollination management in agricultural development plans in the region; and
- to develop pollination enterprises to provide managed bee colonies for crop pollination.

Policy recommendations

Development departments and research institutes need to conduct regularly awareness and capacity building programmes for apple farmers because few know that supplemental pollination services are critical in enhancing the yield and quality of produce.

Public investment in pollinator conservation is required, as are biocentric policy approaches in development programmes, to arrest the decline of pollinators and to manage pollination services to raise the value of production above the current level.

Apple producers in Kashmir should be offered tax specific economic benefits to properly domesticate and manage pollinators.

The government may incentivize entrepreneurship development in the pollination services market.

States should formulate a flagship programme for pollenizers and pollinator management to benefit society and the environment.

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Paddy farmers in Kerala are willing to pay more for a modified crop insurance product

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Abstract We study paddy farmers in Kerala and analyse the factors affecting their willingness to pay for crop insurance and for a hypothetical crop insurance product. The farmers are willing to pay higher premium rates if claims are settled based on the procurement price, instead of cultivation cost, and promptly; and individual losses are accounted for. A farmer's willingness to pay more is influenced positively by their landholding size and negatively by age. Infrastructural support, and efficient implementation, will help to resolve the design-–reality gaps in insurance schemes. Designing popular schemes will reduce the subsidy burden on the public exchequer.

Keywords Willingness to pay, crop insurance, contingent valuation, dichotomous choice method

JEL codes Q14, Q18, G22, C21

Paddy is the staple food of the people of Kerala, the southernmost Indian state; it accounts for 98.50% of the area cultivated with food grains. Paddy cultivation is affected by variations in the weather pattern, and abrupt changes—in the distribution of monsoon spells, untimely rain, extended dry periods, and floods—have led to crop loss and financial crises. But only a few farmers in Kerala voluntarily opted for crop insurance (Anirudh 2019). The growth and coverage of crop insurance schemes in the state, at less than 6% per annum, lags far behind the other states in the country (Mukherjee and Pal 2017). Most farmers depend on government interventions (such as disaster relief funds), gold loans, borrowings, and dissaving to ensure consumption and continue farming during periods of crop loss.

We study the opinions paddy farmers in Kerala have of existing crop insurance products and the factors affecting their willingness to pay. Our study proposes a hypothetical crop insurance product that uses the procurement price to calculate claims—instead of the conventionally used cost of cultivation. The product considers localized damages eligible for claims and guarantees timely settlement of claims. And we try to estimate the farmers' willingness to pay for the product. That understanding will aid policymakers to decide how much of the additional expenditure can be transferred to farmers without escalating the premium cost to an unrealistic level.

Study area

Among all the districts of Kerala, Palakkad has the largest area under paddy cultivation and the maximum sum insured for paddy cultivation under any of the crop insurance schemes. We collected our primary data from Palakkad.

We purposively selected two blocks, Kollangode and Nenmara, because these raised the most crop insurance claims for paddy during 2016-17; for the same reason, we chose two panchayats from Nenmara block, Elevencherry and Pallasana, and two from Kollangode block, Kollangode and Pattanchery.

From each of these four panchayats, we randomly selected 45 farmers who had subscribed to a crop insurance scheme, thus constituting a sample size of 180. We obtained the list of farmers from the Krishi Bhavans (Department of Agriculture and Farmers' Welfare) of the respective panchayats and also from the regional office of the Agricultural Insurance Company of India.

Materials and methods

We used a pre-tested and structured interview schedule to collect the data from farm households. We interviewed the farmers on production constraints, risk management strategies, the drawbacks of the existing crop insurance policies, and their willingness to pay. We also profiled the farmers socio-economically in detail.

Contingent valuation of willingness to pay

Contingent valuation methods use the subjects' responses to calculate their willingness to pay (O'Doherty 1998; Aditya et al. 2018; Subash, Aditya, and Srinivas 2018). Researchers create a hypothetical market and explain it to the subject using the questionnaire and, therefore, elicit their willingness to pay for products not existing at the time of interview. They must clearly explain the reference (status quo) and target levels of every characteristic of interest to the respondents so that the estimate of their willingness to pay is realistic (Horton et al. 2003). Several researchers have employed contingent valuation methods to find the willingness to pay for improvements in water quality (Carson, Flores, and Meade 2001; Alberini and Cooper 2000; Korman 2002).

To elicit farmers' willingness to pay for the proposed crop insurance scheme, we used the single bound contingent valuation method, the probit model, and the maximum likelihood estimation procedure, because the estimates are better than those of direct elicitation. We employed a dichotomous choice method of elicitation: we asked the respondents if they would be willing to pay a particular amount. They may accept the amount (yes) or reject it (no), similar to making market decisions every day based on the price (Freeman 1992).

We had to ensure that we explained the hypothetical crop insurance product well to the respondents because the accuracy of our estimate of the willingness to pay would depend on how well we explained the new product and the respondent understood it.

First, we explained the schemes available at the time of the survey. To estimate crop loss, the Weather Based Crop Insurance Scheme (WBCIS) uses changes in weather variables as a proxy for actual crop loss and predetermines the trigger limit—the minimum or maximum value of a weather variable that does not harm the crop—so that a farmer becomes eligible for compensation whenever a particular weather variable crosses the trigger limit. The farmer has to pay 2% of the sum insured or the actuarial rate, whichever is less. The difference between the actuarial premium rate and the rate of insurance charges payable by farmers is the rate of normal premium subsidy, which is shared equally by the centre and the state.

For crop insurance products based on yield, the loss in yield is estimated directly through crop-cutting experiments; and the compensation is calculated on the basis of the sum insured, indemnity level, and yield loss. The sum insured depends on the scale of finance, derived from the crop cultivation cost, and the claim amount is transferred automatically to the farmer's bank account.

Then, we explained the details of the proposed insurance scheme. The exact phrasing of the scheme posed to farmers was: a new crop insurance scheme is being introduced, in which the compensation would be calculated based on the procurement price of the produce—unlike the existing scheme, in which the compensation covered only the cost of cultivation. Crop loss will be assessed using drones and satellite imagery, and claims will be transferred automatically to the farmers' bank account within 45 days of the reporting of the crop loss. The new scheme will take the area-based approach, but it will provide for accommodating individual losses. All the changes in the proposed scheme are advantages over the existing one and based on the recommendations from the previous studies.

After we explained the scheme, we asked the farmers to pick a lot, each containing the amount INR 300 (USD 4.11), INR 400 (USD 5.49), INR 500 (USD 6.86), INR 600 (USD 8.23), INR 700 (USD 9.60), and INR 800 (USD 10.98). We selected these amounts because farmers paid a premium of INR 400 per acre during the period of our survey and we intended to assess the range of premiums that farmers would be willing to pay for the new scheme. We recorded the farmer's response (yes/no).

To elicit the willingness to pay, Suresh, Gupta, and Mann (2010) use a similar method for a participatory pasture development programme, Subash, Aditya, and Srinivas (2018) use contingent evaluation for a community-driven seed production programme, and Aditya et al. (2018) use contingent evaluation for a crop insurance scheme among the farmers of Punjab.

Inherent in estimating the willingness to pay are several biases: starting point bias, information bias, hypothetical bias, interviewer bias and respondent bias, and the anchoring effect.

In the starting point bias, the initial numbers or range given by the interviewer as an example influences the respondent. The lot is randomly selected in single-bound contingent evaluation, so there is no starting point bias.

If a respondent does not have adequate information on the scheme, they may develop information bias. To avoid it, we explained the proposed scheme to the farmers in detail.

A respondent exhibits hypothetical bias if they behave differently in a hypothetical situation than in a similar real-life situation. Hypothetical bias could be eliminated by emphasizing the consequentiality of the survey and farmer responses (Carson and Groves 2007). The chance that the respondents might overstate their willingness to pay is limited because they may need to pay more in the future and also because we asked them to choose between binary responses, and not state their willingness to pay (Vossler, Doyon, and Rondeau 2012).

Respondents may answer questions in a way that they consider socially acceptable instead of saying what they think. That is the respondent bias. The interviewer's belief, prejudice, or interpretations may affect the response. That is the interviewer bias. Phrasing the questions in a neutral manner would eliminate the respondent bias. Phrasing the information about the new insurance product without expressing the interviewer's belief or assumptions and providing complete neutral sentences where the sentence describes the product without any interpretations would eliminate the interviewer bias. Therefore, we created a neutral statement regarding the new insurance product to avoid both the respondent bias and the interviewer bias.

If farmers are aware of the existing schemes, they would compare their premiums, and terms and conditions, with the proposed scheme; their answers would be based on experience and the existing situation. That is the anchoring effect. To avoid it, we told the farmers that the new scheme was entirely independent of the existing scheme.

For each observation t, we assume that the net gains from subscribing to crop insurance is *U*R, which is related to a set of exogenous variables *x*K.

Next, we use the coefficient β to describe the relation in the probit model and the latent model, assuming the error term, μt, which follows the standard normal distribution, μt~N(0,1) μt~N(0,1),

$$U_t^* = x_t' \beta + u_i \qquad \ldots(1)$$

similar to the probit model,

$$Y_t^* = x_t' \beta + u_i \qquad \ldots(2)$$

when U_t^* and Y^t, satisfies:

y_t= (1, if U_t^*>, 0 otherwise)

where

U_t^* is the latent utility variable, and

Y^t is the observable response (0/1) variable of whether a farmer would subscribe to crop insurance.

