Achieving Agricultural Sustainability: A Luxury or a Necessity

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Copyright Statement

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Abstract

Agriculture is still the mainstay for almost 60 to 70 percent of the rural households in Pakistan. Their livelihood is directly or indirectly dependent on agriculture. However, current agricultural management practices such as intensive use of fertilizers, pesticides/insecticides, and land use intensification has adversely affected the biodiversity and environment sustainability and poses a serious threat to their livelihood. Such management practices have ramification in terms of degraded land, depleted soil fertility, contamination of ground water, and loss of biodiversity. To this end, it is important to see how such harmful impacts could be minimized in such a way that productivity and production tradeoff can be rationalized. We looked at five important crops that have residue after they're harvested: rice, wheat, sugarcane, cotton, and maize. Different crop residue management regimes have been evaluated to analyze their contribution in cost of production and consequently their impact on crop profitability. A detailed profitability analysis of five major crops has been conducted in this regard. Vulnerability of profitability under different crop residue management regimes was conducted through sensitivity analysis to check what would happen if the costs of production went down by 5%, 10%, or 15%, or if they went up by the same amounts. Our findings show that the farmer isn't making as much profit. It gets lower when we add residue management costs and lower if any uncertain situation happens. To increase profit ratios, farmers are using unsustainable practices that aren't good for the environmental health.

Keywords: Agricultural Sustainability, Smallholder Farmer, Profitability, Residue Management.

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Chapter 1: Introduction

1.1Global Agricultural Importance

Agriculture is recognized as a pivotal component of the worldwide economy, contributing to approximately 4% of the global gross domestic product (GDP) (The World Bank, 2023). Sustaining the livelihoods of more than a billion individuals, agriculture stands as the foremost provider of sustenance, textiles, and indispensable commodities. It also plays a pivotal role in fostering economic progress and alleviating poverty in numerous developing countries. Accelerating agricultural productivity in underdeveloped and developing countries will be great challenge in the future (Wik, Pingali, & Brocai, 2008).. Agriculture also holds substantial importance in addressing climate change through the sequestration of carbon in soil and the mitigation of greenhouse gas emissions.

1.2 Pakistan’s Agricultural Importance

Economy of Pakistan is heavily dependent on agriculture accounting for 20.9% of the GDP and engaging 42.3% of the entire workforce (Ministry of Finance, 2023). The country has a vast potential for agricultural development due to its fertile land, diverse climatic conditions, and abundant water resources. Smallholder farmers hold a prominent position within Pakistan's agricultural sector, contending with a myriad of obstacles, including limited access to financial resources, technology, and market opportunities (Thapa, 2011). . Hassan, 2021 states that although farmers are the key players of the agri-food chains, they are considered the ones who are most unimportant and neglected. Evidently, they confront hardships and are denied their rightful access to resources like credit, technology, and market opportunities, all of which serve as obstacles impeding their productivity and financial viability (Saqib S. E., 2018).

1.3 Agriculture effects on livelihoods

The impact of agriculture on livelihoods is not limited to farmers but extends to the entire value chain. But as the agri-food industry grows, so does the opportunity to create jobs connected to agriculture outside of farms (Christiaensen, 2021).he agricultural supply chain comprises a multitude of actors or entities involved in the production, processing, distribution, marketing, and consumption of agricultural commodities. It may include producers, input suppliers, aggregators, processors, distributors, retailers, transporters, packaging and storage providers, financial institutions, regulatory authorities, and certifying agencies. These value chains are conceptualized in three ways (Donovan, 2015): (1) actions that add value from production to sale (Webber, 2009) (2) A consortium of entities engaged in the manufacturing and alteration of consumer goods and services, interconnected through the entirety of the supply network (Riisgaard, 2011) (3) A network comprising essential participants in a strategic value chain collaboratively operating within a broader institutional framework and receiving complementary support services (Da Silva, 2007). In this research, we employ the third systemic and relationship-centered concept, emphasizing the various interpretations of trust within the network of participants along the value chain. Value chain participants are fully interdependent and consequently, they depend on one another to collectively enhance the value chain's overall efficiency (Fritz, 2008). The smooth functioning of the supply chain hinges significantly on socioeconomic and environmental factors (Bhat, 2019). Moreover, farmers embrace novel technologies when they perceive that their adoption will lead to enhancements in their quality of life. The likelihood of this enhancement hinges on the comparative advantage of the technology concerning the attainment of essential household objectives, such as securing an adequate food supply and generating a satisfactory income (Kotu, 2019). However, (Fernandez A. W., 2020) introduced the blockchain concept that seeks to reduce the middleman's intrusion and increase farmer revenues. In this way, a local farmer gets more share for his farming activities, and he gets encouraged to make further improvements to the farm and agricultural products.

1.4 No Poverty and Zero Hunger

Introduction

The United Nations' Department of Economic and Social Affairs has identified 17 key Sustainable Development Goals (SDGs), often referred to as the "2030 agenda" for sustainable development. These 17 goals have been recognized as the foremost priority areas requiring immediate attention and action. Countless individuals rely on agriculture as their primary source of income and a cornerstone of their food security. We have the following three SDGs that are related to our thesis topic: (1) No Poverty, (2) Zero Hunger. We will be Discussing these topics further in detail.

1.4.1 SDG 1: No Poverty

Since the 1970s, eradicating poverty has been a major topic of discussion worldwide. The Sustainable Development Goals (SDGs) were endorsed by 193 UN members in 2015, in which SDG 1 stated as "no poverty" whose objective is to "eradicate poverty in all of its forms everywhere." Most of the people in developing nations are food insecure, trapping many of them in poverty (Dhahri, 2020). (Alkire, 2014) Included that 85% of all impoverished people living in rural settings. As per the data provided by the International Fund for Agricultural Development (IFAD, 2023), many individuals living in rural regions can escape poverty through Agriculture practiced on a small scale (typically with land holdings of around 2 hectares or less), and it is believed that growth in agriculture reduces poverty more, compared to the expansion observed in other sectors. As per the Food and Agriculture Organization (FAO), smallholder farmers play a significant role in producing a substantial portion of the food supply within developing nations. However, they frequently find themselves in a state of considerably lower economic well-being compared to the broader population and experience a lower level of food security when contrasted with urban impoverished individuals (FAO, 2015).

1.4.2 SDG 2: Zero Hunger

The concept of "hunger," often employed in non-scientific settings, deviates from its scientific definition, malnutrition is described as an uncomfortable or distressing condition resulting from inadequate food intake, encompassing a spectrum from temporary physical discomfort to a severe and life-threatening deficiency of nutrients (Meuret, 2022). As outlined by the United Nations' Food and Agriculture Organization (FAO) (WHO, 2019), hunger can be described as the distressing physical sensation that arises due to inadequate dietary energy consumption. When an individual consistently fails to consume a sufficient number of calories to support a normal, active, and healthy lifestyle, this discomfort can become chronic. The UN's Decade for Action on Nutrition reached its midpoint in 2020 (Secretary-General, 2021), however, since 2015, the overall number of persons experiencing extreme food insecurity has increased (United Nations, 2020). According to (Lowe, 2021), one of the seventeen goals within the framework of sustainable development is to eliminate hunger by the year 2030. Achieving the UN Sustainable Development Goals (SDGs) by 2030, with a particular focus on Sustainable Development Goal 2, which aims to eradicate hunger, ensure food security, enhance nutrition, and foster sustainable agriculture, hinges on discovering ways to enhance the nutritional quality of the diets of the poorest individuals. One of the primary objectives of Sustainable Development Goal 2 (SDG 2) is to eradicate hunger and guarantee equitable availability of safe, ample, and nourishing sustenance. Additional objectives encompass eliminating all manifestations of malnutrition, achieving a twofold increase in the productivity and earnings of small-scale food producers, guaranteeing the endurance of sustainable food production systems, executing robust agricultural methods, and safeguarding the genetic diversity of seeds, flora, and fauna. This aim won't be achieved. Hunger is still a major problem worldwide. Approximately 828 million individuals were reported to be experiencing undernourishment in the year 2022 (FAO, UN, 2022), and more population will be at danger. To eradicate hunger, a comprehensive description of the condition that considers calorie deficits (chronic hunger), micronutrient shortages (hidden hunger), and associated issues must be considered (Gödecke, 2019).

Future Predictions for Globe

According to a recent study from the Food and Agriculture Organization (FAO), the global food crisis is becoming worse (FAO, UN, 2022). It has deteriorated tenfold over the past five years. The analysis also demonstrates that, even though the globe became richer and produced more food than ever in the past ten years, hunger has nonetheless skyrocketed. due to the high cost of food, the lack of coordinated effort, and the lack of a worldwide commitment to reducing hunger. WFP is dealing with several issues. The population facing severe hunger continues to increase at a pace that makes it improbable for funding to match, and the expense of delivering food aid has reached an unprecedented level due to the surging prices of food and fuel (World Food Programme, 2023). According to a recently released research, approximately 90 percent of international experts on nutritional well-being and assurance of adequate food supply those surveyed anticipate that without innovation and boldness, global hunger is likely to rise in the coming decade (Devex, 2022).

Pakistan’s Current Situation and Agricultural Production Levels

Food insecurity in emerging nations is an increasing worry. Among emerging nations, Pakistan stands out as one of the most susceptible when it comes to food and nutrition security. While Pakistan has witnessed a consistent decline in its hunger index, in comparison to other emerging countries, there has been minimal advancement

(International Food Policy Research Institute (IFPRI), 2017). Based on the 2018 National Nutrition Survey using the Food Insecurity Experience Scale (FIES), it was determined that 36.9% of households in Pakistan encountered food insecurity (GoP, UNICEF, 2019). Pakistan has undertaken numerous policy initiatives in collaboration with international organizations to address food insecurity by promoting food production and nutrition programs. To foster the growth and progress of the agricultural sector, various initiatives have been put into action. To reduce food insecurity, Pakistan has also developed several governmental programs. In pursuit of the goal of eradicating hunger entirely, initiatives such as the National Zero Hunger Program and the National Zero Hunger Coordination Program have been implemented. The prevalence of undernourishment in Pakistan's population remains significant, standing at 20.3%. Pakistan has a score of 28.5 on the 2019 global hunger index, placing it at position 94. Stunting, wasting, and deficits in micronutrients are all symptoms of Pakistan's extreme levels of famine.

Pakistan's Strategies to meet Global Hunger- Agricultural Intensification

If the the alarming rate of annual population growth persist at 70 million, the global population is projected to reach 10 billion by the close of this century (Campos, 2019). Unexpectedly, developing nations have a significant role in the increase in the global population (Boserup, 2017). As an example, Pakistan ranks as the world's sixth-most populous country (Sheikh, 2012). By 2025, Pakistan is expected to have 234 million people living there. Land intensification has become a significant and pressing issue, nevertheless, because of a rise in the populations of rural and urban areas (Yaqoob, 2022). Therefore, this is the cause of the yearly cropping pattern changing to a short fallow to protracted fallow and the heavy use of numerous cropping systems on highly fragmented land. Due to the unequal distribution of people between rural and urban areas, this issue is becoming worse and is leading to increased food insecurity. In the past few decades, numerous players have advocated for agricultural intensification in developing nations at various sizes and with various motivations. Numerous experts in the fields of agriculture and food security argue that global intensification is necessary to meet the growing demands of an expanding population (Hunter, 2017). Agricultural intensification is any method that increases output while using fewer inputs (Angelsen, 2001), but is typically understood to mean higher yields per acre (Börjeson, 2010). According to some research, agricultural intensification that involves a shift to cash crops and market-oriented agriculture could potentially adversely affect food security and nutritional outcomes(Ickowitz, 2019).

Challenges after Agricultural Intensification

Growing population and rising per capita consumption are predicted to cause environmental pressures caused by human activity to expand even more (Bos, 2013). However, agriculture in Pakistan faces many challenges after adopting agricultural intensification as a strategy to overcome global hunger, such as water scarcity, soil degradation, population growth, and climate change (Pichón, 1997). Such obstacles have a direct impact on both the efficiency and financial viability of the sector, consequently influencing the well-being of individuals relying on agriculture for their livelihoods (McCalla, 2001). The government and other stakeholders like State Bank of Pakistan (SBP) have taken various measures to address these challenges, such as investing in irrigation and water management systems, promoting climate-smart agriculture, and providing access to credit and technology to farmers (Saqib L. &., 2020).

1.5 Sustainable Agriculture

For agricultural operations to continue, natural resource sustainability is crucial. (Pichón, 1997) argued in his paper that if agricultural intensification is desired and sustainability in environmentally degraded areas that are already facing poverty, it must involve a more participatory approach in technology development and diffusion that boosts and diversifies rural incomes, conserves water and soils, and increases the ability of agricultural areas for labor-absorptive capacity. It is assumed that alleviation of poverty from any society is not the only benefit to be gained from the efficient management of naturally scarce resources among farmers, but it may also be useful for sustained productivity increase in ecologically vulnerable areas (Pretty, Agricultural sustainability, 2008). Agricultural environmental sustainability entails the responsible stewardship of the vital natural resources and ecosystems integral to farm operations. It is reported by (Piñeiro, 2020) that programs launched by government which give short-term economic benefit, are highly adopted as compared to the programs that provide ecological services at long run. The government should impose ecosystem payments to make farmers adopt sustainable practices. Observations indicate that urban residents are more inclined to invest in ecosystem services compared to their rural counterparts, and this decision depends upon various factors like education (Ain, 2021).

