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DOCTORAL DISSERTATION

**CULTIVATING A SUSTAINABLE FUTURE: AN
IMPLEMENTATION CASE STUDY OF PERMACULTURE
AND DIGITAL TECHNOLOGIES IN MANAGED FARM
SERVICES CONTEXT**

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TESIS DOCTORAL

CULTIVANDO UN FUTURO SOSTENIBLE: UN ESTUDIO
DE CASO SOBRE LA IMPLEMENTACIÓN DE LA
PERMACULTURA Y TECNOLOGÍAS DIGITALES EN EL
CONTEXTO DE SERVICIOS AGRÍCOLAS
GESTIONADOS

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ABSTRACT

Industrial agriculture's detrimental environmental impact and the growing global demand for food necessitate sustainable agricultural practices. The current study aims to investigate the economic performance and sustainability outcomes of implementing permaculture practices and digital technologies in a managed farm services context in India (two distinct farm types: agroforestry and lifecentric farms), contributing to the growing body of knowledge on sustainable agriculture and highlighting the potential of different implementation approaches to transform the agricultural sector.

A mixed-method sequential research design is used, beginning with qualitative interviews conducted with five experts associated with the single case study organization, Hosachiguru, a leading Indian farming company offering managed farm services, followed by quantitative surveys with 208 farmers (108 from agroforestry and 100 from lifecentric farms). Findings reveal that implementing permaculture practices like rainwater harvesting (mean = 4.64) and water management systems (mean = 4.63), alongside digital technologies like IoT-based moisture management (mean = 4.48) and drip irrigation (mean = 4.52), enhances both economic performance and sustainability outcomes according to the farmers. Notably, lifecentric farmers received higher benefits from certain permaculture practices (e.g., mulching, with a statistically significant difference of $p < 0.001$) and the MyFarm mobile app ($p < 0.01$) compared to agroforestry farmers. Moreover, farmers prioritized non-price factors like concept representation (mean = 4.25), amenities & facilities (mean = 4.08) and developer reputation (mean = 4.05) when purchasing managed farm services, over price (mean = 3.13).

The study's findings underscore the transformative potential of integrating permaculture and digital technologies in diverse farming contexts. Policymakers and educators should develop supportive policies and training for sustainable and digital farming. The study also provides future research directions such as effect of tailored approaches for sustainable agriculture and the need for a longitudinal study to track improvements over time among others.

RESUMEN

El impacto ambiental perjudicial de la agricultura industrial y la creciente demanda global de alimentos hacen necesarias prácticas agrícolas sostenibles. El presente estudio tiene como objetivo investigar el rendimiento económico y los resultados de sostenibilidad de la implementación de prácticas de permacultura y tecnologías digitales en el contexto de servicios agrícolas gestionados en la India (en dos tipos distintos de granjas: agroforestales y granjas centradas en la vida). Con ello, se contribuye al creciente cuerpo de conocimiento sobre la agricultura sostenible y se destacan los diferentes enfoques de implementación con el potencial de transformar el sector agrícola.

Se emplea un diseño de investigación secuencial con enfoque mixto, comenzando con entrevistas cualitativas a cinco expertos vinculados con la organización de objeto del estudio de caso, Hosachiguru, una destacada empresa agrícola India que ofrece servicios de gestión de granjas. Posteriormente, se aplicaron encuestas cuantitativas a 208 agricultores (108 de granjas agroforestales y 100 de granjas centradas en la vida). Los hallazgos revelan que la implementación de prácticas de permacultura, como la cosecha de agua de lluvia (media = 4.64) y los sistemas de gestión del agua (media = 4.63), junto con tecnologías digitales como la gestión de humedad basada en IoT (media = 4.48) y el riego por goteo (media = 4.52), mejora tanto el desempeño económico como los resultados de sostenibilidad, según los agricultores.

En particular, los agricultores de las granjas centradas en la vida obtuvieron mayores beneficios de ciertas prácticas de permacultura (por ejemplo, el acolchado, con una diferencia estadísticamente significativa de $p < 0.001$) y de la aplicación móvil MyFarm ($p < 0.01$) en comparación con los agricultores de granjas agroforestales. Además, al adquirir servicios agrícolas gestionados, priorizaron factores no relacionados con el precio, como la representación del concepto (media = 4.25), las comodidades e instalaciones (media = 4.08) y la reputación del desarrollador (media = 4.05), por encima del precio (media = 3.13).



Los hallazgos del estudio subrayan el potencial transformador de la integración de la permacultura y las tecnologías digitales en diversos contextos agrícolas. Se recomienda que los responsables de políticas y educadores desarrollen normativas y programas de capacitación que respalden la agricultura sostenible y digital. Además, el estudio sugiere futuras líneas de investigación, como el impacto de enfoques personalizados en la agricultura sostenible y la necesidad de un estudio longitudinal para evaluar mejoras a lo largo del tiempo, entre otros aspectos.

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Chapter 1: Introduction

1.1. Introduction

Agriculture, while essential for human survival, is now recognized as the leading force driving global biodiversity loss. This loss occurs through the conversion of natural ecosystems into agricultural lands, the expansion of management practices into traditional landscapes, the release of pollutants and greenhouse gases (GHGs), and the broader impacts on the value chain, including transportation, energy use, and food waste (Dudley & Alexander, 2017). These issues have led to demands for a "reformed, sustainable approach" to agriculture or the development of sustainable agricultural systems.

In the 1960s and 1970s, the focus was on preventing widespread starvation rather than on agricultural sustainability, as resource overuse was not a pressing concern (Brady, 1990). However, as the awareness of the greenhouse effect increased, the detrimental impact of slash-and-burn agriculture in tropical forests, a significant carbon dioxide source, became evident. Sustainable agriculture, defined by its ability to endure over time (Robertson 2015), has become a critical focus in addressing environmental challenges. The second Sustainable Development Goal (SDG2) aims to "End hunger, achieve food security and improved nutrition, and promote sustainable agriculture," recognizing the interconnectedness of promoting sustainable agriculture, empowering small farmers, supporting gender equality, eliminating rural poverty, safeguarding healthy lifestyles, and addressing climate change (United Nations 2015). This emphasis on sustainability extends beyond agriculture into broader business practices. Over the past few decades, sustainability has become a key topic on business agendas as enterprises increasingly recognize their environmental impact and responsibility. This realization has spurred the 'going green' movement, demonstrating that companies can simultaneously reduce pollution and increase profits (Levina, 2015).

At this juncture, the role of Information Systems (IS) and Information Technology (IT) becomes pivotal. The concept of 'Green IS' bridges these domains, advocating that the effective use of IS/IT not only supports the going green movement but also facilitates sustainability in societies more broadly (Dedrick, 2010). IS and IT have the potential to significantly alter human behavior and support the shift to a sustainable society. In the last few decades, these technological advancements have profoundly changed human behavior and, as a result, have opened up new avenues for supporting sustainable farming (Koochafkan, Altieri, & Gimenez, 2012). Contemporary technological advancements, coupled with the increased emphasis on sustainable farming, have led to the exploration and use of innovative natural and digital approaches for sustainable farming, where the principle of Green IS plays a crucial role.

Permaculture, a natural method within agroecology, emerged as a response to growing concerns about the negative impacts of industrial agriculture, evolving into an "international movement and ecological design system" (Ferguson & Lovell, 2014). In the realm of digital technologies, smart farming and precision agriculture have gained prominence. Precision agriculture, described as an "information-led management concept in both plant and animal production based on a wide range of technologies" (Linaza et al. 2021), relies on the digital processing of specific information to enhance decision-making processes. Recent research efforts have demonstrated the ability of technology to advance sustainable agriculture; Sambas et al. (2023) have highlighted the benefits of optimizing irrigation, nutrient allocation and smart farming in Indonesia. Similarly, Bradbury et al. (2023) reported that innovation in soil surveillance systems has helped shift agronomic practices. Unmanned aerial vehicles (UAVs) have been employed in precision agriculture, enabling them to collect and analyze data effectively from multiple sensors in the farms, which ensures that valuable data is acquired from IoT sensors (Sajid, Hayawi, Malik, Anwar, & Trabelsi, 2023). This data acquisition uses fog computing, which processes data closer to its source rather than relying on remote servers. Another recent study by Iba & Lilavanichakul (2023) reported a new agrarian model which

harnesses smart farming technologies for rice cultivation in Japan. Collectively, these studies highlight technology's transformative role in sustainable agriculture. In contrast, smart farming is a "knowledge-based approach where machines can make partially autonomous decisions in collaboration with management systems. These decisions are based on real-time autonomously obtained and processed information, although farmers retain the ability to override them" (Munz, Gindele, & Doluschitz, 2020).

Although permaculture practices and digital technologies for sustainable agriculture have been extensively discussed in scientific and academic research over the past few decades, current studies often focus on innovation and sustainability in agriculture. The role of Information Systems (IS) in sustainability tends to emphasize future goals and outcomes rather than empirical evaluations of real-world farm operations and outcomes. Experts in the IS field have published numerous papers highlighting how IS contributes not only to the economic objectives of organizations but also to their sustainability efforts (Bush, Lederer, Li, Palmisano, & Rao, 2009; Melville, 2010; Pan & Zhang, 2020; Pearlson, Saunders, & Galletta, 2024). Despite growing interest from businesses, governments, and IS researchers, a definitive measure for assessing the capability of organizations to green their IT remains undefined (Cooper & Molla, 2017).

Richard Watson and colleagues (Watson, Boudreau, and Chen, 2010) initiated a discussion on energy informatics, a subfield of IS that explores the potential role of IS in reducing energy consumption and carbon emissions. They argued that ecological sustainability requires recognizing the interconnected nature of environmental problems. In another study, Watson, Lind, and Haraldson (2012) posited that information systems could drive sustainability improvements like they have driven productivity enhancements. They proposed several imperatives for computing professionals to support sustainability: developing IS and networks that integrate significant environmental costs into prices, designing corporate sustainability reporting systems aimed at achieving a more sustainable society,

using effective methods to present product sustainability information to encourage green purchasing, and creating IS that provide precise, actionable, and meaningful information about the environmental impact of personal decisions.

Overall, the insights from Watson et al. (2012) offer a valuable foundation for understanding how the use of IS in farms can influence the economic and sustainability objectives of the agricultural industry.

In the agricultural farm industry context, organizations are increasingly offering managed farm services to interested farmer investors in India. As this is a relatively new sector, there is limited understanding of their processes and contributions to sustainability outcomes while achieving positive economic performance for farmers.

The literature review in Chapter 2 highlights significant research gaps in evaluating the impact of permaculture and digital technologies implementation, with limited research currently in this domain. Scholars within agriculture propose several sustainability frameworks. However, there appears to be a lack of evaluation regarding their application and efficiency.

Furthermore, it is noteworthy that many institutions have articulated sustainability-related objectives within the context of agriculture. For instance, Eyhorn et al. (2019) discuss how organic farming drives sustainability in global agriculture, emphasizing its significant role in environmental and sustainable agricultural practices. Additionally, Meemken and Qaim (2018) provide insights into agricultural sustainability, focusing on the economic and resource utilization aspects. However, a conspicuous absence of empirical evidence detailing the monitoring and reporting of their progress prevails in the scholarly discourse. While digital technologies are increasingly recognized for their potential to enhance agricultural sustainability (Bronson, 2019), there is a gap in the literature regarding their implementation alongside permaculture practices. This study seeks to fill this gap by empirically investigating how digital technologies can be synergistically used alongside permaculture practices to enhance sustainability in agriculture. Additionally, while there is literature on the economic and environmental aspects of sustainable

agriculture (Meemken & Qaim, 2018; Eyhorn et al., 2019), there is a lack of comprehensive studies that highlight the implementation aspects with the social dimensions of sustainability, particularly in the context of emerging economies like India and for new industry offering like managed farm services.

To address these research gaps, the current study aims to bridge this knowledge gap by conducting an empirical study into the implementation of permaculture and digital technologies in managed farm services for agroforestry and lifecentric farms.

The term "agroforestry" was introduced in 1977 to describe a system that integrates forestry and agriculture. Lundgren and Raintree (1982) have defined this concept effectively: "A collective name for land-use systems in which woody perennials (trees, shrubs, etc.) are grown in association with herbaceous plants (crops, pastures) or livestock, in a spatial arrangement, a rotation, or both; there are usually both ecological and economic interactions between the trees and other components of the system." While this formal definition is relatively modern, the practice of incorporating trees into agricultural landscapes has been around for thousands of years (Augère-Granier, 2020). Interestingly, the origins of agroforestry may lie in an inverse approach, with early humans planting crops within forested areas among existing trees (Báder, Németh, Vörös, Tóth, & Novotni, 2023).

Agroforestry farming is a land-use management system that intentionally integrates trees and shrubs into crop and/or animal farming systems to create environmental, economic, and social benefits. It combines agricultural and forestry technologies to create more integrated, diverse, productive, profitable, healthy, and sustainable land-use system (van Noordwijk, 2021) while A life-centric approach incorporates ethical considerations regarding the value and rights of living beings, promoting actions that avoid harm and ensure the dignity and welfare of all forms of life. Examples of measures include stricter conservation areas and a focus on climate justice (Thomas, Mason, & Woodward, 2024). According to Thomas et al. (2024) lifecentric farming is an ethical perspective that prioritizes the well-being of all living beings and their ecosystems.

In agroforestry managed farm services, like forest set-up, large trees are planted (e.g. timber that takes 15+ years to harvest) alongside shrubs and crops in the farms. In contrast, life-centric managed farm services focus on perennial crops (like sugarcane or other fruit plants with harvests of less than two years) and support all aspects of farm experience, such as building a home and having livestock within the farm. The primary focus of the current research effort is to evaluate how these approaches can contribute to economic performance and sustainability outcomes in managed farm services. To achieve this, a single case study methodology is employed with a specific emphasis on agricultural managed farm services offered by Hosachiguru, a prominent agriculture managed farm services company based in Bangalore, India. This approach allows us to gain valuable insights into the real-world applications of permaculture and digital technologies in the agricultural sector. The study offers novel insights into sustainable agriculture by exploring the integration of permaculture, digital technologies, and traditional farming practices in agroforestry and lifecentric farms in managed farm services. The findings show significant differences in sustainable practice adoption across these farm types, emphasizing the economic, environmental, and psychological benefits associated with each. These findings underscore the transformative potential of integrating permaculture and digital technologies in diverse farming contexts. The findings also underline the importance of IoT-based technologies like moisture management systems in improving farm efficiency while also stressing the need for tailored strategies to address socio-economic and gender-specific influences on technology adoption. The study includes quantitative and qualitative analysis to answer the research questions defined below.

1.2. Research questions & objectives

Based on the identified research gap and the lack of empirical data on the subject, the following central research question was developed to guide this study:

“Does implementing permaculture practices and digital technologies improve the economic performance and sustainability outcomes of agroforestry and lifecentric managed farm services?”

This study employs surveys and interviews to answer the above research question. The specific objectives are:

- To assess the impact of implementing permaculture practices in agroforestry and lifecentric managed farm services.
- To assess the impact of implementing digital technologies in agroforestry and lifecentric managed farm services.
- To understand the farmer’s purchasing criteria when buying agroforestry and lifecentric managed farm services.
- To evaluate the current implementation of sustainability practices in managed farm services in India.
- To share learning and best practices for implementing permaculture and digital technologies in a managed farm services context.

The implementation of permaculture practices and digital technologies is measured using surveys (five-point Likert scale) from farmers and interviews with experts. Farmer’s purchasing criteria is measured using a five-point Likert scale across various criteria. The implementation of multiple sustainability practices across both farms is also measured using surveys from farmers and interviews with experts.

1.3. Research significance

This research is anticipated to be valuable to both academic scholars and industry practitioners. The primary contribution lies in quantifying the implementation benefits of natural and technological methods for achieving the economic performance and sustainability outcomes for agricultural farms. The thesis makes key academic contributions by addressing multiple research gaps in the existing literature. While there exists literature on the effect of permaculture in agriculture (Alakendu, Afiya,

Senthilkumar, & Manivannan, 2024; Bhandari & Bista, 2019; Ferguson & Lovell, 2014) and the impact of digital technologies (Linaza et al., 2021). However, these studies have primarily focused on the individual potential of permaculture practices or digital technologies, emphasizing outcomes rather than real-world farm operations. A recent study by McLennon, Dari, Jha, Sihi, and Kankarla (2021) reports that the impact of using both permaculture and digital technologies in agriculture can have several benefits. The current research fills this gap by providing the impact of both these approaches as per the farmers and experts.

Secondly, the existing literature lacks any study that highlights the implementation and effectiveness of these methods within the context of managed farm services, especially in emerging economies like India. Meemken and Qaim (2018) have reported that India has the highest number of organic farmers in the world, i.e. 0.6 million; however, the literature does not include any study that reports about their opinion on these practices and their benefits.

Additionally, the existing literature lacks comparative studies examining the impact of permaculture and digital technologies on distinct farm types. Studies have already been conducted on various agriculture paradigms that look at individual farm types. A study by Saha, Sharmin, Biswas, and Ashaduzzaman (2018) reports farmers' perception of agroforestry practices in Bangladesh, however no study reported impact of lifecentric practices with respect to farmers perception. The current study fills this gap by conducting a comparative analysis of agroforestry and lifecentric farming hence providing insights into their effectiveness in different agricultural contexts.

Lastly, extensive literature has recognized the potential of digital technologies to enhance agricultural sustainability (Laha et al., 2023; Solanki, 2021), there is a gap in literature regarding their practical implementation alongside permaculture practices, particularly in the context of managed farm services. The current study addresses this gap by examining the challenges and opportunities with real-world implementation of these approaches.

The current study also contributes to the growing discourse in sustainable agriculture as it provides empirical evidence on the implementation of permaculture practices and digital technologies in an emerging economy. The study also extends the work of researchers like Garnett et al. (2013), who highlighted the need for food systems sustainability using systematic approaches and by reporting how these integrated approaches can be implemented. Moreover, by focusing on distinct farm types (agroforestry and lifecentric), the research addresses the call for context-specific sustainability assessments in agriculture (Tittonell, 2014). The findings offer valuable insights for refining sustainable intensification strategies and tailoring them to diverse agricultural landscapes.

Practitioners can leverage this research to apply appropriate permaculture practices and relevant digital technologies to lower operational costs (such as labor and farming costs) while enhancing overall farm sustainability. Academics will find this study significant as it will be the first to assess the impact of permaculture and digital technologies on two distinct types of agricultural farms (agroforestry and lifecentric) in India. This research will provide a basis for future studies exploring various dimensions of permaculture and emerging digital technologies, examining their implementation effects on farm economic performance and sustainability outcomes across different farm types. To the best of the author's knowledge, no previous literature has addressed the implementation impact of permaculture and digital technologies on agroforestry and lifecentric farm types within the context of managed farm services.

1.4. Thesis organization

This section outlines the structure of the thesis. The current chapter introduces the topic and outlines the research objectives and significance. Chapter 2 provides a comprehensive literature review, discussing sustainable agriculture extensively, followed by agricultural innovations and various natural and technological approaches. The chapter concludes with the formulation of the research objectives.

Chapter 3 details the methodology adopted for the study, including the research design, approach, data collection, and analysis, as well as the limitations of the methodology. Chapter 4 includes both qualitative and quantitative results, presenting data from questionnaires conducted with two groups (agroforestry and life-centric farmers) and findings from in-depth structured interviews with five agriculture industry experts. Chapter 5 discusses these findings. The thesis concludes with Chapter 6, which offers major insights, implications, learning and best practices.

Capítulo 1: Introducción

1.1 Introducción

La agricultura, aunque esencial para la supervivencia humana, se reconoce ahora como la principal fuerza impulsora de la pérdida global de biodiversidad. Esta pérdida ocurre debido a la conversión de ecosistemas naturales en tierras agrícolas, la expansión de prácticas de manejo en paisajes tradicionales, la liberación de contaminantes y gases de efecto invernadero (GEI), así como los impactos más amplios en la cadena de valor, que incluyen el transporte, el uso de energía y el desperdicio de alimentos (Dudley & Alexander, 2017). Estos problemas han generado demandas para un "enfoque reformado y sostenible" de la agricultura o el desarrollo de sistemas agrícolas sostenibles.

En las décadas de 1960 y 1970, el enfoque se centraba en prevenir la hambruna generalizada en lugar de garantizar la sostenibilidad agrícola, ya que el uso excesivo de los recursos no era una preocupación urgente (Brady, 1990). Sin embargo, con el aumento de la conciencia sobre el efecto invernadero, se hizo evidente el impacto negativo de la agricultura de roza y quema en los bosques tropicales, una fuente significativa de dióxido de carbono. La agricultura sostenible, definida por su capacidad de perdurar en el tiempo (Robertson, 2015), se ha convertido en un enfoque clave para abordar los desafíos ambientales.

El segundo Objetivo de Desarrollo Sostenible (ODS2) busca "poner fin al hambre, lograr la seguridad alimentaria y mejorar la nutrición, y promover la agricultura sostenible", reconociendo la interconexión entre fomentar la agricultura sostenible, empoderar a los pequeños agricultores, apoyar la igualdad de género, eliminar la pobreza rural, garantizar estilos de vida saludables y abordar el cambio climático (Naciones Unidas, 2015).

Este énfasis en la sostenibilidad va más allá de la agricultura y se extiende a las prácticas empresariales en general. En las últimas décadas, la sostenibilidad se ha

convertido en un tema clave en las agendas empresariales, ya que las empresas reconocen cada vez más su impacto ambiental y su responsabilidad. Esta toma de conciencia ha impulsado el movimiento “green”, demostrando que las empresas pueden reducir la contaminación y, al mismo tiempo, aumentar sus ganancias (Levina, 2015).

En este punto, el papel de los Sistemas de Información (SI) y la Tecnología de la Información (TI) se vuelve crucial. El concepto de "Green IS" (Sistemas de Información Verdes) une estos ámbitos, argumentando que el uso efectivo de SI/TI no solo respalda el movimiento ecológico, sino que también facilita la sostenibilidad en la sociedad en general (Dedrick, 2010). Los SI y TI tienen el potencial de alterar significativamente el comportamiento humano y de respaldar la transición hacia una sociedad sostenible. En las últimas décadas, estos avances tecnológicos han cambiado profundamente el comportamiento humano, abriendo nuevas vías para respaldar la agricultura sostenible (Koohafkan, Altieri, & Gimenez, 2012). Los avances tecnológicos contemporáneos, junto con el creciente énfasis en la agricultura sostenible, han llevado a la exploración y uso de enfoques innovadores tanto naturales como digitales para la agricultura sostenible, donde el principio de “Green IS” juega un papel fundamental.

La permacultura, un método natural dentro de la agroecología, surgió como respuesta a la creciente preocupación por los impactos negativos de la agricultura industrial, evolucionando hasta convertirse en un "movimiento internacional y un sistema de diseño ecológico" (Ferguson & Lovell, 2014). En el ámbito de las tecnologías digitales, la agricultura inteligente y la agricultura de precisión han ganado protagonismo. La agricultura de precisión se describe como un "concepto de gestión basado en la información en la producción vegetal y animal, basado en una amplia gama de tecnologías" (Linaza et al., 2021). Se apoya en el procesamiento digital de información específica para mejorar la toma de decisiones. Investigaciones recientes han demostrado cómo la tecnología puede impulsar la agricultura sostenible; por ejemplo, Sambas et al. (2023) destacaron los beneficios

de la optimización del riego, la asignación de nutrientes y la agricultura inteligente en Indonesia. Del mismo modo, Bradbury et al. (2023) informaron que la innovación en los sistemas de vigilancia del suelo ha ayudado a transformar las prácticas agronómicas. Los vehículos aéreos no tripulados (UAVs) se han empleado en la agricultura de precisión, permitiendo recopilar y analizar datos de manera efectiva a partir de múltiples sensores en las granjas, asegurando que se adquieran datos valiosos de los sensores IoT (Sajid, Hayawi, Malik, Anwar, & Trabelsi, 2023). La adquisición de estos datos utiliza la computación en la niebla, que procesa la información más cerca de su fuente en lugar de depender de servidores remotos. Otro estudio reciente de Iba & Lilavanichakul (2023) informó sobre un nuevo modelo agrario que aprovecha las tecnologías de agricultura inteligente para el cultivo de arroz en Japón. Colectivamente, estos estudios resaltan el papel transformador de la tecnología en la agricultura sostenible. En contraste, la agricultura inteligente es un "enfoque basado en el conocimiento en el que las máquinas pueden tomar decisiones parcialmente autónomas en colaboración con sistemas de gestión. Estas decisiones se basan en información obtenida y procesada en tiempo real, aunque los agricultores pueden anularlas" (Munz, Gindele, & Doluschitz, 2020).

Si bien las prácticas de permacultura y las tecnologías digitales para la agricultura sostenible han sido ampliamente discutidas en la investigación científica y académica en las últimas décadas, los estudios actuales a menudo se centran en la innovación y la sostenibilidad en la agricultura. El papel de los Sistemas de Información (SI) en la sostenibilidad tiende a enfatizar objetivos y resultados futuros, en lugar de evaluaciones empíricas de las operaciones agrícolas en el mundo real. Expertos en el campo de SI han publicado numerosos artículos que destacan cómo los SI contribuyen no solo a los objetivos económicos de las organizaciones, sino también a sus esfuerzos de sostenibilidad (Bush, Lederer, Li, Palmisano, & Rao, 2009; Melville, 2010; Pan & Zhang, 2020; Pearlson, Saunders, & Galletta, 2024). A pesar del creciente interés de empresas, gobiernos e investigadores en SI, aún no se ha definido una medida definitiva para evaluar la capacidad de las organizaciones para hacer más ecológica su TI (Cooper & Molla, 2017).

Richard Watson y colegas (Watson, Boudreau y Chen, 2010) iniciaron un debate sobre la informática energética, un subcampo de los SI que explora el papel potencial de estos en la reducción del consumo de energía y las emisiones de carbono. Argumentaron que la sostenibilidad ecológica requiere reconocer la naturaleza interconectada de los problemas ambientales.

En otro estudio, Watson, Lind y Haraldson (2012) postularon que los sistemas de información podrían impulsar mejoras en sostenibilidad de la misma manera en que han impulsado mejoras en productividad. Propusieron varios imperativos para que los profesionales de la computación apoyen la sostenibilidad: desarrollar sistemas de información y redes que integren costos ambientales significativos en los precios, diseñar sistemas de reporte de sostenibilidad corporativa con el objetivo de lograr una sociedad más sostenible, utilizar métodos eficaces para presentar información sobre la sostenibilidad de los productos a fin de fomentar compras ecológicas y crear sistemas de información que proporcionen datos precisos, procesables y significativos sobre el impacto ambiental de las decisiones personales.

En general, los conocimientos de Watson et al. (2012) ofrecen una base valiosa para comprender cómo el uso de los sistemas de información en las granjas puede influir en los objetivos económicos y de sostenibilidad de la industria agrícola.

En el contexto de la industria agrícola, las organizaciones están ofreciendo cada vez más servicios de gestión de granjas a inversionistas agrícolas interesados en la India. Dado que este es un sector relativamente nuevo, existe un conocimiento limitado sobre sus procesos y su contribución a los resultados de sostenibilidad, al mismo tiempo que logran un desempeño económico positivo para los agricultores.

La revisión de la literatura en el Capítulo 2 destaca lagunas significativas en la evaluación del impacto de la implementación de la permacultura y las tecnologías digitales, con investigaciones limitadas en este campo. Los académicos en el ámbito de la agricultura han propuesto varios marcos de sostenibilidad. Sin embargo, parece haber una falta de evaluación sobre su aplicación y eficiencia.

Además, es importante destacar que muchas instituciones han formulado objetivos relacionados con la sostenibilidad dentro del contexto agrícola. Por ejemplo, Eyhorn et al. (2019) analizan cómo la agricultura orgánica impulsa la sostenibilidad en la agricultura global, enfatizando su papel significativo en las prácticas agrícolas sostenibles y medioambientales. Asimismo, Meemken y Qaim (2018) aportan perspectivas sobre la sostenibilidad agrícola, centrándose en los aspectos económicos y en la utilización de recursos. No obstante, en el discurso académico prevalece una notoria ausencia de evidencia empírica que detalle el monitoreo y la presentación de informes sobre sus avances.

Si bien las tecnologías digitales son cada vez más reconocidas por su potencial para mejorar la sostenibilidad agrícola (Bronson, 2019), existe una laguna en la literatura respecto a su implementación en conjunto con las prácticas de permacultura. Este estudio busca llenar este vacío investigando empíricamente cómo las tecnologías digitales pueden emplearse de manera sinérgica junto con la permacultura para fortalecer la sostenibilidad en la agricultura. Además, aunque existe literatura sobre los aspectos económicos y ambientales de la agricultura sostenible (Meemken & Qaim, 2018; Eyhorn et al., 2019), hay una falta de estudios integrales que destaquen los aspectos de implementación junto con las dimensiones sociales de la sostenibilidad, especialmente en el contexto de economías emergentes como India y en nuevas ofertas industriales como los servicios de gestión agrícola.

Para abordar estas brechas, el presente estudio busca cerrar esta brecha de conocimiento mediante un estudio empírico sobre la implementación de la permacultura y las tecnologías digitales en servicios de granja administrada para sistemas agroforestales y granjas centradas en la vida.

El término "agroforestería" fue introducido en 1977 para describir un sistema que integra la silvicultura y la agricultura. Lundgren y Raintree (1982) definieron este concepto de manera efectiva: "Un nombre colectivo para los sistemas de uso de la tierra en los cuales especies perennes leñosas (árboles, arbustos, etc.) se cultivan en asociación con plantas herbáceas (cultivos, pastos) o ganado, en una disposición

espacial, una rotación o ambas; generalmente existen interacciones tanto ecológicas como económicas entre los árboles y otros componentes del sistema." Aunque esta definición formal es relativamente moderna, la práctica de incorporar árboles en los paisajes agrícolas ha existido durante miles de años (Augère-Granier, 2020). Curiosamente, los orígenes de la agroforestería pueden radicar en un enfoque inverso, en el que los primeros humanos plantaban cultivos dentro de áreas boscosas entre los árboles existentes (Báder, Németh, Vörös, Tóth y Novotni, 2023). La agroforestería es un sistema de gestión del uso de la tierra que integra intencionalmente árboles y arbustos en sistemas de cultivo y/o ganadería para generar beneficios ambientales, económicos y sociales. Combina tecnologías agrícolas y forestales para crear un sistema de uso de la tierra más integrado, diverso, productivo, rentable, saludable y sostenible (van Noordwijk, 2021).

Por otro lado, un enfoque centrado en la vida incorpora consideraciones éticas sobre el valor y los derechos de los seres vivos, promoviendo acciones que eviten el daño y garanticen la dignidad y el bienestar de todas las formas de vida. Algunas medidas incluyen la creación de áreas de conservación más estrictas y un enfoque en la justicia climática (Thomas, Mason y Woodward, 2024). Según Thomas et al. (2024), la agricultura centrada en la vida es una perspectiva ética que prioriza el bienestar de todos los seres vivos y sus ecosistemas.

En los servicios agrícolas gestionados bajo un modelo agroforestal, como la configuración de bosques, se plantan grandes árboles (por ejemplo, madera que tarda más de 15 años en ser cosechada) junto con arbustos y cultivos en las granjas. En contraste, los servicios agrícolas gestionados bajo un modelo centrado en la vida se enfocan en cultivos perennes (como la caña de azúcar u otras plantas frutales con cosechas de menos de dos años) y apoyan todos los aspectos de la experiencia agrícola, como la construcción de una vivienda y la integración de ganado en la finca.

El objetivo principal de esta investigación es evaluar cómo estos enfoques pueden contribuir al rendimiento económico y a los resultados en materia de sostenibilidad

en los servicios agrícolas gestionados. Para ello, se emplea un estudio de caso único con un enfoque específico en los servicios agrícolas gestionados por Hosachiguru, una destacada empresa de servicios agrícolas con sede en Bangalore, India. Este enfoque permite obtener valiosos conocimientos sobre la aplicación real de la permacultura y las tecnologías digitales en el sector agrícola.

El estudio ofrece perspectivas novedosas sobre la agricultura sostenible al explorar la integración de la permacultura, las tecnologías digitales y las prácticas agrícolas tradicionales en granjas agroforestales y centradas en la vida dentro de servicios agrícolas gestionados. Los hallazgos revelan diferencias significativas en la adopción de prácticas sostenibles entre estos tipos de granjas, destacando los beneficios económicos, ambientales y psicológicos asociados a cada uno.

Estos resultados subrayan el potencial transformador de la integración de la permacultura y las tecnologías digitales en diversos contextos agrícolas. Además, resaltan la importancia de tecnologías basadas en IoT, como los sistemas de gestión de humedad, para mejorar la eficiencia agrícola, al tiempo que enfatizan la necesidad de estrategias adaptadas para abordar las influencias socioeconómicas y de género en la adopción tecnológica.

El estudio incluye un análisis cuantitativo y cualitativo para responder a las preguntas de investigación definidas a continuación.

1.2. Preguntas de investigación y objetivos

Basado en la brecha de investigación identificada y la falta de datos empíricos sobre el tema, se formuló la siguiente pregunta central de investigación para guiar este estudio:

“¿La implementación de prácticas de permacultura y tecnologías digitales mejora el rendimiento económico y los resultados de sostenibilidad en los servicios agrícolas gestionados agroforestales y centrados en la vida?”

Este estudio emplea encuestas y entrevistas para responder a la pregunta de investigación. Los objetivos específicos son:

- Evaluar el impacto de la implementación de prácticas de permacultura en los servicios agrícolas gestionados agroforestales y centrados en la vida.
- Evaluar el impacto de la implementación de tecnologías digitales en los servicios agrícolas gestionados agroforestales y centrados en la vida.
- Comprender los criterios de compra de los agricultores al adquirir servicios agrícolas gestionados agroforestales y centrados en la vida.
- Evaluar la implementación actual de prácticas de sostenibilidad en los servicios agrícolas gestionados en India.
- Compartir aprendizajes y mejores prácticas para la implementación de permacultura y tecnologías digitales en el contexto de servicios agrícolas gestionados.

La implementación de prácticas de permacultura y tecnologías digitales se mide a través de encuestas (escala Likert de cinco puntos) aplicadas a agricultores y entrevistas con expertos. Los criterios de compra de los agricultores se evalúan utilizando una escala Likert de cinco puntos en diversos criterios. Además, la implementación de múltiples prácticas de sostenibilidad en ambas modalidades de granjas se mide mediante encuestas a agricultores y entrevistas con expertos.

1.3. Importancia de la investigación

Se anticipa que esta investigación será valiosa tanto para académicos como para profesionales de la industria. La principal contribución radica en la cuantificación de los beneficios de la implementación de métodos naturales y tecnológicos para mejorar el rendimiento económico y los resultados de sostenibilidad en granjas agrícolas. La tesis aporta contribuciones académicas clave al abordar múltiples vacíos en la literatura existente. Si bien existen estudios sobre el efecto de la

permacultura en la agricultura (Alakendu, Afiya, Senthilkumar y Manivannan, 2024; Bhandari y Bista, 2019; Ferguson y Lovell, 2014) y sobre el impacto de las tecnologías digitales (Linaza et al., 2021), estos estudios se han centrado principalmente en el potencial individual de las prácticas de permacultura o de las tecnologías digitales, priorizando los resultados sobre la implementación en operaciones agrícolas reales. Un estudio reciente de McLennon, Dari, Jha, Sihi y Kankarla (2021) informa que el uso combinado de permacultura y tecnologías digitales en la agricultura puede aportar múltiples beneficios. La presente investigación llena esta brecha al evaluar el impacto de ambos enfoques según la perspectiva de agricultores y expertos.

En segundo lugar, la literatura existente carece de estudios que destaquen la implementación y eficacia de estos métodos en el contexto de los servicios agrícolas gestionados, especialmente en economías emergentes como la India. Meemken y Qaim (2018) han informado que India tiene el mayor número de agricultores orgánicos del mundo, es decir, (0.6 millones); sin embargo, no hay estudios que aborden sus opiniones sobre estas prácticas y sus beneficios.

Además, la literatura actual no incluye estudios comparativos que examinen el impacto de la permacultura y las tecnologías digitales en diferentes tipos de granjas. Si bien ya se han realizado estudios sobre diversos paradigmas agrícolas enfocados en tipos específicos de granjas, un estudio de Saha, Sharmin, Biswas y Ashaduzzaman (2018) reporta la percepción de los agricultores sobre las prácticas agroforestales en Bangladesh; sin embargo, no se ha realizado estudios sobre el impacto de las prácticas centradas en la vida desde la percepción de los agricultores. La presente investigación aborda esta brecha mediante un análisis comparativo de la agroforestería y la agricultura centrada en la vida, proporcionando información sobre su efectividad en diferentes contextos agrícolas.

Por último, aunque la literatura ha reconocido ampliamente el potencial de las tecnologías digitales para mejorar la sostenibilidad agrícola (Laha et al., 2023; Solanki, 2021), existe una falta de estudios sobre su implementación práctica en

combinación con prácticas de permacultura, especialmente en el contexto de servicios agrícolas gestionados. Este estudio responde a esa laguna al examinar los desafíos y oportunidades de la implementación real de estos enfoques.

La investigación también contribuye al creciente debate sobre la agricultura sostenible, ya que proporciona evidencia empírica sobre la implementación de la permacultura y las tecnologías digitales en una economía emergente. Además, amplía el trabajo de investigadores como Garnett et al. (2013), quienes destacaron la necesidad de la sostenibilidad en los sistemas alimentarios mediante enfoques sistemáticos, y la implementación de estrategias integradas. Al enfocarse en tipos de granjas específicos (agroforestería y agricultura centrada en la vida), esta investigación responde al llamado de Tiftonell (2014) para realizar evaluaciones de sostenibilidad adaptadas a contextos específicos dentro de la agricultura. Los hallazgos ofrecen información valiosa para refinar las estrategias de intensificación sostenible y ajustarlas a diversos paisajes agrícolas.