To develop this regression model in addition to the normally distributed error terms, we assumed that the conditional probability takes the normal form:

$$\Pr(y_t=1|xt) = \Phi(x' t\beta) \qquad \ldots(3)$$

where Φ(·) is the standard normal cumulative distribution function.

The probit model is of the form

$$Y = \alpha + \beta_1 X + \beta_2 B + \varepsilon \qquad \ldots(4)$$

where

Y is the yes/no response,

X is a vector of variables reflecting household, area or other characteristics, B is the bid price and

ε is an error term.

The mean willingness to pay is estimated as

$$WTP = (\alpha + \Sigma(\beta_1 * X^a)/ \beta_2)*-1 \quad \ldots(5)$$

where,

X^a is the mean value of X variables.

This study considers the variables age, sex, education, farming experience, and the area under cultivation of each farmer (Table 1). The area under cultivation, and farmer experience and education, will be positively correlated to a farmer's probability for opting for crop insurance, while age is expected to have a negative relationship (Falola, Ayinde, and Agboola 2013; Afroz, Akhtar, and Farhana 2017; Abebe and Bogale 2014; Aditya, Kishore, and Khan 2020).

Results

We study the socio-economic characteristics of farmers to analyse the factors affecting their willingness to pay for crop insurance (Table 2). All the farmers we surveyed had been educated to primary school level at least. This result coincides with Kerala's high literacy. Over 80% of the farmers in the sample earned less than INR 200,000 per annum.

Willingness to pay for crop insurance scheme and factors affecting willingness to pay

At the time of our survey, the WBCIS premium was INR 400. We offered six bids, from INR 300 to INR 800, with a INR 100 difference between successive bids, to avoid the anchoring effect and get a better spread of values to both sides of the existing rate.

We drew the lots, using the random chit method, in front of the farmers. We checked the frequency of distribution of initial bid amounts; all the initial bids were picked at almost similar frequencies, which ensured the randomization of the initial bids (Table 3).

By demand theory, as the price increases, the demand should decrease; Carson, Flores, and Meade (2001) propose the 'price test' of the robustness of the elicitation process. We tabulated the initial bid offer and the frequency of acceptances (recorded as dummy; 1 = yes, 0 = no) (Figure 1). The model parameters showed that the model fit is good (LR chi2(9) = 33.98, Prob> chi2 = 0.0001, Pseudo R2 = 0.1463) (Table 4).

Landholding size was positively correlated with a farmer's chance of subscribing to a crop insurance scheme, in line with Aditya, Khan, and Kishore (2018), which had shown also that a farmer's chance of subscribing to a crop insurance scheme was negatively correlated with a farmer's age and positively correlated with their experience and area under cultivation. As their age increases, farmers become reluctant to participate in insurance schemes because they consider that the settlement will be inadequate and delayed; they rely on conventional measures to cover crop loss and expect the government to institute relief schemes to compensate for the large-scale loss. The demand for crop insurance is negatively correlated with age and positively correlated with the cultivated area also in Ethiopia (Abebe and Bogale 2014) and the European Union (Liesivaara and Myyrä 2014).

But farmers that have larger landholdings stand to incur loss on a larger scale. Because they are well off and can afford insurance, they use crop insurance products and consider the premium a part of their production cost. The demand for insurance is higher among these farmers, therefore. The additional spending on the crop

Table 1 Summary statistics of variables

Variable	Unit	Description
Age	Years	Age of the farmer
Education	Dummy	Dummy = 1 if the farmer has primary education, 2 if upper primary education, 3 for high school and higher secondary, and 4 for graduate level and above
Experience in farming	Dummy	Dummy = 1 if farmer experience < 30 years, 2 if if farmer experience 10–30 years and 3 if farmer experience > 30 years.
Area	Acres	Total area cultivated by the farmer
Sex	Dummy	Dummy = 1 if the farmer is female 0 otherwise.

Table 2 Socio-economic profile of farmers with crop insurance

Characteristics	Nenmara Block	Kollangode Block	Average
Total households	90	90	
Age (Years)			
30–49	21	29	53.89
50–69	67	60	
Above 70	2	1	
Gender (Dummy = 1 if the farmer is female 0 otherwise)			
Female	22	20	0.23
Male	68	70	
Educational Qualification (Dummy = 1 if the farmer has primary education, 2 if for upper primary education, 3 for high school and higher secondary and 4 for graduate level and above)			
Primary/Upper primary	41	32	2.58
High school/ Higher secondary	34	40	
Degree and above	15	18	
Experience in farming (Dummy = 1 if the farmer has an experience of less than 30 years, 2 if the farmer has an experience between 10 and 30 years and 3 if experience is above 30 years**)**			
Less than 10 years	11.11	21.11	2.52
10–30 years	17.78	13.33	
Above 30 years	71.11	65.56	
Land Holding Pattern (Total area cultivated by the farmer**)**			
Less than 1 ha	64.44	66.67	2.74
1–2 ha	22.22	27.78	
2–5 ha	6.66	5.55	
More than 5 ha	6.68	0.00	

Source Field survey

Table 3 Distribution of initial bid

Initial bid amount	Frequency	Percentage
300	33	18.33
400	28	15.56
500	32	17.78
600	27	15.00
700	32	17.78
800	28	15.56
Total	180	100

Source Field survey

insurance premium accounts for only a meagre portion of their total expenses.

We used the coefficient estimates (Model 1) to estimate the farmers' willingness to pay for the new insurance product: INR 710 (USD 9.74) per acre, or INR 1,753 (USD 24.06) per hectare (Table 5).

The estimates were statistically significant (Table 5). The farmers paid INR 400 (USD 5.49) per acre, or INR 1,000 (USD 13.72) per hectare, in insurance premium during the study period. The actuarial rate for paddy in Palakkad was INR 8,250 (USD 113.24) per acre, 16.5% of the sum insured (INR 50,000 or USD 686.44) per acre. The farmer's share was 2% of the sum insured (INR 1,000 or USD 13.72). The rest of the premium amount (INR 7,250 or USD 99.52) was shared equally by the state and central governments. The farmers were willing to pay an additional INR 310 (USD 4.25) for the hypothetical crop insurance scheme, which can be considered as an upgradation of the existing scheme.

Conclusions

In developing countries, product design and implementation determine the popularity of, and voluntary subscription to, insurance schemes. Many

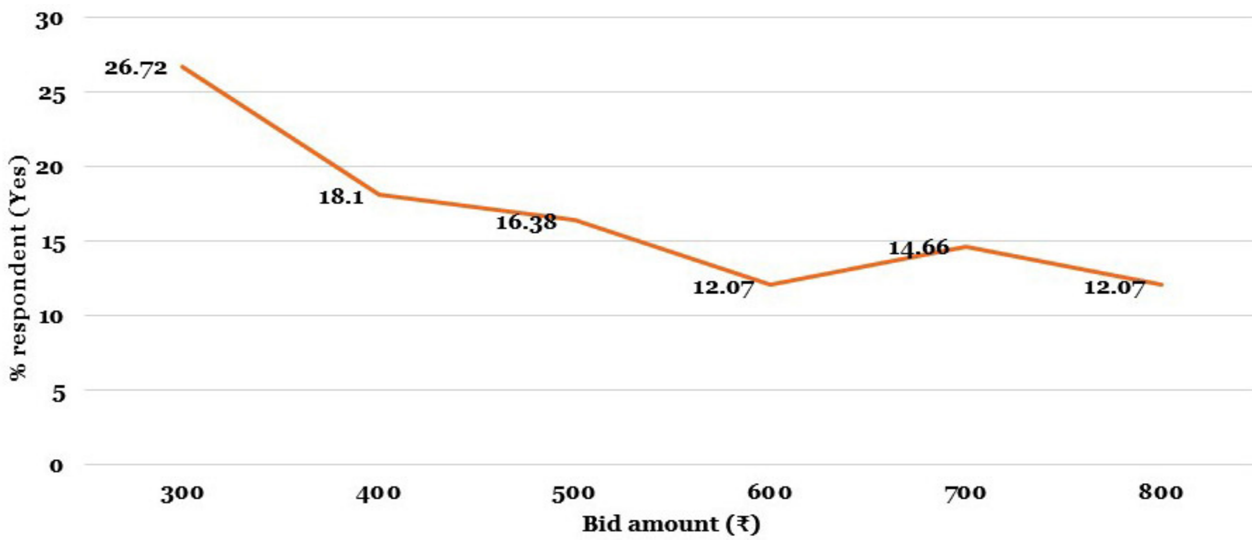

Figure 1 Distribution of initial bids and corresponding answers to estimate farmers' willingness to pay
Source Estimated from the field survey

Table 4 Results of the probit model for estimating WTP for the proposed crop insurance scheme

	Model 1			Model 2		
Variables	Coefficient	Standarderror	P value	Coefficient	Standard Error	P value
Bid	–0.003	<0.000	0.000	–0.003	0.001	<0.001
Age (years)	0.009	0.012	0.456	–0.010	0.020	0.604
Sex (male/female)				–0.400	0.258	0.120
Education						
Upper primary				0.380	0.326	0.243
High school/ pre-degree				0.236	0.301	0.431
Degree holders				0.489	0.444	0.270
Farming experience						
10–30 years				0.079	0.389	0.84
>30 years				0.648	0.419	0.122
Area cultivated (in acre)	0.072	0.039	0.066	0.084	0.047	0.071
Constant	1.163633	.7230632	0.108	1.519	1.139	0.182

Source Field survey

Table 5 Estimated willingness to pay for new crop insurance scheme

	Coefficient	Std. Err.	Z	P>z	[95% Conf.	Interval]
WTP	710.0685	50.98718	13.93	0	610.1354	810.0015

Source Field survey

designs of crop insurance schemes have been experimented with in India, but the coverage is lower than expected (Dey and Maitra 2017)—farmers are reluctant to subscribe to existing crop insurance schemes, because the compensation is inadequate, the existing products do not compensate for localized calamities, and settlements are delayed. However, they are willing to pay a higher-than-current premium for the hypothetical insurance product, because it guarantees that claims will be settled based on the procurement price, instead of cultivation cost, and promptly; and individual losses will be accounted for.