1.6 Objectives of the Study

1. To evaluate costs incurred for a crop and their effect on farmer's profitability.
2. To examine how profitability is affected after adopting various residue management practices.
3. To evaluate farmer's affordability for environmental sustainability.

Chapter 2: Literature Review

2.1 Introduction

It is impossible to overemphasize the value of agriculture (Dong, 2023). The impact of agriculture on ensuring food security, livelihoods and environmental health makes it a crucial worldwide problem (Aznar-Sanchez, 2019). Global food security is based on agriculture's sustainable development. Long-term trends in many areas, including Pakistan, support increasing capital inputs, including the usage of fertilizer (Jayne, 2019). Various methods exist for characterizing sustainable land use in agriculture or the sustainable enhancement of agricultural practices (Yunlong, 1994), however, their primary focus is on methods that seek to integrate the generation of substantial yields while concurrently safeguarding the environment and promoting the welfare of the local populace. For guaranteeing food security, eradicating poverty, and fostering economic growth, agricultural sustainability was essential (Pretty, Agricultural sustainability: concepts, principles and evidence, 2008). Sustainable practices are essential for the long-term productivity and rural development in Pakistan, where agriculture serves as the cornerstone of the economy (Tilman, 2002). Sustainable agricultural systems seek to maximize resource use, reduce harmful environmental effects, and improve resilience to a range of difficulties (Pender, 1998). It examines the five main issues that Pakistan's agricultural industry is now dealing with, including soil degradation, climate change, population increase, water shortages, and pests and weeds (Aditya, 2020). The scholarly literature now available shows an increase in interest in these issues and the quest for long-term solutions.

2.1.1 Soil Degradation

Introduction

One of the most important natural resources is soil, which must be kept healthy to support both agricultural growth and ecological sustainability while delivering a variety of crucial ecosystem services (Wang J. Z., 2023). By sustaining agricultural output, which produces 95% of the world's food, it is an essential medium for human life (Borrelli, 2020). The ability of the soil to carry out a variety of environmental, productive, and habitat-related tasks is referred to as soil quality (Scherr, 1999). If this soil is not good in health and can not be used for vegetative growth, this means that soil has degraded. The term "soil degradation" refers to the degradation of soil quality and functionality due to either human activities or natural disruptions (Lal R. , 2009). Put differently, soil degradation can be defined as the decline in the current or anticipated capacity of soil to carry out essential ecosystem functions, which encompass the cultivation of crops for food, feed, and fiber production, often resulting from one or more degradation processes. According to environmental experts, approximately 62 million hectares of Pakistan's total land area of 79.6 million hectares are at risk of desertification, with particular vulnerability observed in regions such as Sindh, Balochistan, and South Punjab (Business Recorder, 2022).

Types of Soil Degradation

The primary processes responsible for soil degradation encompass the physical aspect, including chemical, and biological factors (Lal R. H., 1989). Physical factors encompass deteriorations in soil structure, the formation of crusts, compaction, and the hastening of erosion processes. Chemical factors encompass aspects such as nutrient depletion, disparities in elemental composition, acidification, and salinization. Biological factors might encompass Soil Organic Matter (SOM) depletion and a decrease in both soil microorganism activity and species diversity. Overexploitation and degradation brought on by inadequate management are endangering their characteristics and functions, which has an influence on both biological and economic productivity (H. Eswaran, 2001).

Symptoms of Soil Degradation

Primary soil issues are linked to processes that lead to soil degradation, including physical, chemical, and biological factors (Commission, 2006). Physical degradation (Ferreira, 2022) may include soil sealing (the procedure of permanently overlaying the ground with non-porous synthetic materials, such as asphalt or concrete) (C.S.S. Ferreira, 2018), soil compaction (densification and deformation caused by machinery (such as wheels, rails, and rollers) or cattle under forces that are too great for the soil to withstand) (Diserens, 2018) and soil erosion (increased topsoil removal from the land surface) (FAO, 2015). Chemical degradation (Ferreira, 2022) could encompass soil organic material, comprising residual plant and animal constituents (such as litter) that have undergone transformation (humification) through bacterial action and are in the process of decomposition due to the soil's warmth and moisture (FAO, 2015), soil contamination (the existence of a contamination, whether it be of a physical, chemical, or biological nature, that exceeds a certain predefined level, leading to the deterioration or impairment of soil functions) (FAO, 2015), soil salinization (when potassium, magnesium, calcium, chlorine, sulfate, carbonate, or bicarbonate are part of the equation) and soil sodification (when involving sodium) (Katerji, 2008). In the end, we have biological degradation (Ferreira, 2022). Fauna communities decompose soil organic matter (including litter) by digesting a portion of it, allowing microbes and invertebrates to break it down more easily. Soil macrofauna regulate SOM dynamics, whereas bacteria and fungi are primarily in charge of nutrient cycling (L. Santorufo, 2014). Ants and earthworms have been identified as significant species that play crucial roles in the regulation of soil nutrients, as well as in shaping the diversity and dynamics within both plant communities and invertebrate soil ecosystems (T. Almeida, 2020).

Unsustainable Technologies/Processes in Pakistan that cause Soil Degradation

Due to the soil's limited ability to store water, the Potohar area of Pakistan has a low propensity to retain water (Siddiqui, 2020). Due to the increasing water loss in this area, valuable topsoil is being lost, and dams, rivers, and water reservoirs are becoming silted. The anticipated annual soil loss might reach 268,619 tons per acre per year, the areas characterized by sharp inclines and riverbeds exhibit the highest levels of soil erosion (Siddiqui, 2020). The country resides within a semi-arid and arid region characterized by a subtropical continental climate, which is presently grappling with salinization and sodification issues. Excessive salt rates are exerting adverse effects on the biological, chemical, and physical attributes of soils. The physical and chemical alterations in the soil environment play a role in shaping the activity of soil bacteria and plant roots, ultimately exerting an influence on the growth and yield of crops. Hence, it is of paramount importance, particularly concerning food security, to transform these saline-affected areas into productive agricultural zones to meet the needs of the swiftly growing population (Syed, 2021). Soil pollution resulting from agricultural activities potentially hazardous substances known as "PTEs" have recently grown, in addition to its impact on farmers, this research has captured the interest of environmental scientists throughout the globe in the last 10 years. Due to their prolonged presence in the environment (LRT), potential for toxicity, persistence, widespread occurrence, and bioavailability, PTEs often pose adverse effects on human health and various other organisms, even when present in minute quantities (Ali, 2019). Another activity performed by local farmers is burning rice residue. However, research on burning indicates, the practice of incinerating rice straw post-harvest could potentially yield both immediate and lasting consequences on soil health, encompassing both positive and adverse effects. In the immediate term, combustion results in the increased accessibility of certain nutrients, such as phosphorus and potassium (Erenstein, 2002), and recent study indicates that it can boost the crop's production, in the upcoming season (Haider, 2012). Nonetheless, it has the potential to result in the depletion of essential plant nutrients such as Sulphur, Nitrogen, and Potash (Gupta, 2004), and adversely impact the local organic Carbon and microbial population (Heard, 2006). Conversely, refraining from residue combustion and its integration might eventually enhance the chemical characteristics of soil (Gupta, 2004).

Sustainable Technologies/Processes adopted to prevent Soil Degradation

An urgent environmental problem that has an impact on ecosystems and human lives is land degradation, which results from both human activity and natural processes. The scientific community pays close attention to soil degradation. This literature covers the body of knowledge on sustainable land degradation remedies to give a thorough overview of the successful methods used globally. To reduce land degradation and maintain soil fertility, soil conservation practices are essential. A key tactic for combating land degradation and guaranteeing the long-term viability of agricultural systems is soil conservation. Natural soil development takes time, resulting in generally stable mature soils that may return to their former state after minor disturbance (Amundson, 2015). But we have some other soil conservation techniques that are helpful in restoring nutrients for soil and in shorter period of time. We have Integrated Pest Management (IPM), conservation tillage, the application of mulches, and the utilization of organic soil enhancements, cover crops, reduced inputs of synthetic fertilizers, mycorrhiza. IPM serves as a decision-guidance framework, integrating pest control methods into a comprehensive management strategy through cost-benefit analysis, while considering the welfare of producers, society, and the environment (Kogan, 1998). Because IPM produces a complex ecosystem with several elements impacting the development rates of the insect populations, it is crucial for sustaining the efficiency of current pest management methods, including synthetic pesticides (Alyokhin, 2020). Modern agriculture frequently uses the tillage technique known as "moldboard ploughing," which inverts the soil to create. n extensively disrupted terrain featuring minimal to nonexistent vegetation debris. These practices offer indisputable agronomic benefits, including soil aeration and loosening, the incorporation of synthetic fertilizers, the blending of organic matter, and the eradication of unwanted vegetation (Ricciardi, 1999). Mulches are a common technique for improving soil health and weed control. The endorsement for the utilization of mulching as a conservation practice has been granted by the National Resource Conservation Service (NRCS), the utilization of a shielding layer comprising plant remnants or other appropriate substances to safeguard soil moisture, regulate soil temperature, mitigate erosion, decrease surface water runoff, inhibit weed growth, and enhance soil characteristics (NRCS , 2013). Living and non-living mulches can be distinguished, to further categorize the latter, it is possible to categorize them into synthetic mulches and organic mulches. Practices for fertilizing soil are crucial for sustaining ecosystems that are in balance and resistant to abrupt occurrences of insect pests (Oelhaf RC , 1978). Instances of such circumstances are increasingly common on farms maintained organically than on farms managed conventionally. To mitigate soil erosion resulting from both wind and water forces enhance the soil by enriching it with nitrogen and various essential nutrients, augment organic content and stimulate biological processes, preserve water, and control weeds, cover crops are cultivated during intercropping seasons between regular crop production (Fageria NK, 2005). It is widely acknowledged that synthetic fertilizers have an impact on insect pest populations in agricultural areas. As nitrogen commonly serves as a constraining factor for insect herbivores, nitrogen levels seem to be particularly significant (MA, 2007). Arbuscular mycorrhizae represent mutually beneficial associations wherein fungi establish symbiotic relationships with vascular plants that belong to the phylum Glomeromycota. Most of the time, these relationships are mutually beneficial and lead to nutrient exchanges between participating species. They are now found in roughly 85% of extant plant families and are likely responsible for the successful colonization of the earth by plants (Wang B. &., 2006).

2.1.2 Water Scarcity

Introduction

For millennia of human progress, water has served as an abundant resource, widely available and often without cost. Nonetheless, a notable shift is underway, particularly in arid regions worldwide, in a context where the scarcity of water poses the most significant challenge to ensuring food security, the well-being of human individuals, the state of human health, and the condition of natural ecosystems. Based on recent research conducted by the International Water Management Institute (IWMI) (Seckler, 1999), in the first quarter of the next century, we predict that 1.4 billion people, or approximately one-fourth of the global population, or around 30% of the inhabitants in developing countries, would live in areas with acute water shortages. By 2025, just over one billion individuals residing in arid zones will have no access to any water. A person is considered to experience water insecurity when they do not have access to uncontaminated water sources, affordable water sources to fulfill their needs for drinking, hygiene, or sustenance. A region may be termed as water-scarce when a significant portion of its population resides in conditions where prolonged periods pass without access to adequate water resources. The fact that there isn't a widely acknowledged definition of water shortage should be noted. The subsequent elements, among others, assess whether a geographical area qualifies as "water-deficient" (a) how the definition of people's requirements is articulated, encompassing the consideration of the environment's water needs for natural ecosystems (b) What fraction of the available resources is allocated or potentially allocatable to fulfill these requirements? and (c) the measures employed to delineate scarcity across time and space. If we possess knowledge regarding the volume of water needed to fulfill the requirements of an individual, we can employ the per capita water availability as a metric to assess the level of water scarcity. The Falkenmark metric, the most widely used measurement, often referred to as the "water stress index," is sometimes recognized as the prevailing standard (Falkenmark, 1989, November). The main natural supply of freshwater on the planet is groundwater. Rapid urbanization, industrialization, and the employment of sophisticated agronomic techniques in agriculture have all affected groundwater quality (Kumar, 2020). Approximately 180 billion cubic meters (bcm) of Pakistan's overall water resources are sourced from the Indus River system, out of this total quantity, a volume of 128 billion cubic meters (bcm) is directed into the distribution network. Precipitation constitutes the secondary origin of water, with an annual volume of approximately 50 billion cubic meters (bcm), groundwater stands as the third-largest source, with an annual quantum of about 50–60 bcm. However, if surface and subterranean water sources are exploited together and by implementing effective planning strategies at both the regional and community levels, an additional 20 billion cubic meters (bcm) of groundwater resources can be further harnessed and utilized. (Samtio, 2023) reveals that most samples are unsafe for irrigation. Many sections of the Indus Basin had salt problems and waterlogging in the past because of inadequate groundwater utilization. In contrast, over usage is currently leading to saltwater intrusion, surface salinization, and groundwater mining (Basharat, 2019).