Los profesionales pueden aprovechar esta investigación para aplicar prácticas de permacultura adecuadas y tecnologías digitales relevantes con el fin de reducir los costos operativos (como los de mano de obra y producción agrícola) y, al mismo tiempo, mejoran la sostenibilidad general de las granjas. Desde una perspectiva académica, este estudio es significativo porque será el primero en evaluar el impacto de la permacultura y las tecnologías digitales en dos tipos distintos de granjas agrícolas (agroforestería y agricultura centrada en la vida) en India. Esta investigación servirá como base para futuros estudios que exploren diversas dimensiones de la permacultura y las tecnologías digitales emergentes, examinando sus efectos en el desempeño económico y los resultados de sostenibilidad en diferentes tipos de granjas. Hasta donde llega el conocimiento del autor, no existe literatura previa que haya abordado el impacto de la implementación de la permacultura y las tecnologías digitales en los tipos de granjas agroforestales y centradas en la vida dentro del contexto de los servicios agrícolas gestionados.

1.4. Organización de la tesis

Esta sección describe la estructura de la tesis. El capítulo actual introduce el tema y expone los objetivos y la importancia de la investigación. El Capítulo 2 presenta una revisión exhaustiva de la literatura, abordando ampliamente la agricultura sostenible, seguido de innovaciones agrícolas y diversos enfoques naturales y tecnológicos. El capítulo concluye con la formulación de los objetivos de investigación. El Capítulo 3 detalla la metodología adoptada para el estudio, incluyendo el diseño de investigación, el enfoque, la recopilación y análisis de datos, así como las limitaciones de la metodología. El Capítulo 4 presenta los resultados cualitativos y cuantitativos, mostrando los datos obtenidos a través de cuestionarios aplicados a dos grupos (agricultores agroforestales y agricultores centrados en la vida) y los hallazgos de entrevistas estructuradas en profundidad con cinco expertos de la industria agrícola. El Capítulo 5 analiza estos hallazgos.

Finalmente, la tesis concluye con el Capítulo 6, que representa las principales conclusiones, implicaciones, aprendizajes y mejores prácticas.

Chapter 2: Literature Review

2.1. Introduction

The word Sustainability is derived from the Latin word "sustinēre" (which combines "sub", which means "up from below", and "tenēre" meaning "to hold"). It has deep historical roots but is a relatively modern concept, which signifies the practices of maintaining, supporting, enduring, and sometimes restraining (Caradonna, 2022; Spindler, 2013). Rural cultures, since antiquity, show evidence of having understood and implemented sustainability. The persistent appeals across millennia, for instance, of Greek philosopher Plato (430-373 BC), the Roman philosopher Pliny the Elder (23-73 AD), and the more recent ones of the German mining administrator von Carlowitz (1645-1714), to name a few, to use natural resources sustainably reflect an enduring consciousness of the dependence of humanity on the environment. The relationship between the physical environment and human society has been overlooked for many years (Dankelman, 2012; Spindler, 2013).

However, efforts have been made to raise awareness about the complex relationship between society and the environment by several modern philosophers namely Brundtland (1987), Ward and Dubos (1972), Carson (2009), Meadows, Randers, and Meadows (2013), and Maathai (2003), along with numerous natural resource users, managers, and prominent organizations like the IUCN (International Union for Conservation of Nature) and the WWF (World Wildlife Fund). Through their dedicated endeavours, they have notably elevated the visibility of humanity's profound dependency on natural resources, further underscoring the paramount significance of an unpolluted and optimally functioning environment for the holistic well-being of both humans and the ecosystem (Natenstedt, Kok, Dankelman, & Tuijthof, 2015).

The appearance of sustainability in the late 1970s and 1980s could be seen as an "explicit social, environmental, and economic ideal." Therefore, numerous

international organizations, which include governments, communities and individuals have strived to harmonize with the core principles of sustainability for the purpose of creating societies which are considered stable, safe, prosperous and environmentally conscious (Caradonna, 2022). Moreover, one of the earliest and most comprehensive definitions of sustainable development has been provided by the 1987 report “Our Common Future” by Gro Harlem Brundtland and the World Commission on Environment and Development, which describes sustainable development as “meeting the needs of the present without compromising the ability of future generations to meet their own needs” (WCED, 1987; Caradonna, 2022; Velten, Leventon, Jager, & Newig, 2015).

Sustainability’s definition normally encompasses an ecological perspective highlighting the interconnectedness of the human society, its economy and the natural environment. According to CaraDonna, Iler, & Inouye (2014), a standard sustainability model demonstrates the relationship between three key elements: the environment, the economy and social equity. Agriculture systems are presently the primary channels for society's food production. The impetus to confirm that these systems provide adequate food has led to agriculture becoming the chief user of land, using almost a third of the earth's total surface area, excluding Antarctica and Greenland (Dudley & Alexander, 2017).

As described earlier research has shown that agriculture is a major contributor of biodiversity loss, releasing pollutants and GHG emissions (Dudley & Alexander, 2017). It also has an impact on the value chain through transportation, energy use and food waste. These issues arising from agriculture have resulted for calls to a much more “reformed sustainable approach” where focus is on sustainable agricultural systems (Robertson, 2015).

These systems mainly focus on three main objectives, which are social equity, environmental health and economic viability (Brodt, Six, Feenstra, Ingels, & Campbell, 2011). Accordingly, early research in the area highlighted that sustainable development could pertain to the maintenance of resources while simultaneously

meeting the material requirements of human beings and safeguarding the environment (Tolba, 1987). Two themes were distinguished in this perspective. The first, an ecocentric position of preservation, focuses on the requirement for strict controls on economic development in a distributed socioeconomic structure. The second, an intense preservationist perspective or ecocentric position of deep ecology, is governed by anxiety about the claims of nonhuman groups (O'Riordan & Turner, 1983).

Some recent researchers have pursued various themes related to sustainable development in agriculture. For example, a focus is on measuring sustainable development in agriculture (Laurett, Paço, & Mainardes, 2021). Moreover, sustainable development can be measured by three factors, namely innovation and technology, natural agriculture, and environmental considerations. In addition, the main predictors of sustainable development are environmental motivations, engagement with sustainability, individual characteristics, external influences and concern for future generations. On the other hand, barriers that can hinder sustainable development are lack of planning and support and insufficient information.

As per Laurett et al. (2021), the results of sustainable practices include socio-environmental benefits and enhanced subjective well-being. Researchers such as Veldkamp (2009) and Piñeiro et al. (2020) have examined the initiation process and the motivating factors behind the adoption of sustainable practices. A systematic review on sustainable agriculture by Velten et al. (2015) categorized themes in sustainable agriculture into goals, strategies, and fields of action. The goals include social responsibility, ecological sustainability, and economic viability.

Sustainable agriculture strategies may include adaptive management, cooperation, and economic or ecological approaches. This also includes the application of knowledge and science in agriculture. Velten et al. (2015) note that fields of action may include agrifood systems, management and technological solutions, social and environmental challenges, social and human capital, and the socio-political and

economic environment. The systematic review of Velten et al. (2015) also pointed out that the most common strategies were economic-based and adaptive management, while the primary fields of action were management and technological solutions.

The diversity of research on agriculture's impact on sustainability indicated that some themes were recurrent: the use of natural agricultural approaches and technology. Although agriculture exemplifies the interaction between humans, nature, and technology, agricultural innovation has typically been viewed through a technological lens. Specifically, its development, utilization, and application (E. P. Andrade et al., 2022). However, some explorations of innovative practices, such as syntropic farming and permaculture, highlight a change in focus towards the interaction between humans and nature. Permaculture in agriculture closely resembles other alternative farming approaches, such as organic or biodynamic farming, agroecology, and agroforestry. These movements traditionally advocate for creating agroecosystems that efficiently use resources and avoid pesticides. Such systems favor local nutrient cycling (e.g., using compost, animal, or green manure) and support biological control by promoting high biodiversity to maintain plant and animal health (Morel et al., 2019).

2.2. Sustainability and IS in agriculture sector

This section discusses sustainability in agriculture, including frameworks, principles, goals, and approaches. The following section also discusses sustainability in information systems (IS), considering that it is the science of digital technologies.

2.2.1. Sustainability in agriculture

Sustainable agriculture refers to an integrated system of plant and animal production practices tailored to specific sites designed to meet human food and fiber needs in the long term. It aims to enhance environmental quality and the natural resource base essential to the agricultural economy, efficiently use non-renewable and on-farm resources, integrate natural biological cycles and controls where appropriate,

sustain the economic viability of farm operations, and improve the quality of life for farmers and society as a whole (Kremsa, 2021).

The Food and Agricultural Organization (FAO) of the United Nations defines sustainable agriculture as the management and conservation of natural resources, combined with technological and institutional changes to meet human needs for current and future generations. This development approach conserves land, water, and genetic resources of plants and animals and is environmentally sustainable, technically appropriate, economically viable, and socially acceptable (Oberč & Arroyo Schnell, 2020).

Initially, sustainable agriculture was understood as a farming system mimicking natural ecosystems (Gomiero, Pimentel, & Paoletti, 2011). The primary goals of sustainable agriculture include preserving natural resources, especially soil and water, minimizing external artificial inputs, recovering from cultivation and harvest disturbances, and maintaining economic and social viability (Gomiero et al., 2011).

2.2.1.1. Frameworks for sustainable agriculture

A framework known as the Framework for Evaluation of Sustainable Land Management (FESLM) was developed by the Food and Agriculture Organization (FAO) for decision-making about the effectiveness of land management practices on sustainability (Dumanski & Smyth, 1994). As per the report, techniques, policies, and actions are integrated into sustainable land management (SLM), which combines socioeconomic principles with environmental considerations to achieve several goals.

- Maintaining and improving productivity and services
- Reducing uncertainties related to production
- Preserving natural resources and inhibiting soil and water degradation
- Being cost-effective
- Gaining social acceptance

The use of the following eight principles has also been reported in the development of the FESLM (Dumanski & Smyth, 1994) :

1. The evaluation of sustainability is for defined types of land usage,
2. The evaluation of sustainability pertains to specific areas of land,
3. Sustainability pertains to a specified period of time,
4. SLM assessments are performed by considering the physical, economic, biological, and social contexts of the areas under consideration. The evaluation of sustainability involves multiple disciplines,
5. Understanding of the processes and practices related to the current land use, if any, and its present suitability should be established prior to recommending any changes based on sustainability evaluation,
6. Scientifically valid procedures and data are the basis of evaluation together with a choice of sustainability conditions and indicators that suggest awareness of both causes and symptoms and,
7. Fresh or amended practices will first be initiated on an experimental scale, and their consequent progress will be carefully monitored.

In order to examine and categorize strategies for transitioning to more sustainable farming practices, Hill and MacRae (1996) employed their "Efficiency/Substitution/Redesign" model. The efficiency stage on the farm is exemplified by modifications in traditional systems that lower the utilisation and misuse of rare and expensive resources. For example, they can group fertilizers, observe pests, ideal siting of crops, and schedule operations. Replacement of products and procedures dependent on resources and disruptive to the environment by one more non-threatening to the environment takes place in the substitution phase. For instance, organic sources replace synthetic nitrogen fertilizers, biological controls replace pesticides, and chisels or discs replace mould-board ploughs. The redesign phase involves identifying and addressing the root cause of problems internally with the help of site-specific designs and management systems instead of depending on external resources. This technique enhances resource independence

and resilience by increasing the environmental and financial diversity of the farm (Hill & MacRae, 1996).

Table 1 Sustainable agriculture approaches (Hill & MacRae, 1996).

Unsustainable	Shallow sustainability		Deep sustainability
Conventional	Efficiency	Substitution	Redesign
Examples			
Factory farm	Low-input and resource-efficient agriculture	Eco-agriculture	Permaculture, natural and ecological farming
Approaches			
High power, imported, non-renewable	Conservation	Solar and renewable	Integrated use of local inputs, reduced demand
Physical/chemical I (soluble fertilizer pesticides, biotechnology)	Physical/chemical/biological I (slow release, band)	Biological and natural materials	Bio-ecological
Imported input-intensive	Efficient use	Alternative inputs	Knowledge/skill intensive
Narrow focus, farm as factory (linear design)	Efficient factory	Benign factory	Broad focus, farm as ecosystem (integrated

Unsustainable	Shallow sustainability		Deep sustainability
Conventional	Efficiency	Substitution	Redesign
and management)			design and management)
Problems as enemies to eliminate and control directly with products and devices	Efficient control (monitor pests, integrated pest management)	Biocontrols and more benign alternative interventions	Prevention, selective and ecological controls (pests as indicators)
Goals			
Maximize production (neglects maintenance) over short-term	Maintain production while improving maintenance	Improved maintenance	Optimise production (emphasises maintenance and system health) over long-term
Create demand, manipulate wants; global marketing	-	-	Meet real needs, mostly local distribution

More recently, Van Cauwenbergh et al. (2007) developed the Sustainability Assessment of Farming and the Environment (SAFE) framework to assess the agricultural sustainability across three spatial levels such as parcel, farm along with broader levels, which include landscape, region or state. Moreover, this framework aims to accomplish its objectives by establishing principles, criteria and indicators.

Another framework which focuses on three subsystems created by Le Gal, Merot, Moulin, Navarrete, and Wery (2010); these subsystems include biophysical, technical and decisional. The framework is based on the concept that agricultural production involves various activities at the farm level, utilizing resources from both the farm and the environment. The management of such a system requires making various decisions related to crops and livestock, organizing farm operations, and selecting and distributing resources over time and space. These decisions can occur at different intervals (daily, weekly, seasonally, or over extended periods) and can be strategic, tactical or operational.

The SAFA (Sustainability Assessment of Food and Agricultural Systems) global framework introduced by FAO in 2014 encompasses themes, sub-themes, and indicators connected to the sustainability goals. These themes are further expanded into sub-themes that relate to individual issues within the themes and have specific objectives. Finally, the indicators are associated with sub-themes and the criteria for measuring sustainable performance. The applicability of these indicators is at the macro level.

An analytical framework was later developed by Therond, Duru, Roger-Estrade, and Richard (2017) to differentiate between agricultural models. Each model represents a specific type of farming system within particular socioeconomic contexts. There are two dimensions of these models: on the vertical axis, there is the balance between external inputs and ecosystem services in the biotechnical functioning of farming systems, and on the horizontal axis, there is the trade-off between farming systems' connections to their socioeconomic settings, whether influenced by global market prices or local integration.

Overall, the different frameworks to explain or direct sustainability in agriculture involve facets such as decision-making (FESLM); strategies for transitioning to forms of agriculture that are more sustainable ("Efficiency/Substitution/Redesign"); assessment of sustainability (SAFE); different sub-systems (Le Gal et al., 2010); and themes/indicators of sustainability (SAFA). However, it appears that there is no

corresponding empirical research related to evaluating their appropriateness and effectiveness, which is an opportunity for future researchers. Similarly, while several approaches to sustainable agriculture are suggested (Hill and MacRae, 1996), there appears to be a lack of corresponding empirical research related to evaluating their appropriateness and effectiveness in diverse, real-world farming contexts.

This study aims to address this gap by empirically examining the impact of two specific approaches, permaculture practices and digital technologies, within the context of managed farm services in India. While the aforementioned frameworks offer valuable theoretical perspectives, this research seeks to provide concrete evidence on the effectiveness of these approaches in achieving economic and sustainability goals across distinct farm types (agroforestry and lifecentric). By quantifying the outcomes of these practices, the study contributes to a better understanding of how sustainable agriculture frameworks can be operationalized and their impact evaluated at the farm level, particularly in emerging economies.

Furthermore, this research aligns with the "Redesign" stage of Hill and MacRae's (1996) model, as it explores the integration of permaculture and digital technologies to create more resilient and resource-independent farming systems. It also complements the SAFA framework by providing empirical data on specific sustainability indicators related to water management, soil health, and biodiversity within the Indian region context.

2.2.1.2. Principles and goals of sustainable agriculture

Sustainable agriculture does not signify a fixed group of processes. Moreover, it is different from organic agriculture since it may or may not continue to use agrochemicals (synthetic fertilizers and pesticides), albeit minimally, if at all. Conservative practices like crop rotation, integrated pest management, natural fertilization, minimal tillage, and biological regulation are fully integrated into farm management (Gomiero et al., 2011). The FAO's five principles for sustainable agriculture cover environmental, social, and economic sustainability: enhancing resource efficiency, protecting natural ecosystems, supporting rural livelihoods,

improving resilience, and promoting strong governance (Oberč & Arroyo Schnell, 2020).

The European Commission also provides distinct goals related to sustainable agriculture. That is, ensuring that farmers receive a fair income, enhancing competitiveness, re-evaluating the supremacy in the food chain, action for climate change, care of the environment, safeguarding terrains and biodiversity, promoting generational regeneration, lively rural zones, protecting the quality of food and health (Oberč & Arroyo Schnell, 2020). Similarly, Pretty (2008) offered various principles relating to agricultural sustainability. They aim to (i) integrate biological and ecological processes like nutrient cycling and nitrogen fixation into food production, (ii) reduce harmful non-renewable inputs, (iii) utilize farmers' knowledge and skills to enhance self-reliance and replace costly external inputs, and (iv) leverage collective capacities to address common agricultural and natural resource issues like pest and watershed management (Pretty, 2008).

Velten et al. (2015) emphasize that sustainable agriculture aims to achieve several key objectives: ethical practices, multifunctionality, safety, stability, and resilience. It also seeks environmental goals like preserving ecosystem functions, natural resources, productive capacities, animal well-being and improving the environment to be in harmony with nature. Social goals include social responsibility, cultural preservation, equity, justice, meeting human needs, providing good working conditions, promoting human well-being, nourishing communities, and enhancing quality of life. Economic goals focus on development, livelihoods, product supply, and a thriving economy. The discussion in this section highlighted the different goals for sustainable agriculture as submitted by many institutions. The above section also notes a lack of empirical evidence which tracks and reports the progress of these goals.

While the existing literature provides a rich tapestry of principles and goals for sustainable agriculture, there remains a gap in empirical evidence demonstrating the actual outcomes of implementing specific sustainable practices, particularly in

relation to the multifaceted goals outlined by organizations like the FAO and the European Commission. Furthermore, most studies focus on evaluating sustainability at a macro or regional level, leaving a gap in understanding the on-farm impacts of sustainable practices (Schader, Grenz, Meier, & Stolze, 2014).

This study aims to contribute to this discourse by empirically examining the economic and sustainability outcomes of integrating permaculture and digital technologies within managed farm services in India. By quantifying the impacts on distinct farm types (agroforestry and lifecentric), the research will provide concrete evidence on the extent to which these practices contribute to achieving the broader goals of sustainable agriculture, such as resource efficiency, environmental protection, and social and economic well-being. This evidence-based approach will not only help validate the theoretical principles but also provide practical guidance for farmers, farm service providers, and policymakers seeking to transition towards more sustainable agricultural practices.

2.2.1.3. Approaches to sustainable agriculture

Approaches pertaining to sustainability may be both substantive (e.g., resource sufficiency and functional integrity) and non-substantive (e.g., promotion of social action). Sustainable agricultural programs generally use human, economic, and biological resources to develop technology and societal establishments. Further, they typically use other agricultural sciences and agronomy to study and propagate techniques and tools for farmers to utilise. Alternatively, they assist decision-making by utilising applied social sciences and fulfilling the resident challenges of rural communities using social organisations (Thompson, 2007).

The literature has extensively discussed a wide array of approaches to sustainable agriculture, providing a comprehensive understanding of the field. These include agroecology, permaculture, organic farming, conservation agriculture, regenerative agriculture, and climate-smart agriculture. Practices used in these methods are conservation tillage, intercropping, crop rotation, cover cropping, crop-livestock integration, integrated nutrient management, biological pest control, efficient water

use, agroforestry, local resources, renewable energy, composting, waste recycling, holistic landscape management, lower cattle densities, reduced inorganic fertilization, less chemical pesticide use, and maintaining diverse landscape elements (Oberč & Arroyo Schnell, 2020).

These approaches share a crucial characteristic: they signify options that farmers may choose and significantly determine how farms will be managed in the long term (Oberč & Arroyo Schnell, 2020). It could be seen, however, from the review of different approaches to sustainable agriculture that there is a need for empirical research to assess their efficacy. As outlined above, the literature offers a wide array of approaches to sustainable agriculture, but there remains a pressing need for empirical research to evaluate their real-world effectiveness. This research will contribute empirical evidence to the ongoing discussion about the efficacy of different sustainable agriculture approaches. The study's focus on managed farm services, a relatively unexplored context in the literature, will provide unique insights into the practical implementation and effectiveness of these approaches in a real-world setting. Furthermore, the comparative analysis of agroforestry and lifecentric farming will offer valuable insights into the suitability of these approaches for different agricultural contexts.

2.2.1.4. Focus on Agroecology

Agroecosystems are "communities of plants and animals interacting with their physical and chemical environments that people have modified to produce food, fiber, fuel, and other products for human consumption and processing." Relatedly, agroecology is the "holistic study of agroecosystems including all the environmental and human elements. It focuses on the form, dynamics, and functions of their interrelationship and the processes in which they are involved" (Altieri, 2002).

It has been suggested that sustainable agriculture development necessitates lowering widely utilised chemical inputs to decrease insecurity of climate and environment while improving production outcomes (Lacombe, Couix, & Hazard, 2018). Agroecology addresses the challenge of reducing chemical use by restoring

natural control in agroecosystems to sustain farming production (Francis et al., 2003). In the "Efficiency/Substitution/Redesign" framework, agroecology falls under Redesign, as it involves transforming farming systems to better align with local ecological, economic, and social conditions and to maintain functional agroecosystems (Lacombe et al., 2018).

Implementing agroecological principles requires significant changes in farming practices, farmers' thinking, and local knowledge and innovation participation. This transformation invites farmers and others to engage in research projects to design innovative farming systems. Five key approaches to co-designing agroecological farming systems are: "De-novo design," "Case-study design," "Niche innovation design," "Co-innovation," and "Activity-centered design." De-novo design focuses on creating innovative cropping system prototypes (Lacombe et al., 2018).

On the other hand, case study design signifies engaging farmers in reflexivity by mimicking the probable effect of their decisions and aiding collective learning. Niche innovation design pertains to designing innovations at the farm level. Co-innovation aims to produce innovations led by practice to sustain the empowerment of farmers in transition pathways to agroecology through hands-on action research. Finally, the activity-centered design aims to aid local farmer groups or a farming segment in resolving structural challenges associated with their activity (Lacombe et al., 2018). Permaculture, specifically, is an alternative agroecology movement and consequently is an "international movement and ecological design system" (Ferguson & Lovell, 2014).

The agroecological approach emphasizes the importance of designing farming systems that are in harmony with local ecological, economic, and social conditions. It promotes biodiversity, minimizes external inputs, and leverages natural processes to create resilient and sustainable agroecosystems (Altieri, 2002). Permaculture, as an alternative agroecology movement, offers a specific framework for achieving these goals through its focus on integrated design, regenerative practices, and ethical resource management (Mollison, 1988). However, while the theoretical

foundations of permaculture are well-established, empirical evidence on its effectiveness in real-world farm operations, particularly within the context of managed farm services, remains limited. Moreover, the integration of permaculture with modern digital technologies, which has the potential to enhance its precision and efficiency, remains largely unexplored in the literature.

This thesis addresses this knowledge gap by directly assessing the impact of permaculture practices, in conjunction with digital technologies, on the economic performance and sustainability outcomes of agroforestry and lifecentric managed farm services in India. It contributes to the broader field of agroecology by providing empirical evidence on the practical implementation and effectiveness of permaculture principles within a specific farming context. Furthermore, by examining the role of digital technologies in enhancing permaculture practices, the research explores the potential for synergistic interactions between traditional ecological knowledge and modern technological advancements in promoting sustainable agriculture.

2.2.2. Sustainability in information systems

Watson et al. (2010) introduced energy informatics, a subfield of Information Systems (IS) focused on reducing energy consumption and carbon emissions. Their fundamental premise was as follows:

$$\text{Energy} + \text{Information} < \text{Energy}$$

Watson et al. (2010) also noted that environmental sustainability extends beyond individual organizations. Ecological sustainability requires understanding the complete and symbiotic interrelation of ecological problems. All elements of a system for energy supply and demand are incorporated into their proposed integrated framework, which has an IS at its core. They suggest that suppliers are of two types: energy and service. Both types of systems share a need for information to manage the flow of their resources. On the demand side, they suggest that providing consumers with information related to their energy use can result in modified usage patterns and reduced overall consumption. Technologies in an intelligent energy

system fall into three categories: sensor networks, flow networks, and sensitized objects. Sensor networks are distributed devices that report the status of physical items or environmental conditions. Flow networks consist of transport elements that facilitate the continuous movement of materials like air, oil, electricity, and water or discrete objects like containers, packages, cars, and people. Sensitized objects are physical goods that detect and convey data regarding their usage. The information system links the other components to offer a comprehensive solution. The functions include collecting data from sensor networks for flow optimization algorithms, dynamically adjusting the network via automated controllers, and providing information to flow network managers for monitoring. It also informs consumers about resource usage, manages supply and demand to avoid high-cost resources during peak times, and enables automation to reduce energy consumption. Additionally, it offers comparative data for benchmarking energy reduction goals and provides performance data to governments (Watson et al., 2010).

Watson et al. (2012) argued that information systems can drive sustainability improvements, similar to how they enhance productivity. They proposed several imperatives for computing professionals to support sustainability. First, information systems should be developed that integrate significant environmental costs into prices (Watson et al., 2012). Second, corporate sustainability reporting systems should be designed to achieve a more sustainable society (Watson et al., 2012). Third, effective methods should be used to collect and present product sustainability information to encourage green purchasing. Fourth, information systems should be created that provide individuals with precise, actionable information about the environmental impact of their decisions (Watson et al., 2012). Overall, Watson et al. (2012) emphasized that an information strategy for environmental sustainability should include accurate pricing and informed perceptions among all societal participants, including individuals, organizations, and governments. There is a need to develop professional standards for processing and storage that minimize environmental impacts while promoting a sustainable society.

George, Merrill, and Schillebeeckx (2021) explored the contribution of digital technologies in dealing with climate change and supporting sustainable development. They highlighted the *sustainability imperative*, which signifies the commitment of businesses to elaborate environmental goals either voluntarily or in response to pressure from governments, investors, and others. On the other hand, the digital imperative refers to the rapid digitalization driven by new technologies, like AI/ML, IoT, and blockchain, which have created a range of disruptive solutions. George et al. (2021) define digital sustainability as organizational efforts to advance sustainable development goals through innovative use of technologies that handle electronic data. These digital activities are less limited by geography and highly scalable, aiming to create socio-ecological value alongside economic benefits, thus balancing profit and purpose (George et al., 2021). Technologies used in digital sustainability include blockchain, AI/ML, big data analytics, IoT devices, mobile applications, and telemetry tools like satellites and drones (George et al., 2021). Additionally, these activities are noted for their high scalability and ecosystem coordination (George et al., 2021).

Brendel and Mandrella (2016) argued that IS quality and utilisation should be considered to develop sustainable impacts as net benefits. Their study revealed three significant fields of future IS research from the perspective of sustainable mobility services. These are IS qualities and usage, IS solutions, and sustainable benefits. Brenner and Hartl (2021) discovered that the level of digitalization affects perceptions of ecological and economic sustainability.

Corbett, Webster, Boudreau, and Watson (2011) proposed that the sustainability measurement principles offer a significant mechanism for building the required links between disciplines. The principles include uniformity, transferability, integrability, accuracy, transparency, granularity, and scope. Corbett (2013) examined how carbon management systems (CMS), a type of green IS, can be designed to promote eco-friendly behaviors among employees. The study found that CMS effectively influences employees' environmental actions. Corbett and Mellouli (2017) used two

real-world cases to show how an Integrated Information Ecosystem facilitates interactions between administrative, political, and sustainability realms.

Galaz et al. (2021) examined the development of AI technologies in high-impact sectors like farming, forestry, and marine resource mining. They identified potential systemic risks in these areas, including algorithmic bias and allocative harms, unequal access and benefits, cascading failures and external disruptions, and trade-offs between efficiency and resilience.

Brandt, Donnellan, Ketter, and Watson (2016) studied how the IS discipline can contribute to increasing the sustainability of smart city initiatives. They built a preliminary framework for IS research in this context using a “resource-based view of the city” (Brandt et al., 2016). Ketter, Schroer, and Valogianni (2023) explored how IS research can create a smart, sustainable mobility ecosystem that benefits users, mobility providers, and the environment. Overall, it could be seen from the review of IS and sustainability that there is a need for empirical research to evaluate the effectiveness of IS to sustainability in specific sectors like agriculture. Moreover, limited IS work focuses on IS for the agriculture sector, a gap that needs to be addressed through future research.

Addressing this research gap, the current study aims to understand the implementation impact of digital technologies and IS on improving economic performance and sustainability among farmers and agricultural experts. From the literature review, additional sub-research questions can be developed to investigate the relationship between digital technologies, IS, economic performance, and sustainability in agriculture.

- What are the current digital technologies and IS being implemented by farmers in India?

This question addresses a critical knowledge gap in the literature by providing an overview of the current state of digital technology adoption in Indian agriculture. This information is crucial for identifying areas for future research and development,

informing policy decisions, and tailoring interventions to promote sustainable agriculture practices.

- How do farmers in India view the economic performance of using digital technologies and IS in their agricultural farms?

By capturing farmers' perceptions of economic performance, this question contributes to the understanding of the value proposition of digital technologies and IS in agriculture, which is essential for promoting their wider adoption and ensuring their alignment with farmers' needs and priorities.

- What are the sustainability outcomes of implementing digital technologies and IS in agricultural farms in India?

This question directly addresses the core research gap by empirically evaluating the impact of digital technologies and IS on sustainability outcomes in agriculture. It contributes to the growing body of evidence on the potential of IS for promoting sustainable agriculture practices and provides valuable insights for policymakers and practitioners.

- What are the barriers and challenges faced by farmers in implementing digital technologies and IS for sustainable agriculture in India?

Understanding the barriers to adoption is critical for developing effective strategies to promote the use of digital technologies and IS in agriculture. This question contributes to the literature by identifying specific challenges faced by Indian farmers, enabling the development of targeted interventions to facilitate the transition towards more sustainable practices.

Possible methods to address these research questions include conducting surveys or interviews with farmers and agricultural experts to gather qualitative and quantitative data on their experiences, perceptions, and challenges related to digital technology implementation and IS utilization in agriculture.

2.3. Innovation and IS in the agriculture sector

To evaluate the impact of innovation on sustainability, the emphasis is on both natural and technological aspects of agriculture. This section presents an overview of natural approaches and technological approaches used in the agriculture sector.

2.3.1 Natural approaches

Despite agriculture being a key example of the interaction between humans, nature, and technology, innovation in this field has often been linked only to technology. Specifically, its development, utilization, and application (Andrade, Pasini, & Scarano, 2020). However, some explorations of innovative practices, such as syntropic farming and permaculture, highlight a change in focus toward the interaction between humans and nature. Conceptually, syntropy is complementary to entropy. While entropy governs the physical and mechanical worlds, syntropy rules the biological world. Moreover, while entropy is associated with the dissipation of energy, syntropy pertains to the concentration of energy (Andrade et al., 2020)

2.3.1.1. *Focus on syntropic agriculture*

Ernst Götsch, a Swiss farmer in the 1980s, developed syntropic agriculture. This method incorporates elements common in agroecology, such as avoiding chemicals, using low-impact technologies, and designing based on ecological succession. However, this approach differs from other agroecological practices as it is centered on syntropy. Syntropy is used not only for interpreting life mechanisms but also for decision-making concerning field management (Andrade et al., 2020). In syntropic agriculture, two key processes from nature are emphasized: stratification and natural succession. Syntropic farmers accelerate ecosystem regeneration by placing each plant in optimal spatial and temporal positions (Andrade et al., 2020).

Syntropic farming is based on principles conforming to the functioning of nature- and forests-ecosystems rather than on methods and techniques that are easily replicable (Brohm & Klein, 2020). The first principle involves viewing agriculture as a regenerative process for ecosystems rather than focusing solely on productivity.

According to Götsch, unconditional love and cooperation should play a leading role rather than competition. The second principle is that the farm should function like a closed system that can self-organize, structure, and become more complex on its own (Brohm & Klein, 2020).

Natural succession, the third principle, is a notion typically related to ecology. Succession signifies ecosystem recovery after a disruption, such as an opening or clearing. Finally, stratification is crucial in syntropic agriculture, inspired by nature. Planting diverse species in different locations and times leads to natural succession. Also, it aids succession—varied densities of vegetation layers result in several photosynthesis layers. Overall, syntropic agriculture is a ‘process agriculture’ rather than an ‘input agriculture’ with the overall purpose being not only to generate organic matter but also to rejuvenate the entire system, which is stimulated through pruning and regrowth (Brohm & Klein, 2020).

The research related to syntropic farming currently focuses on the principles of the approach rather than the outcomes or efficacy. While the literature largely focuses on the theoretical underpinnings of various agroecological approaches, including syntropic agriculture, the need for empirical research evaluating their practical implementation and farmer perceptions remains crucial. Future research should investigate not only the quantifiable outcomes but also the subjective experiences and perspectives of farmers adopting these practices.

This study contributes to this imperative by directly examining farmers' perceptions of the benefits of permaculture practices and digital technologies in the context of managed farm services in India. Specifically, the research investigates how farmers perceive the impact of these approaches on sustainability outcomes, economic performance and overall farm operations. By capturing the perceptions and opinions of farmers, this study will provide valuable insights into the real-world adoption and implementation benefits of permaculture and digital technologies, complementing the existing theoretical literature and informing future research and practice in sustainable agriculture.

2.3.1.2. Focus on permaculture

Permaculture is a type of agroecology developed in response to concerns about industrial agriculture's negative impacts. The discussion about moving from industrial agriculture to methods providing ecosystem services and human food led to the "agroecological transition." This transition is a complex, multi-sector project operating across various temporal and spatial scales and involving diverse groups (Ferguson & Lovell, 2014).

Permaculture is an alternative agroecology movement and an "international movement and ecological design system" (Ferguson & Lovell, 2014). It emerged in the 1970s as a "practical in situ approach" to creating sustainable human communities (Suh, 2014). Unlike industrial agriculture, permaculture focuses on small-scale polyculture and relies on renewable energy and soft technology. In contrast, industrial agriculture depends on annual monoculture and extensive use of fossil fuels, both directly in fertilizers and indirectly in electricity (Suh, 2014; Anand, 2014).

The term permaculture, short for permanent agriculture, was initially developed in Australia by Bill Mollison and David Holmgren. Holmgren (1978) first defined it as "an integrated, evolving design system of perennial or self-perpetuating plant and animal species useful to humans." Mollison (1988) later described it as "the conscious design and maintenance of agriculturally productive ecosystems with the diversity, stability, and resilience of natural ecosystems." Holmgren (2011) further refined it as "consciously designed landscapes that mimic natural patterns and relationships, providing food, fiber, and energy for local needs."

Permaculture is a widespread movement with a unique framework for designing agroecosystems. It plays a significant role in agroecological transition and encompasses various aspects. For instance, permaculture can operate as an agenda to combine awareness and implementation across various fields to promote cooperation among varied sets of researchers, land users, and other interested parties. In addition, permaculture impacts a functional variety of environmental

knowledge (Orr, 1991), providing an accepted and comprehensible combination of intricate socioecological notions. Furthermore, its design orientation provides a unique viewpoint that advocates different possibilities of study in research related to agroecosystems. Finally, the facets of permaculture are exemplified in a global crusade operating, for the most part, independent of the support and authority of large institutions. This indicates occasions for hands-on action research and the use of widespread support and analysis (Méndez, Bacon, & Cohen, 2013). Research, however, also indicates that permaculture's potential to contribute to agroecological transition widely is constrained by various factors, such as the overall separation from science from the perspectives of both an absence of academic research related to permaculture and the overlooking of current scientific viewpoints in permaculture narrative (Ferguson & Lovell, 2014).

Permaculture submits rational, practical principles to generate living spaces that are independent, robust, and fair (Morel et al., 2019). Holmgren (2011) outlined twelve principles for permaculture design, forming the basis of a thoughtful design process. These principles are: (1) observe and interact, (2) catch and store energy, (3) obtain a yield, (4) apply self-regulation and accept feedback, (5) use and value renewable resources and services, (6) produce no waste, (7) design from patterns to details, (8) integrate rather than segregate, (9) use small and slow solutions, (10) use and value diversity, (11) use edges and value the marginal, and (12) creatively use and respond to change (Morel et al., 2019).

Permaculture in agriculture closely resembles other alternative farming methods like organic farming, biodynamic farming, agroecology, and agroforestry. These approaches promote agroecosystems that efficiently use resources and avoid pesticides. They favor local nutrient cycling using compost and manure and enhance biodiversity for plant and animal health (Morel et al., 2019). Moreover, Permaculture, similar to agroecology and agroforestry, emphasizes the spatial association of species, integrating trees, crops, animals, intercropping, and varied landscapes. Soil fertility is also crucial in biodynamic and organic farming. All these methods aim for

a harmonious integration of humans with the environment. However, their origins differ. Biodynamic farming stems from spiritual theosophy, agroecology and organic farming from farm workers' political struggles, and permaculture from self-sufficiency efforts for a post-petroleum world (Morel et al., 2019).

As discussed earlier, "permaculture," short for permanent agriculture, was developed by Bill Mollison and David Holmgren in Australia. Defined by Holmgren (1978) as a system integrating self-sustaining species useful to humans, it evolved to emphasize designing resilient ecosystems that mimic natural patterns and supporting local needs (Mollison, 1988; Holmgren, 2011). There are multiple earth care practices and water management strategies in permaculture described below.

2.3.1.2.1. Permaculture Earth Care Practices

Permaculture earth care practices aim to improve soil quality and overall ecosystem health. Permaculture earth care practices, such as mulching, biomass planting, and chop-and-drop, significantly enhance soil quality as noted by various researchers (Ferguson & Lovell, 2014; Holmgren, 2011; Janzon, 2018; McManus, 2010).

Mulching involves covering the soil surface with organic materials, such as straw, leaves, or wood chips. According to El-Beltagi et al. (2022), mulching conserves soil moisture, suppresses weeds, and enhances soil health by increasing organic matter over time.