Farmer experience is negatively correlated with their willingness to pay; therefore, their reluctance to subscribe to existing crop insurance schemes indicates prior unsatisfactory experience. Especially when large amounts of public money from the exchequer is channelized for providing subsidies, any crop insurance scheme should ensure foolproof implementation at the ground level because any gap between design and reality leads to farmer dissatisfaction and a reluctance to adopt.

Modifying the existing schemes would enhance subscriptions (Mukherjee and Pal 2017; Nair 2010), but it would also require investment (Soner et al. 2020) in infrastructure—referral weather stations, GPS-tagged handheld transmitters of data from crop-cutting experiments, advanced computers, and cloud capturing and processing of weather and/or yield data. This infrastructure is needed for implementation; it should be considered a component of the product design.

Adoption will improve if the provision to accommodate individual losses is introduced and drones and satellite imagery are used to assess crop loss faster. If crop insurance products are dynamic, and they evolve constantly and protect farmers from income fluctuations, farmers will find these products useful, adopt them, and pay more.

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Nutrition-sensitive food systems and biofortified crops

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Abstract The realization that economic growth is a necessary but insufficient condition for improving the nutritional status has led to a paradigm shift in addressing malnutrition through nutrition-sensitive development. Biofortification is one such nutrition-sensitive food system intervention designed to supply crucial micronutrients through staple diets to undernourished populations that may not otherwise be able to consume diversified diets. Biofortified foods can provide 35–50% of the daily estimated average requirement of micronutrients. Biofortification is still at a nascent stage, however, and the state may help in developing a value chain for biofortified. The paper discusses pragmatic policy interventions in that direction.

Keywords Hidden hunger; biofortification; conventional plant breeding; value chain; brand building

JEL codes I31, L66, Q13, Q16, Q18

A healthy immune system is the first line of defence against health threats, including viruses such as the corona virus. Hidden hunger, arising out of micronutrient deficiency, constitutes a roadblock for a healthy immune system, and it is a serious problem (FAO, IFAD, UNICEF, WFP, WHO 2020). Malnutrition is estimated to affect 2 billion people in the world; its burden is unacceptably high (Fan et al. 2019). Hidden hunger is much more widespread in South Asia than in any other part of the world. The extent of anemia among pregnant women in South Asia is 52%, more than the global prevalence of 38%, and 58% among children under five years in Asia (but 43% worldwide). Zinc intake is inadequate for 30% of the population in South Asia but for only 17% worldwide. About 31–57% of preschool children are alarmingly deficient in Vitamin A. Nearly 45% of childhood deaths are associated with malnutrition (Harding et al. 2018).

The diets of rural Indians have much to be desired. The rural population consumes a relatively high share of calories from whole grains and substantially less from protein sources vis-à-vis the EAT-Lancet reference diet (Sharma et al. 2020). The EAT-Lancet diet requires a certain amount of spending but most people in rural India spend just one-fifth of the required budget, with a very meagre amount on meat fish poultry, dairy, and fruits (Gupta et al. 2021). Climate change reduces the iron, zinc, and protein in plants like wheat, rice, maize, and soybean and aggravates the burden of malnutrition in South Asia (Myers et al. 2014).

It is feared that through the economic downturn and other disruptions, the COVID-19 pandemic might worsen all types of malnutrition, including hidden hunger (Osendarp et al. 2020). Deficiencies in micronutrients result in poor health and lower cognitive development, educational outcomes, work productivity, and earnings, thereby reducing the total welfare in society. The malnutrition-related cost is 2.5% of the national income in India (Jitendra 2013) and 9 billion disability-adjusted life years (Qaim et al. 2007).

Paradigm shift in combating malnutrition

Income growth is a necessary but not sufficient condition for reducing malnutrition. This realization led the international development community to focus on direct nutrition-sensitive interventions in the first decade of the 21st century (Gillespie et al. 2013). This is akin to the paradigm shift worldwide in the mid-1970s to taking the basic needs approach and making the associated policy changes to attack deprivation directly.

The chain of events that led to the catapulting of malnutrition to the centre of policy focus started with the widespread outrage at the hunger and malnutrition during the 2007–08 global crisis and the publication of the first Lancet Series in 2008 on maternal and child malnutrition. Frustrated with the lack of discernible improvements in the nutrition status of the masses, several concerned individuals in the United Nations (UN), government, donors, and civil society launched the Scaling Up Nutrition movement in 2010 on the principle that everyone has a right to food and good nutrition. The Scaling Up Nutrition movement has 61 national governments and four Indian states (Jharkhand, Maharashtra, Uttar Pradesh, and Madhya Pradesh) as members. The subsequent Rome Declaration on Nutrition in 2014 at the Second International Conference on Nutrition brought malnutrition into sharp policy focus.

These concerted endeavours crystallized in the form of Sustainable Development Goal 2 in 2015 to "end hunger, achieve food security and improved nutrition, and promote sustainable agriculture" that virtually made the links between agriculture and nutrition explicit (Allen and de Brauw 2018). This brings about a paradigm shift that requires all the development programmes and processes in general and all the programmes in the food system in particular to be nutrition-sensitive (Pingali and Sunder 2017).

The UN General Assembly proclaimed 2016–25 as the Decade of Action on Nutrition, based on the Rome Declaration of Nutrition (RDN. and established institutional mechanisms. Five international organizations[1] have been working together for the first time and publishing annual reports entitled State of Food Security and Nutrition in the World. The International Food Policy Research Institute (IFPRI) has begun publishing annual Global Nutrition Reports. Several governments have started to act to combat malnutrition. India, along with other SUN countries, announced a slew of measures to combat hidden hunger. India's National Nutrition Strategy 2016 includes biofortification through micronutrient-dense foods. The country also started the POSHAN Abhiyaan, a flagship programme, in 2017 (Menon et al. 2021; Suri and Kapur 2020).

Biofortification for combating hidden hunger

Dairy and livestock products, fruits, vegetables, and pulses are dense in micronutrients, but the poor in developing countries do not eat enough of these foods. In India, investments in the improvement of staple crops drove down food prices for a long time in the aftermath of the green revolution, but other foods are inaccessible and unaffordable. Markets have failed to promote the dietary diversity needed for nutritional security. The state must bring the diversity about through supplementation, fortification, and the new route called biofortification (Pingali and Sunder 2017).

Biofortification is the process of increasing the density of vitamins and minerals in a crop through conventional plant breeding and through agronomic and transgenic techniques. The existing biofortified crop varieties follow only the conventional plant breeding methods. The level of nutrients in biofortified crops cannot be as high as in industrial fortified foods but can increase the daily micronutrient intake. Plant breeders endeavour to enrich the plants to provide a sufficient part of the daily estimated average requirement of micronutrients and ease the deficiency in the population.

The deficiency varies by age group, gender, and a host of other factors (Bouis et al. 2017). If C_f is the per capita consumption of the staple, D_f is the density of mineral/vitamin to be enhanced in the staple, R_p is the retention of the mineral/vitamin after processing or storage or cooking, and B_c is the percentage availability after consumption, the extra nutrient supplied through biofortification (EN_b) can be shown as

[1]Food and Agriculture Organization (FAO). International Fund for Agricultural Development (IFAD). United Nations Children's Fund (UNICEF). World Food Programme (WFP). and World Health Organization (WHO).

$$EN_b = C_f D_f R_p B_c \quad \ldots(1)$$

The additional percentage of the estimated average requirement supplied (A_E) can then be obtained by dividing EN_b by the estimated average requirement (E) of the particular mineral/vitamin:

$$A_E = \frac{EN_b}{E} \quad \ldots(2)$$

Biofortification complements the existing interventions and provides micronutrients to vulnerable populations in a relatively easy, cost-effective, and sustainable manner. In rural areas, farm households' consumption of biofortified crops helps reduce malnutrition initially, and the predominantly rural nature of poverty places South Asia in an advantageous position in harnessing biofortification. Later, as markets develop, the urban households start consuming these foods.

The biofortified varieties of food crops have been diffusing in developing countries. These varieties, cultivated by 8.5 million farming households across 14 countries of Africa, Asia, and Latin America, and the Caribbean in 2019, benefitted 42.4 million people (Bouis et al. 2019). In 2018, 500,000 people from farming households consumed iron pearl millet in India, while 240,000 farmers cultivated it in 2019 (Foley et al. 2021). A multi-institutional approach to biofortification was implemented as a global plant breeding strategy, and the pioneering work by Harvest Plus of IFPRI led to the rapid diffusion of biofortified food crops.[2]

Few studies examine the impacts of biofortification on poor farmers in rural areas. These studies find that biofortification raises the micronutrient intake among children and women and that the benefits can be directed towards lower-income groups (Garcia-Casal et al. 2017; Dizon et al. 2021). Studies in several countries find that consumers accept or prefer biofortified foods (Talsma et al. 2017). Biofortified crops provide 35–50% of the daily estimated average requirement of the micronutrients.