Types of Water Scarcity

When there is an insufficient water supply to fulfil the needs of all stakeholders, encompassing ecological requirements, it is said to be "water scarce" (Water & Development Research Group, 2020a). Physical and economic water shortage are the greatest ways to characterize the situation's water scarcity. When an insufficient quantity of water is available to meet all demands, encompassing environmental requirements such as sustaining natural water ecosystems, it leads to a condition known as a tangible water deficit. Among other things, significant environmental deterioration and an increase in conflicts are signs of physical water shortage (FAO , 2009). Water scarcity and stress are its defining characteristics. Water scarcity arises as a consequence of excessive water withdrawals or utilization concerning the accessible water resource. When a resource experiences extensive utilization, it can potentially lead to accessibility challenges and result in unfavorable consequences, such as social and environmental effects (Kummu, 2016). A situation where there is an inadequate supply of water per individual is commonly described as a water deficit. When a substantial populace is compelled to depend on limited resources, "crowded" conditions emerge. As a result, competition may arise, and the resource's capability might not prove adequate to fulfill the demand otherwise inconsequential minor requirements, such as the dispersion of pollutants within a aquatic environment (Kummu, 2016). In regions characterized by ample water resources, economic water scarcity arises from either inadequate investments in water resources or human capacity constraints in meeting the growing demand for water. Lack of sufficient progress in infrastructure development, which makes it difficult for people to access sufficient water for domestic needs and various other purposes, a pronounced susceptibility to variations in seasons, such as inundations and arid spells, along with an uneven allocation of water resources, even in the presence of infrastructure, are all signs of economic water scarcity. Water crises are defined as a dramatic diminished quality and quantity of available freshwater reserves, which exerts adverse effects on both human well-being and economic endeavors (World Economic Forum, 2020).

Unsustainable Technologies/Processes in Pakistan that cause Water Scarcity

The two main types of environmental changes and natural causes of water shortage are man-induced or anthropogenic. Water quality is lowered by pollution and contamination, which makes it unusable for many purposes. Water supply for humans and the ecosystem is significantly impacted by land degradation because it changes hydrological processes. Demand might increase far more than supply. In other words, human factors like population increase and ineffective water management may make natural shortage worse. These and other human activities have the effect of creating artificial water shortage (Pereira, 2009). According to several analysts, the world's top water user or the industry with the biggest demand for water is agriculture (Donnenfeld, 2018). Irrigated agriculture is frequently cited as the primary contributor to water shortage due to its significant water use. Indeed, irrigation is to blame for the wasteful use of water, the overproduction of water byproducts, and the deterioration of water quality. Nonetheless, irrigated farming serves as a vital source of livelihood for a substantial portion of the global rural populace and produces a significant amount of the food produced globally. The current lack of water supplies severely limits irrigated agriculture (Pereira, 2009).

Sustainable Solutions Available for Water Scarcity

Water shortage is a major problem in agriculture, but there are several viable remedies that might lessen its effects. Here are a few instances: Efficient irrigation techniques, water saving technologies, crop selection and crop rotation, rainwater harvesting, etc. Water waste may be considerably decreased by using effective irrigation techniques such as drip irrigation, precision sprinklers, or micro-sprinklers. By directly supplying water to plant roots, these systems reduce runoff and evaporation. Through a comprehensive meta-analysis, it was discovered that drip irrigation, as opposed to floods, irrigation, furrow, sprinkler, and micro-sprinkler irrigation, can conserve ensure water availability and secure crop yields in case of insufficient water supply (Yang, 2023). By delivering real-time data regarding soil moisture levels and crop water needs, emerging technology like soil moisture sensors and automatic irrigation controllers help optimize water use. As a result, water is only used when and where it is required. Crop rotation and selecting crops that are more suited to dry environments can both help to maximize water consumption. Some crops require less water and are more tolerant to drought than others. Crop rotation promotes soil health and breaks disease cycles, allowing for more effective water use (Yu, 2022). In locations with seasonal rainfall, collecting and storing rainwater for use in agriculture may be a successful method. Using methods like building ponds, tanks, or underground storage systems, rainwater may be collected and stored for use later when it's dry (de Sá Silva, 2022).

2.1.3 Climate Change

Introduction

Climate change stands out as one of the foremost challenges confronting our global community at present (Farajzadeh, 2022). Recent decades have seen several natural disasters brought on by climate change, including extreme weather, unforeseen temperature changes, and variations in rainfall. As a result, more people are aware of and committed to managing climate change (Ojo, 2021). For instance, according to the Paris Accord or the 21st Conference of the Parties (COP21), the trajectories of greenhouse gas emissions need to align with the goal of constraining the increase in the global temperature to below 1.5 °C or 2 °C above the levels observed before the Industrial Revolution (Fernandez M. A., 2016). To hasten the fulfilment of these objectives, COP21 also promotes the use of renewable energy sources and the transfer of funding from rich to poor nations. This commitment was reinforced by the COP26 event held in Glasgow spanning from November 1 to November 12, 2021 (United Nations, 2018). Various human actions to suit their wants are causing climate change currently. The Economic Kuznets Curve (EKC) hypothesis has provided a description of this occurrence (Grossman, 1995). This hypothesis contends that a nation would prioritize economic development while ignoring environmental issues. The escalation in income levels will consequently coincide with a surge in pollution. Moreover, if social control and government regulation are in place, pollution will decline with ongoing expansion (Mason, 2003). Global industrialization will increase Greenhouse gas (GHG) releases, result in an increase in worldwide temperatures, and have an adverse impact on the environment. Many nations intend to reach carbon neutrality by 2050-2070, while just 4.5% of nations have already done so (Chen, 2022). Because of the excessive reliance on fossil fuels, the maritime sector also contributes to GHG emissions. In 2018, the shipping industry produced over 1 billion metric tons of CO2 equivalents of greenhouse gas emissions, or roughly 3% of all anthropogenic emissions worldwide (Watanabe, 2022). Carbon emissions are significantly impacted over the long term by the trade and banking industries. Both industries have a substantial influence on the food and energy consumption of nations. Later, this consumption will lead to contamination of the air and water (Imamoglu, 2019). Methane (CH_4) and carbon dioxide (CO_2), two of the main drivers of anthropogenic climate change, are also produced by the agricultural sector. Both gases are composed of leftovers from plants, animal feces, insecticides, and residual fertilizers (Lynch, 2021). Meanwhile, the economy suffers from climate change, which results in lower capital, output, investment, and consumption (Farajzadeh, 2022). The reduction in global food production caused by anticipated changes in climate factors, including rainfall patterns, temperature variations, river flow rates, and the impact of CO_2 fertilization, are projected to amount to a 0.5% shift during the 2020s and a more substantial 2.3% alteration in the 2050s. Food costs would rise by 39% to 33% across the board due to decreased food output, however, particularly concerning cereal grains, as well as sugarcane and wheat, this is especially true. Farm output and pricing variations influence wellbeing and GDP changes (Calzadilla, 2013). Additionally, by the end of the century, rising temperatures in wealthy nations will result in substantial reductions in agricultural gross value added per laborer ranging from 10% to 30% were observed (Farajzadeh, 2022). Moreover, only a limited number of business participants (Biswas, 2022) and academics (Milovanovic, 2022), comprehend the adverse outcomes of climate variation.

Unsustainable Causes of Climate Change

Several unsustainable practices that cause climate change are related to agriculture. Here are some of the crucial elements: deforestation, intensive livestock production, chemical fertilizers, manure management, rice cultivation. Significant greenhouse gas emissions result from the transformation of forests into arable land, particularly for industrial-scale commercial farming is known to be deforestation. Forest's ability to absorb CO_2 from the atmosphere is decreased by deforestation, which releases carbon dioxide that was previously held in trees. Climate change is exacerbated by the growth of intensive livestock agriculture, such as concentrated animal feeding operations (CAFOs). Through the enteric fermentation (digestive process) and manure management processes, these operations generate significant volumes of methane, a strong greenhouse gas. Climate change is a result of agriculture's usage of synthetic fertilizers. Nitrous oxide is a strong greenhouse gas that is emitted both during and after the synthesis and application of fertilizers, especially nitrogen-based fertilizers. Methane and nitrous oxide can be released because of improper management of animal manure, both of which are climate change-causing gases. Methane is a powerful greenhouse gas that is produced when manure is either held in lagoons or allowed to degrade in anaerobic circumstances. Methane emissions are significantly influenced by rice farming, particularly in flooded fields. In flooded rice fields, anaerobic conditions make it easier for methane to be produced and released, which contributes to climate change (Islam, 2022).

Sustainable technologies/Processes available to overcome Climate Change

Owing to the release of greenhouse gases and the consequences of deforestation, and resource use, the agricultural industry contributes significantly to climate change. However, there are several environmentally friendly options that might lessen the influence of climate variability on the agricultural sector. Agroforestry is characterized as the deliberate planting of trees on grassland or croplands. Agroforestry has several, long-established benefits for small-scale farmers in nations with lower and middle incomes (LMICs) (Waldron, 2017). Scholarly investigations have primarily focused on the potential poverty-alleviating effects of agroforestry practices by increasing crop yields, diversifying income sources, and reducing the use of agricultural inputs (Pratiwi, 2019). Using precision farming, agricultural management choices may be adjusted in both time and space. Precision agriculture is built on the management of a parcel's information and communication technology. To effectively manage the agricultural production process and maximize the farming interventions, it seeks to modify the farming practices in response to intra-parcel variability (soil texture, slope value, plant cover, etc.). Organic farming methods encourage biodiversity, enhance the health of the soil, and use fewer synthetic pesticides and fertilizers. Additionally, organic farming helps the soil absorb carbon, which mitigates climate change (Lampkin, 2000). Organic farming methods encourage biodiversity, enhance the health of the soil, and use fewer synthetic pesticides and fertilizers. Additionally, organic farming helps the soil absorb carbon, which mitigates climate change. Practices used in conservation agriculture include crop rotation, low tillage, and soil cover using organic leftovers (Hobbs, 2008). These methods increase soil carbon sequestration, increase water retention, and decrease soil erosion. Stakeholders are giving CA adoption support for farmers and the creation of new knowledge to enhance their performance more time and money. A multi-stakeholder movement made up of official, furthermore, it involves informal networks of communication and cooperation, both domestically and internationally, which extend across individuals and entities operating within the realms of the public sphere, commercial sector, and civil society, CA expansion is still primarily driven by farmers worldwide (Kassam, 2022). Composting and anaerobic digestion are two effective waste management strategies that can reduce greenhouse gas emissions from agricultural waste while generating beneficial organic fertilizers and biogas for energy production. Utilizing lignocellulosic wastes for value-added goods like biofertilizers, biobricks, biocoal, bioplastics, paper, biofuels, industrial enzymes, organic acids, etc. might have an impact on the bioeconomy (Koul, 2022).

2.1.4 Population Growth

Agriculture productivity is significantly impacted by population expansion. The increasing global population has led to a rising need for food, which puts pressure on the agricultural industry to produce more. The following are some significant impacts of population expansion on agricultural output: Increased demand for food, expansion of agricultural land, intensification of agricultural practices, technological advancement, shifts in dietary preferences, urbanization, and loss of farmland. First, increased demand for food is explained by (Daniel, 2022). Demand for food is directly correlated with population expansion. As the global population continues to expand, there arises an imperative to increase food production on a larger scale to fulfil the population's need for food. Agricultural operations frequently spread into new regions to fulfill the dietary requirements of the growing populace. To do this, cropland may need to be cleared of trees or other natural habitats. However, the increase in agricultural land might result in habitat loss, deforestation, and environmental deterioration. (Qin, 2022) explained that without fundamental changes in the agriculture sector, it would be impossible to fulfil the sustainable development goals and the carbon neutrality ambitions. This revolution is said to have been greatly influenced by the quick development of digital technology. The continuing COVID-19 preventive and control efforts have considerably increased, the adoption of digital technology services has become ubiquitous across various sectors of society, and the realm of innovation and research dedicated to sustainable transformation driven by digital technologies and services is rapidly expanding. The demand for limited natural resources essential for agriculture has intensified due to increased competition, such as water, arable land, and energy, as the population expands. Resource shortages and disputes over access to these resources may result from this. It becomes essential to manage natural resources sustainably to maintain long-term agricultural productivity (Azam W. K., 2023). Changes in dietary choices, such as a rise in the demand for meat and dairy products, might result from population expansion. This change calls for more land and resources to produce animals as well as feed crops. Agricultural systems may be under additional stress from meeting these shifting nutritional needs. The effects of vegan, vegetarian, or meat-reduced diets on the environment have been examined in several research as stated by (Chan, 2022). The use of portfolios that represent individual dietary choices has not yet been studied in the literature to determine how dietary changes affect environmental effects. The land that may be used for purposes other than food may also change as people's diets do. Urbanization and population increase frequently go hand in hand, which causes agricultural land to be turned into cities. This may make arable land less accessible and increase the need for existing agriculture to produce more. Loss of farmland can have a detrimental influence on food security and agricultural productivity (Jiang, 2022).

Chapter 3: Research Methodology

This chapter elucidates the chosen research methodology and research strategy employed by the study. This chapter additionally explores the origins of the data. The research instrument employed by the study is also discussed in detail. This chapter also elaborates the procedure for collection of the data and its analysis.

3.1 Materials and Methods

In reaction to environmental shocks including drought, erosion, a perceived reduction in soil fertility, weeds, pests, and diseases, smallholder farmers decide to implement sustainable technology and practices. When deciding whether to adopt a sustainable agricultural practice or not, farmers' decisions may be influenced by resource availability, knowledge, and profitability. For this research project, a secondary research methodology was employed thorough examination of already existing literature and databases form the basis of knowledge. This study attempts to synthesize and advance our knowledge of agricultural sustainability for a smallholder farmer by utilizing the previously developed ideas, results, and interpretations by academics and industry professionals in Pakistan.

To achieve our first objective, we collated data from the databases of State Bank of Pakistan (SBP), Institute of Bankers Pakistan (IBP), Agricultural Marketing Information Service (AMIS).