Biomass Planting method focuses on cultivating fast-growing plants or trees that produce large amounts of organic matter (Barker, MacAdam, Butler, & Sulc, 2012). The biomass generated is used for mulching, composting, and enriching soil, improving its fertility and structure.

Chop-and-Drop is a core permaculture technique where plant material like leaves and branches is cut and left on the ground to decompose naturally. As noted by Anshari and Susilawati (2020), this method replenishes nutrients in the soil and enhances its structure, supporting sustainable ecosystem health.

2.3.1.2.2. Water Management in Permaculture

Effective water management systems in permaculture reduce reliance on external water sources and minimize rainwater runoff. Two key strategies include swales and trenches.

Swales are shallow ditches dug along contour lines to capture, slow, and infiltrate rainwater into the soil. This process recharges groundwater and improves soil moisture retention (Ahmed et al., 2014). Trenches on the other hand are linear excavations designed to redirect and store water within the soil profile. They help enhance water availability and contribute to long-term soil hydration (Amoozegar, Niewoehner, & Lindbo, 2008).

By integrating these practices, permaculture systems foster sustainable land use that supports local ecosystems and communities

2.3.1.2.3. Permaculture practices

Allied with its principles, the practices associated with permaculture include the following:

- Applying a systems approach and terminating the loop regarding supplies and nutrients: harvesting rainwater and composting.
- Employing ecosystem amenities and biodiversity: nitrogen-fixers (clover), pollinators (insect houses, flowers), bats, and birds (food, water features, habitat).
- Placing emphasis on production: substituting grass and lawns with productive crops, cultivating perpetual food plants.
- Fostering nourishing soil: no ploughing, mulching, no artificial or chemical pesticides or fertilisers, cover crops.
- Putting agroforestry into practice, connecting with the layering method: trees provide a cover and shelter along with fruit or nuts, food, and shrubs produce a habitat for wildlife and soil erosion is prevented through ground covers and vines.

- Animals utilised for various functions, encompassing the management of land, production of food and fibre, management of fertility, and safety. For example, free-range chickens can reduce pest populations together by turning the soil and managing weeds. Controlled grazing and silvopasture (integrating trees and grazing livestock on the same land) are additional practices. Hugelkultur: Interring wood to enhance retention of soil water.
- Controlling the flow of water through keyline design.
- No pruning for some followers (originating from natural farming).

In permaculture, the practice of agroforestry, coupled with the layering method, ensures that trees supply fruit and nuts together with a covering and shelter. In addition, shrubs supply food and homes for animals, whereas the ground covers and vines protect the soil from erosion (Oberč & Arroyo Schnell, 2020).

It is evident that the literature related to permaculture has primarily focused on permaculture practices, neglecting the crucial aspect of exploring the efficacy of these practices through empirical research. This is a significant gap that needs to be addressed through future research. The current study fills this gap by measuring the implementation impact of permaculture on increasing economic performance and sustainability outcomes across various agricultural paradigms.

2.3.1.3. Lifecentric and Agroforestry Farming

Amidst the growing concerns about the environmental and social impacts of conventional agriculture, alternative farming models such as lifecentric farming and agroforestry are emerging as promising pathways towards sustainable food production and rural development. These models not only prioritize ecological health but also emphasize social well-being, economic resilience, and cultural preservation. This section delves into the key characteristics, motivations, benefits, and challenges associated with lifecentric and agroforestry farming, particularly within the Indian context.

Lifecentric farming embodies a holistic worldview that places life at the center of agricultural practices, encompassing ecological, social, and personal dimensions

(Wahl, 2016). Wahl (2016) emphasizes the need to move beyond sustainability, which focuses on maintaining the status quo, towards regeneration, which actively restores and revitalizes.

Lifecentric farming draws inspiration from diverse philosophical and spiritual traditions (Capra, 1997). Lifecentric farming in India embodies a holistic approach to agriculture, including a diverse range of practices that prioritize ecological health and social well-being. Central to this philosophy is a rejection of synthetic inputs and a commitment to organic and regenerative agricultural methods that enhance soil health, biodiversity, and ecosystem resilience (Hemenway, 2009). Kimmerer (2013) has noted that lifecentric farmers actively cultivate diverse crops, livestock breeds, and wild species, recognizing the intrinsic value of biodiversity and contributing to the preservation of indigenous knowledge and resources. Beyond mere production, lifecentric farming fosters community-based systems, the concept of building resilience in agriculture through community-based approaches, emphasizing the importance of diversity, local knowledge, and ecological principles (Lengnick, 2014) which strengthens community ties and fosters self-reliance. The lifecentric approach further extends to encompass the social and spiritual dimensions of farming, emphasizing personal growth, a deep connection to the land, and the creation of just and equitable communities (Thomas et al., 2024). In essence, lifecentric farming in India represents a harmonious integration of ecological wisdom, social responsibility, and spiritual awareness in the pursuit of a sustainable and fulfilling agricultural paradigm. India's rich cultural heritage and traditional agricultural practices provide fertile ground for the flourishing of lifecentric farming.

In comparison to lifecentric farming, Agroforestry is the intentional integration of trees and shrubs with crops and/or livestock on the same land unit, has been practiced in India for centuries (Jose, 2009; Plieninger, Muñoz-Rojas, Buck, & Scherr, 2020). It represents a dynamic and multifunctional land-use system that offers a range of ecological, economic, and social benefits. By incorporating trees into agricultural landscapes, agroforestry systems provide a range of ecosystem services, such as

carbon sequestration, soil conservation, and enhanced biodiversity (van Noordwijk, 2021). This approach fosters a more balanced and harmonious relationship between agriculture and the environment, contributing to a more sustainable and resilient food system.

Agroforestry in India includes a diverse tapestry of practices aimed at optimizing land use and promoting ecological harmony (Ramachandran Nair, Mohan Kumar, & Nair, 2009). Practices include windbreaks that serve as protective barriers, shielding crops and livestock from harsh winds and fostering favorable microclimates. These diverse agroforestry practices underscore the potential of integrating trees into agricultural landscapes to create a more sustainable and resilient agricultural paradigm in India. Lifecentric and agroforestry farming represent a paradigm shift towards a more sustainable and equitable agricultural future. By recognizing and supporting these diverse farming models, pressing challenges such as food security, environmental degradation, and rural poverty can be addressed while fostering a more harmonious relationship between humans and the natural world.

2.3.2 Technological approaches

A World Bank report by Deichmann, Goyal, and Mishra (2016) highlighted the instantaneous private benefits generated by digital tools for individuals as these can not only facilitate easier communication between family and friends but also provide access to different information sources and modes of leisure. Extending this to the wider context, technology has been proven to improve economic opportunities, assist with livelihoods, and aid in service delivery. In agriculture, ICT (information and communication technology) has significantly saved time and costs for extension services among African small-scale farmers (Aker, 2011). Additionally, precision tools like GPS, satellite and drone monitoring, and detailed, timely meteorological information are now crucial for modern large-scale farming (Oliver, Robertson, & Wong, 2010).

Discussions of digitization in agriculture often mention precision agriculture (PA) and smart farming. PA is described as an “information-led management concept in both

plant and animal production, based on a wide range of technologies” (Linaza et al., 2021). It relies on the digital processing of specific information to aid decision-making. Smart farming, on the other hand, is a “knowledge-based approach where machines can make partially autonomous decisions with management systems. These decisions are based on real-time, autonomously obtained and processed information, although farmers can always intervene” (Munz et al., 2020). PA has also gained significant traction in the European Union (EU) as a “farming management concept based on observing, measuring, and responding to variability in crops or animal rearing” (Linaza et al., 2021). AI (artificial intelligence) applications and techniques in PA include machine learning (ML), deep learning (DL), robotics, and drones (Linaza et al., 2021).

Digital technology interventions have improved market transparency, increased farm productivity, and streamlined logistics (Deichmann et al., 2016). Information plays a crucial role in farm productivity by influencing farmer behavior and preventing losses from climate-related shocks through early warning systems. These digital tools utilize information from sources like surveys and satellite imagery. Big Data analytics helps agricultural research by integrating and analyzing vast, diverse data to predict livestock behavior, pest outbreaks, soil conditions, and climate (Deichmann et al., 2016). Big Data analytics involves advanced techniques applied to large, varied datasets, including structured, semi-structured, and unstructured data, ranging from terabytes to zettabytes.

These digital tools are useful for all farm sizes, but technologically advanced farms can use precision farming systems. These systems combine satellite images and remote sensing data to provide detailed information about soil status, groundwater levels, and rainfall for specific farm sections. Tools include soil condition sensors, precipitation detectors, and irrigation optimization systems (Deichmann et al., 2016). Precision farming systems also support environmental sustainability by continuously monitoring natural resources and taking appropriate actions before droughts or nutrient depletion occur (Deichmann et al., 2016).

AI has been successfully adapted to various agricultural tasks, either through specially developed tools or through adaptations from other industries (Popa & Roşca, 2011). The adaptability of AI in agriculture is evident in its applications, such as expert systems that manage zones based on factors like soil properties and weather data. These systems can recommend crop rotations, planting densities, water needs, irrigation schedules, fertilizer rates, and the best times for use. They can also diagnose crop diseases and pests, suggest preventative or remedial measures, determine optimal harvesting times, and improve the efficiency of farm machinery and personnel (Popa & Roşca, 2011).

Another AI application in agriculture is the use of sensors for data collection and transmission (Kaewmard & Saiyod, 2014; Morais et al., 2021). These sensors enhance the precision of expert systems and reduce operational time and effort. They can be embedded in farm buildings, machinery, or nearby and include electronic identification tags, collars, and sensors for farm animals. Additionally, AI in agriculture involves robotics and automation, which help increase efficiency and reduce environmental impacts (Popa & Roşca, 2011).

Eli-Chukwu (2019) draws attention to the use of various AI techniques in different facets of agriculture, such as soil management, to predict soil texture and the characteristics of soil moisture. As regards crop management, AI applications and techniques can be utilised, for instance, to schedule crop management activities, predict crop yield, harvest crops, and reduce insects. AI applications can also be utilised in disease and weed management (Eli-Chukwu, 2019).

In another study, Zhao et al. (2020) reported that the data processing rate in agriculture is improved by 92.1% by using AI. Similarly, De, Giri, Mevawala, Nemani, and Deo (2020) draw attention to the use of AI platforms to collect large quantities of information and data and to monitor large quantities of data in real-time to resolve the uncertainties farmers encounter in this sector. Smith (2019) additionally highlights that using AI in agriculture can prospectively help enhance the precision of information concerning happenings on farms by enhancing the aspects being

discovered and assessed, resulting in farmers receiving more precise alerts. In addition, this can also result in an enhanced capacity to understand the rationale behind the occurrence of certain phenomena in farm systems to manage them effectively. Enhanced data and awareness result in enhanced predictions, facilitating better decisions regarding how farm systems can be managed and motivating the creation of systems for decision support and recommendation (Smith, 2019).

In a study set in a Russian context by Mironkina, Kharitonov, Kuchumov, and Belokopytov (2020) highlighted various options for utilizing state-of-the-art digital technologies in enhancing the productivity and effectiveness of farms. The first option pertained to the use of digital platforms for achieving agricultural consultations. Such a platform would permit the condition of an indefinite number of fields to be virtually monitored by agricultural consultants. In addition, these consultants could derive inferences regarding the agrotechnical measures utilized and their effect on the crops under consideration (Mironkina et al., 2020). A second option was related to the use of digital services to provide precise agro-chemistry and climate status. This option, which involves the use of a device, such as a tablet or a phone, to display the rate at which a farmer is advised to apply the requisite fertilizer dose, provides farmers with accurate and timely information. In addition, the present weather is reported on the device in the shape of cloud cover, air temperature, precipitation, and speed and direction of wind in a particular field. Additionally, historical details of the weather and a five-day forecast are provided, giving farmers the confidence to plan their activities effectively. The third option relates to the use of modern digital technologies, such as RFIDs (radio frequency identifiers) and robotic devices with sensors, in animal husbandry, while the fourth option suggests the use of digital technologies for automated quality control of farm products such as goat milk. A fifth option suggests the use of digital technologies in the transportation of agricultural cargo. The last option indicates that digital technologies can be used to automate economic outcomes and risks (Mironkina et al., 2020).

Neethirajan (2023) reviewed the cutting-edge regarding digitalizing animal agriculture with PLF (precision livestock farming) technologies. These technologies include biometric sensors (invasive or non-invasive) to monitor the health and behaviour of an individual animal in real time. The data from the sensors allow farmers to perform population-level analyses. In addition, big data analytic systems process and integrate this real-time information. Further, the use of blockchain technology ensures that animal produce can be safely and certainly traced from farm to table, which is a principal asset in checking outbreaks of disease and preventing associated financial losses and health epidemics related to food. PLF technologies provide livestock agriculture with the capacity to deal with such concerns by increasing transparency and cultivating enhanced customer confidence (Neethirajan, 2023). In a related study, Neethirajan (2023) highlights that AI (artificial intelligence), machine learning (ML), and big data are widely utilised in animal husbandry to perform 24-hour observations of animals and the environment. This can help in gaining improved awareness of animal behaviour and troubles, control and avoidance of disease, and enhanced decision-making for the farmer. One specific area of AI that promises significant improvement in efficiency and reduction of costs across sectors is the digital twin.

Accordingly, Neethirajan (2023) attempted to assess its usage in the context of livestock farming. A digital twin is a “digital replica of a real-world entity that is kept current with a constant influx of data” (Neethirajan, 2023). Prospective tools for digital twins in livestock farming include thermal infrared sensors, respiratory rate sensors, immunosensors, photoplethysmography (PPG), noseband sensors, water flow sensors, accelerometers, pedometers, wireless intraruminal bolus sensors, among others. They submit that PLF is possibly a precursor to the digital twin in animal husbandry. Other prospective uses of digital twins in the area include prediction of animal behaviour, energy management of pigsties, observing the progress of grazing livestock using GPS and WSN (wireless sensor network), understanding the development and progress of dairy animals, livestock monitoring

using computer vision based on AI, comparing animal behaviour using augmented reality, and heat cycle detection for breeding (Neethirajan, 2023).

Verdouw, Tekinerdogan, Beulens, and Wolfert (2021) explored how digital twins can enhance smart farming. They developed a conceptual framework based on the Internet of Things-Architecture (IoT-A) for designing and implementing digital twins. This framework was validated in five smart farming use cases: arable farming, dairy farming, greenhouse horticulture, organic vegetable farming, and livestock farming, as part of the European IoF2020 (Internet of Food and Farm, 2020) project. The authors demonstrated that case-specific control models provide a clear understanding of how digital twins can improve these smart farming systems (Verdouw et al., 2021). Additionally, they identified six types of digital twins (Table 2) based on their role in the lifecycle of real-life objects. They define a digital twin as “a dynamic representation of a real-life object that mirrors its states and behavior across its lifecycle and can be used to monitor, analyse, and simulate current and future states and interventions using data integration, artificial intelligence, and machine learning” (Verdouw et al., 2021).

Table 2 Digital twins (Verdouw et al., 2021)

No	Digital twin	Description
1	Imaginary	Abstract objects that represent and imitate reference entities that are not linked thus far to entities that are physically present in the real world
2	Monitoring	Digital depictions of the (almost) concurrent condition and actions of actual physical entities, together with their path
3	Predictive	Digital estimates of the prospective condition and actions of physical entities utilising predictive analytics and founded on (almost) concurrent data of the tangible twins

No	Digital twin	Description
4	Prescriptive	Smart digital entities that enhance intelligence for suggesting remedial and precautionary actions on the actual entities
5	Autonomous	Functions independently and completely regulate the actions of actual entities without any human intervention, remote or on-site
6	Recollection	Preserve the entire history of real entities that are no longer existent in real-life

Abioye et al. (2022) reviewed research on various machine-learning models used for precision (smart) irrigation management. These models include supervised learning methods like linear regression (Kumar et al., 2017), decision trees (DT) (Arulselvi & Poornima, 2020), support vector machines (SVM) (Suzuki et al., 2013), random forest (RF), K-nearest neighbour (KNN), and naïve Bayes (Jain et al., 2021). Unsupervised models such as k-means clustering, artificial neural network (ANN), and adaptive neuro-fuzzy inference system (ANFIS) are also used (Sharifi et al., 2020). Additionally, deep learning (DL) models like recurrent neural networks (RNN) and convolutional neural networks (CNN), as well as reinforcement learning (RL), are applied in smart irrigation (Agastya et al., 2021; Anuşlu, 2017).

Digital farming solutions specifically oriented towards smart irrigation management include mobile applications that incorporate IoT and machine learning scenarios and web frameworks that can incorporate databases to facilitate visualization, data manipulation, analytics, and remote control. These varied solutions provide farmers with visualization and data analytics, remote irrigation scheduling, regulation of actuators and valves, and advisory services. Abioye et al. (2022) highlight that smart irrigation systems can encounter various challenges, such as the availability, overall experimental datasets, the fitting (over and under) of ML models, cloud and online

web infrastructure accessibility, among others. Nevertheless, Abioye et al. (2022) conclude that the integration of ML approaches and the assimilation of web and mobile solutions in irrigation are anticipated to benefit farmers and users in many ways.

Bacco, Barsocchi, Ferro, Gotta, and Ruggeri (2019) reviewed research on smart farming, highlighting the use of sensing techniques, Farm Management Systems (FMS)/Farm Management Information Systems (FMIS) connected to robotic solutions, and unmanned vehicles for autonomous operations. They also discussed software systems that support agricultural production through IoT-based monitoring and Decision Support Systems (DSSs). Remote sensing systems are used for various applications, including weed mapping, soil organic carbon measurement, yield prediction, plant growth monitoring, crop water stress assessment, plant height measurement, crop cover analysis, real-time crop condition monitoring, phenotyping, and chlorophyll measurement (Bacco et al., 2019).

2.3.2.1. Focus on precision agriculture

Precision agriculture is a modern farming approach that uses sensors to optimize fertilizer, pesticide, and water use (Mintert et al., 2016). It began in the 1980s with the advent of GPS for some farmers in developed countries. Today's precision farming combines GPS with GIS technology, sensors, and advanced software. It relies on a mix of new sensor technologies, satellite navigation and positioning, and the IoT (European Parliament, 2016).

Oliver et al. (2010) proposed integrating farmers' knowledge, precision agriculture tools, and crop simulation modelling to evaluate management strategies for underperforming patches. Their survey of nine cropping fields located in Western Australia revealed that farmers have robust awareness of the spatial coverage and rank performance of areas that perform poorly, in contrast to NDVI or yield maps. Additionally, they found that there is a broad spectrum of soil constraints, physical and chemical, to crop outcomes in such areas, some of which can be enhanced to increase outcome potential, and others where inputs to crops such as fertiliser can

be matched better to poor outcome potential. Precision agriculture technologies (PATs) encompass variable rate nutrient application, pesticide application, irrigation, and planting/seeding. These technologies have the potential to significantly increase crop yield and reduce resource use, making farming more sustainable and economically viable. They also include machine guidance (driver assistance or auto guidance), precision physical weeding technology, and Controlled Traffic Farming, which confines machinery loads to permanent traffic lanes (Balafoutis et al., 2017).

2.3.2.2. Focus on smart farming

Smart farming uses information and communication technology (ICT) to enhance agricultural production through data analysis. This approach motivates the development and promotion of innovative technologies for farmers. Key technologies identified by the European Union (EU) include satellite imagery, agricultural robots, sensor nodes, and unmanned aerial vehicles (UAVs) for aerial imagery (Bacco et al., 2019). Smart farming minimizes waste and boosts productivity by integrating supplementary technologies (Navarro, Costa, & Pereira, 2020). These technologies support plantation monitoring, soil management, pest control, irrigation, and delivery tracking (Bhagat, Kumar, & Kumar, 2019). Resources used include sensors for temperature, humidity, luminosity, and pressure; unmanned flying equipment; ground chemical sensors; video cameras; GPS; agricultural information systems; and communication networks (Stočes, Vaněk, Masner, & Pavlík, 2016).

Navarro et al. (2020) conducted a systematic review on the use of IoT in smart farming. They identified common IoT applications, including chemical control (pesticides and fertilizers), crop monitoring, disease prevention, irrigation control, soil management, supply chain traceability, and vehicle and machinery control. Physical sensors in smart farming were used for crop monitoring (growth, insect and disease detection, active canopy sensing), substrate monitoring (soil temperature, moisture, pH, chemical elements), and environment monitoring (air temperature, humidity, solar radiation, rain, light, atmospheric pressure, wind speed and direction, CO₂ levels), as well as tracking and localization.

In another study, Marescotti, Demartini, Filippini, and Gaviglio (2021) examined how the usage of technological devices (e.g., computers, smartphones, and tablets) was influenced by the outlooks and features of farmers and farms. Hassan et al. (2021) examined different control strategies used in smart farming, such as IoT, multispectral, hyperspectral, aerial imagery, NIR, RGB cameras, thermal cameras, machine learning, and AI techniques. Agricultural challenges, such as plant diseases, weed management, pesticide control, irrigation, and water management, can be quickly resolved using various automated and control techniques. Automation by advanced control strategies has been proven to enhance crop yield and improve soil fertility.

2.3.2.3. Challenges related to the use of digital technologies.

Another line of thought highlights the challenges associated with the digitisation of farming. For example, Bacco et al. (2019) provided insights regarding the technical and non-technical challenges associated with smart farming (Figure 1).

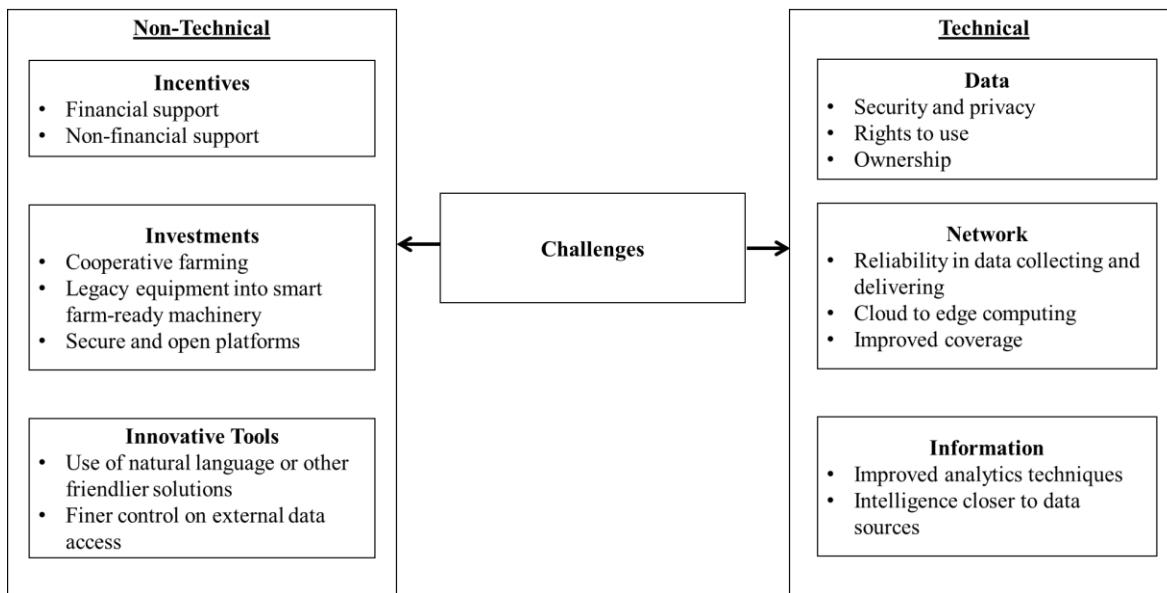


Figure 1 Challenges with smart farming (Bacco et al., 2019, p. 9)

Visser, Sippel, and Thiemann (2021), in another study, determined that digital farming is frequently accurately inaccurate. This is perhaps due to Big Data's granularity and enormous volumes, which are incorrectly associated with extreme

precision. Consequently, they highlight the threat of a 'precision trap,' that is, inflated confidence in the accuracy of Big Data, progressively resulting in a loss of safeguards (farmer observation, analogue data) on farms. The threat of precision traps grows with algorithm complexity, with changes from concurrent evaluation and guidance towards estimating, and with enhanced distance of farmers from field operations. Visser et al. (2021) also highlight a developing 'precision divide.' This refers to the uneven distribution of precision advantages stemming from the rising divide in algorithms between farmers concentrating on staple crops that are well-supplied by technological innovation and farmers growing other crops who have to manage with algorithms that are far less developed or suitable (Visser et al., 2021).

While there are challenges associated with the use of AI in agriculture, such as technology costs, accuracy, response time, and the need for Big Data, there is also significant potential (Eli-Chukwu, 2019; Giri, Dutta, & Neogy, 2020). Eli-Chukwu (2019) emphasizes this potential, particularly in light of the expected growth in agricultural production to support the increasing human population.

While the potential benefits of digital technologies in agriculture are widely acknowledged, the literature also highlights significant challenges, such as the "precision trap" and "precision divide." These challenges underscore the need for empirical research that not only assesses the effectiveness of these technologies but also investigates the farmer's perspective on their implementation and impact. This study aims to contribute to this understanding by exploring the following research questions, grounded in the existing literature and designed to advance the academic discourse on digital technologies in agriculture.

Based on this section, in addition to the RQs mentioned earlier, the following research questions are also formulated to be addressed by the current research.

- What are the benefits and challenges of implementing permaculture practices in agroforestry and lifecentric managed farm services?

This question seeks to explore both the advantages and potential challenges associated with applying permaculture principles in managed farm services. By investigating these aspects, the research aims to provide an understanding of how these practices influence ecological sustainability, soil health, and economic viability in different agricultural contexts. The results will help identify practical strategies for implementing permaculture principles into managed farm services, particularly in areas such as soil regeneration, biodiversity enhancement, and resource efficiency. Moreover, the findings will also highlight any challenges associated with permaculture practices implementation such as initial investment costs, knowledge gaps, and policy constraints, which may require future research efforts for implementation at a large scale.

The study findings can also provide support for scaling these approaches across agroforestry and lifecentric managed farming systems.

- What are the benefits and challenges of implementing digital technologies in agroforestry and lifecentric managed farm services?

This question aims to explore the potential advantages and limitations of integrating digital technologies into agroforestry and lifecentric managed farm services. By examining their real-world application, the research seeks to understand how such technologies can enhance operational efficiency, decision-making, and sustainability in agricultural practices, as well as the barriers that may hinder their adoption.

- What are the farmer's purchasing criteria for agroforestry and lifecentric managed farm services?

By exploring farmer decision-making, this question contributes to the understanding of factors influencing the adoption of sustainable agricultural practices, which can inform the development of targeted interventions and policies.

- What are the sustainability practices currently being implemented in agricultural farms in India?

This question establishes a baseline understanding of the current state of sustainability practices in Indian agriculture, providing a benchmark for evaluating the impact of permaculture and digital technologies. It also contributes to a broader understanding of sustainability adoption in emerging economies.

By employing surveys and interviews with farmers and agricultural experts, this research will gather both quantitative and qualitative data to provide a comprehensive picture of the adoption, impact, and challenges associated with permaculture and digital technologies in agroforestry and lifecentric managed farm services in India. The findings are expected to contribute to the development of more effective and sustainable agricultural practices that benefit both farmers and the environment.

2.4. Theory & Research objectives

The literature review highlights the critical need to address significant research gaps in evaluating the impact of implementing permaculture and digital technologies for sustainable agriculture. Currently, the body of research in this domain remains notably limited. While numerous sustainability frameworks have been proposed within the realm of agriculture, there appears to be a dearth of rigorous evaluations regarding their implementation related applicability and effectiveness.

Building on these insights, the study aims to explore and address the following objectives:

- Investigate the role of permaculture practices in enhancing agroforestry and life-centric farm management.
- Examine how digital technologies are influencing agroforestry and life-centric farm management practices.
- Analyse the criteria farmers prioritize when purchasing agroforestry and lifecentric managed farm services.

- Evaluate the current adoption and implementation of sustainability practices on farms in India.
- Document lessons learned and best practices for integrating permaculture and digital technologies within managed farm services.

2.4.1. Effect of demographics on sustainable practices and technology adoption

Research indicates that demographic variables can significantly influence attitudes towards and adoption of innovative agricultural practices (Hamrita, Deal, Gant, & Selsor, 2021). For example, younger farmers may exhibit a greater inclination towards adopting digital technologies due to their familiarity with digital devices (Milone & Ventura, 2019). This generational divide plays a significant role in shaping technology adoption patterns as earlier research has shown that younger population is more likely to adopt digital technologies (Dutot, 2014; Willis, Scarpa, Gilroy, & Hamza, 2011). A study carried out in Africa showed that younger farmers are more likely to adopt digital and precision agriculture technologies due to their higher digital literacy and openness to innovation, whereas older farmers may rely on traditional methods and hesitate towards adopting technology due to concerns about cost and usability (Challa & Tilahun, 2014). The authors also reported that access to education and financial resources increases the likelihood of farmers integrating modern farming techniques (Challa & Tilahun, 2014). Similarly, Jain (2017) reported that younger farmers tend to engage more actively in agricultural online learning resources. Similarly, the current study's findings may report significant differences when it comes to technology adoption and age of the farmers. Addressing these differences in technology adoption can help improve their inclusion in various farming practices and in achieving the sustainability goals (Dissanayake, Jayathilake, Wickramasuriya, Dissanayake, & Wasala, 2022).

Understanding these dynamics can benefit policymakers, agricultural services, and technology developers by helping them tailor their strategies to specific demographic groups. For instance, younger farmers could serve as early adopters of digital

technologies such as IoT-based moisture management systems, drip irrigation technologies, and farm management mobile applications, while older generations might require additional support or training to improve adoption. By addressing these needs, stakeholders can foster more inclusive and widespread adoption of innovative agricultural practices.

Gender differences also emerge as critical factors, with studies demonstrating that male and female farmers often hold different perspectives on technology adoption and sustainable farming practices, influenced by access to resources, knowledge, and social norms (Ndiritu, Kassie, & Shiferaw, 2014). Literature has shown that male farmers tend to have greater access to financial resources and land ownership which enables them to invest more in digital farming tools (Peterman, Behrman, & Quisumbing, 2014). In comparison, female farmers frequently face barriers related to restrictive land access, limited credit access and fewer opportunities for agricultural training (Mudege, Mdege, Abidin, & Bhatasara, 2017). Understanding these gender-based differences is essential for designing strategies that ensure equitable access to innovative farming solutions. Similarly, the current study's findings may report significant gender differences in permaculture implementation and digital technologies as they have less access opportunities and less access to trainings reported in the literature.

Similarly, these dynamics can benefit various stakeholders to create targeted interventions, such as tailored training programs or resource allocation schemes that address the specific needs of both male and female farmers. This approach can enhance overall participation and ensure that the benefits of digital innovation are shared equitably across genders.

Additionally, socioeconomic status, encompassing factors such as income, land ownership, and access to credit, plays a significant role in implementing permaculture and digital technologies in farming. Individuals with higher socioeconomic status tend to have more resources to invest in new technologies and sustainable practices, leading to a more positive perception of their benefits

Building on these insights, this study explores how demographic variables, such as age, gender, and socioeconomic status influence the adoption and perceived benefits of permaculture and digital technologies. By focusing on these variables within the unique context of managed farm services, the research seeks to provide a thorough understanding of how demographic factors shape farming practices. Additionally, it aims to identify differences in adoption patterns and perceptions across farm types, particularly agroforestry and life-centric managed farms. This exploration contributes to the broader understanding of the role demographic factors play in sustainable agriculture and offers valuable insights for policymakers and practitioners seeking to promote inclusive and effective adoption of permaculture and digital technologies.

2.4.2. Permaculture practices

As discussed in the literature earlier, within the realm of agroecology, permaculture emerges as a transformative approach, developed as a countermeasure to the detrimental impacts of industrial agriculture. Distinguished by its embrace of small-scale polycultures, reliance on renewable energy, and the application of low-impact technologies, permaculture starkly contrasts with the industrial model's preference for large-scale monocultures and its heavy dependence on fossil fuels (Suh, 2014). This paradigm shift towards permaculture represents a radical departure from conventional agricultural practices, positioning itself as a viable alternative focused on sustainability and regeneration. Originating beyond the confines of mainstream agricultural systems, permaculture has cultivated a unique foundation of knowledge and resources dedicated to fostering sustainable living practices (Maye, 2018).

At its core, permaculture is deeply rooted in the principles of sustainable development, drawing upon ecological science to advocate for a systematic reduction in the consumption of energy and resources (Holmgren, 2013). Furthermore, it underscores the value of indigenous knowledge and traditional practices, which have been honed over generations, highlighting the importance of learning from and integrating these time-tested approaches into contemporary

permaculture practices (Holmgren, 2013; Hegarty, 2015). This focus not only enriches the permaculture movement with a wealth of diverse insights but also reinforces its commitment to ecological stewardship and preserving biodiversity.

This study explores the role of permaculture practices in agroforestry and life-centric farms, examining their potential to improve ecological sustainability, biodiversity, and crop yields. By documenting the implementation and impact of these practices, the research seeks to provide valuable insights into how permaculture can contribute to more sustainable and regenerative agricultural systems. Additionally, it investigates how different farm types may influence the effectiveness and benefits of permaculture practices, offering a comparative perspective that can inform future applications and policymaking.

2.4.3. Digital technologies

The earlier literature suggests that implementing digital technologies into agroforestry and lifecentric farms enhances management efficiency, productivity, and resource utilization, surpassing outcomes in projects without such integration. Digital technologies, including precision agriculture, data analytics, and IoT (Internet of Things) devices, offer transformative potential for sustainable farming practices. These technologies enable farmers to monitor environmental conditions, manage resources more effectively, and make informed decisions based on real-time data (Oliver, Robertson, & Wong, 2010).

Precision agriculture, for instance, allows for the precise application of water, fertilizers, and pesticides, reducing waste and environmental impact while increasing crop yields (Oliver, Robertson, & Wong, 2010). Similarly, technology can monitor soil moisture levels and crop health, facilitating timely interventions that enhance productivity and resource efficiency (Deichmann et al., 2016).

Implementing digital technologies in agroforestry and lifecentric farms represents a forward-thinking approach to agriculture, leveraging technology to optimize farming operations. The potential benefits of these technologies are particularly relevant for agroforestry and life-centric managed farms (Abioye et al., 2022; Laha et al., 2023;

Singh, Rao, Kumar, & Rajwade, 2023; Visser, Sippel, & Thiemann, 2021), offering a pathway to more sustainable and productive farming systems.

This study explores the role of digital technologies in enhancing the sustainability and productivity of agroforestry and life-centric farm systems. It seeks to understand the specific benefits these technologies offer, such as improved decision-making, reduced resource consumption, and enhanced crop and soil management. Additionally, the research examines how the adoption and impact of digital technologies may vary between these two farm types, shedding light on the unique needs and challenges associated with each context.

By focusing on the practical applications and implications of digital technologies, this study aims to provide valuable insights for farmers, policymakers, and technology developers. Understanding the experiences and perceptions of farmers regarding digital tools is critical for designing effective interventions, addressing barriers to adoption, and promoting the broader implementation of these technologies in sustainable agriculture.

2.4.4. Farmer's purchasing criteria

The decision-making process of managed farm services buyers is complex and influenced by various factors. Research suggests that upfront costs, particularly the initial purchase price of farmland, often play a disproportionate role in this process (Genesove & Mayer, 2000). This tendency can be attributed to psychological biases such as the anchoring effect, where the initial price acts as a cognitive anchor, influencing subsequent evaluations and decisions. Moreover, studies on consumer behavior in other industries (Mariadas, Abdullah, & Abdullah, 2019; Yusuf & Sunarsi, 2020) have consistently demonstrated the powerful influence of price on purchase decisions. This is particularly true in contexts where consumers have limited information or experience with the product or service, as is often the case with managed farm services. In such situations, price can serve as a readily available and easily understandable heuristic for evaluating values.

While upfront costs are pivotal, other factors also play a crucial role in shaping purchasing decisions. Maintenance costs, the conceptual design of the farm, available amenities and facilities, and the reputation of the developer are all essential considerations. Maintenance costs can influence long-term financial planning, while the farm's concept and design may align with the farmer's vision and operational goals. Similarly, amenities and facilities can enhance the utility and appeal of the managed farm, and the developer's reputation often provides assurance of quality and reliability.

This study seeks to explore and document the various factors influencing farmers' purchasing decisions for managed farm services. By examining the relative importance of these factors, it aims to uncover insights into farmers' preferences and priorities. Understanding these decision-making processes is vital for developers and policymakers to design offerings that align with farmers' needs and address potential barriers to adoption.

2.4.5. Sustainability practices

Permaculture, which is a system of agricultural and social design principles centered around simulating the patterns and features observed in natural ecosystems, has significant potential in India due to its emphasis on ecological harmony and resource efficiency. The country's farming practices are increasingly being influenced by permaculture practices, which aim to create sustainable and self-sufficient agricultural systems.

The relatively varying implementation rate suggests that while the potential for permaculture and digital technologies in farming is high, substantial efforts are needed to mainstream these practices. These efforts could include policy reform, educational initiatives, and investment in digital agriculture technologies to support small and marginal farmers towards a more sustainable and productive agricultural future.

A recent systematic review by Priya and Singh (2024) highlights the low adoption rates of sustainable agricultural practices in India, attributing this low adoption to

limited access to training, financial constraints, and the perceived complexity of implementing these practices. These barriers are particularly significant for small farmers, who often lack the resources and institutional support needed to transition to sustainable methods. The review emphasizes the urgent need for structured interventions to address these challenges and promote wider adoption of sustainable farming. One potential way to overcome these barriers is the role of managed farm services, which provides a structured framework for adopting sustainable agricultural techniques.

Researchers such as Hota and Verma (2022) have noted that digital agriculture technologies, including IoT-based moisture management, precision irrigation, and AI-driven farm monitoring systems, have the potential to enhance resource efficiency and productivity. However, the widespread adoption of these technologies in India remains low due to limited infrastructure, lack of awareness, and financial constraints, particularly in rural regions. These challenges indicate the need for targeted policy interventions, capacity-building programs, and increased investments to ensure that technology-driven sustainable farming solutions are accessible to all farmers, regardless of socioeconomic background.