For children 4–6 years old and for non-pregnant, non-lactating women of reproductive age, biofortified beans provides an additional 35% of the estimated average requirement of iron and biofortified pearl millet an additional 40%. The additional zinc in wheat provides up to 25% of the estimated average requirement and, in rice, up to 40%. Biofortified crops provide the maximum estimated average requirement of 50% in the case of vitamin A in cassava, maize, and sweet potato (Bouis et al. 2019).

Recent studies show that processing methods like cooking do not degrade maize biofortified with zinc (Gallego-Castillo et al. 2021). A meta-analysis determines that consumers are willing to pay 21.6–23.7% more for these crops (Garcia-Casal et al. 2017).

Randomized control trials were conducted in India to test the effectiveness of biofortified crops in reducing micronutrient deficiencies. The results of the trials were positive. When pearl millet fortified with iron and zinc is fed as the staple food to children 2 years old, the quantities absorbed are more than adequate to meet the physiological requirements of iron and over 80% of the physiological requirement of zinc (Kodkany et al. 2013).

Another study (Finkelstein et al. 2017) finds that children eating *roti* and a savory snack (*sev*) made with biofortified pearl millet are 64% more likely to become iron-replete by six months; it increases serum ferritin and total body iron to reverse the deficiency. Biofortified pearl millet improves reaction time in schoolchildren and cognitive skills like attention and memory (Scott et al. 2018) and improves light physical activity in adolescent schoolchildren (Pompano et al. 2021). Eating the high-zinc wheat in New Delhi as whole wheat flour chapatti or porridge reduced the number of days children were sick with pneumonia by 17% and vomiting by 39%; in women, it reduced the number of days they had fever by 9% (Sazawal et al. 2018).

Biofortification is one of the most cost-effective solutions to combat hidden hunger, as per the 2008 Copenhagen Consensus; every dollar spent on biofortification provides a benefit worth 17 dollars (Bouis et al. 2017). Biofortified varieties of food crops yield agronomical gains; infusing micronutrients into cultivars helps growth and yield and does not entail a yield penalty (Yadava et al. 2018). Ex ante studies from

[2]Howarth Bouis, the founder of HarvestPlus, won the World Food Prize in 2016, along with Maria Andrade, Robert Mwanga, and Jan Low.

India and other countries find that the internal rates of return in the pessimistic biofortification scenario are as high as 61% for iron, 53% for zinc, and 35% for vitamin A (Qaim et al. 2007).

More than 290 varieties of 12 biofortified crops have been officially released in over 30 countries: key staples such as iron beans and pearl millet; vitamin A cassava, maize, and orange sweet potato; and zinc maize, rice, and wheat (Bouis et al. 2019). The concerted efforts by the Indian Council of Agricultural Research (ICAR) to harness this process, with active support from HarvestPlus, resulted in the release of several biofortified crop varieties, including multi-nutrient rich cultivars (Table 1). HarvestPlus and its partners have developed wheat lines that can achieve zinc concentration of 60–70 ppm to add 20–25 ppm in the daily diet of children and reproductive-age women (Sazawal et al. 2018).

In 2012, the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) released the first biofortified crop in India, the iron-rich ICTP 8203 pearl millet variety. Later, hybrids like Dhanshakti and ICMH 1201 with 65–74 ppm iron were released. Private companies commercialize these crops under licence from public developers; some crops were included in the Nutri-Farm Pilot Programme of the Government of India. Similarly, high-zinc and high protein varieties are released in rice for cultivation in several states. While high zinc rice Dhan 45 is being cultivated, protein-rich CR Dhan 310 is diffusing faster in Odisha due to its popular base Naveen.

Ex ante studies at the Directorate of Rice Research, Hyderabad show that zinc-enhanced rice can reduce zinc deficiency up to 35% and, at USD 3 for each life-year saved, it is quite cost-effective (Nirmala et al. 2016). The agronomic performance of Dhan 45 is similar to the local check variety. Several multi-nutrient rich cultivators are also released to simultaneously address the deficiency of several nutrients (Table 1).

Several ICAR institutes have developed many biofortified varieties of crops. The Prime Minister of India released 17 varieties on World Food Day 2020 (ICAR-DKMA 2020). The varieties include CR DHAN 315 of rice (excess zinc), HD 3298 wheat (protein- and iron enriched), DBW 303 wheat (protein-enriched), DDW 48 wheat (iron enriched), and maize hybrid varieties 1, 2, and 3 (enriched with lysine and tryptophan). Other varieties of biofortified crops are finger millet CFMV 1 and 2 (rich in calcium, iron, and zinc), small millet variety CCLMV1 (rich in iron and zinc), and yam varieties Shri Neelima and DA 340 (enriched with anthocyanin).

Value chain development and the global experience

To achieve SDG 2, value chains need to be developed for micronutrient-rich foods (Allen and de Brauw 2018). And actors at all nodes of the value chain—consumers, producers, seed developers, breeders—and enablers like civil society groups need to act to develop the value chain (Figure 1).

Consumers accept biofortified food crop varieties to some degree but, as evidenced in the case of iron beans in Rwanda, they do not prefer to trade off nutrition attributes against consumption attributes (Birol et al. 2015). If the information on the nutrition and health benefits of biofortified crops is not provided, consumers pay little more. If the information is provided, however, they pay a significant premium, and they prefer international brands to local brands (Banerji et al. 2016).

The biofortified crop varieties are developed to be more adaptable and find favour with growers (Nestel et al. 2006). Shorter-duration zinc rice with better submergence tolerance became popular in Bangladesh. In India, improving the shelf life of high-iron pearl millet and enabling farmers to cultivate it in the cool season is expected to improve reach in both cultivation and food products (Bouis et al. 2017).

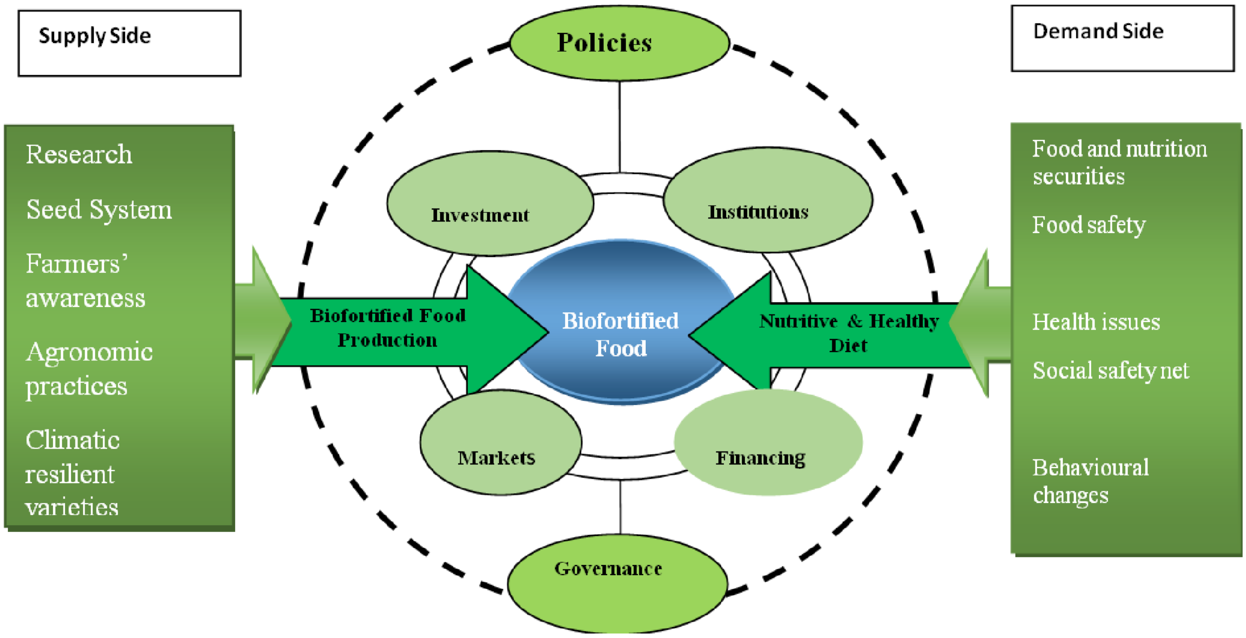
The vibrancy of seed markets determines the strategy for diffusion among growers. The approach in most countries is to engage with the public and private sectors. In countries like Zambia, vibrant seed markets enable the harnessing of seed company networks to mass multiply (Simpungwe et al. 2017). The same strategy is followed in the active seed markets of India. The examples include ICRISAT in the case of pearl millet, HarvestPlus of IFPRI in the case of zinc fortified wheat, and ICAR in the case of rice in Odisha, Telangana, and Chhattisgarh.