For the first objective, we gathered residue management practices costs of Full Burning, Full Incorporation and Full Removal from (AHMED, 2019) and then applied Compounding from Time Value of Money to get their future values. The compounding formula can be expressed as follows:

$$FV = PV\,(1 + i)^{n}$$

(1)

where, FV = future value

PV = Present value

i = Interest Rate/Compounding Rate

n = number of years

We will be using residue management costs as PV, interest rate as given by the SBP policy rate, which is 22% for year 2023, which will be equal for all practices and then number of years will be 4, from year 2019 to 2023. Then we will get the compounded values for the year 2023.

Then we took data for five major crops of Pakistan that produces residue after harvesting (Agricultural Marketing Information Service (AMIS), 2023). This data included cost of production per acre, and it consisted of the following parts: Land preparation, seed and sowing, irrigation, fertilizer, dung, pesticide, weedicide, harvesting, transport, and other expenditures. It also provided data of Net Revenue and Net Profit.

We used these data for each crop efficiently to use profitability analysis. For this purpose, we first found out the per unit cost that incurred for each unit of input in the cost of production. We calculated,

Avg. Rate/Unit (Rs.) = Total cost of Inputs Used / Avg. Units of Input Used

To find the profitability of a farmer, we first found variable costs when all three residue management costs were added to each cost of production, separately.

Variable Costs = Cost of Production + Residue Management Costs 2023 (Full Burning, Full Incorporation, Full Removal)

Then we calculated the gross profit margins to find out how well a farmer turns its sales of agricultural produce into profits.

Gross Profit Margin = Revenue – Cost of Production

In the end, we used sensitivity analysis to identify how many variations in the cost of production and variable costs would impact the profitability of a smallholder farmer. We did two calculations: first for the total cost of production and variable costs and subsequently evaluate the gross profit margins.

Gross Profit Margin = Net Revenue – Cost of Production

Gross Profit Margin = Net Revenue – Variable Costs

We applied sensitivity analysis with the change in total cost of production and variable costs by decreasing 15%, 10% and 5% and then increasing the costs by 15%, 10%, and 5%. We get the data for the uncertain cost change for a farmer.

Chapter 4: Results and Discussions, and Conclusion

4.1 Results and Discussions

In today’s world, where issues with food security, population expansion, and the environment all combine to influence farming practices, it is necessary to achieve agricultural sustainability. Is achieving agricultural sustainability a luxury that only a few farmers can afford, mainly not smallholder farmers, or is it an unavoidable requirement for farmers all throughout Pakistan, a country with a strong agricultural heritage?

The goal of this thesis is to solve the complex web of costs influencing the profitabili ty of a smallholder farmer and necessity of sustainable agriculture practices in Pakistan. We used the methodology explained in the last chapter and got the following results.

Table 1: Residue Management Costs

Residue Management Practices	Cost 2019 (Rs./acre)	Cost 2023 (Rs./acre)
Full Burning	3,424.00	7,585.3
Full Incorporation	4,098.00	9,078.44
Full Removal	2,991.00	6,626.06

As we discussed in the earlier chapter, we took the residue management costs per acre from year 2019 that were stated by (AHMED, 2019). We applied compounding formula from the Time Value of Money, by placing the values in Present Value (PV) as the cost of residue management practices from 2019, “i” the interest rate from (State Bank of Pakistan (SBP), 2023), that was stated 22% for July 2023. The “n” in the for all three costs is same that is 4 years from year 2019 taking it as n=0, till year 2023, where n=4. We can see that our residue management costs per acre have increased significantly over time. Full Burning Cost has increased from Rs. 3,424/acre to Rs. 7,585.3/acre. Full Incorporation cost is highest as in year 2019 Rs. 4,098/acre and it increased to Rs. 9,078.44/acre, as it remained high in 2023. Full Removal cost was 2,991/acre and it increased to Rs. 6,626.06/acre in 2023.

Then the data we collated for five major crops of Pakistan (Crop Reporting Service (CRS), 2023), that leaves residue after harvest, and used it for the profitability analysis of smallholder farmer. First we have Wheat crop data.

Table 2: Wheat- Cost of Production

Total Cost of Production (COP) (Rs./acre)	69,999
Net Revenue (Rs./acre)	83,017
Net Profit (Rs./acre)	11,243
Variable Costs- Full Burning (Rs./acre)	77,584.30
Variable Cost- Full Incorporation (Rs./acre)	79,077.44
Variable Cost- Full Removal (Rs./acre)	76,625.06
Gross Profit Margin- Total COP (Rs./acre)	13,018
Gross Profit Margin- VC Full Burning (Rs./acre)	5,432.7
Gross Profit Margin- VC Full Incorporation (Rs./acre)	3,939.56
Gross Profit Margin- VC Full Removal (Rs./acre)	6,392

The used Total Cost of Production per acre, Net Revenue, and Net Profit. Then we calculated variable costs by adding each residue management cost to the total cost of production separately, and we got the following figures for variable costs of Full Burning= Rs. 77,584.31/acre, Full Incorporation= Rs. 79,077.44/acre and Full

Removal= Rs. 76,624.06/acre. From these variable costs we get an idea that how cost functions with residue management practice. Then calculated gross profit margin. The gross profit margin for total cost of production was highest, Rs. 13,018/acre and lowest for Full Incorporation, Rs. 3,939.56/acre. We also get the visual representation of the data for Variable costs for each residue management costs as follows:

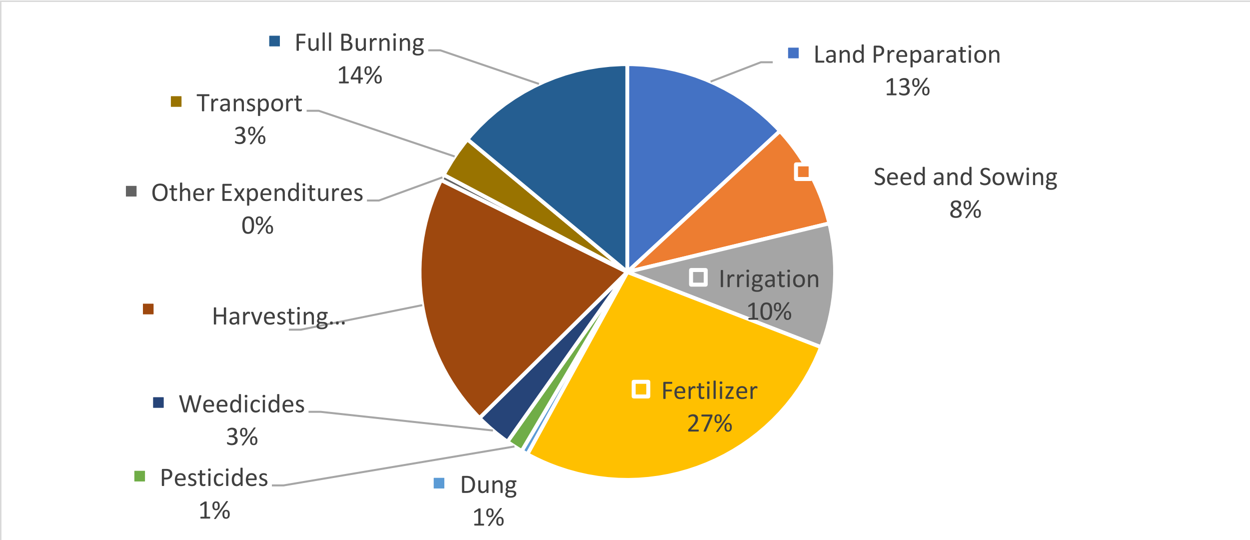

Figure 1: Wheat- Full Burning Variable Cost

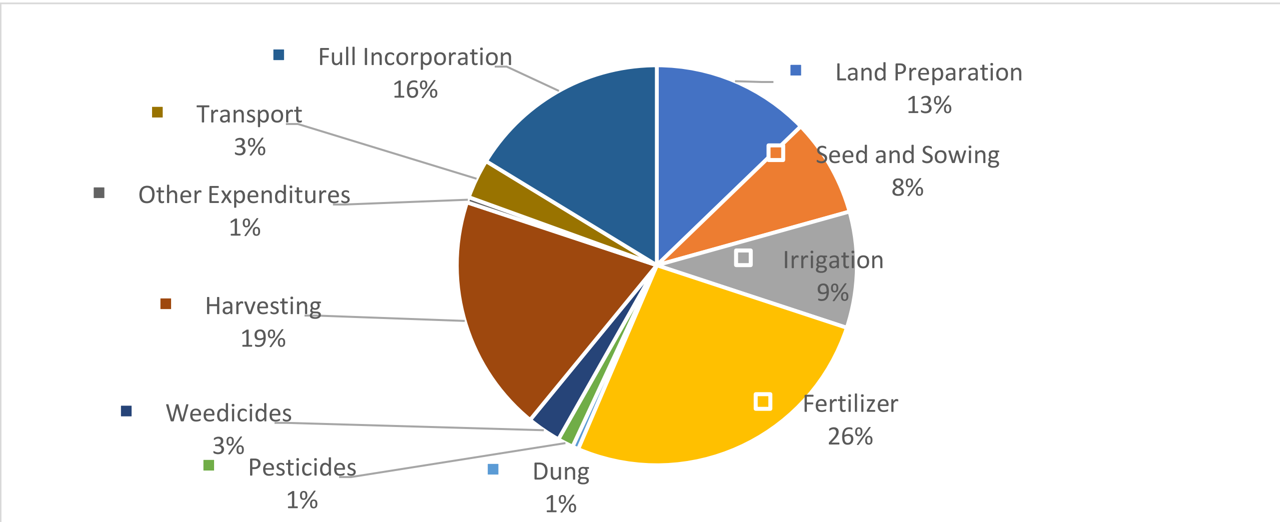

Figure 2: Wheat- Full Incorporation Variable Cost

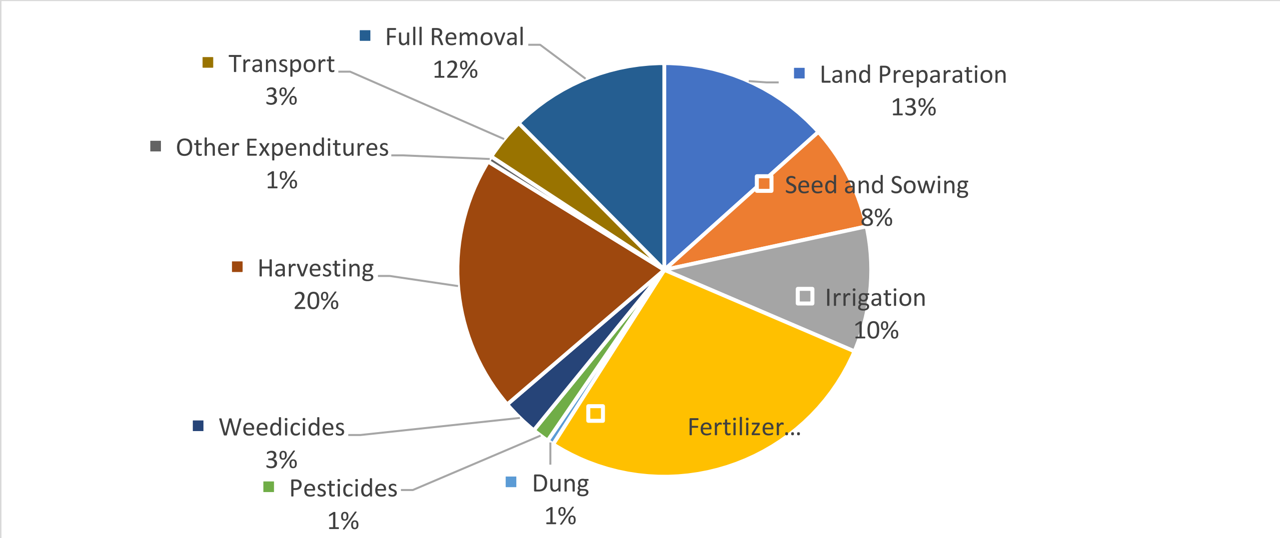

Figure 3: Wheat- Full Removal Variable Cost

Next, we have Rice crop data.

Table 3: Rice- Cost of Production

Total Cost of Production (COP) (Rs./acre)	46,773
Net Revenue (Rs./acre)	86,895
Net Profit (Rs. /acre)	40,122
Variable Costs- Full Burning (Rs. /acre)	54,358.30
Variable Cost- Full Incorporation (Rs. /acre)	55,851.44
Variable Cost- Full Removal (Rs. /acre)	53,399.06
Gross Profit Margin- Total COP (Rs. /acre)	40,122
Gross Profit Margin- VC Full Burning (Rs. /acre)	32,536.70
Gross Profit Margin- VC Full Incorporation (Rs. /acre)	31,043.56
Gross Profit Margin- VC Full Removal (Rs. /acre)	33,495.94

The total cost of production is Rs. 46,773/acre, we also got Net Revenue, and Net Profit values, Rs. 86,895/acre and Rs. 40,122/acre, respectively. Then we calculated the variable costs for each residue management practice. We received the following amounts: Full Burning Variable cost= Rs. 54,358.30/acre, Full Incorporation Variable Cost= Rs. 55,851.44/acre, and Full Removal Variable Cost= Rs. 53,399.06/acre. Then with this variable cost we calculated the gross profit margins with only total cost and with each variable costs. For Total COP, Gross Profit Margin is= Rs. 40,122/acre, for Full Burning= Rs. 32,536.70/acre, for Full Incorporation= Rs. 31,043.56/acre and for Full Removal= Rs. 33,495.94/acre. While the variable costs effect on the total cost of production can be seen clearly by the graphical representation.