The Council on Environment, Energy, and Water (CEEW) report, *Sustainable Agriculture in India 2021: What We Know and How to Scale Up* (Gupta, Pradhan, Jain, & Patel, 2021), supports these findings, stating that while government policies in India promote sustainable agricultural practices, their on-ground implementation is often not adequate due to insufficient infrastructure and lack of institutional support.

Additionally, Gabriel and Gandorfer (2023) highlighted that digital agriculture technologies, such as decision-support tools, AI-driven analytics, and automated irrigation systems offer promising solutions for sustainable farming. However, these technologies are often cost-prohibitive for smallholder farmers and require technical expertise that is lacking in many rural areas. Targeted interventions, including education programs, policy reforms, and investment in managed farm services, are



essential to overcome these challenges and mainstream sustainable agricultural practices in India.

Given these challenges and opportunities, the current study explores the current state of sustainable agricultural practices in Indian farms, with a specific focus on managed farm services. By analyzing implementation rates and identifying key barriers, the current study aims to provide evidence-based insights to guide policymakers, agricultural practitioners, and stakeholders in mainstreaming sustainability through digital solutions and structured farm management models.

Additionally, the study seeks to understand how sustainability practices can be tailored to the needs of different farming contexts, including agroforestry and life-centric farms.

Chapter 3: Methodology

3.1. Chapter overview

The current study employs a mixed-methods sequential approach, combining qualitative and quantitative methodologies to address the research objectives. The qualitative phase was conducted first to collect detailed perspectives from key stakeholders, helping to identify patterns, themes, and key factors relevant to the research problem. These findings guided the design of the subsequent quantitative phase, which aimed to validate and generalize the results through broader data collection and statistical analysis. This sequential approach ensures that qualitative data provides a foundation for understanding the context, while the quantitative data enhances the reliability and applicability of the findings. Combining these methods allows for a more comprehensive examination of the research problem.

The chapter commences with an overview of the considerations influencing the research design of the present study. The research strategy and approach for the study are then described in detail. This includes the sampling strategy, research instruments, data collection, and data analysis, measures for ensuring the quality of the research. Finally, the limitations of the current research and ethical considerations undertaken are described.

3.2. Research design

The selection of a research methodology entails consideration of a philosophical viewpoint, the research question, and the maturity of the matter under consideration (Merriam & Tisdell, 2015). The basis of research designs is unspoken beliefs regarding what we consider knowledge and the legitimacy claims regarding knowledge (Creswell & Poth, 2016). The researcher used the 'research onion' (Saunders, 2014) to guide his selection of the data collection and analysis techniques and the overall strategy for the research (Figure 2).

Examination of the study's overarching research question, “Does implementing permaculture practices and digital technologies improve the economic performance and sustainability outcomes for agroforestry and life-centric managed farm services?” reveals that the study's purpose is to explore and describe the activities and outcomes related to different farm types.

This study focused on understanding the economic performance and sustainability outcomes of implementing permaculture practices and digital technologies in different farm types. Recognizing the complexity and subjectivity of this topic, we adopted a mixed-methods approach, combining interviews and surveys to capture diverse perspectives and experiences (Saunders, 2014).

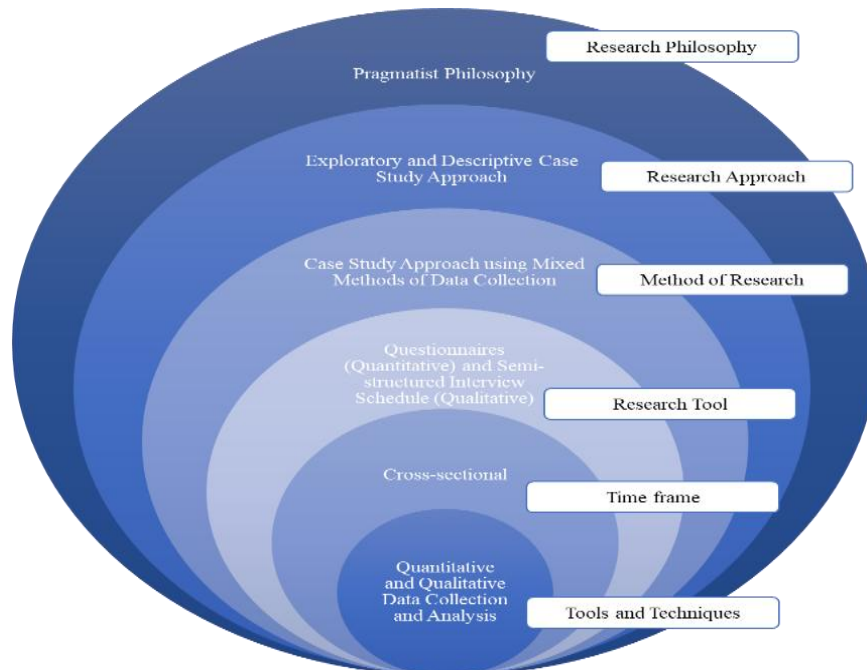


Figure 2 Research Onion as visualised for the study (Saunders et al., 2019)

This approach aligns with a pragmatist perspective, emphasizing practical solutions and the importance of participant insights in addressing our research questions. Our methodology reflects the need for a thorough understanding of the challenges and opportunities presented by permaculture and digital technologies in farming, aiming

to inform future practices and contribute to the broader goals of economic performance and sustainability outcomes in agriculture.

The research design of the current study follows a sequential exploratory approach, where the qualitative phase served as the foundation for shaping the subsequent quantitative phase. This approach has been widely used in studies that aim to combine in-depth contextual understanding with broader validation, as demonstrated in prior research (Berman, 2017).

This methodology has also been adopted in agriculture where Kiefer and Szolnoki (2024) began the research with in-depth interviews to gather qualitative data, which informed the design of a subsequent survey conducted with farmers. This approach allowed the study to build on the qualitative findings and validate them quantitatively. This sequential research design approach was also employed by Nyairo (2020) who used a sequential mixed-methods design to explore the attitudes and perceptions of smallholder farmers toward agricultural technologies in Kakamega County, Kenya.

Another study which employed this approach in an agricultural context is Brandt, Forbes, and Keshwani (2017) where the authors employed a sequential exploratory mixed-methods design to investigate elementary students' agricultural literacy. The research began with semi-structured interviews involving 35 students, providing qualitative data that informed the development of a survey. These assessments were then administered to a sample of 400 elementary students. By integrating qualitative and quantitative phases, the study offers valuable insights into students' knowledge of agriculture.

The current study began with in-depth, semi-structured interviews with key stakeholders from Hosachiguru, including agronomists, business development leaders, and operational managers. These interviews were designed to capture rich, contextual insights into the implementation and impact of permaculture practices, digital technologies, and sustainability strategies in managed farm services.

The qualitative findings provided an understanding of the themes and variables central to the research, such as the motivations for farm ownership, the operational models of agroforestry and lifecentric farms, the challenges of implementing permaculture, and the benefits of digital technologies. These themes guided the formulation of two structured questionnaires tailored for agroforestry and lifecentric farmers.

By adopting this inductive approach, the study ensured that the quantitative instruments were grounded in real-world practices and experiences, enabling the subsequent survey to validate and generalize the insights obtained during the qualitative phase.

3.3. Research Strategy

The purpose of the case study in research is “to perform an in-depth inquiry of a subject or occurrence within its everyday context”, which suits the current study’s objectives. The aim is to generate awareness from an in-depth investigation of permaculture and digital technologies implementation in a managed farm services context.

In selecting a managed farm services organization as the focus of the study, a deliberate choice was made to employ an orthodox case study strategy characterized by its structured and predefined approach. This decision was informed by the desire for a methodical research progression, as Saunders (2014) outlined. Specifically, using a single case study strategy, as Yin (2018) advocated, was purposive, considering the nascent nature of the managed farm industry and the researcher's access to the Hosachiguru organization. It was believed that this organization exemplified typical farm management practices and presented an opportunity to explore a phenomenon previously underexamined in the literature, in line with the insights of Saunders (2014). Further rationale for selecting a single-case study is presented in Annexure A.

The case study aimed to highlight what occurs when permaculture and digital technologies are implemented in two types of farms managed by the case organisation: i.e. agroforestry and lifecentric farms. In social and business research, the case study approach is a research strategy that facilitates scrutiny of an existing phenomenon in its actual setting, particularly when the boundaries between the phenomenon and its setting are not obvious (Yin, 2018). In this study, the ongoing operations of the farms are closely associated with their outcomes and cannot be separated. Consequently, the setting is intentionally a component of the design. Relatedly, a mixed methods approach was utilised to collect data for the study. Overall, this study's methodology was a single case study design using mixed methods (questionnaire and interview data). Primary qualitative data were obtained through semi-structured interviews with five Hosachiguru employees (i.e., the CEO, business development, agronomists, and farm operations managers). The qualitative phase consisted of semi-structured interviews with key stakeholders from Hosachiguru. These interviews provided detailed insights into the implementation of permaculture practices and digital technologies, which subsequently guided the development of the quantitative survey administered to farmers. The quantitative data were obtained through a participant survey of 208 Hosachiguru farmers. The design and content of the interview schedule were based on insights drawn from existing research and the researcher's knowledge and experience. Figure 3 depicts the research design of the current study.

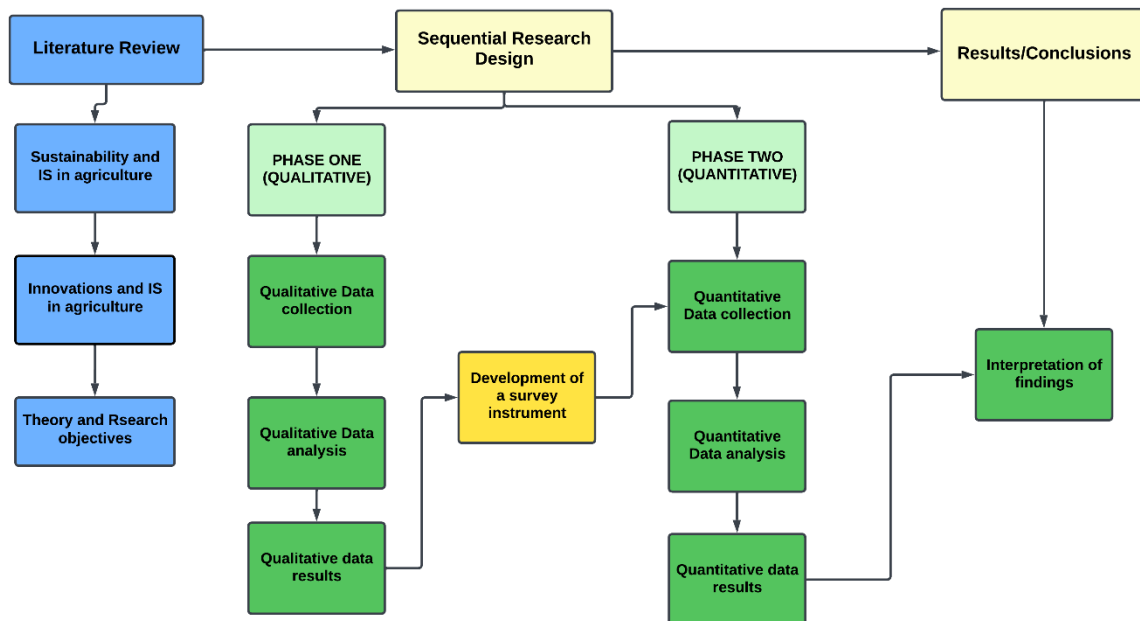


Figure 3 Research design (Sequential exploratory research design inspired by Bremen, 2017)

3.4. Research Approach

The research approach involved identifying and establishing the sample, creating and administering the data collection tools, analysing the data obtained using these tools, determining measures for ensuring quality and establishing the research timeframe.

3.4.1. Sampling strategy

The approach used was principally the non-random sampling strategy termed *purposive sampling*. In purposive sampling, the researcher restricts the sampling to certain cases or kinds of persons who can provide the information necessary for the study. This could be because the cases in question are typical or illustrative and are characteristic of research using case studies (Saunders, 2014). Similarly, the restrictions on persons are for two reasons: they are the only persons with the information, or they satisfy some criteria established by the researcher (Bougie & Sekaran, 2019).

The sampling strategy for the study was undertaken in multiple stages. Firstly, the case organisation selected for the case study was Hosachiguru, a Bangalore-based managed farm services company. Secondly, the researcher identified people for the interviews. At this stage, the purposive sampling involved recruiting five (5) people playing different roles in Hosachiguru, such as the head of business development and hospitality, one of the founders, the head of operations, and two agronomists. The sample was recruited to include all important team members, from management to operations. Finally, the researcher reached out to Hosachiguru farmers for participation in the survey. Since the two lists of farmers provided by Hosachiguru were specifically related to agroforestry and lifecentric farmers, the sampling approach here became *quota* sampling (Saunders, 2014). The researcher ensured that the two groups were sufficiently represented in the study by employing quota sampling. The quota for both groups was based on the total number of farmers falling into the groups. The researcher had a survey response rate of approx. 83% and received 208 usable responses for the survey, with 108 from the agroforestry farmers and 100 from the lifecentric farmers providing statistically significant research findings.

3.4.2. Research instruments

Since the researcher required information related to the impact of implementing permaculture (nature-based solutions) and digital technologies at agricultural farms in India from the perspectives of agroforestry and lifecentric farmers and Hosachiguru internal stakeholders, two principal research instruments were adopted: 1. an interview schedule and 2. a farmer questionnaire – one for agroforestry and one for lifecentric.

3.4.2.1. Interview schedule for experts

Face-to-face interviews were planned as part of the study and were conducted by the researcher using an interview schedule. Typically, three kinds of interviews are popular in research: structured/standardised, unstructured, and semi-structured (Saunders, 2014; Sekaran & Bougie, 2016). Structured interviews are conducted

with a fixed inventory of questions and can be utilised to obtain quantifiable data (Saunders, 2014). On the other hand, the primary purpose of unstructured interviews is to identify significant issues pertinent to the matter under consideration and typically proceed without the previous creation of a fixed or deliberate question sequence (Sekaran & Bougie, 2016). In contrast to the other two, semi-structured interviews commence with a set group of themes and potentially some significant questions associated with them to guide the direction of the interview. Since the study is based on a pragmatic philosophy, the researcher decided to use the set themes and thoroughly explored them with each participant. That is, *semi-structured interviews* were chosen for use in the study. This, the researcher hoped, would help him compare the responses and identify the fundamental experience that was pertinent to the study's objectives (Saunders, 2014).

The researcher devised a single semi-structured interview schedule for the investigation and employed it with the internal stakeholders of Hosachiguru. The timetable encompassed inquiries pertaining to the subsequent topics: agroforestry farms, lifecentric farms, implementation of permaculture and digital technologies, economic performance, and sustainability outcomes. The study incorporated interviews to gather the firm's viewpoints on their methods and the resulting consequences.

Through in-depth discussions with key stakeholders at Hosachiguru, the qualitative phase allowed the researcher to identify major themes, operational challenges, and multiple success factors relevant to implementing permaculture practices and digital technologies in managed farms. The interviewees included agronomists, business development leaders, and farm operations managers, who shared their observations with sustainable agricultural practices in India. The experts also reported adoption challenges of sustainable practices, and the perceived impact on farm productivity and economic viability. These interviews with experts provided the foundational data that informed the development of the quantitative survey instruments.

The qualitative phase revealed several important aspects that influenced the questionnaire design. For example, experts emphasized the importance of specific permaculture techniques such as mulching, rainwater harvesting, and biomass retention in enhancing soil fertility and biodiversity. These findings led to the incorporation of specific questions that were added in the farmers' survey to measure the perceived effectiveness and adoption rates of these practices. Similarly, the in-depth interview discussions with experts also highlighted economic motivations for adopting digital technologies, including cost savings, efficiency improvements, and enhanced farm management. As a result, the quantitative survey included sections evaluating farmers' adoption and perceived satisfaction with digital tools such as IoT sensors, satellite monitoring, and mobile applications to assist farmers.

Moreover, experts who are actively involved in operations of the managed farms shared their views on challenges faced in implementing sustainability practices, including resource constraints, training needs, and infrastructure limitations. These discussions shaped the formulation of Likert-scale items in the survey to measure adoption rates of sustainable practices and their perceived effectiveness. Furthermore, other most frequent themes from the interviews, such as the balance between economic returns and environmental responsibility were included in the questionnaire to measure the purchasing criteria of farmers.

By ensuring that the questionnaire was developed based on experiences of stakeholders in managed farms, the approach enhanced the validity of the survey instrument and the study itself. The questionnaire helped measure the prevalence and impact of these identified themes on a wider scale, thereby allowing the study to validate the qualitative findings through statistical analysis. The next section further presents how the qualitative findings helped in formulating the questionnaire for the farmers.

3.4.2.2 Formulation of questionnaire based on the qualitative findings

The design and content of the farmer questionnaires were directly influenced by the themes and patterns identified in the qualitative phase. Key insights from the interviews were systematically translated into measurable survey items to ensure alignment between the two phases of the study. For example, the question about motivations for farm ownership was formulated based on the interviews, which revealed distinct motivations for purchasing agroforestry (e.g., financial returns and environmental stewardship), and lifecentric farms (e.g., connection to nature and family well-being). These insights shaped the "Farmer's Purchasing Criteria" section, with items evaluating factors like price, maintenance cost, and amenities.

Similarly, for permaculture practices, the experts highlighted practices such as mulching, rainwater harvesting, and biomass planting as critical for improving soil quality and biodiversity. These were incorporated into the questionnaires with Likert-scale items to assess farmers' perceptions of these practices.

When formulating the digital technologies questionnaire items, the qualitative phase identified the use of IoT sensors, drones, and the MyFarm app as important tools in modern farming operations.

The MyFarm app is a mobile application designed by the case study organisation i.e. Hosachiguru to assist farm owners in efficiently managing their farms. The application provides real-time notifications about farm activities, such as irrigation schedules and harvest reminders. Moreover, the monitoring feature supplies real-time data on weather conditions, plant health, and soil quality, empowering farmers to make informed decisions regarding irrigation, fertilization, and pest control. By providing accurate and real time information, the app facilitates the optimization of farming techniques, enhancing productivity while minimizing environmental impact.

Accordingly, questionnaire items were formulated to evaluate farmers' awareness, adoption, and perceived benefits of the MyFarm app alongside other digital

technologies such as IoT-based sensors and agricultural drones. Lastly, the sustainability practices, as identified by experts, were assessed through their implementation levels, measured using a 5-point Likert scale (No implementation at all to Full implementation) to capture the extent of their integration into farming operations.

As the current research is based on a sequential research design, the qualitative phase played a key role in formulating the questionnaire items by ensuring they were grounded in the real-world experiences and perspectives of both experts and farmers. The interviews revealed key permaculture practices such as biomass planting and retention, swale systems for water conservation, and the chop-and-drop method, which were then integrated into the questionnaire for farmers. Farmers were asked to rate the perceived effectiveness of these practices in improving soil health, biodiversity, and yield sustainability, which allowed for an evaluation of their adoption and impact.

Similarly, interview discussions identified specific digital technologies implemented in farm management, including IoT-based moisture sensors, satellite monitoring, and the MyFarm app. Questions were then formulated to measure the perceived benefits of these technologies.

Furthermore, farm-purchasing criteria emerged as a major theme during the qualitative phase. Experts emphasized factors like long-term sustainability, access to digital monitoring tools, and community-based management models as key considerations in farmers' decision-making processes. These insights were directly incorporated into the questionnaire to determine the relative importance of land price, developer reputation, infrastructure, and sustainability features in shaping farmers' purchasing decisions.

By structuring the questionnaire around these themes derived from the interviews, the study ensured a link between the qualitative and quantitative phases, facilitating a thorough exploration of how permaculture practices, digital technologies, and sustainable farming practices are perceived across different farm types.

3.4.2.2. Questionnaire for agroforestry farmers

The close-ended agroforestry questionnaire aims to explore various factors influencing the adoption and effectiveness of agroforestry practices. It covers five main categories: Demographics, Permaculture Practices, Digital Technologies, Sustainability Practices and Farmer's Purchasing Criteria section. In the Demographics section, variables such as age, gender, employment sector, annual income, plot size, purchase price, and frequency of visits to the farm are considered.

The Permaculture Practices section includes seven items, such as the impact of mulching, monocropping, water management, and multi-cropping on soil quality and farm yields. The Digital Technologies section investigates the role of IOT-based systems, drip irrigation, and the MyFarm app in enhancing farming efficiency. The Sustainability Practices section examines tree planting, buffer zones, biodiversity, and local employment policies. Finally, the last section of the questionnaire attempts to understand the farmer's purchasing criteria. Participants were provided with a 5-point Likert scale on these items to facilitate their response. The permaculture and digital technologies implementation are measured on a 5-point Likert Scale from 1-Strongly disagree to 5-Strongly agree, while implementation of sustainable practices is measured on a 5-point Likert Scale from 1-Not implemented to 5-Fully implemented.

3.4.2.3. Questionnaire for lifecentric farmers

The Lifecentric questionnaire focuses on similar themes but tailors them to lifecentric farming practices, emphasizing sustainability and permaculture. It also covers Demographics, Permaculture Practices, Digital Technologies, Sustainability Practices and the Farmer's Purchasing Criteria section. The Demographics section includes variables like age, gender, employment sector, annual income, plot size, purchase price, and frequency of visits to the farm.

The Lifecentric questionnaire's Permaculture Practices section explores variables such as the benefits of earth care practices, intelligent water management, fair share practices, chemical-free farming, rainwater harvesting, and biodiverse plantation

methods. The Digital Technologies section evaluates the efficiency of IOT-based moisture management, drip irrigation, sustainable design philosophy, and the MyFarm app. The Sustainability Practices section includes tree planting, live fences, swales and trenches, local employment policies, and MyFarm app solutions. The Purchasing Criteria section, common to both questionnaires, examines factors like farmland price, maintenance cost, developer reputation, project concept, and available amenities. Similarly in this questionnaire, the participants were provided with a 5-point Likert scale on these items to facilitate their response as done for the agroforestry questionnaire. The complete questionnaire is added in Annexure B.

3.5. Data collection

The data (qualitative and quantitative) for the study was collected between January 2023 and November 2023. A cross-sectional design was used for the study. A cross-sectional study is used when a study presents a “snapshot” of a certain matter under consideration at a certain time (Saunders, 2014).

As mentioned earlier, five (5) persons playing different roles in Hosachiguru were recruited for the interviews. These participants were briefed about the study's purpose and the interview's purpose. In addition, they were assured that their data would be kept confidential, their identities would not be revealed, and they could opt out of the study whenever they wanted. During the interviews, the researcher asked the participants if the audio of the conversations could be recorded to facilitate transcription (Merriam & Grenier, 2019). After obtaining the participants' approval, the researcher proceeded with the interviews. The interviews were conducted face-to-face through video calls using the Zoom application. Notes were taken during the interview to keep track of key points and to seek clarification for these later in the interview if required. Each interview was about 45 – 50 minutes in duration.

The two versions of the questionnaire were administered to farmers using email and WhatsApp social app. Considering that the participants were spread out across different locations in Karnataka state in India, the researcher used digital channels

(email and social app) to conduct the survey. The researcher reached out to participants through Hosachiguru, and the participants were allowed to indicate if they preferred to be contacted via email or WhatsApp by providing their email addresses or contact numbers. The questionnaire was entered into Google Forms, and the link was circulated via email or WhatsApp, depending on the preferred mode of communication of the participants. The first part of the Google Form provided a brief description of the study and the assurance of confidentiality of the data. In addition, the researcher and Hosachiguru's senior leaders used this part to reassure the participants that their data would be utilised only for academic purposes. Completed and fully usable responses were received from 208 participants (108 agroforestry farmers and 100 lifecentric farmers).

3.6. Data analysis

The data obtained from the interviews and questionnaires were analysed using various analysis techniques. The interview data were qualitatively analysed using thematic analysis as well as Natural language processing (NLP).

The survey data were analysed statistically using IBM's SPSS (Statistical Package for the Social Sciences). Suitable statistical tests were utilised to acquire significant interpretations of the data collected from agroforestry and lifecentric farmers. Descriptive statistics such as averages, frequencies and percentages are reported to describe the collected data along with mean and standard deviation. Moreover, inferential statistics to make inferences about the case organisation and participants based on the study data.

t-test to perform comparisons of the means of two groups,

f-test to ascertain the F-distribution of the data,

regression analysis and analysis of variance for several independent variables (IVs) with the Dependent variable (DV).

3.7. Limitations of questionnaire study

Acknowledging the limitations in the methodology shows that the researcher made every effort to strengthen the research (Greener, 2008). One of the limitations of questionnaires is that although participants are encouraged to answer accurately, there may still be biases in participants' responses. When participants respond in a way that makes them look good, it is called response bias (Masuda, Sakagami, Kitaoka, & Sasaki, 2016). To overcome this bias, clear instructions are provided to the participants so they can respond with accurate answers and assure them of their anonymity in the research process (Masuda et al., 2016). The survey design benefited from the earlier qualitative phase, reducing potential issues like lack of clarity or relevance in questionnaire items.

The concept of social desirability bias pertains to the inclination of individuals participating in research to select responses that they see as more socially desirable or acceptable rather than providing responses that accurately reflect their genuine thoughts or emotions. This phenomenon leads to an overemphasis on reporting comments that align with social desirability while downplaying or omitting responses that are considered socially undesirable or less desired (Choi & Pak, 2005). This inclination is hypothesized to be a characteristic of an individual's personality, stemming from their inherent desire for validation. The potential for social desirability bias arises in research endeavours that entail data collection pertaining to personal or socially sensitive matters. For instance, participants may see societal norms as imposing a sense of responsibility towards the environment despite their personal indifference towards environmental concerns. In the above scenario, individuals may choose to express an ecologically conscious stance instead of selecting an alternative that accurately reflects their genuine sentiments (Sedgwick, 2013).

3.8. Ethical considerations

In business research, ethics signifies “a code of conduct or expected societal norms of behaviour” while performing a study (Sekaran & Bougie, 2016, p. 13). It is essential to consider ethical concerns when human participants are involved in a study. This is regardless of whether the research is undertaken face-to-face or indirectly. Attention to ethical concerns is essential throughout a study, and these need continual reflection (Saunders et al., 2019) and assessment (Saunders et al., 2019). The following several ethical considerations (Sekaran & Bougie, 2016) were implemented during the research:

The researcher treated the information provided by the participants as strictly confidential and guarded the privacy of the participants.

The researcher avoided reporting personal or apparently invasive information for the study. This ensured that the anonymity of the participants was ensured.

The participants were treated respectfully during both the interviews and surveys.

The participants were allowed to voluntarily participate in the survey. The participants could also withdraw from participation at any time, together with any data they have provided.

The researcher/agents briefly introduced the study before the interviews and administered the survey questionnaire to the farmers. This was done to inform the participants about the study and explicitly seek their consent to participate. Thus, the informed consent of the participants was obtained prior to their actual participation in the study.

The data obtained from the participants during the study's progress were reported accurately without misrepresentation or distortion.

Chapter 4: Findings

This chapter provides the findings from the questionnaires carried out among two farm type groups of participants (agroforestry and lifecentric farmers) and the in-depth interview of five experts working in the managed farm services industry.

Semi-structured Interviews were conducted first to gather insights, which then informed the development of two sets of questionnaires (one for the agroforestry group and one for the lifecentric farmer group). These tools were used to examine the impact of permaculture practices and digital technologies, the implementation of sustainable practices, farmers' purchasing criteria, and sustainability outcomes across agroforestry and lifecentric farms.

4.1. Qualitative findings

This section provides the findings from the in-depth interviews conducted to achieve the current study's objectives. Five experts from Hosachiguru were identified to further understand the benefits of permaculture practices and digital technologies.

The section first presents the information about the interviewee; the in-depth interviews were structured with 37 questions presented to each participant. This chapter presents the major takeaways from these interviews. The analysis has been done using narrative analysis and NLP using NVivo 14.0.

Data analysis followed a thematic analysis approach (Braun & Clarke, 2006). Five semi-structured interviews were transcribed verbatim and imported into NVivo qualitative analysis software. Initial codes were generated through close readings of the transcripts. These codes were refined and organized into themes representing key patterns across the data. The thematic structure was reviewed and validated iteratively by the research team to ensure rigor and trustworthiness in the analysis. Below is the word cloud generated by NVivo for the five interview participants; as we can see, the most discussed terms are permaculture practices and information,

which were the major themes in the interviews. Complete interview questions have been added to Annexure D.

This section is divided into several sub-sections, starting with the details of the five participants, followed by their responses on agroforestry farmers and lifecentric farmers, their differences, permaculture practices, and digital technologies. The qualitative findings section concludes with the key insights from the interviews.



Figure 4 Topics discussed by the interview participants (using NVivo)

The word cloud generated using NVivo (Figure 4) highlights the most frequently discussed topics by the participants. The variations in font size represent the frequency of occurrence, with larger words appearing more frequently in the text.

4.1.1. Interviewee details

The five participants are all working in the Hosachiguru firm and come from diverse educational backgrounds with varying years of experience in different industries. Their roles within Hosachiguru seem to align with their experiences and educational qualifications. Notably, there is a mix of agriculture-specific and broader work experiences, highlighting a multidisciplinary team at Hosachiguru. Table 4 below provides the details of the participants.

Table 3 Interview participants' details

Name	Educational Background	Years in agriculture industry	Current Position
Participant #1	Post-graduation	7.5 years	Senior Agronomist
Participant #2	Engineering and Management Studies	20 years	Head of business development and Hospitality
Participant #3	Graduation in Mechanical Engineering	29 years	Founding director and chairman
Participant #4	Bachelor of Commerce	8 years	Operations Head
Participant #5	Agriculture graduate with specialization in agronomy	7 months	Junior Agronomist

The responses from the five participants provide a comprehensive overview of their educational backgrounds, work experiences, and current roles within Hosachiguru.

4.1.2. Agroforestry farms

Multiple questions related to agroforestry were asked of the participants, and this section presents the results from these questions about agroforestry. The responses from the participants provide a comprehensive overview of Hosachiguru's involvement in agroforestry, a practice they have been engaged with since 2011. All participants provided details, with some emphasizing the biodiversity of these agroforestry projects and outlining how farmers can diversify their plots for potential passive income through timber cultivation alongside fruit trees. Participant #2 highlights the pragmatic approach to timber cultivation, noting the benefits of time and a natural process due to the less immediate intervention required compared to other crops. Participant #3 recounts the company's journey since its formal inception in 2014 and operational commencement for co-farmers in 2011. He specifies the varieties of trees planted in these agroforestry projects, such as "teak, sandalwood,

mahogany,” and a selection of fruit and berry plants, aligning with Participant #2’s description. Another participant brings an operational perspective, contrasting agroforestry with other types of farming by highlighting its lesser water requirements and the resilience of forest species compared to commercial or horticulture crops.

All five participants' responses show that Hosachiguru’s agroforestry farms are a well-established, biodiverse, and thoughtfully managed aspect of their operations, offering both ecological benefits and potential financial returns for the involved co-farmers. Hosachiguru is dedicating a substantial 90% of its land to these ventures, as echoed by the participants' responses.

4.1.2.1. Agroforestry operating model & practices being implemented

The responses from the research participants provide valuable insights into the operating model for agroforestry and the role of Hosachiguru in its management. Participant #2 emphasized the minimal intervention required in agroforestry, stating that they enter the farm only around "10 or 12 times a year" for tasks such as pruning and compost application. This leads to cost-effectiveness for farmers. He also mentioned the efficient management of large farms, with a daily workforce of "30 to 40 labor workers."

Participant #3 highlighted Hosachiguru's role as a "managed farm services provider," taking care of all aspects, from agronomy to security. They employ agronomists to oversee plant health, and supervisors and managers handle execution. Importantly, they engage local farmers, offering employment opportunities and contributing to the community.

Participant #4 echoed a similar model, with "4 to 5 qualified agronomists" and in-house teams managing various tasks. They also employ around "40 to 50 labor workers" daily, along with in-house ground teams for various activities.

Participant #5 and Participant #1 stressed the importance of a well-managed team, including agronomists, supervisors, and skilled labor workers. They involve local

villagers who have invaluable local knowledge and skills. For instance, the Abhivrudhi managed farm project utilizes "30 to 40 labor workers" daily from nearby villages. The Table 5 below provides the themes that were identified from the interview related to agroforestry practices being implemented and the number of participants who reported it.

Table 4 Agroforestry practices being implemented (interviews)

No	Agroforestry being implemented	References (number of participants reporting it)
1	Windbreaks	5
2	Live fences	4
3	Trees at boundaries	4
4	Biomass planting	4
5	Trees along streams	2
6	Bulk planting	1

The responses collectively underscore the cost-efficiency and effectiveness of agroforestry, largely due to minimal intervention and the dedication of a skilled team overseeing farm operations. The involvement of local labor workers, with their specific knowledge of the area, greatly contributes to the success of Hosachiguru's agroforestry model. This holistic approach ensures both sustainable farming practices and community engagement.

These findings align with the quantitative results, where farmers highly rated the employment of local workers as a sustainability practice (Mean = 4.76) and recognized the importance of minimal intervention for cost-effectiveness. Additionally, the preference for agroforestry among investors seeking passive income and long-term returns further supports expert-reported distinctions between

agroforestry and lifecentric farming—with agroforestry being more commercially driven.

4.1.2.2. Agroforestry practices & effect on the environment

The responses to the question about agroforestry practices in Hosachiguru reveal a consensus on the use of several methods, albeit with some individual variations in emphasis and detail. A common practice identified by all participants is the use of live fences and windbreaks. Participant #2 mentions, "Typically, we are using live fences nowadays," and Participant #1 emphasizes this by stating, "We do use live fences," indicating that it is a standard practice across the board. Windbreaks are also a recurring theme, as Participant #2 describes the whole land acting as a windbreaker due to the abundance of tall tree species, and Participant #1 confirms, "definitely there will be windbreaks."

Biomass planting is another technique that several participants describe. For example, Participant #1 provided a detailed explanation: "This is a concept which is new. Based on the chop and drop method, we want to use this biomass." Participant #4 also concurs with the practice of biomass planting.

There is, however, some discrepancy in how the participants view the use of trees on boundaries. Participant #2 argues against this practice in their context, stating that "I will not say trees on boundaries because it's a forest," suggesting that the concept doesn't apply in a heavily forested area. In contrast, Participant #1 mentions the use of boundary trees or shrubs for aesthetics and protection: "Instead of trees, you can say shrubs will be there. For example, lantana camara and bougainvillea (plant types) will be there."

Trees along streams and rivers are acknowledged by Participant #5 and Participant #1, with the latter detailing, "Some of our farms are definitely exactly on the bunds of rivers or the bunds of the streams."

The customization of agroforestry practices to individual needs is highlighted by Participant #2 and Participant #1. Participant #2 notes, "Depending upon what each

one's choice is, we set them up accordingly," indicating a personalized approach. Similarly, Participant #1 mentions options for "pollinator gardens or any small kinds of shrubs."

In summary, the responses show a general agreement on the use of live fences, biomass planting, and windbreaks, with some divergence in the application and acknowledgment of boundary trees and trees along watercourses.

The participants are also in consensus that agroforestry has positive or neutral environmental impacts. These impacts include key benefits such as windbreaks, live fences, biomass planting, and tree planting along water bodies. These practices are widely implemented in managed agroforestry systems to enhance soil health, reduce erosion, and support biodiversity. The minor differences in perspectives such as whether boundary trees are necessary reflect the adaptable nature of agroforestry, which allows for customization based on land conditions and ecological needs. Overall, there is a consistent belief among the participants that agroforestry is environmentally friendly, with minor discrepancies related to the specific reasons behind this belief.

These findings are supported by the quantitative results, where farmers rated multi-cropping and planting combinations of trees highly (Mean = 4.48), reflecting their recognition of diversified planting as a key sustainability practice. Similarly, the employment of local farmers, another sustainability-driven practice, was rated significantly high (Mean = 4.76), supporting the qualitative findings that local knowledge contributes to effective agroforestry management.

Additionally, while the implementation of trees along boundaries and near water bodies was reported with moderate adoption (Mean = 3.65) by the farmers, this aligns with the qualitative findings, where some experts emphasized the importance of trees in riparian zones, while others argued against the necessity of boundary trees in certain contexts (Participant #1 and #2).

Together, these findings demonstrate that agroforestry is perceived as a scalable and adaptable environmental strategy, with high adoption of core sustainable practices but some flexibility in implementation depending on individual farm conditions. The alignment between qualitative findings and quantitative findings strengthens the validity of these practices in promoting sustainability within managed farm services.

4.1.2.3. Reasons for purchasing agroforestry farms

Participants in the study identified various motivations for purchasing agroforestry farms, highlighting the appreciation of land value, environmental contributions, the aspiration to own agricultural land, and the desire for a personal connection to nature as primary drivers.

Table 5 Reasons for purchasing agroforestry farms (interviews)

No	Reasons for purchasing agroforestry farms	References (number of participants reporting it)
1	Have own farmland	3
2	Investing in land	4
3	Love for nature	2
4	Away from city	2
5	Spend time with family	2
6	Passive income	2

Participant #2 emphasized the tangible and intangible returns on investment, stating, "One is, he understands land as a value. Second is, in the process of managing this land, we're also contributing back to mother earth," and "it contributes sort of passive income to him as well in the long run." This highlights the multifaceted appeal of agroforestry, combining financial benefits, environmental stewardship, and a sense

of personal fulfilment. The Table 6 presents the reasons for purchasing agroforestry farms as reported by the participants.

Participant #4 touched upon the personal and familial aspects of purchasing agroforestry farms, describing the desire to "be a little closer to nature" and "give the farm experience to their kids." He also acknowledged the environmental benefits of agroforestry, specifically citing "water conservation" and "groundwater recharging" as significant contributions.