However, farmers will grow biofortified food crop varieties only if these fetch better prices than the older

Table 1 Progress in the release of biofortified crop varieties in India

Crop	Variety/Hybrid	Improved vitamin/ mineral/amino acid	Developer
Pearl millet	ICTP 8203 ICMH 1201 HHB 299, AHB 1200	Iron Iron and zinc Iron	HarvestPlus Indian Council of Agricultural Research Chaudhary Charan Singh-Haryana Agricultural University and ICRISAT Vasantrao Naik Marathwada Krishi Vidyapeeth, Parbhani under AICRIP of Indian Council of Agricultural Research
Rice	DRR Dhan 45,	Zinc	Indian Institute of Rice Research, Hyderabad
	DRR Dhan 49 CR Dhan 310	 Protein	 National Rice Research Institute, Cuttack
	CR Dhan 311	Protein and zinc	National Rice Research Institute, Cuttack
Wheat	BHU 3 and BHU 6	Zinc	HarvestPlus
	WB 02	Zinc and iron	Indian Institute of Wheat and Barley Research, Karnal
	HPBW 01	Iron and zinc	Punjab Agricultural University, Ludhiana
	Pusa Tejas, Pusa Ujala	Protein, iron, and zinc	ICAR-Indian Agricultural Research Institute, Regional Station, Indore
	MACS 4028	Protein, iron, and zinc	Agharkar Research Institute, Pune
Sweet potato	Orange fleshed Sweet Potato	Vitamin A	HarvestPlus
	Bhu Krishna	Anthocyanin	Indian Council of Agricultural Research
Maize	Pusa Vivek QPM9 Improved	Provitamin A, lysine, and tryptophan	Indian Agricultural Research Institute, New Delhi
	Pusa HM4 Improved	Tryptophan and lysine	Indian Agricultural Research Institute, New Delhi
	Pusa HM8 Improved	Tryptophan and lysine	Indian Agricultural Research Institute, New Delhi
	Pusa HM9 Improved	Tryptophan and lysine	Indian Agricultural Research Institute, New Delhi
Lentil	PusaAgeti Masoor IPL 220	Iron Iron and zinc	Indian Agricultural Research Institute, New Delhi Indian Institute of Pulse Research, Kanpur
Soybean	NRC-127	KTI-free	Indian Institute of Soybean Research, Indore
Mustard	Pusa Mustard 30	Low erucic acid	Indian Agricultural Research Institute, New Delhi
	Pusa Double Zero Mustard 31	Low erucic acid and low glucosilates	Indian Agricultural Research Institute, New Delhi
Cauliflower	Pusa beta Kesari 1	Beta carotene	Indian Agricultural Research Institute, New Delhi
Potato	Bhusona	Beta carotene	Central Tuber Crops Research Institute, Trivandrum
Pomegranate	Solapur lal	Iron, zinc, and vitamin C	National Research on Pomegranate, Pune

Source Adapted from Yadava et al., (2018)



Source Adapted from Joshi (2018)

Figure 1Value chain development of biofortified food crops

varieties, only if they can improve production and income (Nuthalapati et al. 2020), and they have access to processing techniques and processors (Low et al. 2017). These factors of adoption must be kept in mind when biofortifying a food crop variety and promoting cultivation—through the use of demonstration plots by agricultural extension personnel, public service radio programmes, and social marketing techniques such as those used by food companies (Bouis et al. 2017).

In producing and diffusing micronutrient-dense biofortified foods, behavioural change communication — common in health sector interventions—is central (Meenakshi et al. 2010). The heterogeneity of consumers warrants that communication strategies are segmented and targeted. Short messages are more impactful and cost-effective (Banerji et al. 2016). Social marketing strategies can catalyse the diffusion and consumption (Uchitelle-Pierce and Ubomba-Jaswa 2017) of biofortified crops as demonstrated in a randomized trial by Cornell University in Maharajganj of Uttar Pradesh (Merckel 2019). The study concluded that information and knowledge must be curated and made accessible to the target population physically, culturally, and timely. The experience of diffusing high-iron varieties of pearl millet in India reveals that the rabi crop does not have suitable varieties, the trait is invisible, the grains are not segregated, and their shelf life is poor (Karandikar et al. 2018). Brand building and detection kits ought to be developed to overcome this, apart from developing biofortified pearl millet varieties suitable for rabi and with better shelf life.

The interest of multinational companies is slow to develop, and small and medium-size companies can create demand for biofortified grains and food even before supplies reach scale. When the production and supply of foods become sufficient, food products with desirable consumption attributes need development and distribution by small and medium-size processing companies that can detect nutrients and have a certification system. Private sector participation is essential in creating sustainable markets for biofortified seeds and foods, but NGOs remain important in delivering the nutrition information to vulnerable households. The partnership between World Vision and HarvestPlus is an example (McDonald et al. 2017).

In India, ICAR has stipulated the minimum iron content for pearl millet hybrids; this is the first global standard. Also, ICAR has set up a Consortia Research Platform for biofortification research; the platform conducts research on nutritionally enhancing rice, wheat, maize, pearl millet, sorghum, and minor millets. The government declared millets with high nutritive value as nutricereals and includes them in the public distribution system (PDS). That might help the distribution of iron-rich pearl millet.

Biofortification is endorsed as a public health strategy to fight hidden hunger by World Bank, World Food Programme, Bill and Melinda Gates Foundation, USAID, UKAID, several UN organizations, donor agencies, and national and subnational governments. The State of Food Security and Nutrition 2020 has, for the first time, endorsed biofortified foods to reduce micronutrient deficiency (FAO, IFAD, UNICEF, WFP, and WHO 2020). Several countries including India support this intervention and have incorporated biofortification into their national nutrition strategies. But much more needs to be done to produce these novel crops, create demand, and facilitate consumption.

So far, biofortification has centred on coaxing producers to grow orange-fleshed sweet potato because the biofortified varieties of other crops have been commercialized only in the past few years—the development of the value chain for biofortified crops is a recent phenomenon. Consumers are wary of mixing regular sweet potatoes with orange-fleshed sweet potato and complain that it is soft and mushy, indicates market research by HarvestPlus. A nuanced approach is needed to attract the different age groups to consume these foods. The adopting farmers sometimes stifle the flow of information to other prospective growers out of the fear of losing their niche, though there is a contagion effect (Uchitelle-Pierce and Ubomba-Jaswa 2017). The strategies for the delivery of biofortified food crops in any country or region have to be devised considering these factors and undertaking some research.

Conclusions

Economic growth and agricultural production have been consistent and high but have not reduced malnutrition or hidden hunger; therefore, the food system must become sensitive to nutrition. The SDG 2 formalizes the notion.

Biofortification has the potential to ameliorate malnutrition and its adverse consequences. Its cost effectiveness increases with time because once the initial investment, in breeding, is over, the incremental costs are minimal. When used as part of a comprehensive approach, biofortification provides 35–50% of the daily estimated average requirement of micronutrients, especially for the rural poor.

Consumers are willing to pay 21.6–23.7% more for high iron pearl millet and high zinc wheat. Several food products are developed from these crops. Mainstreaming the nutrient traits into all relevant crop pipelines is a challenge. The criteria for minimum micronutrient levels should be set during the varietal release stage, duly considering all relevant facts.

Generating demand is another challenge. The agriculture and health ministries need to communicate and collaborate with other government organizations and stakeholders to educate producers and consumers on the nutrition from food agenda. Social marketing methods and behavioural change communication will help in promoting the consumption of biofortified varieties.

The seed sector must be incentivized to promote adoption and production. The evidence from the adoption of orange-fleshed sweet potato in Africa shows that subsidies will be required for the initial diffusion of biofortified crop varieties (Low et al. 2017). Farmer producer organizations can be encouraged to produce biofortified varieties and develop linkages with private sector organizations that can brand and package the produce for sale. Product labeling, or certification, is important for developing the value chain for biofortified grains and processed foods, as are detection kits for easily and cheaply determining the micronutrient level in food products.

Processors and private retailers can be persuaded to carry biofortified foods, and these can be included in the Mid-Day Meal Scheme and PDS. Scaling up would require researching the kind of food products that would attract urban consumers, labelling them appropriately, and developing niches. The Food Safety and Standards Authority of India may promote processed biofortified foods and include these as a certain share of fortified foods, as the governments in several states have mandated fortification.

The use of biofortification to fight against hidden hunger has some limitations, however. Biofortification has only just progressed beyond orange-fleshed sweet potato with many varieties of several crops; and the current studies on consumer acceptance and willingness depend on the scanty data of only a few crops like sweet potato and cassava. In the long run, nutritional security is conditional on achieving dietary diversity with higher incomes and better functioning markets. Research is needed to understand the impact of consuming several biofortified crops on nutrient intake, total nutrient absorption, nutrition, and health and on the efficacy of these foods for a wider range of age and gender groups, including infants, over a longer period.

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An analysis of the demand and uptake of agricultural insurance in developing countries

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Abstract Climate change, natural risks, and market price fluctuations impact agricultural production and farm income. The risks can be smoothened by using concepts from insurance, but numerous challenges constrain the demand and uptake of agricultural insurance products. We review the products in developing countries for insights into formulating an agricultural insurance scheme for Sri Lanka and we find a range of products that have potential. The government and policymakers can use our findings to develop and implement an agricultural insurance scheme in Sri Lanka that serves as a risk management tool.