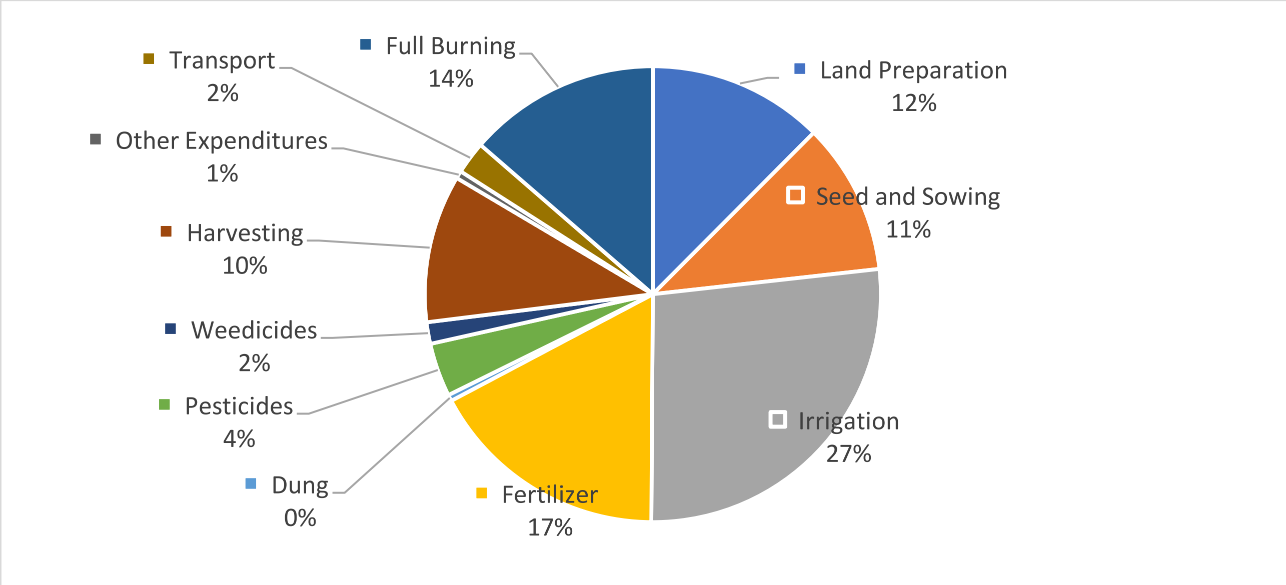

Figure 4: Rice- Full Burning Variable Cost

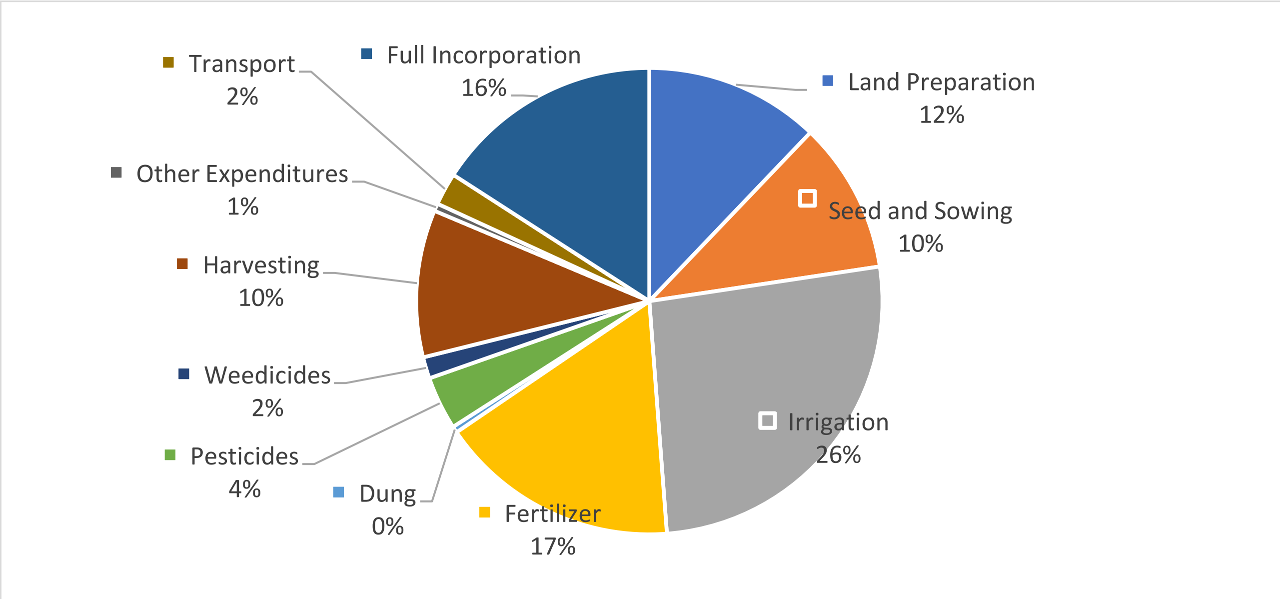

Figure 5: Rice- Full Incorporation Variable Cost

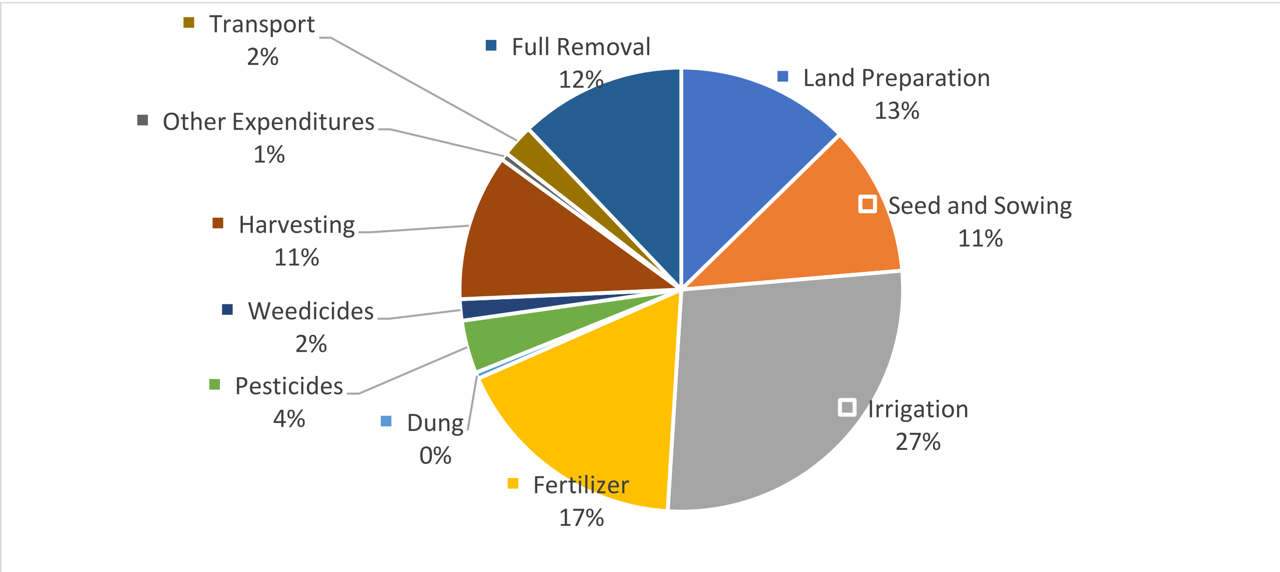

Figure 6: Rice- Full Removal Variable Cost

The third crop we got is Sugarcane.

Table 4: Sugarcane- Cost of Production

Total Cost of Production (COP) (Rs./acre)	117,955
Net Revenue (Rs./acre)	166,275
Net Profit (Rs./acre)	24,128

Variable Costs- Full Burning (Rs./acre)	125,540.30
Variable Cost- Full Incorporation (Rs./acre)	127,033.44
Variable Cost- Full Removal (Rs./acre)	124,581.06
Gross Profit Margin- Total COP (Rs./acre)	48,320
Gross Profit Margin- VC Full Burning (Rs./acre)	40,734.70
Gross Profit Margin- VC Full Incorporation (Rs./acre)	39,241.56
Gross Profit Margin- VC Full Removal (Rs./acre)	41,693.94

First, we have the total cost of production, net revenue, and net profit data for Sugarcane. Then we calculated the variable costs for each of the following residue management costs: Full Burning= Rs. 125,540.30/acre, Full Incorporation= Rs. 127,033.44/acre, Full Removal= Rs. 124,581.06/acre. In the end we calculated Gross Profit Margins for each cost. Total COP have Rs, 48,320/acre, Full Burning= Rs. 40,734.70/acre, Full Incorporation= Rs. 39,241.56/acre, Full Removal= Rs. 41,693.94/acre. Then we created visual representation of the variable costs for each residue management cost.