Participants also emphasized the appeal of owning farmland, spending quality time with family away from cities, and viewing agroforestry as a promising investment for future prospects. Participant #1 particularly highlighted the contemporary relevance of this trend, stating,

"Nowadays, we have seen that in Bangalore city or any other city, the crowd is too much. If anybody wanted to spend their weekends away from the city, definitely they can opt for this agroforestry system." – Participant #1, Senior agronomist

In summary, the participants illuminated the multifaceted appeal of agroforestry investments, encompassing financial returns, environmental stewardship, cultural connections to agriculture, personal and familial fulfilment, and an escape from urban pressures. These motivations collectively illustrate the comprehensive value proposition of agroforestry, resonating with individuals on economic, environmental, and emotional levels.

The qualitative findings highlight the biodiversity-focused and cost-effective practices of agroforestry farms. To further validate the findings gathered from the experts, quantitative analysis provides broader validation by assessing whether these practices are perceived similarly across a larger sample of farmers.

The qualitative findings highlight that agroforestry farms are primarily purchased for financial investment (4/5 participants) and personal connection to nature (2/5 participants) among others. These motivations align with the quantitative findings, where concept representation (Mean = 4.25) and the reputation of the farmland

developer (Mean = 4.05) were rated significantly higher than the initial cost of farmland (Mean = 3.13). This suggests that farmers prioritize long-term value, sustainability, and managed services over price considerations when making investment decisions.

Additionally, the importance of environmental contributions, such as groundwater recharging and water conservation, mentioned in the interviews, is supported by high agreement in the survey responses regarding the benefits of multi-cropping in agroforestry (Mean = 4.48) and the role of permaculture practices in improving soil health (Mean = 4.55). Furthermore, the qualitative emphasis on agroforestry as a passive income source is reinforced by the survey, where participants placed strong importance on amenities and facilities (Mean = 4.08), reflecting a preference for well-managed farm services that enhance property value over time.

These findings demonstrate that agroforestry is not just viewed as an agricultural investment but as a long-term asset that offers financial returns, sustainability benefits, and an enhanced lifestyle.

4.1.3. Lifecentric farms

The concept of lifecentric farms, as offered by Hosachiguru, is consistently described across the responses as an experience that goes beyond mere agriculture or leisure, instead offering a deeply personal and life-affirming connection with nature. Participant #2 provides a profound insight, suggesting the term "lifecentric" over "lifestyle," emphasizing a deeper connection. Lifecentric farming provides a tangible connection to nature, and serves as an ethical investment in the future.

"It is a source of food which comes to their home every week, so from that perspective, this is beyond lifecentric for the farmers." – Participant #2, Head of Business Development

This sentiment is echoed by Participant #3, who describes their farms as "lifecentric projects" that allow farmers "to have the experience of life" through biodiversity and a connection with nature.

The participants highlighted the value of the farms as a legacy and a source of well-being rather than a financial investment. Participant #2 notes this legacy aspect by saying it's an "asset that will never stop giving," while Participant #4 discusses the farms' appeal in the context of social awareness and the drive to "improve the nature, to develop the ecosystem.

" People who choose to do lifecentric farming mainly are very socially well aware of what the future generation exactly requires, because when we had this COVID in 2019, most of the people struggled in the cities; all they wanted was to go back to their native or be in the farm or somewhere out of the city and lot of people are so interested in coming into this lifecentric project to only to improve the nature, to develop the ecosystem, lot of our farmers are very enthusiastic in this particular lifecentric project. They are not worried about the return of investment or anything."
– Participant #4, operation head

The concept of gifting and privilege recurs, with 4 out of the 5 participants all touching on the idea that these farms are a "gift" to future generations. A common theme across the responses is the minimization of the importance of financial returns in favour of the environmental and personal benefits of being close to nature.

4.1.3.1. Lifecentric farms operating model & effect on environment

As per the participants, the operating model for lifecentric farming involves end-to-end management with a focus on both communal areas and individual farm plots. All participants acknowledge that Hosachiguru provides full services, with an option for individuals to take over some aspects if they choose. Participant #2 emphasizes the two-tiered management approach, where "we continue to maintain as part of the overall community" the common areas and offer services for private plots, which some may choose to manage independently after the initial setup period ("initial five years"). This is supported by the other responses.

Regarding personnel involved in the lifecentric model, the participants reported that around 20-30 labor workers are involved depending on the nature of the work. Participant #4 adds that the staff includes skilled operators for various farm

equipment, and they have a practice of knowledge sharing among farms ("they train other skilled labor workers also"). This suggests a dynamic allocation of labor based on need and project size, as well as an emphasis on training and skill development within the workforce. Overall, the responses portray a labor-intensive operation with a significant commitment to sustainability and community, leveraging both skilled labor and technology. The figures provided for labor vary slightly but not significantly, suggesting a general agreement on the scale of the workforce required for such operations.

When asked about the effect on the environment, the responses present a range of perspectives. Participant #2 takes a strong stance, claiming that lifecentric farms only add value to the environment and do not contribute to any harm. Participant #3 offers a more refined view, acknowledging that while most of the farming is done sustainably and regeneratively, there may be some environmental impact in the construction phase, where materials like cement and limited plastic are used.

Participant #4, Participant #5, and Participant #1 all firmly assert that there is no environmental harm in lifecentric farms, with Participant #5 suggesting it benefits the environment. These responses generally align with their belief that lifecentric farms is environmentally friendly, although Participant #3 introduces the idea of potential environmental trade-offs during construction.

4.1.3.2. Reasons for purchasing lifecentric farms

The responses to the question about why people purchase lifecentric farms highlight a shared sentiment among the participants about the desire for a connection with nature and the inherent value of the land.

A key motivation that emerges across the answers is the intrinsic love for nature. Participant #2 mentions that farmers are "passionate about trees, passionate about nature," aligning with Participant #1's and Participant #5's notion of someone who "loves being with nature" and wants to "experience farm life away from urban life." This theme is echoed by Participant #4, who emphasizes the desire to be "closer to nature" and to "experience the farm life, green life."

There's also a practical consideration identified by Participant #2, who notes that:

"...people see value in land ownership but are daunted by the challenges associated with it, such as legal hurdles and resource mobilization."

He states that farmers come to them because they want to own land that is "hassle-free." This is a unique insight that the others do not specifically mention but is implied in the desire for a weekend retreat that is both accessible and ready for enjoyment, as Participant #1 describes, "They have their own farm, own cottage area."

Furthermore, Participant #3 introduces the notion of a "mature farmer" who values "biodiversity and nonchemical farming and a natural way of living," suggesting that there's a demographic that is not only interested in the lifecentric aspect but also in sustainability and eco-friendly practices. He also highlights the feasibility of "work from home or farm" due to internet availability, suggesting that these investments are practical for ongoing use and not just occasional retreats.

The Table below presents the purchasing reasons as reported by the five participants.

Table 6 Reasons for purchasing lifecentric farms (interviews)

No	Reasons for purchasing lifecentric farms	References (number of participants reporting it)
1	Green heart	2
2	Land value	2
3	Nature and away from city	4
4	Spend time with family	3

Collectively, these responses reveal that while the emotional pull towards nature is a common thread, the practical benefits of owning hassle-free, potentially work-compatible farmland add to the appeal of lifecentric farm investments.

The qualitative insights suggest that lifecentric farming emphasizes personal values, biodiversity, and sustainable living. Quantitative data can validate these findings by examining patterns across a broader population to confirm whether these themes are widely shared among lifecentric farmers. Quantitative results could also identify specific factors, such as the importance of concept representation or the role of amenities, that influence farmer preferences.

The qualitative findings indicate that lifecentric farmers are primarily driven by an emotional connection to nature (4/5 participants), a preference for spending time with family (3/5 participants), and the prospect of farmland investment (2/5 participants). These motivations are strongly reflected in the quantitative findings, where concept representation (Mean = 4.86) was rated as the most important purchasing criterion, significantly higher than in the agroforestry group (Mean = 3.69, $p < 0.001$). This suggests that lifecentric farmers prioritize the alignment of farm projects with sustainability, biodiversity, and personal well-being over traditional financial considerations.

Additionally, the survey findings show that lifecentric farmers place significantly higher importance on amenities and facilities (Mean = 4.61) compared to agroforestry farmers (Mean = 3.58, $p < 0.001$). This aligns with qualitative responses, where participants described lifecentric farms as places for relaxation, family retreats, and long-term personal fulfillment. Similarly, the reputation of the farm developer (Mean = 4.83) was a major factor for lifecentric farmers, suggesting that they value the developers ability to maintain ecological integrity and sustainable land use.

The practical considerations of owning a "hassle-free" farm, as mentioned by Participant #2, are supported by survey responses indicating that lifecentric farmers are more likely to consider sustainability practices (e.g., swales and trenches for water retention, Mean = 4.27) as a key part of their investment. The emphasis on "work-from-farm" feasibility, noted in the interviews, is also reflected in the higher

adoption of MyFarm App updates (Mean = 4.03) among lifecentric farmers, showing their reliance on digital technologies to manage their properties remotely.

These findings confirm that lifecentric farming is not just about land ownership but about embracing a lifestyle centered around nature, sustainable living, and convenience. The stronger preference for concept representation, amenities, and developer trust in the quantitative results validates the qualitative findings that lifecentric farmers are motivated by a long-term vision of environmental responsibility and personal well-being rather than immediate financial returns.

4.1.4. Difference between agroforestry and lifecentric farms

The responses gathered reflect a consensus that lifecentric and agroforestry farms differ primarily in their objectives and outputs.

Table 7 Lifecentric differences from agroforestry (interviews)

No	Lifecentric farms differences from agroforestry farms	References (number of participants reporting it)
1	Lifecentric focus on environment	4
2	Less focus on returns in lifecentric as compared to agroforestry	3
3	Away from city and near nature	3
4	Aesthetically pleasing	1

Participant #2 defines agroforestry broadly, incorporating both timber and food forests, where the emphasis can vary from producing edible fruits to timber or even medicinal plants, depending on the farmer's preferences ("They could either go in for kind of a food forest or a timber forest"). He identifies a key distinction in that lifecentric farmers tend to focus more on personal experience and enjoyment, such

as taking mangoes home ("people tend to look at more of experience"), whereas agroforestry farmers focus on returns, especially from timber production.

Participant #3 introduces the concept that agroforestry projects are generally farther from the city and have a focus on returns with "less on facilities and biodiversity" compared to lifecentric projects, which are "very heavy on biodiversity, natural methods of farming" and include amenities for enjoyment and living. This contrasts lifecentric projects with agroforestry by the latter's proximity to urban areas and its blend of agricultural productivity with lifecentric amenities.

Participant #4 and Participant #5 both point out that agroforestry is seen as a long-term investment where "return on investment plays a major role," suggesting a more commercial and profitability-oriented approach compared to lifecentric farms. Participant #4 emphasizes that despite the focus on returns, there is still a contribution to nature and an expectation of land value appreciation.

Participant #1 reiterates the point made by others that agroforestry is focused on tree cultivation for long-term returns, whereas lifecentric farms are about creating a "food forest" and "making the environment green," implying a greater emphasis on ecological benefits and immediate personal enjoyment over financial returns.

All participants align on the premise that agroforestry is more commercially driven and long-term in its financial outlook, while lifecentric farms are characterized by their focus on biodiversity, personal enjoyment, and immediate use-value. There are no significant discrepancies among the responses; rather, they complement each other by highlighting different aspects of the two-farming context.

4.1.4.1. Costs associated with farms

The responses regarding the costs associated with farms show that there is a consensus that costs are initially high but tend to decrease over time, especially with sustainable practices. However, there are varying perspectives on how these costs are managed and the factors that influence them.

Participant #2 acknowledges the increasing input costs but is optimistic about the long-term reduction in maintenance expenses, stating, "over a period of time, it becomes a lot easier to maintain without any hassle." He emphasizes the self-sustaining nature of mature farms, where passive systems and biodiverse crops reduce the need for active management and input costs.

Participant #3 contrasts agroforestry with permaculture-supported farms, highlighting that:

"One-time setup cost is higher for agroforestry." But also recognizes that the value delivered to farmers in permaculture practices, supported by digital technology, is significantly higher. He suggests that while maintenance costs might not drop significantly, the overall value and ease of operation improve.

Participant #4 presents a more conservative view, stating, "Costs will always be increasing," especially due to the rising costs of labor and the decreasing availability of farmworkers. He does concede that certain sustainability practices, such as producing their own fertilizer, can mitigate some expenses, but he does not foresee a drastic reduction in costs.

Participant #5 offers a perspective based on economies of scale, arguing that "Costs associated with farm maintenance with respect to large area is reducing," as the cost per unit decreases when maintenance operations are spread over a larger area.

Participant #1 echoes this sentiment, reinforcing the idea that costs diminish as the scale of operation increases, particularly after the initial few years of establishment. He mentions, "definitely the cost day by day it is reducing," especially after the farm reaches a certain maturity and can, to some extent, self-manage.

Across the responses, the common themes are the initial high costs of establishing a farm, the eventual decrease in costs due to the farm's natural ecosystem services, and the beneficial impact of scale. While there is some discrepancy in the optimism about the extent to which costs can be reduced, ranging from significant decreases

to more modest reductions, all acknowledge the dynamic nature of farm costs and the influence of sustainability practices and scale on these expenses.

The qualitative findings highlight key distinctions between agroforestry and lifecentric farms, such as differing objectives, focus areas (e.g., returns vs. biodiversity), and farming practices. Quantitative data can enrich these findings by providing a broader understanding of whether these differences are observed across a larger sample of farmers. By offering numerical evidence, the quantitative results can validate and refine the qualitative insights, making the distinctions between the two farm types more robust and generalizable.

These qualitative findings align with the quantitative findings from the survey. The participants in the quantitative survey also acknowledged the role of sustainability practices in reducing costs over time. For example, "drip irrigation solutions" (Mean = 4.13 for agroforestry and 3.87 for lifecentric) were seen as effective in reducing operational costs, particularly in water usage. Similarly, "the employment of local farmers" (Mean = 4.18 for agroforestry and 4.15 for lifecentric) was recognized as a cost-effective sustainability practice by both groups, supporting the qualitative finding that involving local labor helps reduce maintenance costs. Furthermore, the survey showed that "maintenance costs" were rated significantly lower by lifecentric farmers (Mean = 3.20) compared to agroforestry farmers (Mean = 3.38), aligning with the finding that lifecentric farms, emphasize more on biodiversity as compared to on-going costs. The quantitative and qualitative data together highlight the importance of sustainable practices in managing long-term costs across both agroforestry and lifecentric farms.

4.1.5. Permaculture practices

The participants uniformly affirm that Hosachiguru implements permaculture practices in their projects. Participant #2 reveals that permaculture was an implicit part of Hosachiguru's approach even before the term was familiar to them, referencing activities like no-till farming and water conservation as innate to permaculture.

"We have adopted even before we heard the word permaculture."

He also delves into the philosophy behind permaculture, pointing out its core tenets of earth care, people care, and fair share, suggesting a holistic and ethical approach to agriculture ("It's all about making sure that we're able to do regenerative agriculture").

All participants reported a strong alignment with permaculture practices in their farming projects, though the degree of implementation may vary between projects, with newer ones seeing a more intense application. The similarities in responses highlight a shared understanding of permaculture's value and philosophy, while any discrepancies seem to relate to the degree of integration and familiarity with the term 'permaculture' itself rather than its principles.

Participant #3 speaks to the adherence to the 12 basic principles of permaculture, indicating a deliberate and intense application in newer projects, although less so in older ones ("in the new projects, in a very intense manner, we follow these principles"). This is complemented by the use of syntropic and biodynamic farming to expedite the creation of forest environments, which aligns closely with permaculture practices ("We are very closely following the principles of permaculture").

Participant #4 confirms the use of permaculture practices and suggests a timeline for when Hosachiguru became aware of and interested in permaculture ("a few years ago, and that is how we wanted to do permaculture farming"). Similarly, Participant #5 acknowledges the widespread use of permaculture across all farms, particularly highlighting the practices aimed at water catchment and preventing erosion ("In every farm, we are using this").

4.1.5.1. Implementation of permaculture practices

The participants report a common commitment to permaculture due to its alignment with principles of sustainability, regeneration, and natural farming. Participant #2 articulates this by emphasizing the long-term value of land and the need to avoid

practices that degrade it, reflecting on the negative impacts of conventional agriculture ("We have seen a lot of lands become fallow through the green revolution"). His focus is on enhancing the soil's microbial activity and, by extension, its carbon content ("some of our land which had just 0.15% of carbon... now it's almost 1.5% of carbon").

Participant #3, with over a decade of experience, reiterates the importance of regenerative and sustainability practices, stating that permaculture ensures that "the farm should become more and more productive" and not demand repeated inputs ("whatever you create once, it should not demand the inputs from you again and again"). He views permaculture as a strategic choice for long-term rewards and farmer satisfaction, projecting that positive farmer feedback in the coming years will encourage wider implementation ("We will have at least 3 or 4 projects where we can demonstrate our own farms").

Participant #4 and Participant #5 both highlight permaculture as a system that efficiently uses natural elements such as "sun, water, and soil, wind" and conserves basic resources ("The concept of permaculture is a purely natural farming system"). Their definitions underscore the holistic use and storage of energy to improve soil and plant health.

Participant #1's response dovetails with the others by recognizing the cyclical nature of permaculture, where inputs from nature are returned to it, fostering a balance between extraction and replenishment.

"Whatever we are taking from the nature, we are giving back to the nature."

He emphasizes the importance of maintaining the carbon-nitrogen ratio through the incorporation of biomass into the soil, which is essential for plant growth. Across all responses, there is a consensus that permaculture is chosen for its sustainable, regenerative, and natural farming approach that benefits the soil, conserves resources, and is expected to be more productive and beneficial in the long term. There are no major discrepancies in their answers; instead, there's a cohesive

narrative that permaculture is integral to their farming methodology due to its environmental and economic sustainability.

"Not one drop of water went out of our farm after implementing the permaculture earthworks," - Participant #3.

"We have to make sure the water is not flowing out from our farm because it is an important element or energy which we have to make sure we store and use it." – Participant #4.

The similarities across responses demonstrate a consistent implementation of permaculture's foundational principles like observing and interacting with the environment, capturing and storing energy, and applying self-regulation and feedback mechanisms.

4.1.5.2. Challenges when implementing permaculture practices

The experts reported both conceptual and practical issues faced by individuals implementing permaculture practices. A common theme across the responses is the unpredictability of weather and the impact of environmental changes on traditional permaculture practices.

Participant #2 discusses the erratic weather patterns, noting, "We don't know when it rains, we don't know how much it rains," which leads to the adaptation of modern practices to maintain the value of the land without deterioration. This view is echoed by Participant #4, who points out the need to "observe and react based on the climatic conditions," indicating a reliance on technology like "soil moisture sensors" and drones to manage these unpredictable elements efficiently. Scalability and the translation of permaculture practices to large-scale operations are other challenges brought up by participants.

Throughout the responses, a dichotomy is evident between adhering to permaculture practices and modifying them with modern technology to mitigate environmental unpredictability. There's a consistent thread regarding the need for adaptation, education, and innovative thinking in the field of permaculture to make it

viable and sustainable in the long term. Despite their shared concerns about environmental challenges and scalability, the participants emphasize resilience and adaptability through the integration of technology and education, showing a readiness to evolve traditional practices to meet contemporary needs.

Table 8 Challenges when implementing permaculture (interviews)

No	Challenges	References (number of participants reporting it)
1	Weather unpredictability / nature	3
2	Limited understanding of what is permaculture and no formal training	3
3	Lack of state-of-the-art equipment in India	1
4	Variation in land topography	1

Regarding the training of permaculture practices, the responses indicate that while there is no formal university program for permaculture training mentioned by the participants, Hosachiguru and its staff have sought education through various permaculture design courses (PDC) and consultations with experts in the field.

Participant #5 confirms that relevant staff have received training through a PDC course, while Participant #1 provides a detailed account of training received from a specific permaculture institute, Swayam, and mentions hands-on support for a particular project, Dhaanvi, guided by permaculture practices ("We had around 3 days training program... They have helped us").

The similarities across the responses are clear: each representative acknowledges the importance of formal training in permaculture and cites specific courses or institutions from which they or their team members have received education. They

also mention the practical application of these principles in their projects, although the depth of description varies.

4.1.5.3. Permaculture ethics: Care for the earth, care for people and a fair share of resources.

The responses to the question on permaculture ethics from Participant #2, Participant #3, Participant #4, Participant #5, and Participant #1 reflect a common understanding and application of the three core permaculture ethics: “care for the earth, care for people, and fair share of resources” at Hosachiguru farm sites, albeit with nuanced differences in practices and experiences.

For "care for the earth," there is a shared emphasis on preserving and enhancing soil health and water conservation. Participant #2 highlights the importance of earthworks and passive irrigation systems, noting, "We do a lot of earthworks. It could be streams, riparian zones, staggered trenches, micro bunds, swales," while Participant #3 mentions the avoidance of tilling to protect "microbes and macro-organisms." Participant #1 focuses on replenishing consumed nutrients with biomass planting and composting: "We are doing biomass planting and also applying a lot of compost materials." All participants acknowledge the importance of a sustainable and regenerative approach to farming practices, indicating a common thread of soil and water conservation as essential for the care of the earth.

Regarding "care for people," the participants underscore a commitment to safety and well-being by avoiding harmful chemicals, which Participant #2 states should "not harm any of this, not just people but also the flora and fauna." Participant #3 and Participant #4 both stress the importance of educating and caring for farm staff and community, with Participant #4 explaining the farm's ethos as: "Whoever working in the farm interacts with them well, understands their challenges, understand their requirement." This collective approach suggests a holistic view of people's care, incorporating both physical health and community well-being.

On the ethic of "fair share," there is a consensus on allowing nature's participants their share of the farm's bounty. Participant #2 condemns excessive human interference with nature, telling a cautionary tale about the Chinese sparrow cull that led to ecological imbalance, while Participant #4, Participant #5, and Participant #1 mention allowing wildlife to partake in the farm's output, with Participant #5 specifying, "for 40 plants of mango, 2 plants can eat by birds." The practice of allowing wildlife to share the farm's produce seems to be a tangible manifestation of the "fair share" ethic, promoting biodiversity and ecological balance.

4.1.5.4. Effects of permaculture practices

In their responses to the impact of permaculture practices on soil health, all participants from Hosachiguru seem to observe positive changes over time in nutrient content, biodiversity, and pH (potenz Hydrogen) levels, although they note these improvements require a gradual process. Participant #2 notes the long-term benefits, stating that after several years, the system becomes "self-regulating" and that the diversity of plants contributes to soil conservation and microbial activity, which in turn stabilizes soil pH ("once the microbial activity is high, you don't really have to bother pH," Participant #2). This sentiment is echoed by Participant #3, who underscores the importance of biomass and native plant species in improving soil health.

"The introduction of biomass, dry matter, fresh matter, green matter and farmland manure into the pits... helped us manage plants grow very well," - Participant #3

Participant #4 focuses on the importance of soil moisture for microbial activity, which consequently balances pH levels.

"When there is proper moisture level in the soil, the microbial activity will be very well... all these pH problems, all these will automatically get neutral," - Participant #4

All participants share a belief in the self-regulating capability of permaculture systems, especially regarding pH levels. The emphasis across the board on mulching and maintaining soil moisture as a means of enhancing microbial activity—

and thereby the soil's ability to regulate itself—is a common thread. No discrepancies are evident in the fundamental principles they outline; rather, they collectively underscore a holistic approach to soil management that relies on permaculture practices to create resilient, self-sustaining agricultural ecosystems.

Regarding the performance of water bodies after the implementation of permaculture practices, the responses suggest a cohesive understanding of the importance of strategic land management in conserving water and preventing soil erosion. The similarities in the responses are pronounced: all participants recognize the critical role of structural and biological strategies in water conservation and soil preservation.

The qualitative findings indicate a strong alignment with permaculture principles and a shared emphasis on sustainability and regeneration. Quantitative analysis can enhance these insights by measuring the perceived benefits of specific permaculture practices across a larger sample in both agroforestry and lifecentric farmers. It can also identify any significant differences in how these practices are valued by different groups i.e. agroforestry versus lifecentric farmers. Quantitative data could further explore whether factors like farmer demographics affect the implementation or perceived benefits of permaculture practices, helping to contextualize the qualitative themes.

4.1.6. Digital technologies

This section presents the responses of the participants when discussing the digital technologies in farms, their application, benefits, and reasons for implementation.

4.1.6.1. Digital technologies implemented

Based on the responses of the participants, it is evident that Hosachiguru has implemented several core digital technologies across its operations.

The Table 10 below presents the digital technologies being implemented and the number of participants reporting their implementation during interviews.

All participants mentioned the use of soil moisture sensors and weather forecasting, which are critical for efficient irrigation and plantation management. This is evidenced by Participant #2's mention of "soil moisture sensors" to optimize growth and by Participant #4's stating that they use "moisture sensors, rain prediction sensor, wind velocity, air moisture," indicating a strong reliance on technology to guide farming practices. All five participants reported drone use, while four participants reported the use of sensors and satellite-based monitoring.

Table 9 Digital technologies being implemented (interviews)

No	Digital technologies being implemented	References (number of participants reporting it)
1	Drones	5
2	Sensors	4
3	Satellite based monitoring	4
4	CCTV	3
5	GPS	3
6	MyFarm app	4

The use of drones for land analysis and planning is another common thread across the responses. Participant #2 details their use in evaluating "the entire watershed, the elevation, the soil structure," while Participant #5 and Participant #1 mention the utility of drones in land acquisition, with Participant #1 emphasizing the ability to "shoot that entire farmland... and bring back that drone video."

There's also a shared emphasis on farmer-oriented digital platforms, particularly the MyFarm mobile app. Participant #2 speaks of it as a means to "seamlessly deliver information to our farmers," a point reiterated by Participant #4, who notes that updates are given "to co-farmers on a daily basis on our MyFarm mobile app." Participant #1 similarly points to the MyFarm mobile app as a tool for farmers to check updates on their farmland.

Moreover, the participants refer to digital technology for operational efficiency. Participant #3's comprehensive response details the use of digital tools for land surveying, tracking tractor usage, and implementing security measures through digital cameras. He also notes the integration of weather stations providing environmental data to both the head office and to the farmers. Additionally, he highlights the "centralized digitized irrigation management system," which aligns with the other responses underscoring the importance of digital technologies in irrigation.

In summary, there is a consensus among the responses regarding the implementation of digital technologies for soil and moisture analysis, drone surveys, weather forecasting, and farmer engagement through the MyFarm mobile app.

4.1.6.2. Digital sensors and their applications

In analysing the responses regarding the types of sensors used by Hosachiguru and their applications, a clear pattern emerges with a focus on weather stations, soil moisture sensors, and tracking technologies.

All participants reference the use of soil moisture sensors, emphasizing their deployment at different depths to monitor irrigation needs effectively. Participant #2 specifies the use of sensors at "30 centimetres" and "90 centimetres," with the goal of optimizing water availability to plants ("once it is already flooded at 60 centimetres or 90 centimetres, then we stop the irrigation"). This detail on specific depths correlates with Participant #4's, Participant #5's, and Participant #1's descriptions of primary and secondary sensors placed "1 foot" and "2 feet" below the surface to assess moisture at various levels.

Additionally, there is a unanimous mention of technology that aids in the monitoring and managing of farm operations, such as GPS trackers on tractors and CCTV for remote guidance, as noted by Participant #2 ("in every tractor we have GPS") and confirmed by Participant #1 ("We are also having some CCTV monitoring"). The integration of these technologies facilitates precision agriculture by ensuring that operations like de-weeding or mulching are completed efficiently and monitored remotely.

Furthermore, the responses touch upon the utilization of weather stations, a critical tool mentioned by Participant #2 and echoed by Participant #3, which aids in the forecasting of weather conditions to make informed decisions on irrigation and disease management. The mention of drones by Participant #3 and Participant #1 for tasks such as analysing plant health and monitoring for disease highlights an innovative approach to agricultural management, expanding the toolkit beyond static sensors to dynamic aerial surveillance.

4.1.6.3. Digital technologies to drive the sustainability commitment

There is a general agreement that digital technologies play a significant role in advancing Hosachiguru's commitment to sustainability. However, each response illuminates different aspects of how technology integrates with sustainability practices.

Participant #2's detailed response emphasizes the value of digital technologies in enhancing the precision and effectiveness of sustainability efforts, articulating that "Technology helps us measure things" and "what is measured gets controlled" (Participant #2). This idea is supported by the concept of real-time feedback on critical parameters like soil moisture and pH levels, facilitating timely interventions and transparent communication with stakeholders, which is crucial for maintaining the sustainable management of their properties.

Participant #3 points to scalability and remote monitoring as key benefits of digital technology, underscoring its role in enabling "less number of wrong decisions" and "more of timely decisions" (Participant #3), suggesting that technology is a cornerstone for efficiency and accuracy in decision-making processes.

Participant #4 acknowledges a "little bit of contribution" from digital technologies to sustainability, positioning them as tools for operational efficiency and predictive analysis in "activity planning, scheduling, and operating" (Participant #4) while also somewhat downplaying their role by stating that core sustainability practices like

water catchment and using solar energy "has nothing to do with technologies" (Participant #4).

Participant #5 highlights farmer appreciation for digital tools, mentioning "sensor-based moisture measurement" as a popular technology, suggesting that such innovations are both a selling point and an operational tool (Participant #5).

Participant #1 discusses the integration of digital technologies more broadly, noting that they are crucial for modern agricultural practices and providing information to farmers. He describes specific technologies like GPS for machinery and platforms like "TalkingLands", which aids in decision-making about land investment, implying that these tools are instrumental in making more informed, sustainable choices (Participant #1).

In these responses, a common theme is the importance of digital technology in supporting sustainability through enhanced monitoring, decision-making, and communication. The responses collectively underscore a transition to digital agriculture as a strategic move for Hosachiguru to enhance sustainability practices.

The qualitative results underscore the importance of digital technologies such as soil sensors, drones, and the MyFarm app as discussed extensively by the experts. Quantitative analysis can help determine how widely these technologies are adopted and which specific tools farmers find most beneficial. It can also provide a broader perspective on whether perceptions of these technologies differ based on farm type (agroforestry vs lifecentric) or demographics (young vs old farmers, males' vs females etc). This could help contextualize the qualitative findings and identify trends or patterns that may not emerge from the interview data alone.

4.1.7. Key insights from the interviews

The interviews included 37 questions in the form of a structured interview, in which the participants were asked questions on all aspects of permaculture practices and digital technologies in agroforestry farms and lifecentric farms. The Table below provides key insights from these interviews.

Table 10 Key insights from the interviews

No	Topic	Major Insights	References
1	Agroforestry farms and impact on the environment	<ul style="list-style-type: none"> • Agroforestry is viewed as more commercially driven, long-term, and focused on returns. • Agroforestry farming emphasizes minimal intervention, efficient management, and engagement with local communities, ensuring cost-effectiveness and sustainability. • Agroforestry practices include live fences, windbreaks, biomass planting, and customization based on individual needs. Overall, the participants agree that agroforestry has positive or neutral environmental impacts. 	Table 5 & 6
2	Lifecentric farms, and their impact on the environment	<ul style="list-style-type: none"> • Lifecentric farming emphasizes biodiversity, personal enjoyment, and immediate use-value. • Lifecentric farming is portrayed as an emotionally rich, environmentally friendly, and family-oriented venture, providing a deep connection to nature beyond mere agriculture or leisure. • Participants emphasize the value of farms as a legacy, contributing to well-being, and serving as an ethical investment in the future. • While opinions vary slightly, there is a general belief that lifecentric farming is environmentally friendly, with some acknowledging potential environmental trade-offs during construction. 	Table 7 & 8
3	Motivation for purchasing	<ul style="list-style-type: none"> • Agroforestry: Motivations include appreciation of land value, environmental contributions, cultural connections to agriculture, and personal and 	Table 6 & 7

	agroforestry and lifecentric farms	<p>familial fulfilment. Financial returns are coupled with environmental stewardship.</p> <ul style="list-style-type: none"> • Lifecentric: Farmers are driven by a desire for a connection with nature, a love for trees, hassle-free land ownership, and the practical benefits of owning work-compatible farmland. 	
4	Digital technologies implemented	<ul style="list-style-type: none"> • The participants reported the implementation of various digital technologies, including soil moisture sensors, weather forecasting, and drones for land analysis. • The MyFarm mobile app facilitated farmer engagement, and digital tools were used for operational efficiency and precision agriculture. 	Table 10
5	Permaculture practices implemented	<ul style="list-style-type: none"> • All participants reported a strong alignment with permaculture practices in their farming projects, emphasizing earth care, people care, and fair share. • The degree of permaculture implementation varied between projects, with newer ones showing more intense application. 	All five participants reported implementation
6	Challenges in the implementation of permaculture practices	<ul style="list-style-type: none"> • Weather unpredictability and environmental changes were common challenges mentioned by participants in implementing permaculture practices. • Adaptation, education, and innovative thinking were highlighted as crucial for overcoming challenges and ensuring viability. • Participants noted a lack of formal university programs for permaculture training. 	Table 9

7	Ethics of Permaculture	<ul style="list-style-type: none"> • Participants emphasized "care for the earth" through practices like earthworks, passive irrigation, and avoidance of tilling. • "Care for people" included a commitment to safety, well-being, and education for farm staff and the community. • "Fair share" involved allowing wildlife to partake in the farm's produce, promoting biodiversity. 	<p>All five participants reported implementations of these principles</p>
8	Benefits of permaculture practices	<ul style="list-style-type: none"> • Permaculture practices positively affected soil health, with participants observing improvements in nutrient content, biodiversity, and pH levels over time. • Mulching and maintaining soil moisture were common practices to enhance microbial activity and self-regulation. • Permaculture practices were effective in strategic land management, conserving water, and preventing soil erosion. 	<p>All five participants reported benefits in soil health and water conservation.</p>

4.2. Quantitative findings

This section presents the results of the quantitative data, collected using a questionnaire survey administered via digital channels. The findings aim to validate and expand upon the qualitative insights presented earlier. Specifically, the quantitative data examines the demographics of the sample, the perceived benefits of permaculture and digital technologies, and farmers' purchasing criteria, along with the implementation of sustainability practices for both lifecentric and agroforestry farmer group.

By providing numerical evidence, the quantitative findings build on the themes identified in the qualitative section, offering a perspective on how widely these practices are perceived by farmers. For example, the survey results provide a much broader perspective on whether the patterns observed in the qualitative interviews, such as the positive impacts of permaculture practices (e.g., mulching, biomass planting, water conservation techniques) and the adoption of digital technologies (e.g., IoT-based moisture management, MyFarm mobile app), are similarly reported by a larger sample of farmers. The quantitative data allows us to identify the prevalence of these practices across agroforestry and lifecentric farms and assess whether farmers' experiences align with expert insights on the effectiveness and benefits of these sustainability strategies. This includes analysing the statistical significance of factors such as farm type (agroforestry vs. lifecentric), as well as demographic variables like age and gender, to further understand how these elements influence the perceived effectiveness of the practices discussed in the interviews.

The mean value of each item, along with the standard deviation, is reported to provide a sense of variability and agreement within the responses, adding more clarity and validity to the qualitative findings with the help of quantitative data.

The analysis investigates how farm type (agroforestry vs. lifecentric) and demographic variables (gender – male vs Female, age etc) influence variables of interest, including:

- Permaculture practices implementation benefits (IVs)
- Digital technology implementation benefits (IVs)
- Farmer purchasing criteria (IVs)
- Sustainability practices implementation (IVs)

The analysis uses farm type and demographic variables as dependent variables, while the IVs vary by context. The analysis employs logistic regression, t-test and one-way ANOVA.

4.2.1. Demographic variables

208 participants filled out the questionnaire (108 for the agroforestry farmers and 100 for the lifecentric farmers). Four items were added to the questionnaires to gather data on the demographics of the participants. The items collected data on age, gender, income, and the employment sector.

In terms of age, many of the participants (45.68%) were between 31 and 40 years old, indicating a relatively young sample. Participants aged 41-50 years accounted for 36.54% of the total, while those 51-60 years old comprised 12.02%. 3.85% of participants were over 60 years old, demonstrating a diverse age range. This diversity suggests a broad perspective in the survey responses.

Table 11 Demographics of the participants (questionnaire)

Demographic variables	Frequency	Percent
Farming type		
Agroforestry farmers	108	51.92
Lifecentric farmers	100	48.07

Age		
21-30 years	4	1.93
31-40 years	95	45.68
41-50 years	76	36.54
51-60 years	25	12.02
More than 60 years	8	3.85
Gender		
Male	166	79.81
Female	42	20.19
Income in INR		
< 20 lakhs	75	36.06
20-50 lakhs	94	45.2
51-99 lakhs	30	14.43
More than 1 crore	9	4.33
Employment sector		
Private	164	78.85
Government	8	3.85
Retired	10	4.81
Others	26	12.5

Regarding gender, the sample was predominantly male, constituting 79.81% of the participants. Females made up the remaining 20.19%. While there is a significant gender imbalance, it is essential to note the female perspective in the study, as it can provide unique viewpoints on the topics being surveyed. This gender imbalance is a limitation of the current study, as the data may not fully capture the perspectives of female farmers, who could have different attitudes or experiences regarding farming practices, permaculture, and digital technologies. Future research should aim to address this limitation by including a more balanced gender representation,



allowing for a deeper understanding of gender-based differences in farming practices and motivations.

In terms of income, the survey participants were distributed across various income brackets. A significant portion (36.06%) had an annual income of less than 20 lakhs (approx. USD \$24,000), indicating a substantial representation of lower-income individuals. Additionally, 45.2% fell in the 20-50 lakhs bracket, signifying a sizable middle-income group. The presence of participants earning 51-99 lakhs (14.43%) and more than one crore (4.33%) illustrates the diversity in the economic backgrounds of the participants.

Concerning employment sectors, many participants were employed in the private sector (78.85%), indicating a strong corporate presence in the sample. A small percentage worked in the government (3.85%) and were retired (4.81%), highlighting a mix of active and retired professionals. Additionally, there were participants in other sectors (12.5%), further diversifying the employment backgrounds of the sample.

Three more questions were added to measure the size of plots owned, the price paid for the plot, and the frequency of visits to the farmland made by the participants. The distribution of plot sizes from 208 participants indicates that the average plot size falls below half an acre, with 35.6% of plots being a quarter acre and a cumulative majority (79.8%) being less than a half-acre, highlighting a preference for moderately sized plots. Of the 208 participants surveyed, the majority (93.2%) were purchased for less than 50 lakhs (approx. USD \$60,000). This suggests that the mean purchase price is toward the lower end of the market, with high-value transactions above one crore (approx. USD 120,000) being very rare at only 1%.