Keywords Agricultural insurance, demand, developing countries, Sri Lanka, uptake

JEL codes Q18, D81, O1

The main risks to the agricultural sector are price risk, due to price volatility, and production risk, due to production uncertainties (Ibrahim 2012). Agricultural insurance is a specialty line of property insurance that is used as a financial instrument to transfer agriculture-related production risks to third parties through the payment of premiums that reflect long-term costs (Turek-Rahoveanu and Andrei 2012). Mechanization has brought complexity to agricultural businesses, and a wide range of traditional insurance policies—personal accident, fire, vehicle, machinery, and liability insurance—have become important parts of an agricultural insurance package (Iturrioz 2009). Developing-country farmers prevent or mitigate the influences of disastrous events in ways that depend on their wealth and income (Smith and Watts 2019), but the real demand for agricultural insurance is unresolved in both developed and developing countries (Vandeveer 2001). We review the literature to identify the agriculture insurance products existing in developing countries, their strengths and limitations, and the factors that affect demand and uptake to identify the potential of agricultural insurance products in Sri Lanka.

Methodology

We reviewed the literature to analyse the demand and uptake of agricultural insurance in developing countries. We chose the studies so that we could answer the following research questions on agricultural insurance.

- What products do different countries use?
- What affects demand and uptake?
- What are the strengths and limitations of the existing schemes?
- What is the potential of agricultural insurance products in Sri Lanka?

We used the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines to develop this review. We included a standard protocol with an evidence-based framework. We performed the current literature survey on Google Scholar for the period from 2000 to September 2021.

We searched websites related to agricultural insurance using all the possible keywords: “agriculture AND insurance", "agriculture AND insurance AND types", "agriculture AND insurance AND demand", "agriculture AND insurance AND uptake", "agriculture AND insurance AND strengths", "agriculture AND insurance AND limitations" and "agriculture AND insurance AND developing countries".

We added the terms "Sri Lanka", "China", and "India" to these phrases to maximize the number of related studies. We included studies on the agricultural insurance products currently used in developing countries and the demand, uptake, strengths, and limitations of the products.

We reduced the studies selected based on the research target. We excluded studies conducted before 2000 in developed countries, studies on the governance of agricultural insurance, and studies presenting information not related to insurance products or demand, uptake, strengths, or limitations.

Our systematic literature review comprised four steps: identification, screening, eligibility, and inclusion. We selected studies using web search engines such as Google Search and Google Scholar. The initial search included working papers, conference proceedings, and peer-reviewed journal articles. We used the PRISMA guidelines to filter the results (Figure 1).

The process generated 64 studies: 63 articles from Google Scholar and one article from the web search for "climate change, agriculture, and food security",

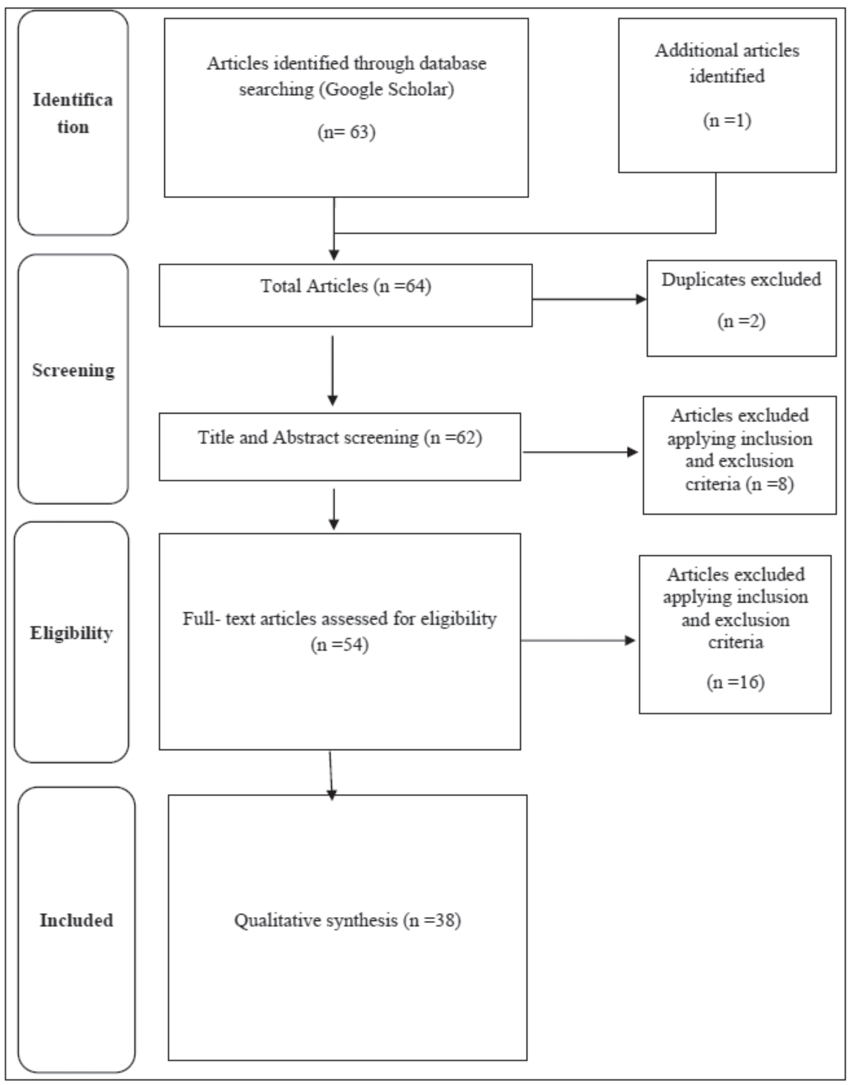

Figure 1 PRISMA flowchart of the analysis of the demand and uptake of agricultural insurance in developing countries

which was identified from the reference list of a selected paper. Two articles were duplicated; removing these let 62 articles remain. We screened these based on their titles and abstracts. Applying the exclusion and inclusion criteria excluded 8 articles. We assessed these 54 articles in full. Applying the exclusion and inclusion criteria excluded 16 articles and reduced the number of articles eligible for qualitative synthesis to 38 (Figure 1).

Results and discussion

Agricultural insurance products available

Farmers have had access to agricultural insurance in various forms since at least the 1920s (Smith and Goodwin 2009). More than 100 nations have implemented crop insurance programmes to reduce the impact of bad weather on farmers' revenue (Table 1) (Mahul and Stutley 2010).

The main types of crop insurance are multi-peril crop insurance, which offers full indemnity and acts as a comprehensive cover, and named peril insurance, which covers only specified dangers (like hail and dew). Most middle-income countries use multi-peril crop insurance.

Index-based insurance pays out depending on the historical underlying index, such as rainfall and area yield (Chatterjee and Oza 2017). Today, tens of millions of farmers worldwide utilize index insurance products (Greatrex et al. 2015).

Agricultural insurance includes livestock insurance, a minor but important component. Mongolians have put their effort into building index-based cattle insurance but they have had mixed outcomes (Chatterjee and Oza 2017).

Factors affecting the demand for agricultural insurance

Demand implies the desire to acquire a commodity and their willingness and ability to pay for it; therefore, demand is the number of consumers willing and able to buy products during a period. Demand is determined by the price of a product/service and of its alternatives, complementary goods, income, consumer expectations of future prices, and taste and preferences (Tsikirayi et al. 2012). The demand for agricultural insurance affects the socio-economic and cultural aspects of life—gender, culture, religion, trust, and access to marital status—that commercial farmers evaluate in their decision to purchase agricultural insurance (Table 2) (Tsikirayi et al. 2012). To understand the importance of insurance for a country's agricultural activities, therefore, it is important to identify the economic and socio-cultural factors of the demand for agricultural insurance (Sihem 2019).

Price is one of the main factors of the demand for agricultural insurance. The farmer pays a monthly or annual premium for a fixed compensation. An adverse selection in the insured pool suggests that manufacturers with different levels of loss risk have different elasticities of demand. The sensitivity of the demand for agricultural insurance to its determinants is the elasticity of demand. When all other conditions are the same, the demand for agricultural insurance is correlated with the premiums that farmers are willing to pay. High premiums and low coverage reduce the demand for certain policies, while low premiums and high coverage increase utilization (Sihem 2019).

Agricultural risk can be managed through alternatives to insurance such as diversification and cooperatives once access, and costs and benefits, are assessed. Income factors include income from agriculture and off-farm activities. The higher the level of agricultural income, the greater the need for agricultural insurance to prevent the loss of income. Off farm income can be seen as a form of diversification and a risk management tool, and it may reduce the demand for agricultural insurance. Some other factors that impact farmers' preferences for agricultural insurance are age, experience, education, landholding size, the insurance company's reputation, and satisfaction with the insurance company (Tsikirayi et al. 2012). In developing countries, the level of farmers' education affects the demand for agricultural insurance.