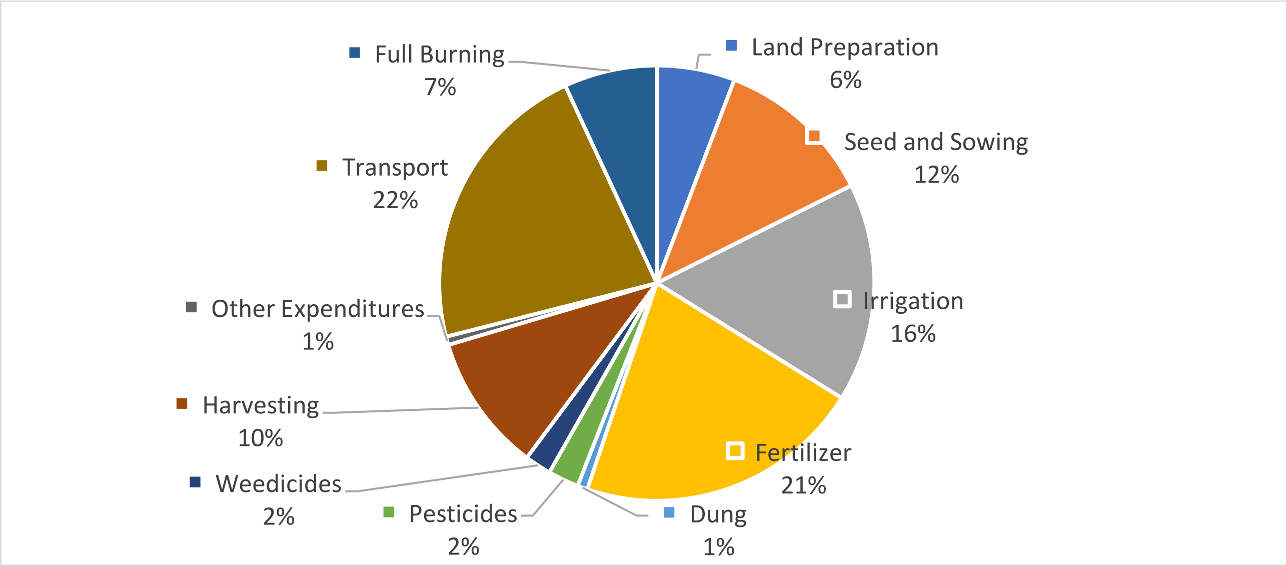

Figure 7: Sugarcane- Full Burning Variable Cost

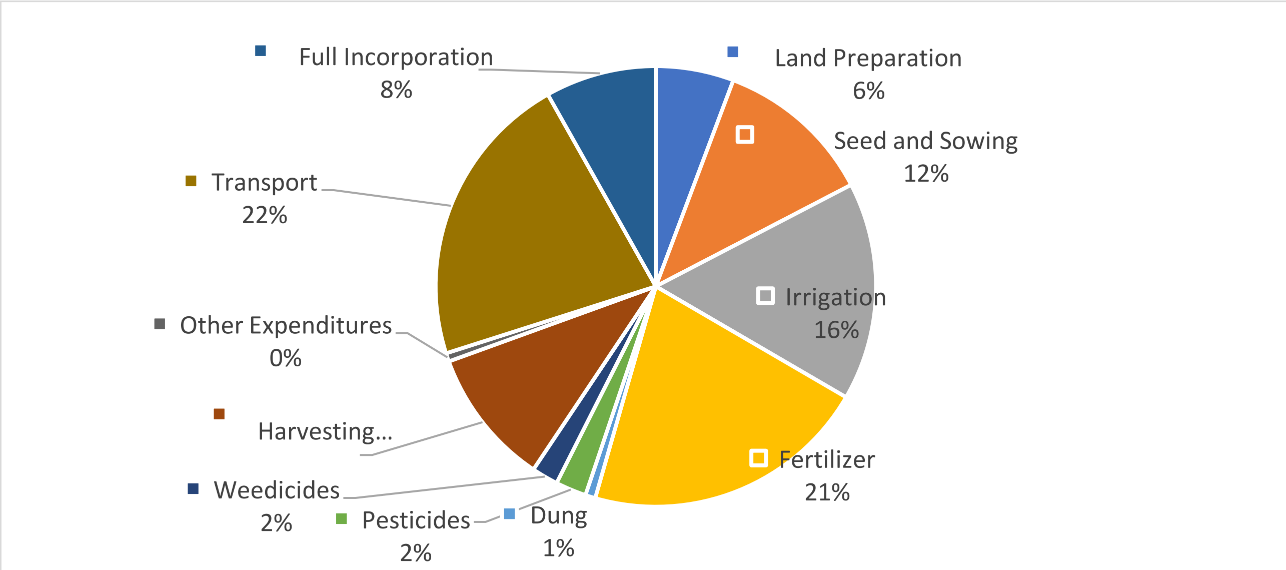

Figure 8: Sugarcane- Full Incorporation Variable Cost

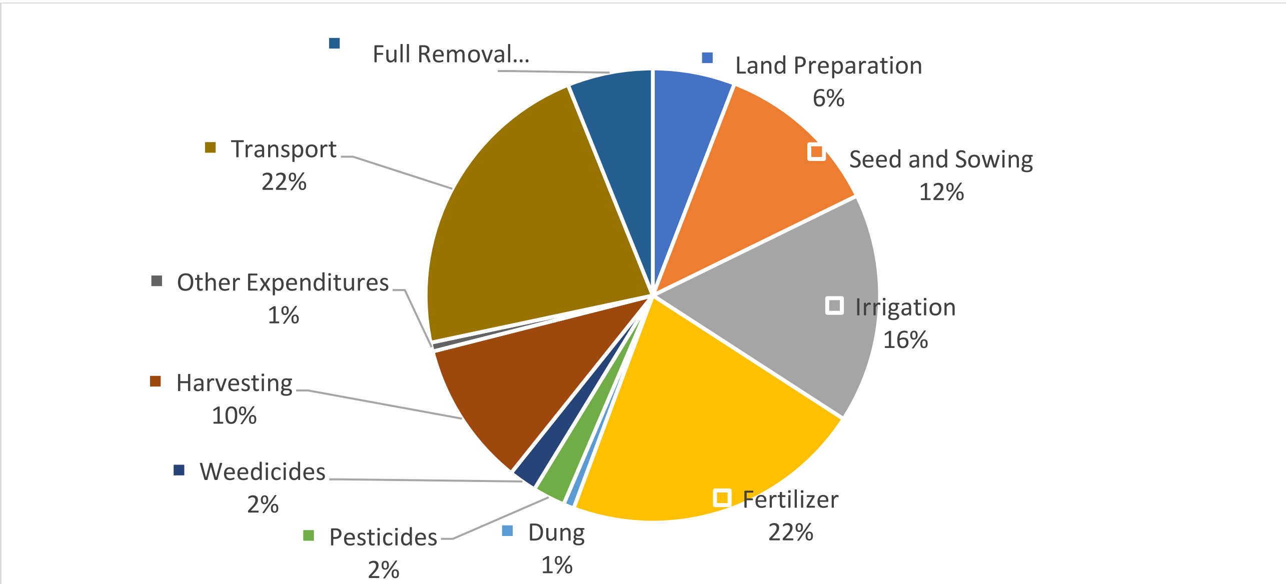

Figure 9: Sugarcane- Full Removal Variable Cost

The fourth crop data we have is for Cotton.

Table 5: Cotton- Cost of Production

Total Cost of Production (COP) (Rs./acre)	76,155
Net Revenue (Rs./acre)	100,272
Net Profit (Rs./acre)	24,117
Variable Costs- Full Burning (Rs./acre)	83,740.30

Variable Cost- Full Incorporation (Rs./acre)	85,233.44
Variable Cost- Full Removal (Rs./acre)	82,781.06
Gross Profit Margin- Total COP (Rs./acre)	24,117
Gross Profit Margin- VC Full Burning (Rs./acre)	16,531.70
Gross Profit Margin- VC Full Incorporation (Rs./acre)	15,038.56
Gross Profit Margin- VC Full Removal (Rs./acre)	17,490.94

We got the amounts for total cost of production, net revenue, and net profit per acre. We calculated the values of variable costs of residue management practices: Full Burning= Rs. 83,740.30/acre, Full Incorporation= Rs. 85,233.44/acre, Full Removal= Rs. 82,781.06/acre. Then gross profit margins were calculated for total cost and variable costs as: Rs. 24,117/acre, Rs. 16,531.70/acre, Rs. 15,038.56/acre, Rs. 17,490.94/acre, respectively. The data for Variable costs has been depicted by the graphical representation for better understanding.

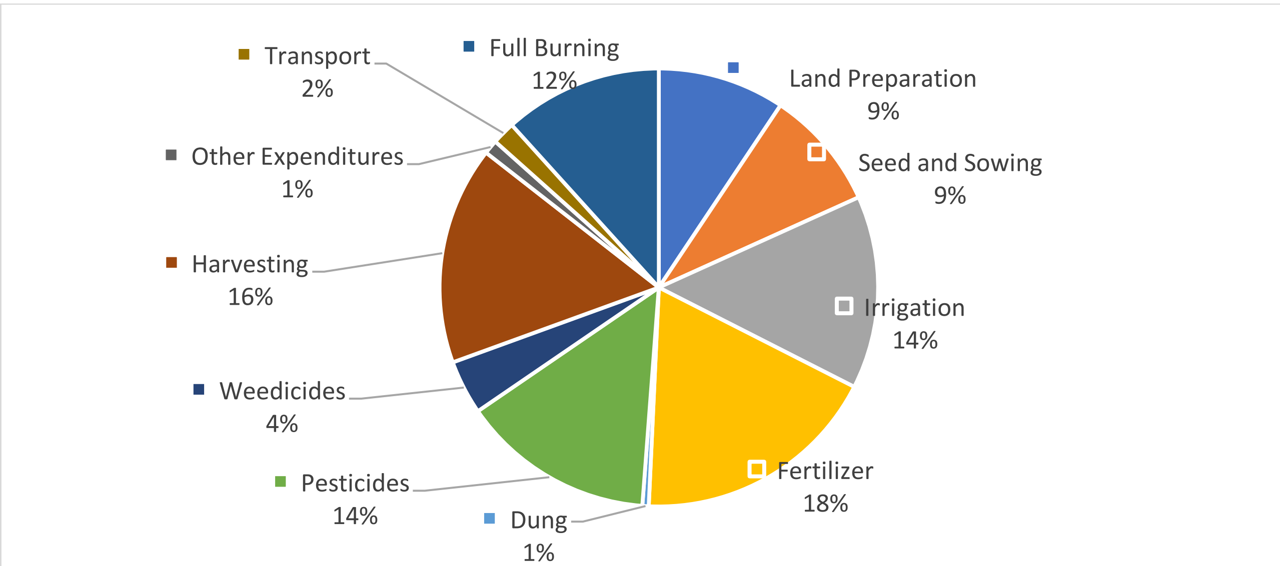

Figure 10: Cotton- Full Burning Variable Cost

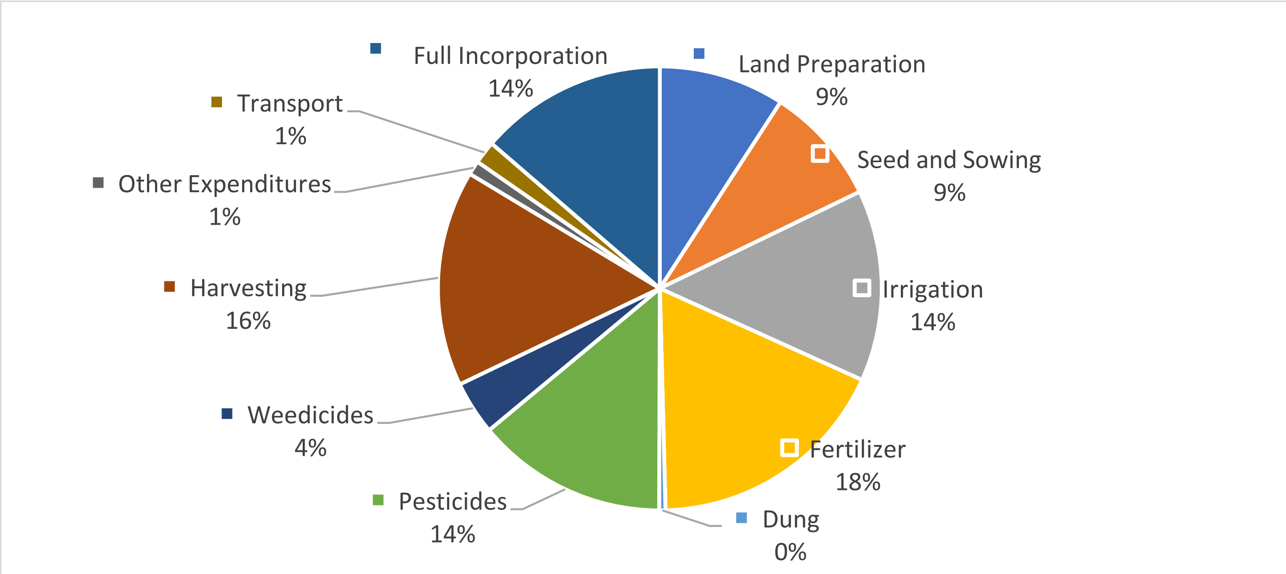

Figure 11: Cotton- Full Incorporation Variable Cost

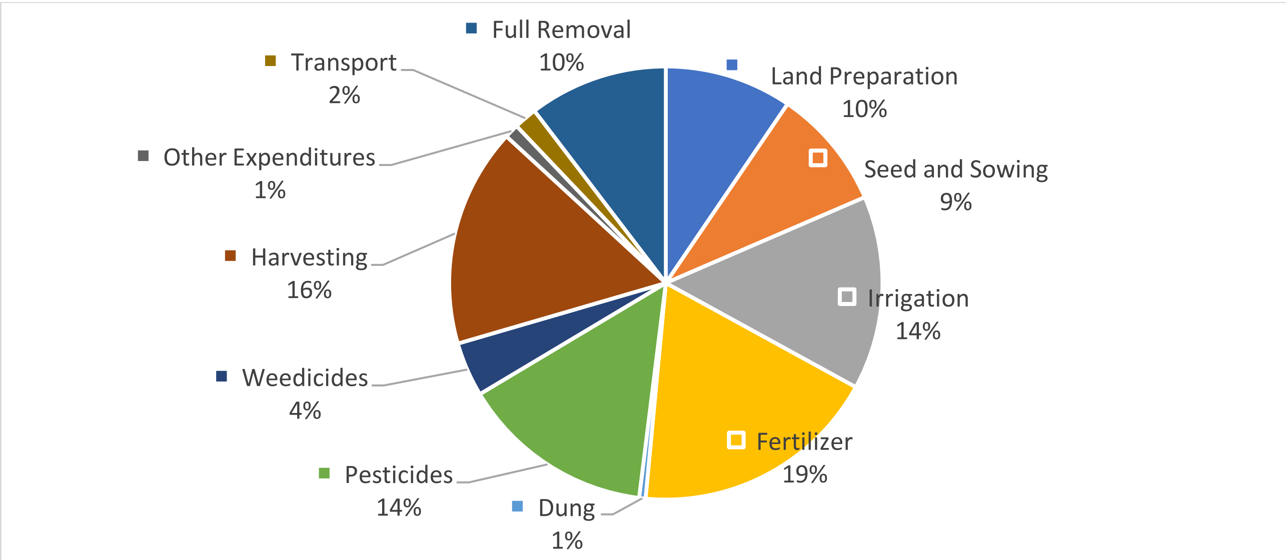

Figure 12: Cotton- Full Removal Variable Cost

The last major crop data we have is Maize, that leaves residue after harvest.

Table 6: Maize- Cost of Production

Total Cost of Production (COP) (Rs./acre)	78,580
Net Revenue (Rs./acre)	104,528
Net Profit (Rs./acre)	25,948
Variable Costs- Full Burning (Rs./acre)	86,165.30

Variable Cost- Full Incorporation (Rs./acre)	87,658.44
Variable Cost- Full Removal (Rs./acre)	85,206.06
Gross Profit Margin- Total COP (Rs./acre)	25,948
Gross Profit Margin- VC Full Burning (Rs./acre)	18,362.70
Gross Profit Margin- VC Full Incorporation (Rs./acre)	16,869.56
Gross Profit Margin- VC Full Removal (Rs./acre)	19,321.94

The data available for Maize is its total cost of production, net revenue, net profit. We first calculated the variable costs for full burning, full incorporation, full removal: Rs. 86,165.30/acre, Rs. 87,658.44/acre, Rs. 85,206.06/acre. Then we calculated the gross profit margins for total COP= Rs. 25,948/acre, Full Burning= Rs. 18,362.70/acre, Full Incorporation= Rs. 16,869.56/acre, Full Removal= Rs. 19,321.94/acre. Variable costs data is presented in the following pie charts.