Analysing “visit frequency to properties” among 208 participants, the data leans towards less frequent visits, with 35.6% visiting quarterly and only 19.2% visiting monthly, indicating that the average visitation frequency is likely between monthly and quarterly. Analysing these demographics can provide a comprehensive understanding of the participants' backgrounds, which is essential for drawing meaningful conclusions from the survey data.

4.2.2. Permaculture practices

Seven items were added to both questionnaires to assess the implementation impact of permaculture practices and their benefits according to the participants. Both groups of participants were asked these questions to understand their views towards permaculture practices and their benefits. Four items were asked from both groups, while three items were exclusive for each group. Table 13 below provides the mean scores for all these items. The standard deviation (SD) of these items is reported to give a sense of response variability within each group.

The results indicated that both groups rated the statement highly regarding the effectiveness of permaculture earth care practices, such as mulching and chop-and-drop techniques in improving soil quality, with an overall mean of 4.55 (SD = 0.78). The agroforestry group had a slightly lower mean of 4.37 (SD = 0.87) compared to the lifecentric group, which had a mean of 4.74 (SD = 0.62).

For the assertion that water management systems can reduce reliance on bore/rainwater, the combined mean was 4.63 (SD = 0.72), with the agroforestry group at a mean of 4.56 (SD = 0.75) and the lifecentric group at a mean of 4.7 (SD = 0.68), suggesting a consensus that permaculture water conservation techniques are beneficial. The belief that practicing permaculture practices results in chemical-free yields received a mean score of 4.43 (SD = 0.84) across participants. The mean scores from the agroforestry group (4.35, SD = 0.84) and the lifecentric group (4.51, SD = 0.83) were similar, demonstrating a shared confidence in permaculture methods for producing organic yields.

Furthermore, permaculture earth care practice, such as rainwater harvesting, was rated as a beneficial technique to reduce rain dependency, with a mean of 4.64 (SD = 0.78) for the combined groups. The agroforestry and lifecentric groups reported means of 4.58 (SD = 0.85) and 4.7 (SD = 0.69), respectively.

Table 12 Permaculture practice questionnaire - results

Questionnaire Item	#	Group	Mean (SD)	Agroforestry	Lifecentric
Permaculture earth care practices like mulching, biomass planting, chop and drop, help improve the quality of soil.	208	Both	4.55 (0.78)	4.37 (0.87)	4.74(0.62)
Water management systems like swales, trenches, and streams that hold rainwater aid in reducing dependency on bore/rainwater.	208	Both	4.63 (0.72)	4.56 (0.75)	4.7 (0.68)
If permaculture practices are implemented, it results in yields that are free from chemicals	208	Both	4.43 (0.84)	4.35 (0.84)	4.51 (0.83)
Permaculture earth care practices, like rainwater harvesting, can help reduce rain dependency.	208	Both	4.64 (0.78)	4.58 (0.85)	4.7 (0.69)
Permaculture people care practice (engaging local people) can help in better community engagement	108	Agroforestry	4.76 (0.61)	-	-
In agroforestry, when only one type of crop is grown, it is likely to impact the soil quality over a period of time	108	Agroforestry	4.19 (0.93)	-	-
In the agroforestry model of farming, following multicropping practices aids in improving the variety of trees and crops which in result leads to a healthy and diverse flora and fauna.	108	Agroforestry	4.48 (0.77)	-	-

Questionnaire Item	#	Group	Mean (SD)	Agroforestry	Lifecentric
Fair share practices are beneficial for the environment and aid in creating a healthier ecosystem for birds/animals.	100	Lifecentric	4.68 (0.7)	-	-
Biodiverse plantation methods like planting native trees, fruit trees, grasses, aid in improving plant immunity.	100	Lifecentric	4.72 (0.7)	-	-
The design philosophy of the project is sustainable	100	Lifecentric	4.56 (0.77)	-	-

The agroforestry group exclusively responded to the items on permaculture people care practice, the impact of mono-cropping on soil quality, and the benefits of multi-cropping in agroforestry systems. They strongly agreed that engaging local people in permaculture practices can improve community engagement (mean = 4.76, SD = 0.61). At the same time, they recognized the negative impact of mono-cropping on soil quality over time (mean = 4.19, SD = 0.93) and affirmed the advantages of multi-cropping for biodiversity (mean = 4.48, SD = 0.77).

Lastly, the lifecentric group exclusively rated items on fair share practices, biodiverse plantation methods, and the sustainability of the project design philosophy. They expressed strong agreement that fair share practices create a healthier ecosystem (mean = 4.68, SD = 0.7) and that biodiverse plantation improves plant immunity (mean = 4.72, SD = 0.7). The sustainability of the design philosophy received a high mean score of 4.56 (SD = 0.77), reflecting a positive perception of the project's environmental sustainability. In summary, the data reflect a generally high perception of the efficacy and benefits of permaculture practices in both agroforestry and lifecentric approaches, with some variation between the two groups.

In the next sub-sections, the effect of farm type, age, gender, and income on the benefits of permaculture practices are analysed.

4.2.2.1. Effect of farm type on benefits of permaculture practices

As can be seen in Table 13, four questions were asked from both groups of participants (agroforestry and lifecentric farmers). In all four items, the mean score is higher for the lifecentric group. Regression analysis and t-tests are carried out to check if the difference is statistically significant.

Binary Logistic Regression (BLR) analysis (Table 14) is carried out to examine the relationship between four permaculture practices (the independent variables) and the farm type (the dependent variable). The BLR model offers a clear understanding of how certain sustainable farming practices may be more prevalent or significantly associated with either agroforestry or lifecentric farming systems.

The four permaculture practices included in the analysis are mulching, biomass planting, chop-and-drop techniques, and rainwater harvesting, among others. The analysis reports on if the adoption of these practices is associated with a higher probability of a farm being categorized as either agroforestry or lifecentric. For example, it will help assess if biomass planting is perceived to be more beneficial in agroforestry farms, which may be focused on long-term returns and soil health.

Table 13 Effect of farm type on benefits of permaculture practices

	B	Std. Error	Significance
(Constant)	-3.459	1.319	.009
Mulching, biomass planting, chop and drop help improve the quality of soil.	.841***	.292	.004
Water management systems like swales, trenches, and streams that hold rainwater aid in reducing dependency on bore/rainwater.	-.113	.304	.709

Permaculture earth care practices result in yields that are free from chemicals	.004	.216	.985
Permaculture earth care practices, like rainwater harvesting ponds, can help reduce rain dependency.	.007	.235	.976
Model Summary			
R ²	0.087		
Correctly Classified Cases (%)	62%		
Model Fitness			
Omnibus Test of Model Coefficients (X ² (4))	14.054		0.007

Notes: * $p \leq 0.10$, ** $p \leq 0.05$ *** $p \leq 0.01$, *Mulching, biomass planting, chop and drop help improve the quality of soil*** (significant at 1% level)*

The model fitness is confirmed using the Omnibus test of Model coefficients, $X^2(4) = 14.054, p=0.007$). The R square value is 0.087 and the model correctly classified 62% of the cases. See Table 14 above for the binary logistic regression analysis results.

As can be seen in Table 14, the constant term is significant ($p = 0.009$), suggesting a significant intercept for the regression line. Out of the four variables, only the variable, i.e., “mulching, biomass, planting, chop and drop” has a positive coefficient and is significant ($p=0.004$), indicating a positive relationship with the dependent variable. This shows that this variable has an effect of farm type, with the lifecentric group showing a higher positive effect of this permaculture practice as compared to the agroforestry group. The reason of other three items not being significant could be due to the high agreement between the two groups, as both groups rated the benefits of these practices highly, with mean scores ranging from 4.35 to 4.7. This

suggests a consensus on their importance, potentially leaving little room for significant differences between the two groups. Moreover, as discussed in the literature, the implementation benefits of permaculture practices can be influenced by various contextual factors, such as water availability, market demand, and existing farming practices (Lovell, 2017). The study area where these managed farms are located has abundant water resources. This could be the reason both agroforestry and lifecentric farmers might not perceive a strong need for additional water management practices. This aligns with findings suggesting that the benefits of water management are more pronounced in water-scarce regions (Permaculture Research Institute, 2023). Similar to water management, the benefits of rainwater harvesting might be less pronounced as the study area receives abundant rainfall and has a well-developed irrigation network. This resonates with the idea that farmers' motivations for adopting permaculture practices are diverse and context-dependent (Lovell, 2017).

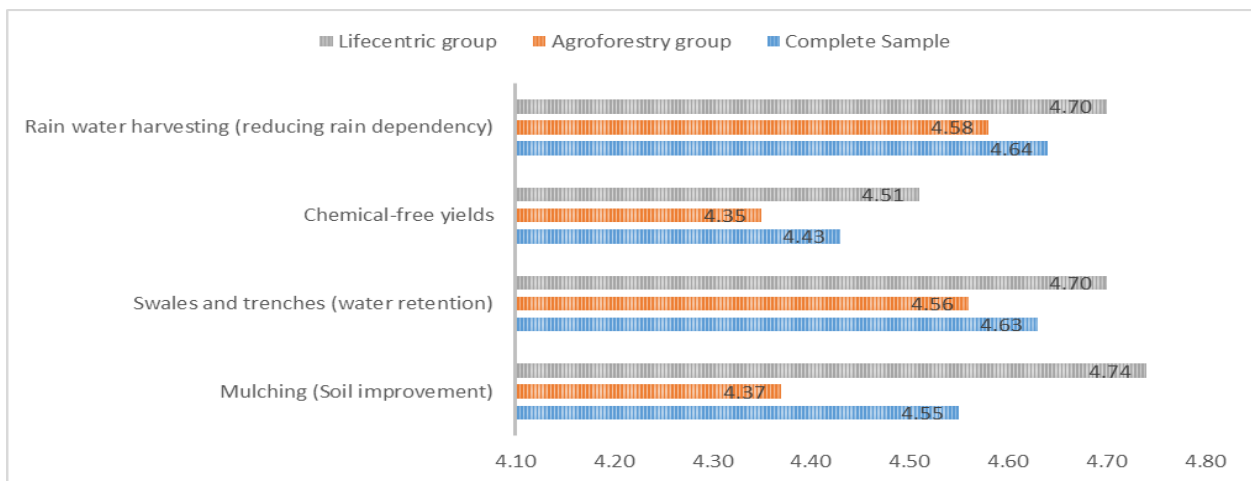


Figure 5 Permaculture practices implementation benefits (both groups)

The independent samples t-test indicated that there was a statistically significant difference in agreement with the first statement (about mulching and chop and drop technique) between the agroforestry group ($M = 4.36$, $SD = 0.86$) and the lifecentric group ($M = 4.74$, $SD = 0.61$); $t(206) = -3.61$, $p < 0.001$. There was also a statistically significant difference in agreement with the statement about water management

systems like swales, trenches, and streams between the agroforestry group ($M = 4.56$, $SD = 0.74$) and the lifecentric group ($M = 4.70$, $SD = 0.67$); $t(206) = -1.46$, $p = 0.025$. This shows that lifecentric farmers have a statistically significant higher benefit of this permaculture practice.

When the statement about chemical-free yields are compared for both groups, there was no statistically significant difference in agreement with the statement between the agroforestry group ($M = 4.343$, $SD = 0.8334$) and the lifecentric group ($M = 4.510$, $SD = 0.8226$); $t(206) = -1.456$, $p = 0.29$. Rainwater harvesting through permaculture practice had a partially significant difference between the two groups, where the lifecentric group scored this statement higher. Lifecentric group ($M = 4.700$, $SD = 0.6890$) and agroforestry group ($M = 4.574$, $SD = 0.8450$); $t(206) = -1.172$, $p = 0.061$.

4.2.2.2. Agroforestry permaculture practices - Effect of gender, age, and income on benefits

A t-test was carried out to check the impact of gender on the benefits of implementing permaculture practices in agroforestry. There are 23 females and 85 males in the agroforestry group sample.

As can be seen in Table 15 below, there are statistically significant differences between males and females in three items, which are swales and retention (water retention), rainwater harvesting (reducing rain dependency), and multi-cropping benefits with a p-value of 0.010, 0.006 and 0.046 respectively. Males scored significantly higher on the implementation benefits being swales and retention (water retention), permaculture being beneficial for rainwater harvesting, and multi-cropping benefit with a mean score of 4.61, 4.62, and 4.51 as compared to 4.35, 4.39, and 4.35 respectively for females.

Males scored higher than females on all items except the soil improvement (not statistically significant, $p=0.603$) item, which shows that the implementation benefits of permaculture practices are higher among males than females.

**Table 14 Permaculture implementation benefits & effect of gender
(agroforestry)**

Permaculture practices' benefits	Complete Sample	Males	Females	p-value (t-test)	Effect size (Cohen's d)
Mulching (Soil improvement)	4.36	4.35	4.39	0.603	-0.047
Swales and trenches (water retention)	4.56	4.61	4.35	0.010	0.309
Chemical-free yields	4.34	4.34	4.35	0.279	-0.008
Rainwater harvesting (reducing rain dependency)	4.57	4.62	4.39	0.006	0.232
Engaging local people (community engagement)	4.76	4.78	4.70	0.123	0.109
Mono-cropping	4.19	4.19	4.17	0.830	0.016
Multi-cropping benefits	4.47	4.51	4.35	0.046	0.182

One-way ANOVA was carried out to check the effect of age on the implementation benefits of the permaculture practices. There were no statistically significant differences between the five age groups defined in the questionnaire; this is largely due to limited participants in some age groups, with the majority being 31-40 years and 41-50 years (See Table 12). The participants are then grouped into two groups, "Age 40 and below" and "41 years old and above". T-test is carried out to check differences between these two groups, and there are no statistically significant differences between these two groups in terms of the implementation benefits of the permaculture practices. When we check the effect size, the highest effect size is for rainwater harvesting, which shows that males consider the impact of rainwater harvesting more positively than female farmers. One-way ANOVA was carried out to check the effect of income on the implementation benefits of the permaculture practices. There were no statistically significant differences found due to income.

4.2.2.3. Lifecentric permaculture practices - Effect of gender, age, and income on implementation benefits

A T-test was carried out to check the impact of gender on the implementation benefits of permaculture practices in the lifecentric group. There are 19 females in the sample of the lifecentric group and 81 males.

Table 15 Permaculture implementation benefits and effect of gender (lifecentric)

Permaculture practices' implementation benefits	Complete Sample	Males	Females	p-value (t-test)	Cohen's d
Mulching (Soil improvement)	4.74	4.78	4.58	0.064	0.294
Swales and trenches (water retention)	4.70	4.73	4.58	0.103	0.188
Chemical-free yields	4.51	4.57	4.26	0.033	0.318
Rainwater harvesting (reducing rain dependency)	4.70	4.70	4.68	0.578	0.025
Fairshare practice	4.68	4.69	4.63	0.330	0.075
Biodiversity	4.72	4.75	4.58	0.108	0.215
Sustainable design philosophy	4.56	4.54	4.63	0.736	-0.116

As can be seen in Table 16 above, there are statistically significant differences between males and females in only one item, i.e., chemical-free yields, where males scored significantly higher than females, with a mean value of 4.57 and 4.26, respectively. The effect size checked using Cohen's d also confirms that in this item, the Cohen's d value is the highest, showing that males have a significantly higher benefit of chemical-free yields using permaculture practices.

Males scored higher than females on all items except the design philosophy (not statistically significant, $p=0.736$) item, which shows that the implementation benefits of permaculture practices are higher among males than females.

One-way ANOVA was carried out to check the effect of age on the implementation benefits of the permaculture practices. There were no statistically significant

differences between the five age groups defined in the questionnaire; this is largely due to limited participants in some age groups, with the majority being 31-40 years and 41-50 years (See Table 12). The participants are then grouped into two groups, “Age 40 and below” and “41 years old and above”. T-test is carried out to check differences between these two groups, and there are no statistically significant differences between these two groups in terms of the implementation benefits of the permaculture practices. One-way ANOVA was carried out to check the effect of income on the implementation benefits of the permaculture practices. There were no statistically significant differences found due to income.

The quantitative results support the qualitative findings by specifically highlighting the positive impact of permaculture practices such as mulching, biomass planting, and rainwater harvesting on improving soil quality and reducing water dependency. For example, the questionnaire results showed that both agroforestry and lifecentric farmers rated the effectiveness of mulching and chop-and-drop techniques highly, with the lifecentric group giving these practices a significantly higher rating (Mean = 4.74) compared to the agroforestry group (Mean = 4.37). This aligns with the qualitative findings, where participants emphasized the role of these practices in enhancing biodiversity and promoting ecological balance in lifecentric farming. Additionally, the survey confirmed a broad consensus across both groups that permaculture practices lead to chemical-free yields (Mean = 4.43), which further supports the qualitative finding that both farming types are committed to sustainability.

These findings provide a clearer understanding of the specific ways in which permaculture practices are perceived and applied within different farming models, reinforcing the shared commitment to sustainability while also highlighting key differences in their implementation.

4.2.3. Digital technologies

The data collected from 208 participants (n=108 for agroforestry and n=100 for lifecentric) highlights the significant impact of digital technologies. The participants,

when asked to rate the importance of various digital tools, provided consistent high ratings across the board. Three of the questions were asked from both groups, while one question was asked exclusively from the agroforestry group.

Table 16 Digital technologies questionnaire - results

Questionnaire Item	Participants	Group	Mean (SD)	Agroforestry	Lifecentric
IOT-based moisture management helps increase water use efficiency.	208	Agroforestry & Lifecentric	4.48 (0.77)	4.40 (0.81)	4.56 (0.73)
Drip irrigation can deliver better yields at lower cost.	208	Agroforestry & Lifecentric	4.52 (0.69)	4.53 (0.69)	4.52 (0.71)
MyFarm mobile app can provide vital farm information quickly for better decision-making.	208	Agroforestry & Lifecentric	3.92 (1.05)	3.65 (1.14)	4.22 (0.86)
MyFarm mobile app is the best mode of communication for farm updates.	108	Agroforestry	3.81 (1.16)	-	-

One of the key findings pertained to the use of IoT-based moisture management systems in enhancing water use efficiency. On a scale of 1 to 5, the overall mean score was 4.48, with a standard deviation of 0.77, indicating a strong positive perception of this technology. Notably, the lifecentric group rated it slightly higher (mean 4.56, SD = 0.73) than the agroforestry group (mean 4.40, SD = 0.81). This suggests a slightly stronger confidence in the technology among the lifecentric group participants.

Similarly, the effectiveness of drip irrigation systems in delivering better yields at lower costs was highly rated, with an overall mean of 4.52 and a standard deviation of 0.69. This consensus was remarkable as both groups recorded nearly identical means and standard deviations, reflecting a unanimous belief in the benefits of this technology.

Regarding the use of the MyFarm mobile app for quick access to vital farm information, the overall mean score was 3.92, with a standard deviation of 1.05. However, a divergence was observed between the groups. The lifecentric group rated it significantly higher (mean 4.22, SD = 0.86) compared to the agroforestry group (mean 3.65, SD = 1.14). This variation might be attributed to different experiences or expectations regarding the utility of the app.

Lastly, exclusively within the agroforestry group, MyFarm mobile app was evaluated as a mode of communication for farm updates. It received a mean score of 3.81 with a standard deviation of 1.16, suggesting a moderately positive reception but indicating potential areas for improvement or differing communication preferences within this group.

4.2.3.1. Effect of farm type and benefits of digital technologies

As can be seen in Table 17, there are differences in the implementation benefits of digital technologies between the two groups.

This section presents the results of a regression analysis and t-test to find out if these differences are statistically significant. The benefits of digital tools (e.g., IoT-based moisture management, MyFarm mobile app) serve as IVs, analyzed against farm type and gender (DVs).

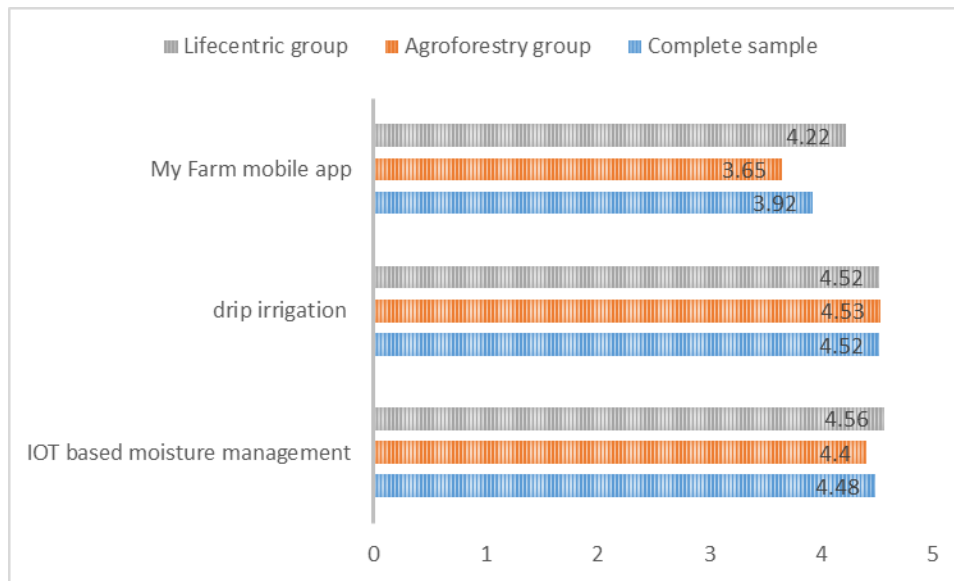


Figure 6 Digital technologies implementation benefits

When rating the benefits of IOT-based moisture management, the lifecentric group rated it higher. The difference in the implementation benefits is partially significant, $t(206) = -1.512$, $p = 0.063$. The benefit of drip irrigation is unanimous, and no statistical difference was found using the t-test ($p=0.991$).

Lastly, the benefit of the MyFarm mobile app is as much higher among the lifecentric group, verified by the t-test where the difference in means is statistically significant, $t(206) = -4.064$, $p < 0.01$.

Regression analysis was conducted to examine whether the differences in the perceived benefits of three digital technologies (e.g., IoT-based moisture management, drip irrigation, and the MyFarm mobile app) are statistically significant between the two farm types. The purpose of the regression analysis is to assess how these digital technologies (the independent variables) influence the farm type (the dependent variable).

The expected outcome of this analysis is to determine how the perceived benefits of digital technologies vary based on the farm type. The three digital technologies are

independent variables, and the farm type (agroforestry vs. life-centric) serves as the dependent variable.

This approach helps understand whether there are distinct technological needs or preferences based on farm type. The results indicate if the farm type has a statistically significant impact on the perceived benefits of these technologies, further explaining how technology's perceived effectiveness varies across different agricultural practices.

Table 17 Effect of Farm Type on the Adoption of Digital Technologies

Variable	Coefficient (B)	Standard Error (SE)	p-Value
Constant	-1.48	1.068	0.166
Digital technologies, like IoT-based moisture management, help increase water use efficiency.	0.283	0.285	0.321
Digital technologies, like drip irrigation, can deliver better yields at lower cost.	-0.500*	0.296	0.092
Digital technologies, like the MyFarm mobile app, can provide vital farm information quickly for better decision-making.	0.604**	0.167	<0.001
Model Summary			
R ²	0.118		
Correctly Classified Cases (%)	62.5%		
Model Fitness			
Omnibus Test of Model Coefficients (χ ² (3))	19.255		<0.001

Notes: * $p \leq 0.10$, ** $p \leq 0.05$ *** $p \leq 0.01$, Drip irrigation: *(partial significance at 10% level), MyFarm mobile app: *** (significant at 1% level) IoT-based moisture management: Not statistically significant ($p > 0.05$)

The R square value is 0.118 and the model correctly classified 62.5% of the cases. The model fitness is confirmed using the Omnibus test of Model coefficients, $X^2(3) = 19.255, p < 0.001$). See Table 18 above for the regression analysis results.

The coefficient for IoT-based moisture management is positive (0.283), but the p-value (0.321) is greater than the significance threshold of 0.05, indicating that the effect of farm type on the adoption of this technology is not statistically significant. This suggests that both agroforestry and lifecentric farmers perceive similar benefits (Agroforestry mean score 4.40 and lifecentric mean score 4.56) from IoT-based moisture management in terms of water use efficiency.

The coefficient for drip irrigation is negative (-0.5), with a p-value of 0.092, indicating that while the relationship between farm type and drip irrigation adoption is not statistically significant at the 0.05 level, it is *partially significant*. This could suggest that lifecentric farms may have slightly lower perceived benefits from drip irrigation compared to agroforestry farms (Mean score 4.52 compared to 4.53 for agroforestry), but the difference is not substantial enough to be conclusive.

Out of the 3 variables, only the variable, i.e., “digital technologies like MyFarm mobile app, can provide vital farm information quickly for better decision making,” has a positive coefficient and is significant ($p < 0.001$), indicating a positive relationship with the dependent variable. This shows that only this variable has an effect on farm type, with the lifecentric group having a higher benefit of the MyFarm mobile app (Mean score of 4.22 compared to 3.65 for agroforestry farmers). Lifecentric farmers are likely to find more value in the MyFarm app's ability to provide quick and vital farm information, which might reflect a stronger emphasis on data-driven decision-making or more advanced technological needs within the lifecentric farming approach.

4.2.3.2. Effect of gender, age, and income on implementation benefits of digital technologies.

This section presents the effect of gender, age, and income on the implementation benefits of using digital technologies in farming. Out of 208 participants, 166 are

males and 42 are females, while for the last item in the agroforestry group, there are 85 males and 23 females.

As shown in the Table 19, females scored higher on the benefits of IOT-based moisture management, drip irrigation, and the MyFarm mobile app. When checked using a t-test, if these differences are statistically significant, only the benefit of the MyFarm mobile app is significantly higher in females, $t(206) = -0.530$, $p = 0.029$. In the last item, which was only asked from the agroforestry group, the females scored lower as compared to males when presented with the statement that MyFarm mobile app is the best mode of communication. However, this difference is only partially significant ($p=0.071$).

Table 18 Gender-Based Analysis of Digital Technology Adoption in Farming

Digital technologies	Mean - complete sample	Males	Females	p-value (t-test)	Effect size (Cohen's d)
Digital technologies, like IOT-based moisture management, help increase water use efficiency.	4.48	4.47	4.50	0.705	-0.039
Digital technologies like drip irrigation can deliver better yields at lower cost	4.52	4.50	4.62	0.351	-0.171
Digital technologies, like the MyFarm mobile app, can provide vital farm information quickly for better decision-making	3.92	3.91	4.00	0.029	-0.091
MyFarm mobile app is the best mode of communication for farm updates	3.81	3.88	3.57	0.071	0.265

When we look at the effect size, for the IOT-based moisture management and My Farm mobile app can provide useful information, the effect sizes are very small (close to zero), indicating negligible differences between male and female

participants in terms of efficiency or usefulness. For drip irrigation, the negative effect size is small, suggesting a slight preference or better outcomes by female participants compared to male participants, although the difference is still relatively small.

One-way ANOVA is used to check the effect of age on the implementation benefits of digital technologies. The analysis shows that there are differences due to age in the MyFarm mobile app item (MyFarm mobile app can provide vital farm information quickly for better decision-making). The one-way ANOVA for this item shows that age has an effect on the implementation benefits of the MyFarm mobile app, $F(4, 203) = 2.502$, $p = 0.04$. A post-hoc test Bonferroni is then carried out to check which age groups have statistically significant differences. The test result shows that there are significant differences between the two age groups ($p=0.03$). The Bonferroni analysis shows that the age group 41-50 years old (Mean = 4.16) has a statistically higher benefit of the MyFarm mobile app as compared to the age group 31-40 years old (Mean = 3.68).

Similarly, one-way ANOVA is carried out to check the effect of income on the implementation benefits of digital technologies; however, no effect of income could be found due to the income of participants. This shows that income does not impact the implementation benefits related to digital technologies.

The quantitative data underscores the widespread adoption and perceived benefits of digital technologies like IoT-based moisture management, drip irrigation, and the MyFarm mobile app, which were also emphasized by the experts in the interviews as transformative tools in modern farming. The lifecentric group's higher ratings for the MyFarm mobile app and IoT technologies align with qualitative findings that highlight their focus on technological integration to achieve sustainability and convenience. In contrast, the agroforestry group, while valuing digital tools, expressed an operational perspective. This differentiation aligns with qualitative insights that agroforestry farmers prioritize long-term profitability, whereas lifecentric farmers are motivated by lifestyle and ecological benefits. Together, these results

reveal how digital technology adoption reflects differing priorities while serving as an enabler towards sustainable agriculture across both farming types.

4.2.4. Farmer's purchasing criteria

The participants of the study were asked to rank the reasons on a 5-point scale for understand their purchasing criteria. A higher score means a higher importance of the reason for purchasing the managed farm services. The participants were given five purchasing criteria and were asked to rank them based on their preferences. These items included the initial price of the land, the maintenance cost of the land, the reputation of the developer, concept representation, amenities, and facilities.

Table 19 Comparison of Farmer Purchasing Criteria between Agroforestry and Lifecentric Farm

Reasons	Mean (Std deviation)	Agroforestry	Lifecentric	P-value t-test	Cohen's d
The price of farmland	3.13 (1.57)	3.08 (1.56)	3.16 (1.57)	0.617	-0.05
Maintenance cost of the farm plot	3.3 (1.51)	3.38 (1.36)	3.2 (1.65)	0.001	0.12
Reputation of the farmland developer	4.05 (1.41)	3.32 (1.58)	4.83 (0.54)	<0.001	-1.281
Concept representation	4.25 (1.17)	3.69 (1.36)	4.86 (0.38)	<0.001	-1.18
Amenities and facilities	4.08 (1.21)	3.58 (1.35)	4.61 (0.71)	<0.001	-0.954

The participants ranked concept representation (Mean score 4.25), amenities & facilities (Mean score 4.08), and the reputation of the farmland developer (Mean score 4.05) significantly higher than the price of the farmland (Mean score 3.13), as shown in Table 20 above. This indicates that the primary criteria for farmers when purchasing farmland are not based on the initial cost.

Additionally, Table 20 presents p-values from the t-test conducted to determine if there are differences between the lifecentric and agroforestry groups. For three

criteria, excluding the price of the farmland and maintenance cost, the lifecentric group scored significantly higher than the agroforestry group. This suggests that these aspects are more important in the lifecentric group than the agroforestry group.

The observed differences between lifecentric and agroforestry farmers suggest distinct priorities, particularly for the lifecentric group. This can be attributed to multiple factors discussed in the literature. Lifecentric farming often embodies a broader philosophy that extends beyond agricultural production to encompass ecological sustainability, social well-being, and personal fulfilment. This holistic perspective may lead lifecentric farmers to place a higher value on concept representation (project aligns with their values and vision for a sustainable lifestyle). They might seek projects that prioritize biodiversity, community building, and ethical practices), amenities, and facilities, reputation of the developer (A developer's track record of commitment to sustainable practices and community engagement could be more crucial for lifecentric farmers who are seeking a trusted partner in their pursuit of a sustainable lifestyle). These findings further reinforce the need to recognize the diverse motivations and priorities within the farming community. Lifecentric farmers represent a growing segment with distinct values and preferences. Tailoring marketing strategies, project designs, and communication approaches to resonate with their holistic and community-centric perspectives can be key to fostering successful and sustainable agricultural initiatives.

A binary logistic regression analysis is conducted to assess how various purchasing criteria influence the likelihood of a farm being classified as either agroforestry or lifecentric. In this analysis, the independent variables are the five purchasing criteria, which includes price of farmland, maintenance cost, reputation of the developer, concept representation, and amenities and facilities. The dependent variable is the farm type, which distinguishes between agroforestry and lifecentric farms.

The expected outcome of this model is to identify which of the purchasing criteria are most strongly associated with the farm type. This analysis reports whether factors like concept representation (alignment with values) or the reputation of the

farmland developer play a more significant role in either of these farms (agroforestry vs lifecentric), which might prioritize other criteria like price or maintenance costs.

Table 20 Examining the Effect of Purchasing Criteria on Farm Type

Variable	Coefficient (B)	Standard Error (SE)	p-Value
(Constant)	-8.863	1.692	.000
Price of the farmland	-.343	.247	.165
Maintenance cost of the farm plot	-.280	.248	.259
Reputation of the farmland developer	1.186***	.293	.000
Concept representation	.785**	.357	.028
Amenities and facilities	.535**	.264	.043
Model Summary			
R ²	0.552		
Correctly Classified Cases	79.8%		
Model Fitness			
Omnibus Test of Model Coefficients ($\chi^2(5)$)	111.29		< 0.001

Notes: * $p \leq 0.10$, ** $p \leq 0.05$, *** $p \leq 0.01$

Concept Representation, Amenities and facilities ** (significant at 5% level), Reputation of the farmland developer*** (significant at 1% level), Price of the farmland and maintenance cost of the farmland (not significant at 5% level)

The R square value is 0.552, which shows the model predicts 55.2% of the variance in the model and correctly classified 79.8% of the cases. The model fitness is confirmed using Omnibus test of Model coefficients, $\chi^2(5) = 111.29$, $p < 0.001$). See Table 21 above for the binary regression analysis results.

The coefficient for the price of the farmland is negative (-0.343), but the p-value (0.165) is above the 0.05 significance threshold. The lack of statistical significance here supports the earlier findings from the t-test, where both agroforestry and

lifecentric farmers rated the price similarly in importance. This suggests that while the price is a consideration, it is not the primary driving factor for purchasing farmland, with other criteria, such as the developer's reputation and project alignment with personal values, playing a more decisive role.

Similarly for the maintenance cost, the coefficient is negative (-0.280), with a p-value of 0.259, indicating that this variable does not significantly affect farm type. The results show that agroforestry and lifecentric farmers place similar importance on the maintenance costs of the land. This finding aligns with the previous t-test results, where no significant difference in the importance of maintenance cost was found between the two farm types.

In three factors there are statistically significant differences with lifecentric farmers showing a higher importance of these factors. The reputation of the farmland developer shows a positive coefficient of 1.186, with a highly significant p-value of less than 0.001. This suggests that lifecentric farmers place significantly more importance on the reputation of the developer than agroforestry farmers. This aligns with the notion that lifecentric farmers are likely looking for developers who align with their values of sustainability, community building, and ethical practices. The reputation of the developer is a key indicator of trust, especially for lifecentric farmers who seek developers who prioritize these aspects in their projects.

The concept representation variable shows a positive coefficient of 0.785, with a significant p-value of 0.028. This result indicates that lifecentric farmers place significantly more importance on how well the concept of the farm aligns with their personal values, philosophy, and vision for sustainable living. This reflects the holistic approach to farming that is characteristic of the lifecentric model.

Lastly, The coefficient for amenities and facilities is positive (0.535), and the p-value (0.043) is statistically significant, indicating that lifecentric farmers rate amenities and facilities significantly higher than agroforestry farmers. Lifecentric farmers interested in the quality of life and the facilities available to them as noted by the experts in the interviews as well.

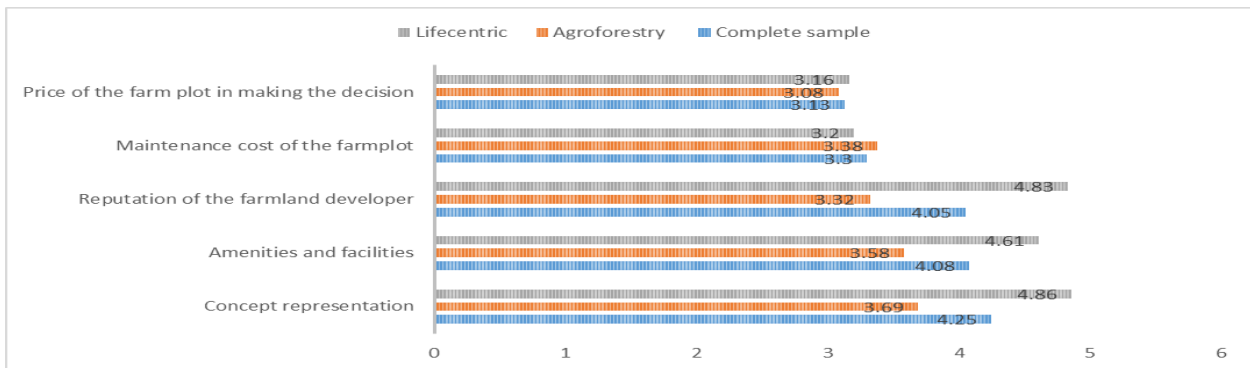


Figure 7 Farmers' purchasing criteria

4.2.4.1 Effect of gender, age, and income on farmer's purchasing criteria

This section looks at the effect of gender, age, and income on farmer's purchasing criteria. The differences between males and females are checked using t-test, in one of the five items, i.e., the reputation of the farmland developer is considered more important for females as compared to males, with a mean score of 4.119 and 4.030, respectively. This difference is statistically significant ($p=0.034$)

There are also differences due to age in terms of the farmer's purchasing criteria, with the age group 41-50 years old (Mean score 4.421) rating the reputation of the farmland developer much higher than the age group 31-40 years old (Mean score 3.779). This difference is significant, checked using one-way ANOVA ($p = 0.029$)

Another interesting relationship observed in the study is the impact of a farmer's income on their purchasing criteria. Notably, there are statistically significant differences between the income groups of 20-50 lakhs per annum and 51-99 lakhs per annum regarding the importance placed on the reputation of the farmland developer. This relationship was analysed using a one-way ANOVA. The analysis revealed that the income group earning 20-50 lakhs per annum rated the reputation of the farmland developer significantly higher (Mean score = 4.298) compared to the income group earning 51-99 lakhs per annum (Mean score = 3.50). This difference in mean scores is statistically significant ($p = 0.041$).