Index insurance schemes are piloted where potential customers have little experience with insurance, an index product, or an insurance company or its agents. Developing these new markets requires companies to sensitize potential consumers about the concepts of insurance and index insurance products (Jensen and Barret 2016). Because demand is influenced by trust—farmers pay the premium at the beginning of the insurance contract and, therefore, bear the entire risk associated with the performance of the contract—

Table 1 Types of insurance programme

Country	Insurance programme	Reference
Zambia	Inputs like fertilizer may be lucrative only in favourable weather conditions. Smallholder farmers can offset the risk of investing in such inputs by purchasing index insurance as a well-designed index insurance contract can protect against catastrophic crop loss.	Murray and Farrin (2014)
Mali	The cotton area yield index insurance provides three-level payments according to the yield distribution; cotton farmers use index insurance contracts to minimize the basic risk.	Elabed et al. (2013) Stoeffler et al. (2016)
Morocco	The rainfall index for wheat covers the crop loss due to extreme rainfall.	Wairimu et al. (2016)
Kenya, Tanzania, and Rwanda	Farmers protect against crop loss in extreme weather conditions during the cropping season by purchasing index insurance based on weather stations and on satellites. Dairy livestock insurance covers pregnancy loss for calving cows.	Wairimu et al. (2016)
China	The government subsidizes more than 70% of crop insurance premiums. Like the multi-peril crop insurance (MPCI) in the United States (US), crop insurance is the foremost insurance programme, and it improves farmer welfare.	Ke (2015)
Sri Lanka	Agriculture relies on rainfall and irrigation in this tropical country. Index insurance products compensate farmers based on predetermined regulations and thresholds. A pure rainfall index insurance product might cover the risk of farmers who rely on rain-fed or modest irrigation; hence, it reveals the losses of farmers that are caused by adverse weather conditions.	Arandara et al. (2019)
	The government first introduced crop insurance in 1958 as a voluntary scheme. The Agriculture and Agrarian Insurance Board continues to operate and implement this indemnity-based crop insurance scheme, with periodic changes. A private insurance business launched rainfall index insurance for the first time in 2010. The government introduced crop insurance as a mandatory requirement for farmers who received fertilizer subsidies from the government. In 2016, the government initiated loan protection insurance to cover agricultural loans taken by farmers.	Wickramasinghe (2019)
	Climate insurance is a form of crop insurance that covers key climatic risks. One scheme, that was combined with the fertilizer subsidy programme, is required; all the other climate insurance schemes are voluntary.	
India	The government initiated the Comprehensive Crop Insurance Scheme (CCIS) in April 1985. The content and scope of the CCIS was improved and the new National Agricultural Insurance Scheme (NAIS) was made compulsory for loanee farmers. Insurance is available to all farmers regardless of farm size.	Jain (2004)
	The Farm Income Insurance Scheme has been introduced to protect farmers' income by combining the mechanisms for insuring production and market risks.	
	More than 9 million farmers use rainfall insurance as part of a government-mandated programme.	Dercon et al. (2014)
Ghana	The usage of rainfall insurance by farmers in northern Ghana is increasing rapidly.	Karlan et al. (2014)
	Smallholder farmers use crop weather (drought) index insurance (WII). Multi peril crop insurance (MPCI) is aimed at commercial farmers with a minimum farm size of 50 acres/20 hectares as well as other agro–value chain participants.	Ankrah et al. (2021)
	Farmers use multi-peril insurance for poultry indemnity insurance for all types of birds, including exotic and local varieties, that are raised in an intense manner of production.	

Contd...

	The area yield index insurance scheme is undergoing experiments. Initial trials had been conducted in the Jirapa District of Ghana's Upper West Region.	
Zimbabwe	Agricultural insurance usually takes the form of property insurance. The most frequent type, recognized as "named peril" or "hail insurance", is targeted primarily at commercial farmers.	Tsikirayi et al. (2012)
	Tobacco yields a larger revenue than any other farming activity, and tobacco hail insurance takes the first place in the purchase of cover and contributes the greatest proportion to the agricultural insurance portfolio.	
	Property insurance covers farm buildings, farm equipment such as tractors and trailers, and farm machinery such as irrigation equipment.	
Malawi	The relative evapotranspiration index is used to protect maize farmers from drought.	Leblois et al. (2014)
West Africa	The most viable index insurance contract for grain farmers is based on the normalized difference vegetation index (NDVI), a remotely sensed satellite-based measure of vegetation density.	Hill (2010)
Developing countries in Europe and North America	Crop hail insurance is the most popular; private insurance companies transact it on a commercial basis in nations where hail occurs more than 50 days per year.	Jain (2004)

Source Literature survey, 2021

customers should have legal recourse. In developing countries, the government should control crop insurance programmes to reduce the premium burden on smallholders; such assistance and control could help reduce the burden of premium on smallholder farmers (Owusu et al. 2021). Thus, farmers may demand an agency type of crop insurance programme.

Factors affecting the uptake of agricultural insurance

Farmers' acceptance or adoption of agricultural insurance is its uptake. The uptake is determined by forecasts of yield, revenue, and drought, and of their effects; the insurance revenue expected; and the probability of receiving claims (Tsikirayi et al. 2012). The uptake is determined also by farmers' awareness of the insurance products available, type of insurance and access to it, cost of premium, losses experienced by farmers in the past, education, gender, and caste (Table 3) (Aditya et al. 2018).

Insurance helps farmers to cope with the risk of loss; it does not increase their income. If farmers understand that, they may be expected to take less time to decide to insure their crops (or not), but it will not necessarily improve uptake (Heenkenda 2011). The lease negatively impacts adoption: farmers who rent more land are less likely to purchase insurance products (Aditya et al. 2018).

Strengths and limitations of agricultural insurance schemes

Index insurance is a cost-effective alternative to traditional insurance (Hazell et al. 2010). Index insurance helps households to reduce their reliance on unfavourable coping strategies and to increase investments in riskier production (Cai et al. 2015); thus, it helps them to improve their ability to enhance farm revenue (Karlan et al. 2014). In developing countries, index insurance offers rural agricultural households social protection and improves their standard of living (Jensen and Barrett 2016). In regions where poor rural peoples practise rain-fed agriculture and where financial market failures are common, index insurance minimizes vulnerability and enhances productivity growth (Hazell and Hess 2010). However, in the light of multi-cropping, income diversification, and data limitations, designing an index that effectively proxies for the losses of the insured is difficult (Nikolova et al. 2011).

Index insurance is more transparent when considering the compensation, but it cannot be implemented in Sri

Table 2 Factors affecting the demand for agricultural insurance

Factor	Nature of Impact	Reference
Education	The coverage of the Pradhan Mantri Fasal Bima Yojana (PMFBY) is low because farmers in India are not aware of this insurance programme.	Ghosh et al. (2021)
Access	Access is poor—farmers must travel several kilometres to reach the nearest financial institution.	Ghosh et al. (2021)
Culture	Africa Ltd launched a takaful, sharia-compliant indexed livestock insurance product in Kenya that provides drought coverage to expand formal insurance markets to Muslim pastors.	Jensen and Barret (2016)
	An index-based livestock insurance product proposed in northern Kenya was not compatible with sharia law and, therefore, inaccessible to millions of Muslim pastors in the region.	
Farmer's risk aversion	Most farmers in China prefer direct subsidies to China Crop Insurance (CCI) because the effect of CCI is less than that of the direct subsidies in all scenarios of farmer's risk aversion.	Ke (2015)
Gender	More male farmers than female farmers participate in agricultural insurance schemes in Nigeria.	Kolawole and Oluwatusin (2018)
Marital status	More married farmers than single farmers purchase agricultural insurance in Nigeria to reduce their family's vulnerability to risks.	Kolawole and Oluwatusin (2018)
Farming type	Commercial farmers in Nigeria demand agricultural insurance and insured farmers do most of the commercial farming. This may be the reason that insurance schemes induce farmers' confidence in taking risks and adopting new and improved farming technologies.	Kolawole and Oluwatusin (2018)
Price/premium of insurance	The demand for high-premium crop insurance is low among credit-constrained farmers in Ghana in sub-Saharan Africa.	Owusu et al. (2021)
Agency type of crop insurance programme: private/ government	Cocoa farmers in Ghana in sub-Saharan Africa demand the government agency–type of crop insurance programme rather than the private agency–type.	Owusu et al. (2021)
Religion	Christian farmers in Europe, North America, and South America are more likely than Muslim farmers to take agricultural insurance.	Sihem (2019)
Trust	A randomized controlled study finds that when farmers in Ghana observe member withdrawals or insurance payments on their social networks, their demand for insurance increases. In the absence of a formal contract enforcement agency, trustworthy informal institutions have filled most of the demand–supply gap for insurance in developing countries.	Karlan et al. (2014)
	The index insurance utilization rate on the standard marketing channel is only 8% in Ethiopia, but it doubles to 15% when marketing is done through iddir. Executives are usually quite trustworthy in the dissemination of insurance products.	Belissa et al. (2019)
Government assistance and involvement	Government assistance reduces the premium burden on smallholder farmers.	Owusu et al. (2021)
Farmers' collective action	Farmers in the Dominican Republic are willing to purchase group index insurance contracts; 64% of the farmers who provide contracts collectively purchase index insurance while creating new opportunities for insurance providers to construct loans and cover more farmers.	Vasilaky et al. (2020)