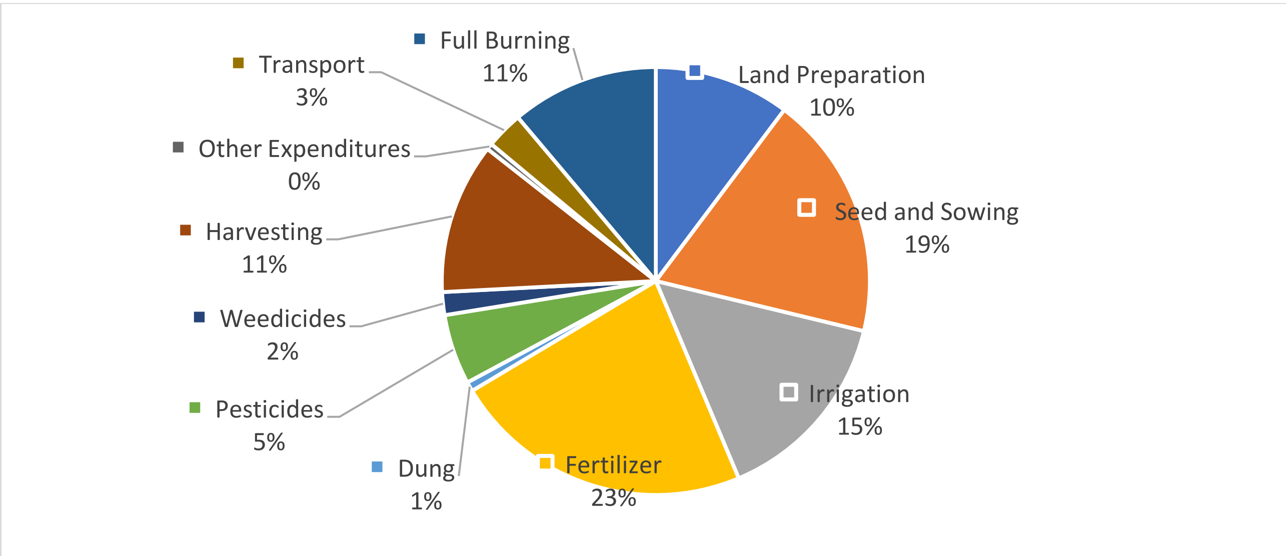

Figure 13: Maize- Full Burning Variable Cost

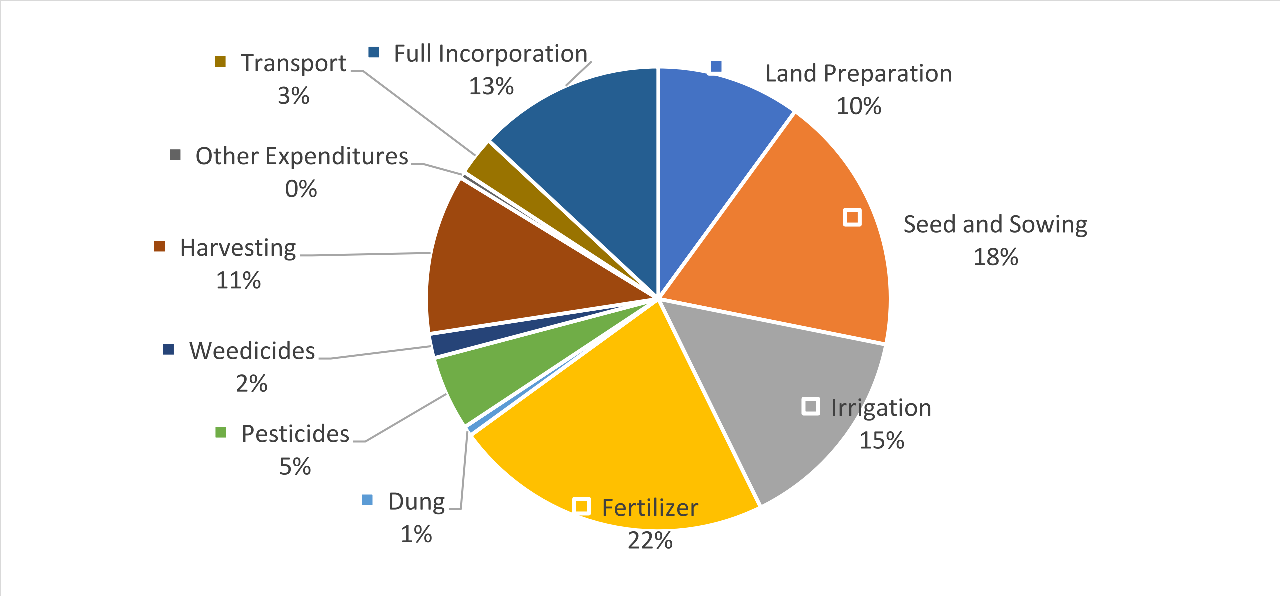

Figure 14: Maize- Full Incorporation Variable Cost

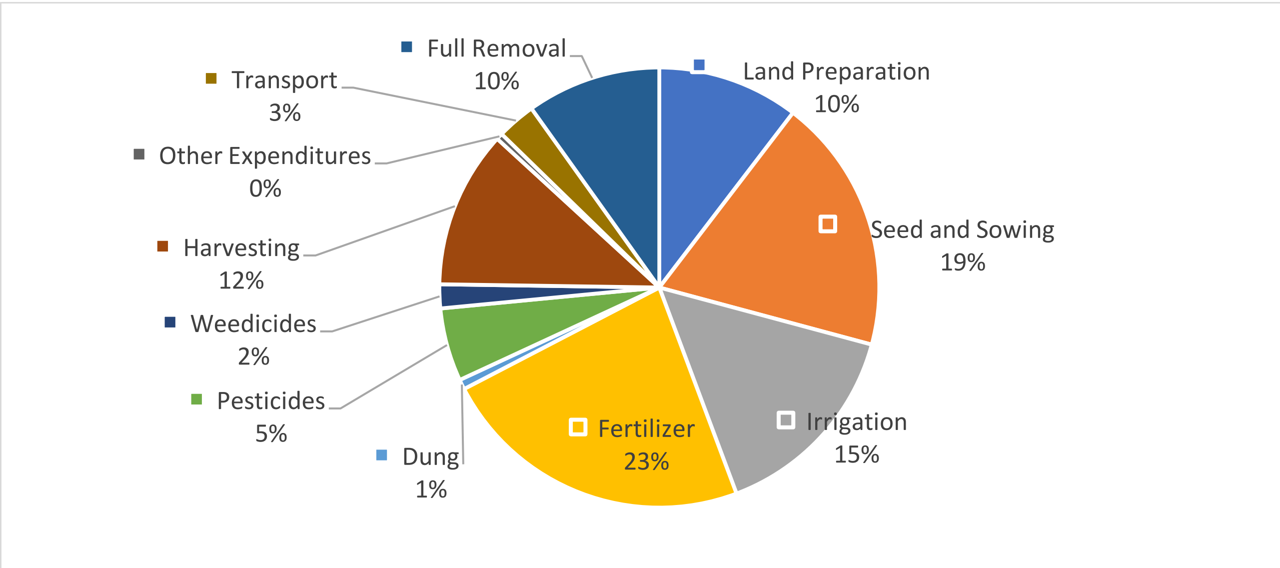

Figure 15: Maize- Full Removal Variable Cost

At last, we calculated sensitivity analysis to determine what would be the effect on the profitability of a smallholder farmer if the total cost and the variable costs decreased and increased by 15%, 10% and 5%.

Wheat	**-15%**	**-10%**	**-5%**	**5%**	**10%**	**15%**
COP	59,499.15	62,999.1	66,499.05	73,498.95	76,998.9	80,498.85
Full Burning	76,447	76,826	77,205	77,964	78,343	78,722
Full Incorporation	77,716	78,170	78,624	79,531	79,985	80,439
Full Removal	75,631	75,962	76,294	76,956	77,288	77,619

Rice	**-15%**	**-10%**	**-5%**	**5%**	**10%**	**15%**

COP	39,757.05	42,095.7	44,434.35	49,111.65	51,450.3	53,788.95
Full Burning	53,220.505	53,599.77	53,979.035	54,737.565	55,116.83	55,496.095
Full Incorporation	54,489.674	54,943.596	55,397.518	56,305.362	56,759.284	57,213.206
Full Removal	52,405.151	52,736.454	53,067.757	53,730.363	54,061.666	54,392.969
Sugarcane	**-15%**	**-10%**	**-5%**	**5%**	**10%**	**15%**
COP	100,261.75	106,159.5	112,057.25	123,852.75	129,750.5	135,648.25
Full Burning	124,402.505	124,781.77	125,161.035	125,919.565	126,298.83	126,678.095
Full Incorporation	125,671.674	126,125.596	126,579.518	127,487.362	127,941.284	128,395.206
Full Removal	123,587.151	123,918.454	124,249.757	124,912.363	125,243.666	125,574.969
Cotton	**-15%**	**-10%**	**-5%**	**5%**	**10%**	**15%**
COP	64,731.75	68,539.5	72,347.25	79,962.75	83,770.5	87,578.25
Full Burning	82,602.505	82,981.77	83,361.035	84,119.565	126,298.83	84,878.095
Full Incorporation	83,871.674	84,325.596	84,779.518	127,487.362	86,141.284	86,595.206
Full Removal	82,602.505	82,981.77	83,361.035	84,119.565	84,498.83	84,878.095
Maize	**-15%**	**-10%**	**-5%**	**5%**	**10%**	**15%**
COP	66,793	70,722	74,651	82,509	86,438	90,367
Full Burning	85,027.505	85,406.77	857,86.035	86,544.565	86,923.83	87,303.095
Full Incorporation	86,296.674	86,750.596	87,204.518	88,112.362	88,566.284	89,020.206
Full Removal	84,212.151	84,543.454	84,874.757	85,537.363	85,868.666	86,199.969

Table 7: Sensitivity Analysis- Total Cost and Total Variable Cost

It is seen that the total COP for all crops is increasing from -15% sensitivity to +15% sensitivity. The same trend ds followed by the variable costs of all crops: it is increasing with the increase in residue management costs.