The quantitative findings confirm and extend the qualitative insights regarding the importance of reputation, concept representation, and amenities in influencing lifecentric farmers' purchasing decisions. Qualitative data highlighted the emotional and lifestyle-driven motivations of lifecentric farmers, such as a desire for nature-connected experiences and long-term legacy creation, which are reflected in the quantitative results on these factors. In contrast, agroforestry farmers, who prioritize returns on investment, ranked maintenance costs slightly higher than lifecentric farmers, which also aligns with qualitative descriptions of their more commercially driven approach. The results also validate the qualitative findings related to the preferences of both agroforestry and lifecentric farmers.

By integrating these perspectives, it becomes clear that purchasing decisions are shaped by a blend of practical and philosophical considerations, differing significantly across farm types.

4.2.5. Sustainability practices

The questionnaire aimed to measure the implementation of sustainability practices in the farms of 208 participants, utilizing a scale from 1 (not implemented at all) to 5 (fully implemented). The descriptive statistics provide valuable insights into the participants' perceptions of the implementation of these practices in their respective farms. Table 22 below presents the mean values of these items.

The practice of planting trees at boundaries and near water bodies was moderately implemented across both groups, with a slightly higher implementation in the lifecentric group. Buffer zones also saw moderate implementation, again with the lifecentric group marginally ahead.

A higher implementation level was observed in planting a combination of crops, with the agroforestry group slightly leading. The employment of local farmers was the most implemented practice across both groups, with nearly identical scores. Drip irrigation solutions were more popular in the agroforestry group than in the lifecentric group. Specific to the agroforestry group, mulching operations showed a high level of implementation.

Table 21 Comparison of Sustainability Practice Implementation between Agroforestry and Lifecentric Farms

Implementation of sustainability practices	Group	Complete Sample	Agroforestry	Lifecentric
Trees at boundaries, near homesteads and along streams and rivers	Both	3.65 (1.21)	3.55 (1.15)	3.76 (1.27)
Buffer zone	Both	3.46 (1.27)	3.39 (1.17)	3.52 (1.38)
Planting combination of crops	Both	4.03 (1.09)	4.09 (0.99)	3.95 (1.18)
Local farmers employed	Both	4.17 (1.02)	4.18 (0.86)	4.15 (1.16)
Drip irrigation solution	Both	4.13 (1.07)	4.36 (0.88)	3.87 (1.19)
Mulching operations on your farm plot	Agroforestry	4.14 (1.05)	-	-
Swales & trenches - Lifecentric	Lifecentric	4.27 (0.9)	-	-
MyFarm mobile app - Lifecentric	Lifecentric	4.03 (1.15)	-	-

Exclusive to the lifecentric group, swales and trenches and the usage of the MyFarm mobile app were highly adopted. Overall, both groups demonstrated strong engagement in sustainability practices, with certain practices like local farmer employment and diverse crop planting receiving especially high implementation rates.

4.1.4.1. Effect of farm type on implementation of sustainability practices

As shown in Table 22 above, five sustainability practices were presented to both groups of farming to rate their implementation on a scale of 1-5.

This section presents the analysis from a regression analysis and t-test, which shows if there is an effect of farm type on the implementation of sustainability practices.

The binary regression aims to examine how different sustainability practices, such as trees at boundaries, buffer zones, planting combinations of crops, employing local farmers, and drip irrigation solutions, influence the likelihood of farm type classification (agroforestry vs. lifecentric). The independent variables in the model represent various sustainability practices, while the dependent variable is farm type, which categorizes the farms into agroforestry and lifecentric groups.

The expected output of this model is to identify which sustainability practices are significantly associated with farm type. The analysis reveals if certain practices, such as drip irrigation or the employment of local farmers, are more commonly linked to agroforestry farms, while others, such as biodiversity-focused practices (e.g., trees at boundaries, multi-cropping), are associated with lifecentric farms.

The Omnibus test of model coefficients ($\chi^2(5) = 25.306$, $p < 0.001$) confirms that the model as a whole significantly fits the data, meaning that at least one of the independent variables (sustainability practices) significantly predicts the farm type. Finally, this model allows us to determine the relative importance of each sustainability practice in defining the nature of a farm.

Table 22 Effect of Agroforestry and Lifecentric Farm Types on Sustainability Practice Implementation

Variable	Coefficient (B)	Standard Error (SE)	p-Value
Constant	0.737	0.716	0.303
Trees at boundaries, near homesteads, along streams and rivers	0.174	0.183	0.341
Buffer zone	0.229	0.195	0.240
Planting a combination of crops	-0.055	0.208	0.790
Local farmers employed	0.459**	0.236	0.050
Drip irrigation solution	-0.956***	0.237	<0.001

Model Summary			
R ²	0.118		
Correctly Classified Cases	62.5%		
Model Fitness			
Omnibus Test of Model Coefficients ($\chi^2(5)$)	25.306		< 0.001

Notes: * $p \leq 0.10$, ** $p \leq 0.05$, *** $p \leq 0.01$

Local farmers employed ** (significant at 5% level), Drip Irrigation solution*** (significant at 1% level)

The variables "Drip irrigation solution" and "Local farmers employed" appear to be statistically significant, as their p-values are less than 0.05. In the context of sustainability practices in farms, it seems that the use of "Drip irrigation solutions" and the employment of "Local farmers" have a significant impact on whether the farm is categorized as "Agro" or "Lifecentric." The other variables, such as "Trees at boundaries," "Buffer zone," and "Planting combination of crops," do not appear to be statistically significant in this model (See Table 23 above). This shows that the implementation of these two practices (drip irrigation and employment of local farmers) is significantly higher in the agroforestry group than in the lifecentric group. The analysis done above shows there are high implementation rates of these sustainability practices. Moreover, in two items, statistically significant differences were found in "Local farmers employed" and "Drip irrigation solution", where agroforestry group reported implementation significantly higher than lifecentric group.

Additionally, no significant effects of age and gender were found on the implementation of sustainable practices, as determined by one-way ANOVA ($p > 0.05$). However, for two specific items measured among lifecentric farmers, "Swales & trenches" and the "MyFarm app," income was found to have a significant effect.

The income group earning 20-50 lakhs per annum reported a significantly higher implementation of "Swales & trenches" (Mean score = 4.404) compared to the income group earning more than one crore (Mean score = 3.20), with a p-value of

0.032. Similarly, the same income group (20-50 lakhs) scored higher on the implementation of the MyFarm app compared to the income group earning 51-99 lakhs per annum, with this difference also being statistically significant ($p = 0.014$).

Quantitative findings affirm the high implementation rates of sustainability practices like diverse crop planting and employing local farmers, which were also described in the qualitative data by the experts as essential components of both agroforestry and lifecentric models. However, the quantitative analysis provides deeper insights into group-specific variations, such as the higher adoption of drip irrigation by agroforestry farmers and the high preference for swales and trenches among lifecentric farmers. These findings complement qualitative narratives that emphasized the distinct goals of each group: agroforestry focusing on efficient resource use and cost-effectiveness, and lifecentric emphasizing ecological balance and community engagement. Together, these results highlight how shared sustainability principles are tailored to meet the unique objectives of each farming approach.

Chapter 5: Discussion

This chapter presents a discussion on the findings presented in the previous chapter. The chapter is divided into five sections: first, a discussion on agroforestry and lifecentric farms as per the participants, sustainability practices in farming, permaculture practices in farming, digital technologies in farming, and purchasing criteria for a farmer. Both the quantitative surveys from farmers and the qualitative interviews with five experts in farming provide insightful perspectives on contemporary agricultural practices, particularly focusing on agroforestry farms, lifecentric farms, and permaculture. These insights are crucial in understanding the evolving landscape of sustainable agriculture.

The current study uses interviews and surveys to measure the economic performance (e.g., cost of labor, farming cost) and sustainability outcomes (e.g., reduced water usage, reduced chemicals) at farm levels. The section below presents the summary of the findings based on research objectives outlined earlier using the quantitative analysis.

5.1. Summary of findings based on research objectives

The findings of this study provide a thorough understanding of the interplay between farmer demographics, permaculture practices, digital technologies, and the Indian agricultural context. The results reveal that while there are statistically significant differences in some areas, broader trends suggest a complex and multifaceted picture.

5.1.1. Demographic Differences and Benefits

There are limited statistically significant differences based on farmers' age, gender, and income in relation to the implementation benefits of permaculture and digital technologies. Notably, gender emerged as a significant factor in specific contexts:

- Three items out of seven in agroforestry permaculture practices (gender). These three items were Swales and trenches (water retention), Rainwater harvesting (reducing rain dependency) and Multi-cropping benefits by implementing permaculture practices.
- One item out of seven in lifecentric permaculture practices (gender) i.e. Chemical-free yields.
- One item out of four in digital technologies (gender) i.e. MyFarm mobile app.
- One item out of four in digital technologies (age) i.e. MyFarm mobile app.

These findings emphasize the need for a gender-specific approach when designing and promoting sustainable agricultural practices and technology interventions. They align with prior research highlighting gender disparities in access to information, adoption of technology, and decision-making in agriculture (Doss, 2001; Peterman et al., 2014).

5.1.2. Benefits of Permaculture Practices

The benefits of permaculture practices were reported highly across both agroforestry and lifecentric farm types. A statistically significant difference was found in the implementation benefit of practices such as “Mulching, biomass planting, and chop and drop help improve the quality of soil,” with lifecentric farmers reporting higher benefits.

The high mean scores highlight the importance of permaculture in enhancing soil quality and fostering sustainability. This aligns with the literature's emphasis on permaculture's role in regenerating ecosystems and improving biodiversity (Holmgren, 2011; Ferguson & Lovell, 2014).

These findings contribute to the ongoing discourse by providing empirical evidence that supports theoretical claims about the efficacy of permaculture. For example, the practices mentioned align with Hill and MacRae's (1996) "Redesign" model of

sustainable agriculture, which emphasizes systemic approaches to resource independence and ecological resilience. Furthermore, this study complements the frameworks such as the SAFA (Sustainability Assessment of Food and Agricultural Systems) and FESLM (Framework for Evaluation of Sustainable Land Management), which stress adaptive management and site-specific strategies for sustainability (Dumanski & Smyth, 1994; Velten et al., 2015).

However, the findings also raise questions about barriers to wider adoption, as discussed in the literature. Challenges such as the lack of training, financial constraints, and inadequate policy support highlighted in studies by Priya and Singh (2024) and Hota and Verma (2022) could explain why some benefits of permaculture practices are not uniformly perceived. This underscores the need for targeted interventions, such as capacity-building programs and financial incentives, to bridge the gap between theoretical potential and practical implementation.

5.1.3. Benefits of Digital Technologies

Digital technologies demonstrated significant benefits across both farm types, with lifecentric farmers reporting statistically higher benefits for tools such as the MyFarm app. These findings reinforce the growing body of evidence supporting the role of precision agriculture tools in improving implementation outcomes (Altieri, 2002; Whitfield et al., 2021).

Studies by Oliver et al. (2010) and Deichmann et al. (2016) emphasize that technologies like IoT, precision agriculture, and mobile apps enhance resource efficiency, decision-making, and sustainability outcomes, all of which align with the observed benefits in this study.

The higher perceived benefits among lifecentric farmers may reflect their alignment with the principles of regeneration and holistic management, as emphasized by Wahl (2016). These findings extend the literature by highlighting how digital tools can complement ecological farming practices to optimize operations. This integration has been supported in the literature as well for blending traditional ecological knowledge with modern technological advancements (Altieri, 2002; George et al., 2021).

However, the study also reinforces the challenges highlighted in the literature, such as the "precision trap" and "precision divide" (Visser et al., 2021). The partial significance in benefits for IoT-based moisture management systems and the unanimous agreement on drip irrigation reflect disparities in the adoption and perception of these tools, potentially influenced by access, affordability, and contextual factors. The need for tailored approaches to digital technology adoption, as discussed by Watson et al. (2010) and Gabriel & Gandorfer (2023), becomes important in this context.

5.1.4. Prioritization of Farmland Attributes

Contrary to the initial assumption, farmers prioritized the reputation of the developer, the farm concept, and amenities over the initial buying price of farmland. This result underscores the importance of trust and value-added offerings in farm purchasing decisions.

5.1.5. Implementation rates of sustainability practices

The study results also show that sustainability practices are implemented at generally low rates in agricultural farms in India. Farmers across both groups reported high implementation rates, with average scores exceeding 3.0 on a 5-point Likert scale for all surveyed practices. This finding highlights a disconnect between awareness of benefits and the actual implementation rates, suggesting that infrastructural, socioeconomic, and policy-level barriers may play a role (Meijer et al., 2015).

5.1.6. Contributions to Literature

This study makes several significant contributions to existing academic literature:

- **Gender-Specific Approach:** The findings reinforce the importance of incorporating gender-specific considerations into the design and promotion of agricultural systems and technologies to ensure inclusivity and equity.

- **Empirical Validation in Indian Agriculture:** The study validates the effectiveness of permaculture practices and digital technologies within the Indian agricultural context, contributing to the global empirical evidence base.
- **Implementation Challenges:** The contrasting results regarding implementation rates call for further research into the barriers hindering broader adoption of sustainability practices.

The findings underscore the importance of promoting agroecological practices and technology integration. However, the observed gaps between awareness and implementation point to the need for addressing infrastructural challenges, improving accessibility, and creating policy frameworks that support farmers in adopting sustainable practices at scale. Future research should focus on identifying and mitigating these barriers to facilitate widespread adoption and maximize the benefits of sustainable agriculture.

5.2. Permaculture practices

In recent years, there has been growing interest in integrating permaculture techniques into agroforestry and adopting methodologies prioritizing people, indicating a shift towards sustainable agriculture.

The farmers' high average rankings for permaculture earth care activities, including mulching, biomass planting, and chop-and-drop procedures, have highlighted their efficacy in enhancing soil quality. The average score was 4.55, with a standard deviation of 0.78. The agroforestry group had a slightly lower score of 4.37 with a standard deviation of 0.87, while the lifecentric group had a higher score of 4.74 with a standard deviation of 0.62. This disparity could be attributed to differences in execution or regional environmental circumstances. The significance of these practices in improving soil health is consistent with the findings of RJ and Singh (2023), who emphasized the difficulties and advantages of permaculture in paddy-based agroforestry systems in Meghalaya. They underscored the role of permaculture in enhancing soil health and preserving the ecosystem. The interview

participants also commonly saw the beneficial influence of permaculture on soil health and water bodies. The focus on mulching, preserving soil moisture, and promoting microbial activity is consistent with permaculture's methodology for establishing self-sufficient agricultural ecosystems (Rodale Institute, 2020).

The alignment with permaculture practices, emphasizing earth care, people care, and fair share, is a significant insight from the interviews. This approach aligns with Holmgren's (1978) foundational principles of permaculture. The challenges in implementation, such as weather unpredictability, echo the concerns raised by Holmgren (2002), who emphasizes the need for adaptive strategies in permaculture.

Similarly, water management systems like swales, trenches, and streams were highly rated (Mean = 4.63, SD = 0.72), indicating a consensus on their role in reducing dependency on external water sources. This is consistent with the broader strategies for environmental conservation and sustainability discussed by M. Singh (2023), who highlighted the significance of water conservation techniques in sustainable agriculture.

The belief in permaculture practices leading to chemical-free yields received a mean score of 4.43 (SD = 0.84), demonstrating confidence in permaculture methods for producing organic yields. Additionally, rainwater harvesting was seen as beneficial in reducing rain dependency, with a mean score of 4.64 (SD = 0.78). These are similar to Alam, McClain, Sikka, Daniel, and Pande (2022) findings, where farmers reported that rainwater harvesting benefited their crops and helped reduce dependence on rain.

The unanimous agreement among the interviewees from Hosachiguru highlights the integral role of permaculture in their agricultural practices. One participant's insight reveals an organic implementation of permaculture, even before the term became mainstream, with practices like no-till farming and water conservation being inherent to their approach. This early adoption underscores a commitment to the permaculture ethos of earth care, people care, and fair share, reflecting a holistic and ethical approach to agriculture (McManus, 2010).

The participants' commitment to permaculture is rooted in its alignment with sustainability and natural farming practices. The response by the participants focuses on enhancing soil microbial activity and carbon content, which is a direct response to the detrimental effects of conventional agriculture, highlighting a shift towards more sustainable practices (Rodale Institute, 2020). Similarly, another participant's emphasis on regenerative practices aligns with the permaculture principle of creating self-sustaining systems that require minimal external inputs (Holmgren, 2002). The participants' adherence to the core permaculture ethics of "care for the earth, care for people, and fair share" is evident in their practices. The emphasis on soil health, water conservation, and avoiding harmful chemicals aligns with the permaculture principle of creating sustainable and regenerative systems. The commitment to community well-being and safety and allowing nature to share the farm's bounty reflects a holistic approach to agriculture that considers ecological balance and biodiversity. As highlighted by the experts, the ethics of permaculture focus on care for the earth and people and fair share. These principles are foundational to permaculture and are well-articulated by Holmgren (2002). The observed benefits on soil health and water conservation align with the findings of Ferguson and Lovell (2014), who discuss the ecological benefits of permaculture practices.

A consistent theme across the interviews is the alignment with permaculture practices, though the extent of implementation varies, especially in newer projects. This variation suggests an evolving understanding and application of permaculture, adapting to each project's specific needs and contexts. The emphasis on syntropic and biodynamic farming methods further aligns with permaculture's principles, aiming to create sustainable and regenerative agricultural systems (Brock, 2017).

The unpredictability of weather patterns and environmental changes poses significant challenges to traditional permaculture practices, as noted by the interview participants. Participants' observations about adapting to these changes with modern technology like soil moisture sensors and drones indicate a need for

innovation in permaculture practices. The dichotomy between traditional permaculture practices and modern technological adaptations highlights the evolving nature of permaculture in response to contemporary environmental challenges.

As indicated by the participants, the lack of formal university programs for permaculture training suggests a gap in formal education in this field. However, the reliance on permaculture design courses and consultations with experts demonstrates a commitment to education and the practical application of permaculture practices (Tran Ho, Lepage, & Fang, 2023).

The lifecentric farmer group strongly agreed that fair share practices create a healthier ecosystem (mean = 4.68, SD = 0.7) and that biodiverse plantation methods improve plant immunity (mean = 4.72, SD = 0.7). The sustainability of the design philosophy was also highly rated (mean = 4.56, SD = 0.77). The agroforestry farmer group specifically acknowledged the benefits of engaging local people in permaculture practices for community engagement (mean = 4.76, SD = 0.61), as highlighted in the study by Ingram, Maye, Kirwan, Curry, and Kubinakova (2014). Their research highlighted the shared values and expertise in permaculture, emphasizing its role in community engagement and learning (Ingram et al., 2014). They also recognized the negative impact of mono-cropping on soil quality (mean = 4.19, SD = 0.93) and affirmed the advantages of multi-cropping for biodiversity (mean = 4.48, SD = 0.77), as discussed in the research by Sadiq, Li, Rahim, and Tahir (2021). This research explored the impact of conservation tillage on soil physicochemical characteristics under wheat mono-cropping systems. It discusses how different tillage strategies, including conservation tillage, affect soil quality, emphasizing the negative impacts of mono-cropping on soil health (Sadiq et al., 2021).

The farmers' emphasis on permaculture's positive effects on soil health, water conservation, and the avoidance of chemicals aligns with extensive literature documenting these benefits. Studies like Kremen and Miles (2012) demonstrate that

agroecological methods, akin to permaculture practices, promote biodiversity, soil health, and reduced reliance on external inputs. Moreover, farmers' challenges in implementing permaculture due to unpredictable weather patterns resonate with the growing discourse on climate-smart agriculture. Integrating technology into permaculture, as the participants suggest, aligns with the recommendations of Lipper et al. (2014), who emphasize the need for technological innovation and adaptation to mitigate climate change impacts on agriculture.

The lack of formal permaculture training programs noted by the experts highlights an area for potential development. The increasing popularity of permaculture design courses signifies a growing interest in this field, potentially leading to more structured educational offerings and benefits of these trainings (Friedman & Katz, 2021). The strong emphasis on biodiversity, fair share practices, and community engagement aligns with the ethical and holistic dimensions of permaculture.

5.3. Digital technologies

The findings of this study contribute to a growing field of research on digital agriculture, which has increasingly highlighted how technology positively impacts agricultural efficiency and decision-making. Both the quantitative and qualitative results from this study align with previous research, reinforcing the rising importance of digital tools in agriculture.

Implementing digital technologies in agriculture has become increasingly important, as evidenced by the data collected from 208 participants in this study. The participants were asked to rate the importance of various digital tools, and their responses offered valuable insights into the implementation benefits of these technologies in the agricultural sector. Based on the interview of the five participants, it has become apparent that Hosachiguru's utilization of digital technologies in agriculture mirrors a more significant shift in the industry toward precision farming and sustainable practices.

This discussion will analyse these findings in relation to existing literature, highlighting the impact of digital technologies like IoT-based moisture management, drip irrigation, and mobile agricultural apps on farming practices. The unanimous emphasis on soil moisture sensors and weather forecasting tools among the participants of the interviews reflects the growing adoption of Internet of Things (IoT) technologies in agriculture. According to a study conducted by Kamilaris, Kartakoullis, and Prenafeta-Boldú (2017), IoT applications in agriculture have significantly increased, particularly in areas such as soil and water management, which are essential for improving crop yield and resource efficiency (Kamilaris et al., 2017). The use of drones for land analysis, as mentioned by the participants, is also becoming increasingly popular. A study conducted by Zhang and Kovacs (2012) underscores the capability of unmanned aerial vehicles (UAVs) to provide detailed and accurate land analysis, which is essential for precision agriculture (Zhang & Kovacs, 2012).

The study revealed a strong positive perception of IoT-based moisture management systems, with an overall mean score of 4.48 (SD = 0.77) from the farmers. The lifecentric group rated this technology slightly higher than the agroforestry group. This reflects the findings of Solanki (2021), who emphasized the role of IoT in enhancing water use efficiency in agriculture. Solanki's review highlighted the potential of IoT-based systems to improve water management and cut down on waste. These IOT-based systems significantly contribute to precision agriculture by helping farmers use water more efficiently and minimize waste. This is particularly relevant in the context of climate change and water scarcity, as noted by Laha et al. (2023), who argued that such technologies are crucial for sustainable water management in agriculture.

The effectiveness of drip irrigation systems in delivering better yields at lower costs was also highly rated (mean 4.52, SD = 0.69). This consensus is supported by the work of C. D. Singh et al. (2023), who developed a smart IoT-based drip irrigation system for precision farming. Their research demonstrated that such systems not

only conserve water but also enhance crop yield and quality. This validates the idea that implementing these techniques can improve yields, as the farmers in this study have also reported.

The specific use of soil moisture sensors at varying depths, as detailed by the interview participants, is a prime example of precision agriculture. A study by Liakos, Busato, Moshou, Pearson, and Bochtis (2018) reveals the significance of precision agriculture technologies, like soil moisture sensors, for improving irrigation and reducing water usage, which is vital for sustainable farming practices. The integration of GPS trackers and CCTV for farm management, as mentioned by the interview participants, resonates with the growing trend of smart farming. Tey and Brindal (2012) explore how these technologies improve the efficiency and oversight of farming operations, which results in improved resource management and a lower environmental footprint.

The MyFarm mobile app, designed for quick access to vital farm information, received an overall mean score of 3.92 (SD = 1.05). The lifecentric group rated it significantly higher than the agroforestry group. This variation might be due to different experiences or expectations regarding the app's utility. Ahmad, Alvino, and Marino (2022) discussed the importance of integrating digital tools like mobile apps in agriculture. They revealed that such tools could significantly enhance decision-making and productivity in farming if designed skillfully. The high mean score underscores the significance of these tools in enhancing farmers' experience. When the app is discussed with the interview participants, the responses represent a shift towards farmer-oriented digital platforms in agriculture. This trend is supported by Wolfert, Ge, Verdouw, and Bogaardt (2017), who note the increasing role of digital platforms in connecting farmers with consumers and other stakeholders, thereby increasing transparency and engagement in the agricultural value chain (Wolfert et al., 2017).

The interview participants' views on the role of digital technologies in advancing sustainability resonate with the findings of Bronson (2019), who argues that digital

agriculture can play a pivotal role in enhancing sustainability through improved resource management and decision-making. Moreover, the participants stressed the importance of real-time feedback and scalability for sustainable agriculture because it allows for more accurate and timely interventions that help minimize waste and boost productivity.

However, the somewhat reserved acknowledgment of digital technologies' contribution to sustainability by one of the interview participants (Participant #4) reflects a nuanced perspective in the literature. As Carolan (2017) points out, while digital technologies do offer significant benefits, they are not a panacea for all sustainability challenges in agriculture and must be integrated thoughtfully within broader sustainable practices.

The regression analysis and t-tests conducted in this study reveal the nuanced differences in the implementation benefits of these digital technologies between the two groups. The statistical significance of these differences, particularly for the MyFarm mobile app, underscores the varying impacts and acceptance levels of digital technologies in different farm type contexts.

The study also explored the effects of gender, age, and income on the implementation benefits of digital technologies. Interestingly, females rated the benefits of the MyFarm mobile app significantly higher than males. This finding reflects the broader trends observed in technology adoption, where personal factors such as gender identity and income play a critical role (Nawaz, 2020). In agriculture, research by Okidim, Odukwo, and Ozah (2023) further supports this, highlighting how socio-economic determinants like education, gender, and annual farm income influence the adoption of modern agricultural technology. Butler (2020) emphasizes the role of gender in the adoption of mobile technology, noting that across low- and middle-income countries, women are often less likely to own mobile phones or use mobile internet.

Additionally, Siska (2022) identifies that demographic factors, including gender, age, and income, are key influences on adopting digital banking, suggesting a parallel in

the agricultural sector. These studies collectively suggest that gender can significantly influence the perception and adoption of technology in agriculture.

Age also affects the implementation benefits, especially for the MyFarm mobile app. The significant differences between age groups in their ratings indicate that age may affect how farmers perceive and utilize digital technologies in agriculture. The study on the adoption of digital agricultural services by smallholder farmers in Ghana highlights important trends and factors influencing this process (Miine, Akorsu, Boampong, & Bukari, 2023). The study by Miine et al. (2023) also underscored the influence of sociodemographic characteristics (age, income, marital status), farm characteristics, and institutional factors on adopting these digital technologies. Younger farmers were likelier to adopt these technologies than older ones, suggesting the need for targeted strategies to encourage broader adoption across age groups.

A similar study conducted in Brazil surveyed 504 Brazilian farmers to understand their adoption of precision and digital agriculture technologies (Bolfe et al., 2020). Regarding the adoption of digital technology, 84.1% of farmers used at least one type of technology. The most common technologies were related to Internet access and connectivity (70.4%) and mobile applications, digital platforms, and software for obtaining general information (57.5%). However, 15.9% of rural producers did not use any digital technologies. Farmers reported various positive impacts from using digital technologies, including increased agricultural productivity (64.7%), easier marketing and planning (62.7%), reduced production costs (62.3%), and increased profits (60.9%). These benefits demonstrate the potential of digital technologies to enhance efficiency and profitability in agriculture.

The responses from the five participants involved in Hosachiguru's operations provide valuable insights into the current state of digital agriculture and its alignment with sustainability practices. The emphasis on soil moisture sensors, weather forecasting, drone technology, and farmer-oriented digital platforms is consistent with the trends observed in the broader literature. These technologies enhance

precision farming, improve resource efficiency, and foster better stakeholder engagement, which are essential components of sustainable agriculture. However, as the literature suggests, the implementation of these digital technologies should be viewed as part of a larger strategy towards sustainability rather than standalone solutions. The insights from Hosachiguru's experience thus contribute to a growing body of evidence supporting the transformative potential of digital technologies in agriculture while also highlighting the need for a balanced and integrated approach to sustainability.

Implementing digital technologies, such as soil moisture sensors and weather forecasting, is a growing trend in modern agriculture. The use of these technologies for operational efficiency and precision agriculture is supported by the work of Zhang, Wang, and Wang (2002), who discuss the benefits of precision agriculture technologies in enhancing farm productivity and sustainability. The insights from the qualitative interviews provide a comprehensive understanding of current trends in sustainable agriculture, highlighting the importance of agroforestry farms, lifecentric farms, and permaculture. These practices, supported by digital technologies, offer promising pathways for achieving environmental sustainability, economic viability, and personal fulfillment in agriculture.

In conclusion, this study contributes to the growing body of literature on digital agriculture. The findings affirm the significant role of digital technologies in enhancing agricultural efficiency and decision-making. The variations in ratings among different groups, influenced by factors such as farm type, gender, and age, highlight the importance of considering diverse needs and contexts in the implementation of digital technologies in agriculture. This study underscores the transformative potential of digital technologies in farming, aligning with the broader trend toward precision agriculture and sustainable farming practices.

5.4. Sustainability practices

Research on incorporating sustainability practices in agriculture is of utmost importance, especially given the worldwide environmental issues and the need for sustainable development. The current study offers valuable insights into the implementation of environmentally friendly methods in agricultural operations while specifically focusing on two farm types: agroforestry and lifecentric. This discussion consolidates the study's results and situates them within the broader context of existing research on sustainable agriculture. A total of 208 farmers participating in the study were introduced to various sustainable farming methods, and they were asked to provide their level of adoption.

The study's findings revealed that a significant number of 208 participants have reported implementation of a range of sustainability practices to a moderate to high degree. Moreover, the widespread implementation of methods such as planting trees along property lines, engaging local agricultural workers, and implementing drip irrigation systems has been notably observed. These findings are consistent with the growing recognition of agroforestry as a sustainable land-use strategy. According to Jose (2009), agroforestry practices, which involve the integration of trees with agricultural and animal production, have several ecological and economic advantages, such as increased biodiversity, soil preservation, and carbon sequestration.

The greater use of drip irrigation in the agroforestry group, as compared to the lifecentric group, supports the existing literature that highlights the importance of water conservation in sustainable agriculture. A study conducted by C. D. Singh, Rao, Kumar, and Rajwade (2023) highlighted the importance of drip irrigation as an essential element in maximizing water use efficiency, which is a vital component of sustainable agriculture practices.

The study's regression analysis and t-test findings indicate significant disparities in the implementation of specific sustainable measures depending on the type of farm.

The variables "Drip irrigation solution" and "Local farmers employed" differed due to farm type. This assertion is supported by Pretty, Toulmin, and Williams (2011), who argued that the implementation of sustainable practices often depends on specific factors related to each farm, such as the farming system employed and the economic and social conditions of the local area.

The absence of statistical significance regarding techniques such as "Trees at Boundaries" and "Buffer Zone" in distinguishing farm types suggests a more widespread implementation of these practices across these farms. This perspective aligns with the conclusions of Altieri (2002), who pointed out in his study that specific agroecological methods have gained widespread acceptance in various farming systems owing to their established environmental advantages.

The study's conclusions have numerous ramifications for policy and practice. The significant prevalence of initiatives such as employing local farmers and cultivating a variety of crops highlights the vital role of community engagement and biodiversity in fostering sustainable agriculture. This aligns with the principles of community-based natural resource management, which prioritizes utilizing local knowledge and being actively involved in the sustainable use of resources (Berkes, 2004).

Furthermore, the disparities in the use of techniques such as drip irrigation between agroforestry and lifecentric groups emphasize the need for tailored strategies in advocating for sustainable agriculture. Practitioners and policymakers should consider the unique needs and attributes of various farming systems when creating and implementing sustainability projects.

Future investigations should focus on examining the fundamental reasons behind the decision to adopt or avoid particular sustainability practices, analyzing factors such as cost-effectiveness, level of understanding and consciousness, and cultural beliefs. Additionally, longitudinal studies could provide valuable information about how these practices are adopted over time and their lasting impacts on farming productivity and environmental sustainability.

The results of this study highlight the significance of customized approaches in advancing sustainable agriculture, the involvement of indigenous groups and biodiversity to support sustainable agriculture, and the role of local communities and biodiversity in these practices. Given global environmental challenges, research like this can provide important guidance for encouraging sustainable farming methods.

5.5. Farmer's purchasing criteria

The present study involved surveying farmers to determine their criteria for purchasing the farm. Participants were asked to rate different aspects on a 5-point scale, with a higher score indicating a higher priority level. The elements considered were the farmland's initial buying pricing, maintenance expenses, the developer's standing, the concept's depiction, and the available services and facilities.

Several aspects of purchasing a farm significantly impact a farmer's decision-making process. A study by Ceesay, Ndiaye & Gitteh (2023) examines the impact of environmental conditions and resource availability on agricultural decision-making in rural Gambia, specifically in the context of climate change adaptation approaches. The authors emphasized the significance of characteristics such as household income, farmland size, and availability of credit, which are also likely to be important in a farmer's purchasing criteria.

Moreover, a study conducted by Xin and Ying (2012) on the selection of ecological compensation modalities for farms in Wuhan City found that farmers' choices are highly influenced by factors such as family income, education level, and awareness of environmental issues. These findings indicate that the farmer's purchasing criteria is influenced by economic and educational considerations, as well as environmental consciousness.

An intricate interaction of economic, environmental, and practical considerations determines the farmer's purchasing criteria. Research conducted in various settings and allied disciplines offers an essential understanding of these decision-making processes, emphasizing the significance of elements such as the presence of

resources, advantages, concerns about sustainability, and socio-economic circumstances.

The farm plot price, with a mean score of 3.13 (SD = 1.57), did not show a significant difference between the two farm types, agroforestry and lifecentric, as evidenced by a p-value of 0.617 in the t-test. This implies that although price is considered, it is not the primary determinant in the decision-making process as a farmer's purchasing criteria. This finding aligns with the study conducted by Ceesay et al. (2023), which observed that although economic aspects hold significance, they are frequently overshadowed by other factors in agricultural decision-making (Ceesay et al., 2023).

The maintenance cost, with a mean score of 3.3 (SD = 1.51), exhibited a statistically significant disparity ($p = 0.001$) between the two types of farms. The developer's reputation was highly esteemed, with an average score of 4.05 (standard deviation = 1.41), and exhibited a significant disparity among different types of farms ($p < 0.001$). Agapiou (2020) emphasized the significance of reputation and implementation benefits in the decision-making process within construction-related industries, which aligns with the present findings.

The concept representation, with an average score of 4.25 (standard deviation = 1.17), exhibited a significant difference ($p < 0.001$) between the two types of farms. This discovery aligns with the broader body of literature that highlights the significance of conceptual clarity and vision in shaping decisions. The significance of idea representation in the agriculture industry, as emphasized by Xin and Ying (2012), indicates that the manner in which a development project is presented and its congruence with the buyer's values and objectives might be a determining factor.

The amenities and facilities, with a mean score of 4.08 (SD = 1.21), showed a significant difference between the two types of farms ($p < 0.001$). This suggests that these aspects are highly appreciated, and their relevance varies depending on the type of farm. This aligns with previous studies that emphasized the increasing significance of amenities in the development of agricultural land (Ceesay et al., 2023).

Significantly, the reputation of the farmland developer ($p < 0.001$) and the availability of amenities and infrastructure ($p < 0.001$) were identified as strong indicators. This discovery aligns with the broader body of work highlighting the significance of qualitative elements in making decisions about land development (Agapiou, 2020).

To summarize, the study offers significant insights into the elements that influence the farmer's purchasing criteria approach. Although initial buying pricing is an aspect to consider, it is not the most important. However, upkeep expenses, developer reputation, idea representation, and amenities and facilities are more influential factors, with their significance varying based on the specific type of farm. These findings have ramifications for managed farm services developers and farmers in the agricultural industry, emphasizing the necessity to prioritize reputation, conceptual clarity, and the supply of facilities to attract potential buyers.

5.6. Agroforestry and lifecentric farms

As the experts (5 interview participants) described, agroforestry is a commercially driven approach that integrates minimal intervention and efficient management, including practices like live fences and windbreaks. The emphasis on sustainability and community engagement in this model reflects Jose's (2009) observations about agroforestry's positive effects on biodiversity and soil conservation. Moreover, the expert's opinions on the cost-effectiveness and long term benefits of agroforestry have been validated by the findings of Udawatta and Jose (2011) that highlighted the economic benefits along with environmental conservation. The idea of lifecentric farming, which emphasizes biodiversity and personal enjoyment, aligns well with the principles of holistic agriculture. The participants believe that this approach strengthens our connection to nature and is also seen as an ethical investment for the future. These views were also supported by Altieri (2002), who stresses the importance of biodiversity in sustainable farming. The emotional richness and family-oriented nature of lifecentric farming echo the findings of Wilson (2010), who discusses the psychological benefits of close interactions with nature in farming.

As noted by the participants, the dynamic management and commitment to sustainability are essential for the conservation of the environment. Pretty (2008) has also supported this perspective by highlighting the positive environmental impacts of sustainable farming practices. Moreover, it is also important to recognize the environmental trade-offs in construction projects, as highlighted by Horlings and Marsden (2011), who point out the challenges of attaining true sustainability in agriculture. The following paragraph discusses the motivation for investing in agroforestry and lifecentric farms as per the experts interviewed.

Experts have outlined several motivations behind investing in agroforestry and lifecentric farming, which include land value appreciation, environmental contributions, and personal fulfillment. These motivations echo the findings of Stern (2004), who points out that sustainable land management is tied to cultural and personal values. Additionally, the financial and environmental aspects of agroforestry investment align well with the findings of Mercer (2004), who has discussed the economic benefits of environmentally responsible farming.

5.7. Future research directions

The study highlights the moderate to high implementation of sustainability practices among farmers. Key practices include planting trees, employing local farmers, and using drip irrigation. These practices align with the practices of agroforestry and sustainable land use. Future research should investigate the barriers and facilitators to implementing these practices more widely. This could include exploring the economic viability, knowledge gaps, and cultural attitudes towards sustainable farming practices. The study also reveals the need for tailored approaches in promoting sustainable agriculture. Future longitudinal studies may track improvements over time using permaculture practices and digital farming techniques and their impact on farm productivity and environmental sustainability.

Research could also focus on developing context-specific strategies that consider the unique needs and characteristics of different farming systems. Another area for



future research is the formal education and training in permaculture. Studies could explore the development of university programs and the effectiveness of existing permaculture design courses.

Chapter 6: Conclusion

This chapter synthesizes the findings of the current study, linking the perspectives of farmers and experts in farming to broader scholarly discussions. The chapter reflects on the implementation of permaculture and digital technologies across agroforestry and lifecentric farms. Moreover, the chapter also reflects on the purchasing criteria of farmers and implementation of sustainable practices in farming in managed farm services across India.