Source Literature survey, 2021

Table 3 Factors affecting the uptake of agricultural insurance

Factor	Nature of impact	Reference
Access	Zimbabwe has a limited network of branches of companies that offer agricultural insurance. Most branches are located in Harare, the capital, and in some main cities. Few farmers have access to insurance, therefore, ultimately resulting in lower uptake.	Tsikirayi et al. (2012)
	Most paddy farmers in rural Sri Lanka live far from the offices of insurance companies and are unlikely to purchase agricultural insurance.	Riyath and Geretharan (2016)
Loss experienced by farmers	Farmers who have experienced loss in Zimbabwe mostly purchase agricultural insurance.	Tsikirayi et al. (2012)
Type of insurance	The revenue from farming tobacco is high in Zimbabwe, and farmers are willing to insure their crop against hail, more than livestock, farm implements, and comprehensive farm cover.	Tsikirayi et al. (2012)
Nature of farming enterprise	Farming tobacco in Zimbabwe has higher costs and profits than farming grain, and so tobacco farmers insure more than grain farmers.	Tsikirayi et al. (2012)
Risk management tools adopted by farmers	Farmers in Zimbabwe diversify farm activities and adopt mixed farming to mitigate risk, reducing their uptake of insurance.	Tsikirayi et al. (2012)
Awareness	Fewer than 30% of farmers in India are aware of the concept of insurance or the existence of insurance schemes or they do not meet the prerequisites for buying insurance products.	Aditya et al. (2018)
	Farmers in Sri Lanka exposed to paddy insurance awareness programmes have bought insurance, but few others are aware of paddy insurance.	Riyath and Geretharan (2016)
Education	Educated farmers in India are more likely to buy insurance.	Aditya et al. (2018)
	Educated farmers in Ghana buy insurance faster than uneducated farmers. Farmers in Sri Lanka who have little knowledge of crop insurance buy less of insurance products.	Heenkenda (2011)
Landholding size	Larger the farm size in India, higher the level of marketable securities, increasing the opportunity for farmers to choose a formal source of credit bundled with insurance products.	Aditya et al. (2018)
Caste	Lower-caste farmers in India have a lower probability of choosing insurance.	Aditya et al. (2018)
Tenancy	According to the current schemes, leased land in India can be insured by submitting evidence of the joint use harvest/lease agreement, but such documents are difficult to produce because most crop sharing leases are completed through word of mouth.	Aditya et al. (2018)
	Leasing itself may be a coping mechanism, helping landlords and tenants share the risk, and may affect the uptake of insurance.	
Gender	The uptake of weather index insurance is higher among male farmers in Ghana than among female farmers.	Ankrah et al. (2021)
Availability	Few agricultural insurance products are available in southern Ghana; therefore, even the farmers who are aware of insurance cannot purchase it.	Ankrah et al. (2021)

Source Literature survey, 2021

Lanka because the rainfall data is not available timely (Wickramasinghe 2019). Both the irrigation and rainfall variables have interacted in the crop plantation, but the current index insurance product in Sri Lanka is based solely on rainfall—which presents various complications and increases the basis risk (Arandara et al. 2019)—and neither irrigation nor rainfall could be included within the index. The product relies on a variety of data sources, but the limitations of the data infrastructure constrain the development of a robust product (Arandara et al. 2019). Indemnity insurance requires crop loss to be evaluated, but evaluations are costly and time-consuming (Wickramasinghe 2019).

Crop insurance compensates farmers for major crop loss due to climatic variables, plant disease, and pests (Jain 2004). In most developing countries, crop insurance claims are projected to be around 15% of crop value, and the administration expenditure at 5%; but the premium, 20% of the crop value, is uneconomic. And crop insurance schemes face several constraints: the absence of reliable, long-term data on crop yield and loss, financial and human resources, land tenure records, and professional reinsurance support; and farmers' poverty and poor awareness of agricultural insurance (Jain 2004).

In Sri Lanka, farmers use crop insurance to acquire agricultural loans from traditional financial institutions. The institutions debit the insurance premium from the farmers' loan amount automatically, and the farmers are unaware both of the debit and that they have purchased insurance.

In Zambia, the index insurance scheme does not define the future payoff, and farmers must pay the premium upfront. If the purchase of insurance becomes mandatory, cash-strapped, risk-averse farmers may invest less in productive inputs (Murray and Farrin 2014).

In China, the risk of crop loss is low; therefore, the insured value is low. Their crop insurance programme covers only the cost of physical planting, about 25–40% of crop returns (Ke 2015). In Ghana, some farmers say that the agricultural insurance system is somewhat expensive (Ankrah et al. 2021). In India, comprehensive agronomic practices should be used to develop the weather index insurance scheme (Chatterjee and Oza 2017).

Typically, insurance schemes protect against low-frequency, high-severity risks only; these do not provide a total risk management solution. Multi-peril crop insurance covers a wide range of agricultural risks but it is costly to manage because it requires farm-level underwriting and loss assessment. Named peril insurance covers a small range of risks and is easier and less expensive to administer. Index-based insurance eliminates moral hazard and guarantees minimal claims and administrative expenditure, but the application of basis risk frequently results in payouts that are not in line with real losses, causing farmers to be dissatisfied. Traditional indemnity-based insurance has high administrative costs and is vulnerable to moral hazard, and, therefore, impractical in most circumstances.

Cattle insurance is based on a mutual concept that eliminates moral hazard completely and minimizes administration costs. Cattle insurance programmes are tiny and may take a long time to scale up, but they appear to be working in certain regions (Chatterjee and Oza 2017). Farm insurance is expensive; therefore, most middle-income countries subsidize it substantially. Most governments subsidize the premium; some subsidize the claims or offer indirect reinsurance to keep the rates low. Almost 50% of the gross premium is subsidized globally. The entire cost of farm insurance to governments, including premium subsidies, is nearly 68% of the gross premium (Mahul and Stutley 2010).

The potential of insurance products in Sri Lanka

Agriculture has played an important role in the Sri Lankan economy in the past, but it currently contributes less than 7% to the gross domestic product (GDP). Agriculture is focused on tea, coconut, spices, and rubber for export, and paddy, vegetables, and crops for consumption. But Sri Lanka is among the countries that are most vulnerable to adverse climate impacts, according to the Global Climate Risk index, and its agriculture sector is prone to climate risks, like droughts, floods, and changes in rainfall. Alternating floods and droughts nationwide in the recent past have severely affected many agricultural districts. Also, agriculture is subjected to many production and income risks and uncertainties. Therefore, farmers can use the mechanism of crop insurance to manage risk, and the potential to implement weather-based index insurance for the crops grown for import and export in Sri Lanka is high (Wickramasinghe 2019). The country already has crop loss insurance for paddy (Nilwala and Jayarathna 2018).

Small-scale farmers in the Ampara district of Sri Lanka have accepted index-based micro-insurance. They use it as a tool to manage the risk of production loss caused by natural disasters. The demand for micro-insurance is high and concentrated in irrigated areas. Farmers prefer higher coverage than offered by the existing traditional insurance schemes. This indicates that index-based micro-insurance schemes can be introduced into the highly irrigated areas in Sri Lanka (Heenkenda 2011).

In rural agricultural areas, the mechanisms for delivery and collecting premiums are difficult to set up. Farmer organizations are popular, familiar, and trusted, and they have improved the efficiency of insurance delivery (Heenkenda 2016). Paddy farmers' organizations can collect premiums from farmers and provide them customer service while companies provide insurance and marketing products.

Designing and starting micro-insurance programmes, especially for index insurance, seems to be a very expensive process for private insurers. The government can engage in research and development (R&D) for the design phase. In the context of public-private partnerships, the metrology division could partner with insurance companies or companies that provide index base coverage. The metrology division obtains a wide range of meteorological data, which insurers can purchase to develop and implement index micro insurance schemes.

In Sri Lanka, the postal department is a public institution and its network is widespread in rural areas. Insurance and service companies can offer micro insurance programmes through the post office network (Heenkenda 2016). Micro insurance providers have to compromise between the low ends of the poor sector while maintaining full cost recovery. Special subsidy schemes can be financed through Samurdhi, the government's comprehensive poverty reduction scheme that extends over most of the country, and used to incentivize the poorest farmers to purchase crop insurance (Heenkenda 2016); the subsidy can be reduced as the farmers move up the income ladder.

Conclusion

Farmers in developing countries use a variety of agricultural insurance products. The demand for agricultural insurance is affected by controllable factors (access, farmer's risk aversion, farming type, insurance price or premium, agency type of crop insurance programme [private / government], and farmers' collective action) and by uncontrollable factors (education, religion, culture, gender, trust, and marital status).

Of the controllable factors, education, trust, access, and insurance premium affect demand the most, and these should be focused on to raise the demand for insurance. Most of the uncontrollable factors determine demand in developing countries such as India, Africa, Kenya, and Nigeria.

The factors of uptake are some demand factors, such as education, access, and gender; and loss previously experienced by farmers, insurance type, nature of the farming enterprise, the risk management tool farmers adopt, awareness, landholding size, caste, tenancy, and the availability of insurance.

The uptake has been far below expectations; it can be improved by enhancing farmers' awareness and education, ensuring that insurance is available and farmers can access it, and providing satisfactory compensation for the previous damage. Caste and gender negatively affect uptake, especially in India.

Insurance is a cost-effective means for farmers to cope with unexpected risks, minimize vulnerability, and enhance productivity and farm revenue, but some limitations prevail: the data required is not available, the coverage of insurance is limited, and the premium is too high for the poor farmers. Some insurance products, such as cattle insurance, are limited to certain regions. In Sri Lanka, the index insurance product is based solely on rainfall, despite the interrelation of the variables. Companies must enhance the strengths of the existing insurance products and mitigate their limitations to facilitate uptake.

Risks and uncertainties are inherent in agricultural production and income, and Sri Lanka must institute and implement programmes to withstand these and uplift the farmers' standard of living. The type of crops cultivated in an area and its climate should determine the type of the new agricultural insurance product formulated and introduced. The government can use farmer organizations and Samurdhi to incentivize low-income farmers to participate in crop insurance programmes.

The findings of this study will help the Sri Lankan government and other authorities to fill the demand–uptake gap in the existing agriculture insurance products and develop effective products. But the results of this study are limited by its focus on developing countries; the insurance products in developed countries should be evaluated in future research.

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