The study contributes to understanding contemporary agricultural practices, especially in agroforestry and lifecentric farms as well as permaculture practices underpinned by digital technologies. The study's findings emphasize the significance of implementing sustainable practices with digital technological advancements in agriculture to enhance a farm's economic performance and achieve sustainability outcomes. The current study has implications for practitioners and policymakers, underscoring the need for context-specific strategies and the importance of considering diverse perspectives in agricultural development. As reflected in the study's findings, the evolving landscape of sustainable agriculture presents a complex yet promising future, requiring continuous research and adaptive strategies to navigate the challenges and opportunities.

6.1. Key insights and implications

This thesis has explored various aspects of sustainable agriculture, focusing on agroforestry, lifecentric farms, permaculture practices, digital technologies in farming, and the farmer's purchasing criteria. The findings offer valuable insights into the motivations, challenges, and outcomes associated with these systems and provide suggestions for future research and practice.

Agroforestry and lifecentric farming represent two distinct yet complementary approaches to sustainable agriculture (Brodt et al., 2011). Agroforestry integrates minimal intervention with efficient management practices that enhance biodiversity, soil conservation, and ecosystem health (Jose, 2009; Udawatta & Jose, 2011) while lifecentric farming focuses on fostering biodiversity and personal fulfilment, contributing to environmental sustainability as well as the psychological well-being of farmers (Pretty, 2008; Wilson, 2010). The findings also show that investment in agroforestry and lifecentric farms is driven by land value appreciation, environmental contributions, and personal fulfilment with differences across lifecentric and agroforestry farmers (Mercer, 2004; Stern, 2004).

The study also highlights the importance of permaculture practices in improving soil health and reducing water dependency. Techniques such as mulching, biomass planting, and chop-and-drop, alongside water management strategies like swales and trenches, were shown to significantly enhance farm's sustainability similar to the findings of RJ & Singh (2023) and Singh et al., (2023). These findings provide empirical support about permaculture's potential to regenerate ecosystems and foster resource efficiency (Holmgren, 2002; Ferguson & Lovell, 2014). However, the implementation of these practices is not without barriers, as reported by the experts, there is a need for formal education and training programs in permaculture, highlighting the current lack of such formal programs and warranting further research into their effectiveness.

Digital technologies have emerged as an important force in sustainable agriculture, offering precision and efficiency in resource management (Kamilaris et al., 2017; Singh et al., 2023). Tools such as IoT-based moisture management systems, drip irrigation, and mobile applications like MyFarm were found to enhance decision-making and operational efficiency (Ahmad et al., 2022; Liakos et al., 2018). Notably, Female farmers rated the benefits of digital technologies like mobile apps (MyFarm app) higher as compared to their male counterparts, indicating gender influences in technology adoption (Butler, 2020; Nawaz, 2020). Moreover, Young farmers are also

more likely to adopt digital agricultural technologies, suggesting the need for age-specific adoption strategies for technology adoption in agriculture (Miine et al., 2023). These findings highlight the need for targeted strategies that consider demographic differences and validate existing literature on the role of technology in bridging knowledge gaps and enhancing agricultural productivity (Liakos et al., 2018; Nawaz, 2020).

The findings highlight the importance of integrating traditional agricultural practices with modern technological innovations for sustainable agriculture. However, while digital technologies have many advantages, as reported in the current study, it is important to integrate them carefully alongside broader sustainable practices (Carolan, 2017).

Sustainability practices, including tree planting and employing local farmers (Berkes, 2004), were widely adopted across farm types. This demonstrates their importance in enhancing biodiversity and community engagement (Jose, 2009; Singh, 2023). However, significant variations in adoption rates were observed between agroforestry and lifecentric farms, influenced by farm-specific variables and socioeconomic circumstances (Pretty et al., 2011). This underscores the need for context-specific strategies that address the unique needs and challenges of different farming systems. Lastly, acknowledging and addressing environmental trade-offs during construction and farming practices is crucial for achieving true sustainability (Horlings & Marsden, 2011).

Farmers' purchasing decisions were found to be influenced by factors other than the initial price alone, with greater importance placed on maintenance costs, the reputation of developers, concept representation, and amenities (Agapiou, 2020; Ceesay et al., 2023). The study further reinforces that qualitative factors like reputation and amenities play a significant role in selecting a farmland developer as compared to price (Xin & Ying, 2012). This highlights a shift towards valuing qualitative factors in decision-making. These findings suggest that developers and

policymakers must prioritize transparency, community engagement, and sustainability in their offerings to align with farmers' evolving preferences.

Future research should delve deeper into the barriers and facilitators to adopting sustainable practices, considering cultural, economic, and knowledge-based factors, to ensure inclusive and effective transitions towards sustainable agriculture. Future research efforts should also focus on developing context-specific strategies for sustainable agriculture across various farm types, considering the unique needs of each farming system.

6.2. Shared learning and best practices

Based on the current research findings, this section presents shared learning and best practices for implementing permaculture and digital technologies in the context of managed farms. These practices are categorized into six main components described below.

a. Implementing Permaculture Practices

The adoption of permaculture practices is key for achieving sustainable agriculture. This study underscores the importance of focusing on sustainable design and resource conservation to create resilient agricultural systems. Techniques such as mulching, chop-and-drop, and water management systems not only enhance soil health but also reduce water dependency. These practices align with the principles of permaculture, emphasizing resource efficiency and ecosystem health. The findings show that farmers reported improved crop yields, biodiversity, and soil quality, providing evidence for their practical benefits in managed farm contexts. This highlights the necessity of promoting permaculture as a regenerative approach to farming.

b. Implementing Digital Technologies

The current research highlights the potential of digital technologies in agriculture. IoT-based solutions, such as soil moisture sensors, have proven effective in precision farming by optimizing resource use and improving decision-making. Data analytics further enables efficient farm management by offering actionable insights based on real-time data. Their adoption reflects the increasing demand for smart farming solutions, and the current study emphasizes that farmers with access to these tools experience significant improvements in efficiency and sustainability.

c. Addressing Implementation Challenges

Despite the benefits, the study identifies critical barriers to the adoption of permaculture and digital technologies, including a lack of technical knowledge, high initial costs, and resistance to change. To address these challenges, the findings recommend strategies such as subsidizing costs, offering practical training programs, and promoting awareness about long-term benefits. Overcoming these barriers is essential for scaling sustainable practices and ensuring their adoption across diverse agricultural contexts.

d. Monitoring and Evaluation

Effective implementation of sustainable practices requires a vigorous monitoring and evaluation framework. The study highlights the need for regular assessments to track progress and adapt practices as needed as reported by experts in the current study. Establishing clear indicators for sustainability, such as soil health, water usage, and crop diversity ensures that practices remain effective and aligned with the sustainability goals.

e. Community Engagement and Education

The findings underscore the critical role of engaging local communities in sustainable farming practices. Community involvement not only enhances the adoption of permaculture but also fosters a sense of ownership and shared responsibility. Additionally, educating farmers on the benefits and applications of digital

technologies is vital for bridging knowledge gaps. Empowering communities through education ensures the sustainability of these initiatives in the long term.

f. Collaboration and Research

The study emphasizes the importance of collaboration among stakeholders in agriculture i.e., farmers, researchers, policymakers, and agricultural service providers to drive innovation and scalability. Collaborative efforts enable the pooling of resources, sharing of knowledge, and co-creation of solutions tailored to local needs.

Furthermore, continuous research and development are essential to refine existing practices and develop new ones. For example, the integration of AI and machine learning with permaculture systems represents a promising area for future exploration. Encouraging collaboration and research ensures that sustainable farming practices evolve to meet the challenges of changing environmental and socio-economic conditions.

6.3. Practical implications

Based on the quantitative and qualitative findings, the following are the practical implications based on the current study.

Table 23 Implications of the current study's results

Quantitative Results	Qualitative Results
For agricultural practitioners	
Understanding the diverse perceptions and practices across different farming models can guide tailored approaches to agriculture.	Recognizing the value of combining natural farming practices with modern technology for sustainable agriculture.
Recognizing the importance of digital technologies in enhancing farm efficiency and decision-making.	Emphasizing community engagement and local employment in farming operations.

For policymakers and educators	
Developing policies that support implementing sustainability practices in agroforestry and lifecentric farms.	Focusing on the development and support of permaculture training programs.
Encouraging the implementation of digital technologies in agriculture for improved resource management.	Encouraging policies that support sustainable agricultural practices and digital innovations in farming.
For managed farm services developers and farmers	
Building a strong reputation and providing essential amenities can be pivotal in attracting potential buyers.	Understanding the long-term benefits and sustainability of investing in agroforestry and lifecentric farms.
Understanding the different priorities of various farming groups can guide the development of more appealing farm projects.	Considering the emotional and environmental returns alongside financial gains.

Capítulo 6: Conclusión

Este capítulo sintetiza los hallazgos del estudio, vinculando las perspectivas de los agricultores y expertos en agricultura con debates académicos más amplios. Se reflexiona sobre la implementación de la permacultura y tecnologías digitales en las explotaciones agroforestales y centradas en la vida. Además, se examinan los criterios de compra de los agricultores y la implementación de prácticas sostenibles en los servicios agrícolas gestionados en India.

El estudio contribuye a la comprensión de las prácticas agrícolas contemporáneas, particularmente en agroforestería y agricultura centrada en la vida, así como en la aplicación de la permacultura respaldada por tecnologías digitales. Los hallazgos enfatizan la importancia de integrar prácticas sostenibles con avances tecnológicos para mejorar el rendimiento económico de las explotaciones agrícolas y alcanzar objetivos de sostenibilidad. Los resultados de la investigación tienen implicaciones tanto para profesionales del sector como para responsables de políticas públicas, resaltando la necesidad de estrategias adaptadas al contexto y la importancia de considerar diversas perspectivas en el desarrollo agrícola. Como se refleja en los hallazgos, el panorama de la agricultura sostenible es dinámico y presenta tanto desafíos como oportunidades, lo que requiere una investigación continua y estrategias adaptativas para su evolución.

6.1. Ideas clave e implicaciones

Esta tesis ha explorado diversos aspectos de la agricultura sostenible, centrándose en la agroforestería, las explotaciones agrícolas centradas en la vida, las prácticas de permacultura, las tecnologías digitales en la agricultura y los criterios de compra de los agricultores. Los hallazgos ofrecen valiosas perspectivas sobre las motivaciones, desafíos y resultados asociados con estos sistemas, además de proporcionar sugerencias para futuras investigaciones y prácticas.

La agroforestería y la agricultura centrada en la vida representan dos enfoques distintos pero complementarios de la agricultura sostenible (Brodt et al., 2011). La agroforestería integra una intervención mínima con prácticas de gestión eficientes que mejoran la biodiversidad, la conservación del suelo y la salud del ecosistema (Jose, 2009; Udawatta & Jose, 2011), mientras que la agricultura centrada en la vida se enfoca en fomentar la biodiversidad y el bienestar personal, contribuyendo tanto a la sostenibilidad ambiental como al bienestar psicológico de los agricultores (Pretty, 2008; Wilson, 2010). Los hallazgos también muestran que la inversión en agroforestería y en explotaciones agrícolas centradas en la vida está impulsada por la valorización de la tierra, las contribuciones ambientales y la satisfacción personal, con diferencias entre los agricultores de ambos sistemas (Mercer, 2004; Stern, 2004).

El estudio también destaca la importancia de las prácticas de permacultura para mejorar la salud del suelo y reducir la dependencia del agua. Técnicas como el acolchado, la plantación de biomasa y el método de corte y caída, junto con estrategias de gestión del agua como los canales de infiltración y las zanjas, demostraron mejorar significativamente la sostenibilidad de las explotaciones agrícolas, en consonancia con los hallazgos de RJ & Singh (2023) y Singh et al. (2023). Estos resultados proporcionan evidencia empírica sobre el potencial de la permacultura para regenerar ecosistemas y fomentar la eficiencia en el uso de los recursos (Holmgren, 2002; Ferguson & Lovell, 2014). Sin embargo, la implementación de estas prácticas no está exenta de barreras. Según los expertos, es necesario desarrollar programas formales de educación y capacitación en permacultura, lo que pone de manifiesto la actual carencia de tales programas y la necesidad de futuras investigaciones sobre su efectividad.

Las tecnologías digitales han surgido como una fuerza clave en la agricultura sostenible, ofreciendo precisión y eficiencia en la gestión de recursos (Kamilaris et al., 2017; Singh et al., 2023). Herramientas como los sistemas de gestión de humedad basados en IoT, el riego por goteo y aplicaciones móviles como *MyFarm*

han demostrado mejorar la toma de decisiones y la eficiencia operativa (Ahmad et al., 2022; Liakos et al., 2018). Es destacable que las agricultoras valoraron en mayor medida los beneficios de las tecnologías digitales, como las aplicaciones móviles (*MyFarm*), en comparación con sus homólogos masculinos, lo que indica una influencia de género en la adopción tecnológica (Butler, 2020; Nawaz, 2020). Además, los agricultores jóvenes mostraron una mayor propensión a adoptar tecnologías digitales agrícolas, lo que sugiere la necesidad de estrategias de adopción específicas por edad en el sector agrícola (Miine et al., 2023).

Estos hallazgos subrayan la importancia de desarrollar estrategias focalizadas que consideren diferencias demográficas y validan la literatura existente sobre el papel de la tecnología en la reducción de brechas de conocimiento y el aumento de la productividad agrícola (Liakos et al., 2018; Nawaz, 2020). Asimismo, resaltan la necesidad de integrar las prácticas agrícolas tradicionales con innovaciones tecnológicas modernas para lograr una agricultura verdaderamente sostenible. No obstante, si bien las tecnologías digitales ofrecen múltiples ventajas, como se evidencia en el presente estudio, su implementación debe realizarse de manera cuidadosa y alineada con prácticas sostenibles más amplias (Carolan, 2017).

Las prácticas de sostenibilidad, como la siembra de árboles y la contratación de agricultores locales (Berkes, 2004), fueron ampliamente adoptadas en los distintos tipos de granjas, lo que demuestra su importancia para mejorar la biodiversidad y fortalecer el compromiso comunitario (Jose, 2009; Singh, 2023). Sin embargo, se observaron diferencias significativas en las tasas de adopción entre las granjas agroforestales y las lifecentric, influenciadas por variables específicas de cada explotación y por circunstancias socioeconómicas (Pretty et al., 2011). Esto resalta la necesidad de desarrollar estrategias adaptadas a cada contexto, que aborden los desafíos y requerimientos particulares de cada sistema agrícola. Asimismo, es fundamental reconocer y mitigar los impactos ambientales derivados de la construcción y las prácticas agrícolas para alcanzar una verdadera sostenibilidad (Horlings & Marsden, 2011).

Las decisiones de compra de los agricultores no se basaron únicamente en el precio inicial, sino que factores como los costos de mantenimiento, la reputación de los desarrolladores, la representación conceptual y los servicios adicionales cobraron mayor relevancia (Agapiou, 2020; Ceesay et al., 2023). El estudio refuerza la idea de que los factores cualitativos, como la reputación y las comodidades, desempeñan un papel más significativo que el precio en la selección de un desarrollador de tierras agrícolas (Xin & Ying, 2012). Esto sugiere una transición hacia una toma de decisiones basada en el valor percibido y la calidad de los servicios ofrecidos. En consecuencia, los desarrolladores y los formuladores de políticas deben priorizar la transparencia, la participación comunitaria y la sostenibilidad en sus propuestas para alinearse con las preferencias cambiantes de los agricultores.

Las investigaciones futuras deberían profundizar en las barreras y facilitadores para la adopción de prácticas sostenibles, teniendo en cuenta factores culturales, económicos y de conocimiento, con el fin de garantizar transiciones inclusivas y efectivas hacia la agricultura sostenible. Además, sería pertinente centrar los esfuerzos en el desarrollo de estrategias adaptadas a cada contexto agrícola, considerando las particularidades y necesidades específicas de cada sistema de producción.

6.2. Aprendizajes compartidos y mejores prácticas

Basándose en los hallazgos de la investigación actual, esta sección presenta los aprendizajes compartidos y las mejores prácticas para la implementación de la permacultura y las tecnologías digitales en el contexto de granjas gestionadas. Estas prácticas se categorizan en seis componentes principales, que se describen a continuación.

a. Implementación de prácticas de permacultura

La adopción de prácticas de permacultura es clave para lograr una agricultura sostenible. Este estudio resalta la importancia de enfocarse en el diseño sostenible y la conservación de recursos para crear sistemas agrícolas resilientes. Técnicas como el acolchado (mulching), el método de corte y abandono (chop-and-drop) y los sistemas de gestión del agua no solo mejoran la salud del suelo, sino que también reducen la dependencia del agua. Estas prácticas están alineadas con los principios de la permacultura, que enfatizan la eficiencia en el uso de los recursos y la salud del ecosistema. Los hallazgos muestran que los agricultores reportaron mejoras en el rendimiento de los cultivos, la biodiversidad y la calidad del suelo, lo que proporciona evidencia sobre sus beneficios prácticos en el contexto de las granjas gestionadas. Esto resalta la necesidad de promover la permacultura como un enfoque regenerativo para la agricultura.

b. Implementación de tecnologías digitales

La investigación actual destaca el potencial de las tecnologías digitales en la agricultura. Las soluciones basadas en el Internet de las Cosas (IoT), como los sensores de humedad del suelo, han demostrado ser eficaces en la agricultura de precisión al optimizar el uso de recursos y mejorar la toma de decisiones. El análisis de datos permite una gestión agrícola más eficiente al proporcionar información procesable basada en datos en tiempo real. Su adopción refleja la creciente demanda de soluciones de agricultura inteligente, y el estudio actual enfatiza que los agricultores con acceso a estas herramientas experimentan mejoras significativas en eficiencia y sostenibilidad.

c. Abordar los desafíos de implementación

A pesar de los beneficios, el estudio identifica barreras críticas para la adopción de la permacultura y las tecnologías digitales, como la falta de conocimiento técnico, los altos costos iniciales y la resistencia al cambio. Para abordar estos desafíos, los hallazgos recomiendan estrategias como subvencionar los costos, ofrecer

programas de capacitación práctica y promover la concienciación sobre los beneficios a largo plazo. Superar estas barreras es esencial para escalar las prácticas sostenibles y garantizar su adopción en diversos contextos agrícolas.

d. Monitoreo y evaluación

La implementación efectiva de prácticas sostenibles requiere un marco riguroso de monitoreo y evaluación. El estudio destaca la necesidad de evaluaciones regulares para seguir el progreso y adaptar las prácticas según sea necesario, como lo indican los expertos en el estudio actual. Establecer indicadores claros para la sostenibilidad, como la salud del suelo, el uso del agua y la diversidad de cultivos, asegura que las prácticas sigan siendo efectivas y alineadas con los objetivos de sostenibilidad.

e. Participación comunitaria y educación

Los hallazgos subrayan el papel crucial de involucrar a las comunidades locales en las prácticas agrícolas sostenibles. La participación comunitaria no solo mejora la adopción de la permacultura, sino que también fomenta un sentido de pertenencia y responsabilidad compartida. Además, educar a los agricultores sobre los beneficios y aplicaciones de las tecnologías digitales es vital para cerrar las brechas de conocimiento. Empoderar a las comunidades a través de la educación garantiza la sostenibilidad de estas iniciativas a largo plazo.

f. Colaboración e investigación

El estudio enfatiza la importancia de la colaboración entre los actores clave en la agricultura, es decir, agricultores, investigadores, responsables de políticas y proveedores de servicios agrícolas, para impulsar la innovación y la escalabilidad. Los esfuerzos colaborativos permiten la agrupación de recursos, el intercambio de conocimientos y la co-creación de soluciones adaptadas a las necesidades locales. Además, la investigación y el desarrollo continuos son esenciales para perfeccionar

las prácticas existentes y desarrollar nuevas. Por ejemplo, la integración de la inteligencia artificial y el aprendizaje automático con los sistemas de permacultura representa un área prometedora para la exploración futura. Fomentar la colaboración y la investigación asegura que las prácticas agrícolas sostenibles evolucionen para enfrentar los desafíos de las condiciones ambientales y socioeconómicas cambiantes.

6.3. Implicaciones prácticas

Con base en los hallazgos cuantitativos y cualitativos, las siguientes son las implicaciones prácticas derivadas del estudio actual:

Tabla 24: Implicaciones de los resultados del estudio actual

Resultados Cuantitativos	Resultados Cualitativos
Para los practicantes agrícolas	
Comprender las diversas percepciones y prácticas a través de diferentes modelos agrícolas puede guiar enfoques adaptados a la agricultura.	Reconocer el valor de combinar prácticas agrícolas naturales con tecnología moderna para una agricultura sostenible.
Reconocer la importancia de las tecnologías digitales en la mejora de la eficiencia de la granja y la toma de decisiones.	Resaltar la participación comunitaria y el empleo local en las operaciones agrícolas.
Para los responsables de políticas y educadores	
Desarrollar políticas que apoyen la implementación de prácticas de sostenibilidad en la agroforestería y en las granjas centradas en la vida.	Enfocarse en el desarrollo y apoyo de programas de capacitación en permacultura.

Fomentar la implementación de tecnologías digitales en la agricultura para una mejor gestión de recursos.	Fomentar políticas que respalden las prácticas agrícolas sostenibles y las innovaciones digitales en la agricultura.
Para los desarrolladores de servicios agrícolas gestionados y los agricultores	
Construir una reputación sólida y ofrecer servicios esenciales puede ser crucial para atraer a compradores potenciales.	Comprender los beneficios a largo plazo y la sostenibilidad de invertir en agroforestería y en granjas centradas en la vida.
Comprender las diferentes prioridades de los diversos grupos agrícolas puede guiar el desarrollo de proyectos agrícolas más atractivos.	Considerar los beneficios emocionales y ambientales junto con las ganancias financieras.

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Annexure A: Single case study rationale

Yin (2018) describes a case study as “an empirical inquiry that investigates a contemporary phenomenon (the ‘case’) in depth and within its real-world context, especially when the boundaries between phenomena and context may not be evident.” Within this approach, using qualitative and quantitative approaches to obtain data is acceptable as a means to gather various forms of evidence, scrutinize different variables, and enlarge truth and knowledge (Taplay, Jack, Baxter, Eva, & Martin, 2015; Yin, 2014). Moreover, this diversity of approaches facilitates the creation of robust evidence in a study (Yin, 2014).

The single case study design was chosen for the present study because the researcher believed that the case study of a single farming company would help capture the common conditions and circumstances of the operations of farming companies in general. Moreover, since this study seeks to explore the perspectives of persons located in the context of managed farming in detail, the case study approach offers opportunities for in-depth scrutiny.

The basis of the robustness of case study research is in its ability to profoundly scrutinize a multi-faceted societal occurrence in real-life environments (Yin, 2018). This approach was thus chosen since it permits a researcher to explore a situation thoroughly, in this instance, the functioning of a system of managed farms (Andreoli & Tellarini, 2000).

Nevertheless, the researcher was aware of the concerns associated with using the case study approach. For example, the case study has been stereotyped as an ineffectual approach based on the perception that it is characterised by inadequate rigor, high levels of effort, or the seeming lack of ability to generalise outcomes (Yin, 2014). These apparent inadequacies signify the subjective character of the case study content and the associations between the researcher and participants of the research that may result in allegations of preconceived notions. In particular, using a single case study also invites questions regarding how well the findings from one

case can be generalised. However, the researcher had clarity regarding the purpose of the single case study. Its purpose is to enlarge and construct theory or ‘analytic generalisation’ in contrast to verifying theory or ‘statistical generalisation’ (Yin, 2014). This assertion upholds the part case study research plays as an exploratory instrument. Consequently, the case study approach is an appropriate method that aligns with the purposes of this research (Stake, 2013).

Overall, this study was exploratory as it focused on learning about the probable impacts on the economic performance and sustainability outcomes for different farm types when permaculture practices and digital technologies are implemented. It was a study of the experiences of one organisation, in a relatively new upcoming industry, namely Hosachiguru. A case study approach was utilised as the overall strategy for research. Thus, it guided the research planning and practice and the implementation of data collection and analysis. This aligns with Yin’s definition of a case study as “an all-encompassing research method—covering the logic of design, data collection techniques, and specific approaches to data analysis” (Yin, 2014). Table A.1 summarises the rationale for choosing the case study strategy for the present study.

Table A.1 Rationale for choosing case study research strategy

Aspects of case study research	Factors impacting the use of this strategy in the present study
Type of research question (Saunders, 2014) ‘What’	<ul style="list-style-type: none"> • The exploratory research question for the study: “Does implementing permaculture practices and digital technologies improve the economic performance and sustainability outcomes of agroforestry and lifecentric managed farm services?”
Type of case study (Saunders, 2014) <ul style="list-style-type: none"> • Exploratory, descriptive 	<ul style="list-style-type: none"> • Expected to provide details regarding managed farm operations in India. • The process of research will be defined and structured prior to starting the study.

Aspects of case study research	Factors impacting the use of this strategy in the present study
<ul style="list-style-type: none"> • Orthodox • Single 	<ul style="list-style-type: none"> • Purposive selection of a single case to investigate operations and outcomes of managed farms.
<p>Criteria for choosing the case (Stake, 2013)</p> <ul style="list-style-type: none"> • Access 	<ul style="list-style-type: none"> • The researcher has a relationship with the case. • Organisation is willing to contribute to the study and welcomes the opportunity to share knowledge. • Organisation is willing to learn and implement pertinent findings from the study.
<p>Multiple methods of data collection (Saunders, 2014; Yin, 2018)</p>	<ul style="list-style-type: none"> • Secondary and primary information sources. • Review of existing literature related to sustainability, sustainable agriculture, innovative approaches to agriculture using permaculture and digital technologies, and the impacts of these on sustainability in agriculture. • Farm operation records, annual reports related to the operations of the two types of farms and their outcomes. • Semi-structured interviews with employees of the case organisation to obtain insights regarding operations and outcomes of the managed farms; and • Surveys with farmers of the managed farms services to obtain insights regarding their perspectives regarding the operations and outcomes of farms.
<p>Strategies for quality assurance</p>	<ul style="list-style-type: none"> • Existing literature used to develop tools for data collection. • Tools reviewed by experts (e.g., professor) prior to use. • Use of multiple, independent sources of data.

Aspects of case study research	Factors impacting the use of this strategy in the present study
(Denzin et al., 2023; Stake, 2013; Yin, 2018) <ul style="list-style-type: none">• Triangulation	

Annexure B: Lifecentric farmer questionnaire

Sr #	Variables	Groups
Demographics		
1	Age	21-30, 31-40, 41-50, 51-60, >60
2	Gender	Male, Female, Non-Binary
3	Employment Sector	Private, Government, Retired, Homemaker, other
4	Annual Income	<20 lakhs, 21-50 lakhs, 51-99 lakhs, >1 crore
5	Plot Size (in acres)	_____
6	Purchase Price	<20 lakhs, 21-50 lakhs, 51-99 lakhs, >1 crore
7	Frequency of visit to the farm	Weekly, monthly, Quarterly, bi-annually, once a year, More than a year
Permaculture practices		
8	Permaculture earth care practice like mulching, biomass planting, chop and drop, help improve the quality of soil.	1: Strongly disagree 2: Disagree 3: Neither agree nor disagree 4: Agree 5: Strongly Agree
9	Intelligent water management system like swales & trenches that hold rainwater aids in reducing dependency on bore/rainwater.	1: Strongly disagree 2: Disagree 3: Neither agree nor disagree 4: Agree 5: Strongly Agree
10	Fair share practices are beneficial for the environment and aids in creating a healthier ecosystem for birds/animals.	1: Strongly disagree 2: Disagree 3: Neither agree nor disagree 4: Agree 5: Strongly Agree
11	Earth care practices are free from chemicals	1: Strongly disagree 2: Disagree 3: Neither agree nor disagree 4: Agree 5: Strongly Agree

12	Rainwater harvesting can help reduce dependency on rain.	1: Strongly disagree 2: Disagree 3: Neither agree nor disagree 4: Agree 5: Strongly Agree
13	Biodiverse plantation method like planting native trees, fruit trees, grasses etc, aids in improving plant immunity.	1: Strongly disagree 2: Disagree 3: Neither agree nor disagree 4: Agree 5: Strongly Agree
Digital technologies		
14	IOT based moisture management and tracking system aids in efficient usage of water.	1: Strongly disagree 2: Disagree 3: Neither agree nor disagree 4: Agree 5: Strongly Agree
15	Drip irrigation can deliver better yields at lower cost.	1: Strongly disagree 2: Disagree 3: Neither agree nor disagree 4: Agree 5: Strongly Agree
16	The Design Philosophy of the Project is Sustainable	1: Strongly disagree 2: Disagree 3: Neither agree nor disagree 4: Agree 5: Strongly Agree
17	MyFarm app provides vital information without any hassle or delay.	1: Strongly disagree 2: Disagree 3: Neither agree nor disagree 4: Agree 5: Strongly Agree
Sustainability practices		
18	Trees at boundaries, near homesteads and along streams and rivers	1: Not implemented 2: Implemented to a limited extent 3: Implemented to a small extent 4: Implemented to a moderate extent 5: Fully implemented
19	Live fences and hedges	1: Not implemented 2: Implemented to a limited extent 3: Implemented to a small extent 4: Implemented to a moderate extent 5: Fully implemented
20	Planting combination of crops (Biodiversity)	1: Not implemented 2: Implemented to a limited extent 3: Implemented to a small extent 4: Implemented to a moderate extent 5: Fully implemented
21	Swales and trenches	1: Not implemented 2: Implemented to a limited extent 3: Implemented to a small extent 4: Implemented to a moderate extent 5: Fully implemented
22	Local farmers employment policy	1: Not implemented 2: Implemented to a limited extent 3: Implemented to a small extent 4: Implemented to a moderate extent 5: Fully implemented



23	Drip irrigation solution	1: Not implemented 2: Implemented to a limited extent 3: Implemented to a small extent 4: Implemented to a moderate extent 5: Fully implemented
24	MyFarm app solutions	1: Not implemented 2: Implemented to a limited extent 3: Implemented to a small extent 4: Implemented to a moderate extent 5: Fully implemented
Farmer's purchasing criteria		
25	Price	1: Not important at all 2: limited importance 3: Little importance 4: Moderate importance 5: Very Important
26	Recurring maintenance Cost	1: Not important at all 2: limited importance 3: Little importance 4: Moderate importance 5: Very Important
27	Reputation of the Developer	1: Not important at all 2: limited importance 3: Little importance 4: Moderate importance 5: Very Important
28	Overall Concept and theme of the Project	1: Not important at all 2: limited importance 3: Little importance 4: Moderate importance 5: Very Important
29	Amenities & Facilities	1: Not important at all 2: limited importance 3: Little importance 4: Moderate importance 5: Very Important

Annexure C: Agroforestry farmer questionnaire

Sr #	Variables	Groups
Demographics		
1	Age	21-30, 31-40, 41-50, 51-60, >60
2	Gender	Male, Female, Non-Binary
3	Employment Sector	Private, Government, Retired, Homemaker, other
4	Annual Income	<20 lakhs, 21-50 lakhs, 51-99 lakhs, >1 crore
5	Plot Size (in acres)	_____
6	Purchase Price	<20 lakhs, 21-50 lakhs, 51-99 lakhs, >1 crore
7	Frequency of visit to the farm	Weekly, monthly, Quarterly, bi-annually, once a year, More than a year
Permaculture practices		
8	In Agroforestry practices like mulching, biomass planting, chop and drop, help improve the quality of soil.	1: Strongly disagree 2: Disagree 3: Neither agree nor disagree 4: Agree 5: Strongly Agree
9	In Agroforestry when only one type of crop is grown it is likely to impact the soil quality over a period of time	1: Strongly disagree 2: Disagree 3: Neither agree nor disagree 4: Agree 5: Strongly Agree
10	Water management system like swales, trenches and stream that holds rainwater aids in reducing dependency on bore/rainwater.	1: Strongly disagree 2: Disagree 3: Neither agree nor disagree 4: Agree 5: Strongly Agree
11	In agroforestry farming following multicropping practices aids in improving the variety of trees and crops which in result leads to a healthy and diverse flora and fauna.	1: Strongly disagree 2: Disagree 3: Neither agree nor disagree 4: Agree 5: Strongly Agree
12	In agroforestry farm if permaculture practices is practiced it results in yields that are free from chemicals	1: Strongly disagree 2: Disagree 3: Neither agree nor disagree 4: Agree 5: Strongly Agree

13	Rainwater harvesting can help reduce dependency on rain.	1: Strongly disagree 2: Disagree 3: Neither agree nor disagree 4: Agree 5: Strongly Agree
14	Engaging local people/farmers can help in better community engagement	1: Strongly disagree 2: Disagree 3: Neither agree nor disagree 4: Agree 5: Strongly Agree
Digital technologies		
15	IOT based moisture management and tracking system aids in efficient usage of water.	1: Strongly disagree 2: Disagree 3: Neither agree nor disagree 4: Agree 5: Strongly Agree
16	Drip irrigation can deliver better yields at lower cost.	1: Strongly disagree 2: Disagree 3: Neither agree nor disagree 4: Agree 5: Strongly Agree
17	MyFarm app provides vital information without any hassles	1: Strongly disagree 2: Disagree 3: Neither agree nor disagree 4: Agree 5: Strongly Agree
18	MyFarm app is the best mode of communication for farm updates	1: Strongly disagree 2: Disagree 3: Neither agree nor disagree 4: Agree 5: Strongly Agree
Sustainability practices		
19	Trees at boundaries, near homesteads and along streams and rivers	1: Not implemented 2: Implemented to a limited extent 3: Implemented to a small extent 4: Implemented to a moderate extent 5: Fully implemented
20	Buffer zone for your farm plot	1: Not implemented 2: Implemented to a limited extent 3: Implemented to a small extent 4: Implemented to a moderate extent 5: Fully implemented
21	Planting combination of crops (Biodiversity)	1: Not implemented 2: Implemented to a limited extent 3: Implemented to a small extent 4: Implemented to a moderate extent 5: Fully implemented
22	Local farmers employment policy	1: Not implemented 2: Implemented to a limited extent 3: Implemented to a small extent 4: Implemented to a moderate extent 5: Fully implemented
23	Drip irrigation solution	1: Not implemented 2: Implemented to a limited extent 3: Implemented to a small extent 4: Implemented to a moderate extent 5: Fully implemented



24	Mulching operations on your farm plot	1: Not implemented 2: Implemented to a limited extent 3: Implemented to a small extent 4: Implemented to a moderate extent 5: Fully implemented
Farmer's purchasing criteria		
25	Price of the Farm plot in making the decision	1: Not important at all 2: limited importance 3: Little importance 4: Moderate importance 5: Very Important
26	Maintenance Cost of the farm plot	1: Not important at all 2: limited importance 3: Little importance 4: Moderate importance 5: Very Important
27	Reputation of the Farmland Developer	1: Not important at all 2: limited importance 3: Little importance 4: Moderate importance 5: Very Important
28	Concept Representation	1: Not important at all 2: limited importance 3: Little importance 4: Moderate importance 5: Very Important
29	Amenities and Facilities	1: Not important at all 2: limited importance 3: Little importance 4: Moderate importance 5: Very Important

Annexure D: Interview questions for experts

1. Please tell me a little bit about yourself, educational qualifications, and overall work experience.
2. How long have you worked in Hosachiguru? What is your current position?
3. Please describe agroforestry farms as offered by Hosachiguru in your own words. How many agroforestry farms does Hosachiguru have?
4. How long have you provided agroforestry options? What percentage of the land is devoted to agroforestry options.
5. What do you feel are the reasons a person would invest in agroforestry option?
6. What is the operating model for agroforestry. What is Hosachiguru's involvement? For example, how many persons are involved on a day-to-day basis? What are the resources used to maintain the farm?
7. Which of the following agroforestry practices are there in Hosachiguru? You can select more than one item.
8. What are the tree types planted per farm plots?
9. Please describe lifecentric farming as offered by Hosachiguru in your own words.
10. Where are the lifecentric farm locations? How many farmers have purchased lifecentric farming options?
11. What they feel are the reasons a person would invest in a lifecentric farm option?

12. What is the operating model for farming? What is Hosachiguru's involvement. for example, how many persons are involved on a day-to-day basis. What are the resources used to maintain the farm?
13. In your opinion, what is the difference between life-centric farms and agroforestry farms?
14. Does Hosachiguru use permaculture practices? If yes, when and where did you first hear about this?
15. Why did Hosachiguru choose this method of farming? What do you get from the use of permaculture? What are the reasons permaculture is practiced?
16. Did the company receive any formal training in this matter? From whom or where? What kind of support did you receive in implementing permaculture practices?
17. What is the extent of permaculture practices used at Hosachiguru farms. What are the different aspects of permaculture practices used?
18. Have you experienced difficulties or challenges with permaculture, both as a concept and putting into practice?
19. Are you aware of the following ethics of permaculture? Please explain how these are viewed and implemented at Hosachiguru farm sites? Care for the earth, care for people, fair share of resources.
20. Which of the following permaculture practices are implemented in Hosachiguru. You can select more than 1 item.
21. What are the different digital technologies implemented by Hosachiguru in farms? Do you use artificial intelligence software and applications?
22. Please list or describe the sensors used and the area of their use.
23. Does the term sustainable development indicate anything to you? How do you believe this can be implemented in agriculture?

24. Is there any environmental harm in lifecentric farming? If yes, please elaborate.
25. Is there any environmental harm in agroforestry farming? If yes, please elaborate.
26. Does the decision to use permaculture practices have anything with Hosachiguru's commitment to sustainability. Please explain why or why not.
27. Does the decision to use digital technologies have anything with Hosachiguru's commitment to sustainability. Please explain why or why not.
28. What are your water management strategies? Please elaborate.
29. How has the soil responded to the use of permaculture practices as regards to nutrients, biodiversity, pH levels, etc., please explain.
30. How have water bodies performed after the implementation of permaculture practices as regards to biodiversity, nutrients, and salinity? Please explain.
31. What are the different renewable and non-renewable sources of energy at the farms and what is the dependency on them. Please explain.