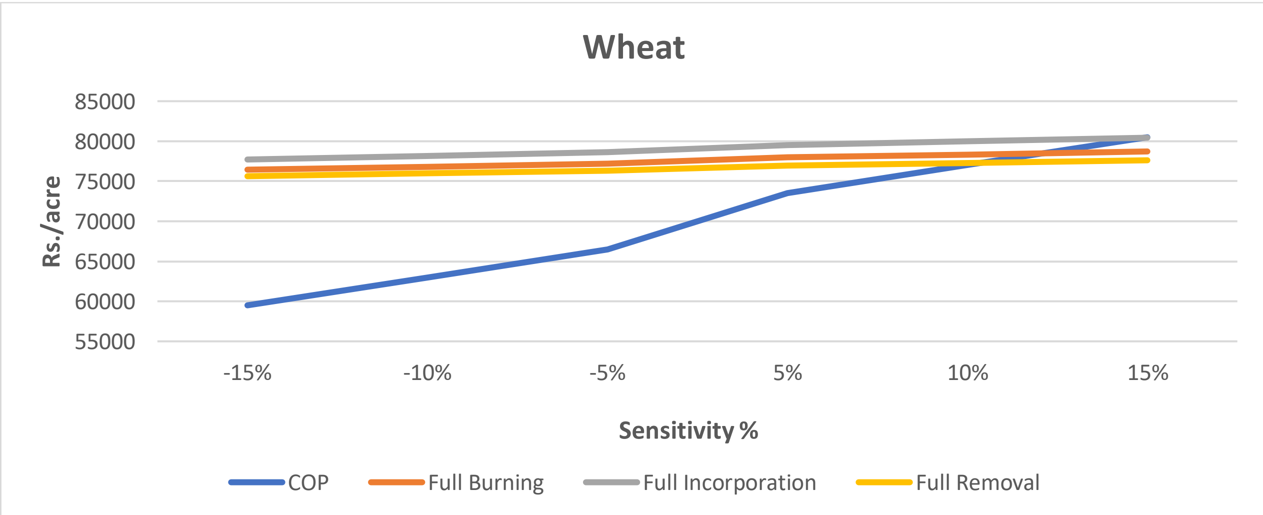

Figure 16: Sensitivity Analysis, Wheat- Total Cost and Variable Costs

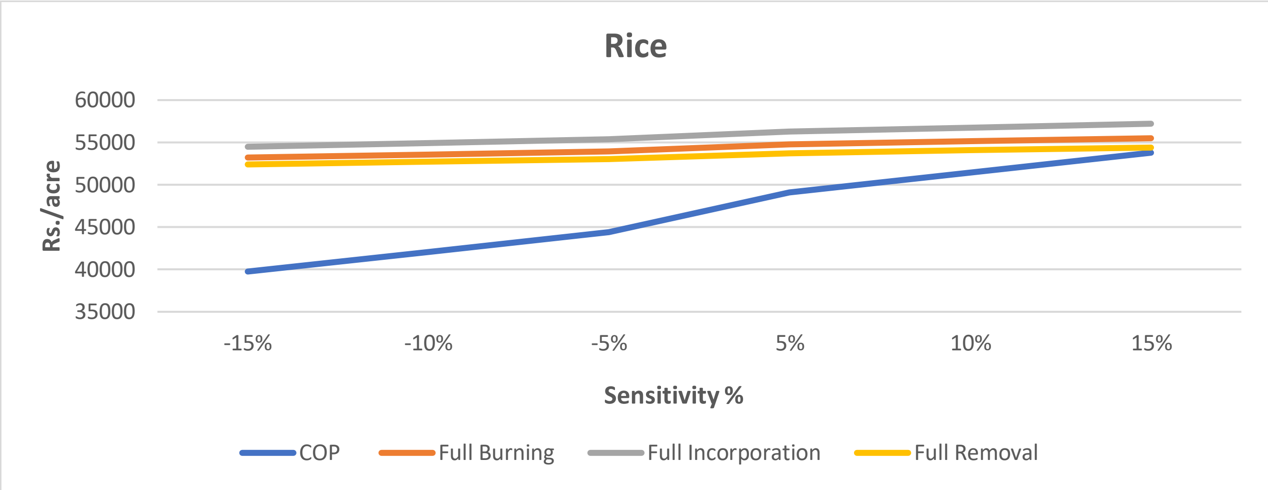

Figure 17: Sensitivity Analysis, Rice- Total Cost and Variable Costs

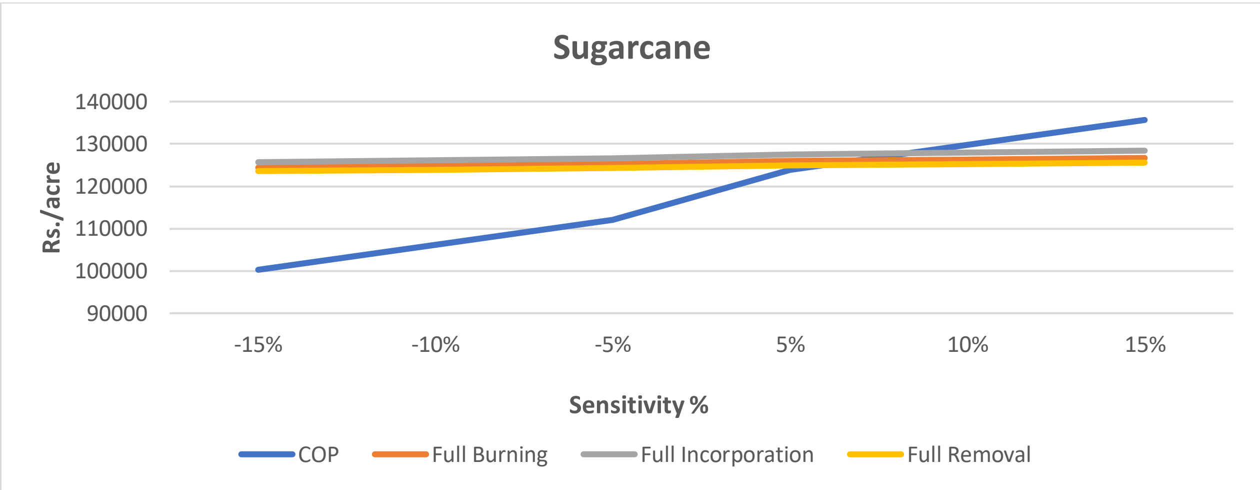

Figure 18: Sensitivity Analysis, Sugarcane- Total Cost and Variable Costs

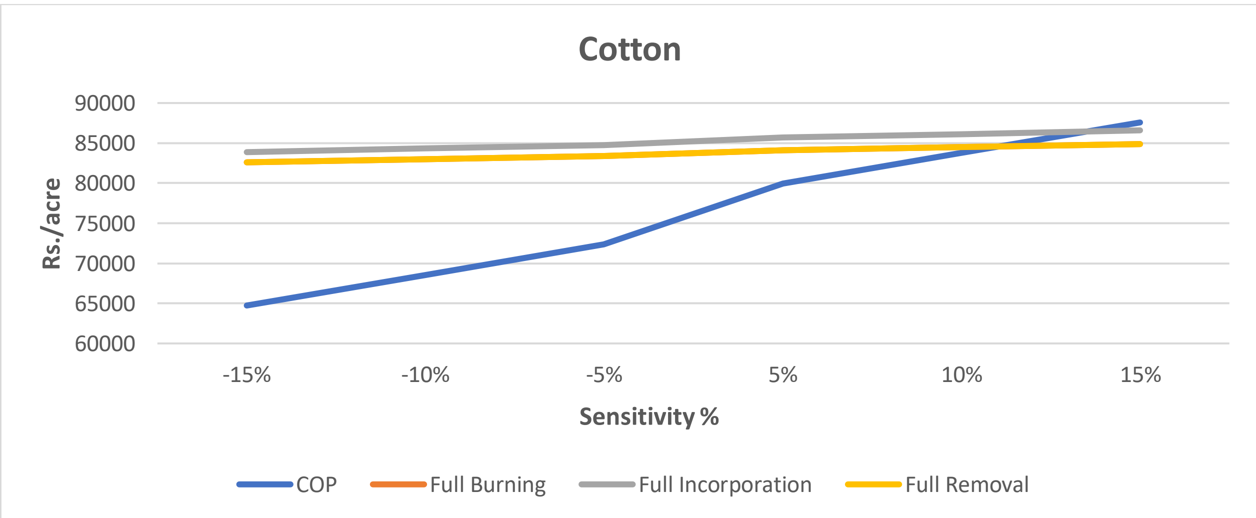

Figure 19: Sensitivity Analysis, Cotton- Total Cost and Variable Costs

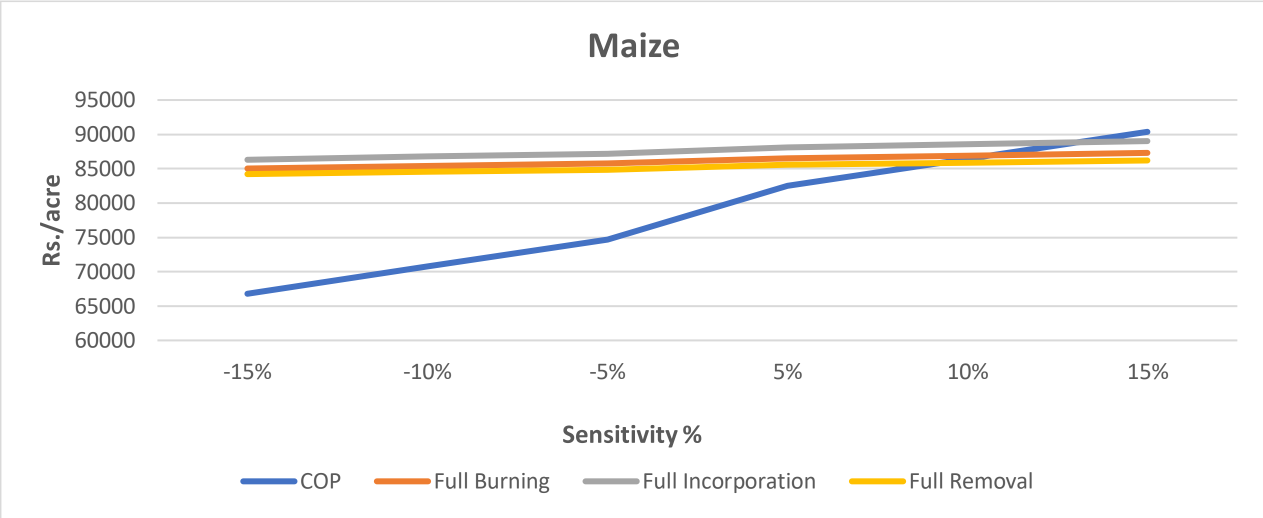

Figure 20: Sensitivity Analysis, Maize- Total Cost and Variable Costs

Next, we did sensitivity analysis for the gross profit margins with total cost and the variable costs. First, we used the same costs as above for the sensitive analysis of gross profit margins. The results are discussed in table further.

Table 8: Sensitivity Analysis- Gross Profit Margin

Wheat	**-15%**	**-10%**	**-5%**	**5%**	**10%**	**15%**
COP	23,518	20,018	16,518	9,518	6,018	2,518
Full Burning	6,570	6,191	5,812	5,053	4,674	4,295
Full Incorporation	5,301	4,847	4,393	3,486	3,032	2,578
Full Removal	7,386	7,055	6,723	6,061	5,729	5,398
Rice	**-15%**	**-10%**	**-5%**	**5%**	**10%**	**15%**
COP	47,137.95	44,799.3	42,460.65	37,783.35	35,444.7	33,106.05
Full Burning	33,674.495	33,295.23	32,915.965	32,157.435	31,778.17	31,398.905
Full Incorporation	32,405.326	31,951.404	31,497.482	30,589.638	30,135.716	29,681.794
Full Removal	34,489.849	34,158.546	33,827.243	33,164.637	32,833.334	32,502.031
Sugarcane	**-15%**	**-10%**	**-5%**	**5%**	**10%**	**15%**
COP	66,013.25	60,115.5	54,217.75	42,422.25	3,6524.5	30,626.75
Full Burning	41,872.495	41,493.23	41,113.965	40,355.435	39,976.17	39,596.905
Full Incorporation	40,603.326	40,149.404	39,695.482	38,787.638	38,333.716	37,879.794
Full Removal	42,687.849	42,356.546	42,025.243	41,362.637	41,031.334	40,700.031
Cotton	**-15%**	**-10%**	**-5%**	**5%**	**10%**	**15%**
COP	35,540.25	31,732.5	27,924.75	20,309.25	16,501.5	12,693.75
Full Burning	17,669.495	17,290.23	16,910.965	16,152.435	15,773.17	15,393.905

Full Incorporation	16,400.326	15,946.404	15,492.482	14,584.638	14,130.716	13,676.794
Full Removal	18,484.849	18,153.546	17,822.243	17,159.637	16,828.334	16,497.031

Maize	-15%	-10%	-5%	5%	10%	15%
COP	37,735	33,806	29,877	22,019	18,090	14,161
Full Burning	19,500.495	19,121.23	18,741.965	17,983.435	17,604.17	17,224.905
Full Incorporation	18,231.326	17,777.404	17,323.482	16,415.638	15,961.716	15,507.794
Full Removal	20,315.849	19,984.546	19,653.243	18,990.637	18,659.334	18,328.031

With this analysis it is observed that the total COP gross profit margin for each crop is decreasing as the sensitivity increases in a trend from -15% to +15%. This is the result of the increasing total costs. The same trend is followed by the gross profit margins with the variable costs decreasing. It is clearer with the graphical representation.

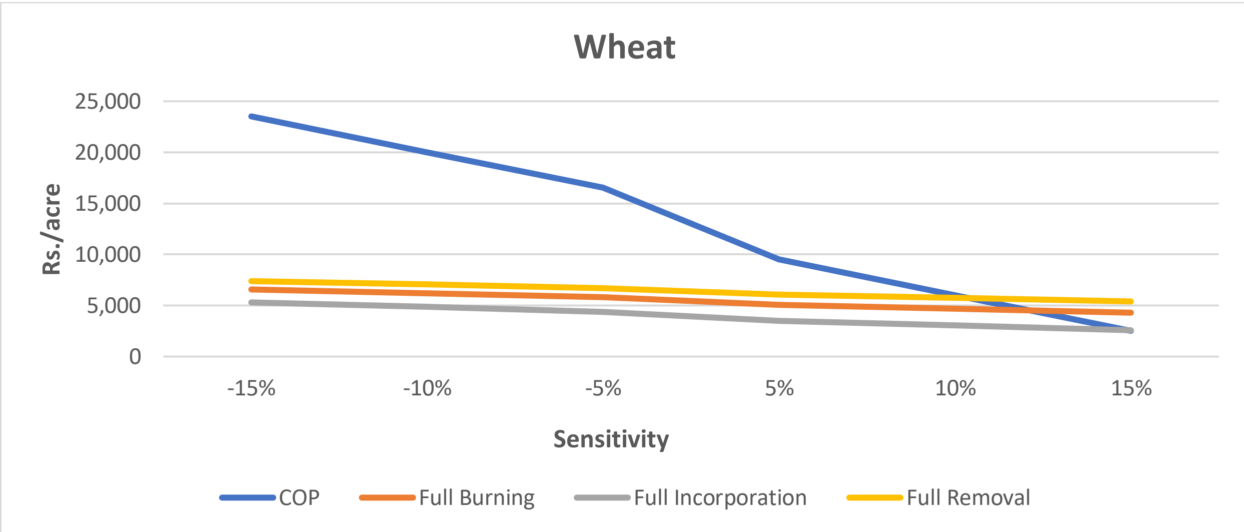

Figure 21: Sensitivity Analysis, Wheat- Gross Profit Margin

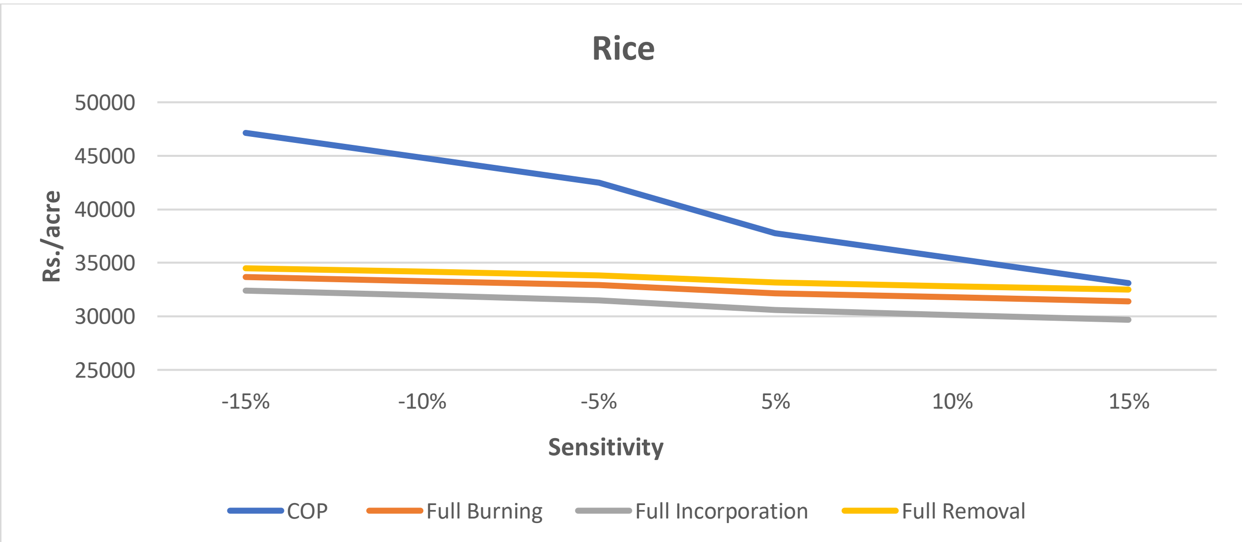

Figure 22: Sensitivity Analysis, Rice- Gross Profit Margin

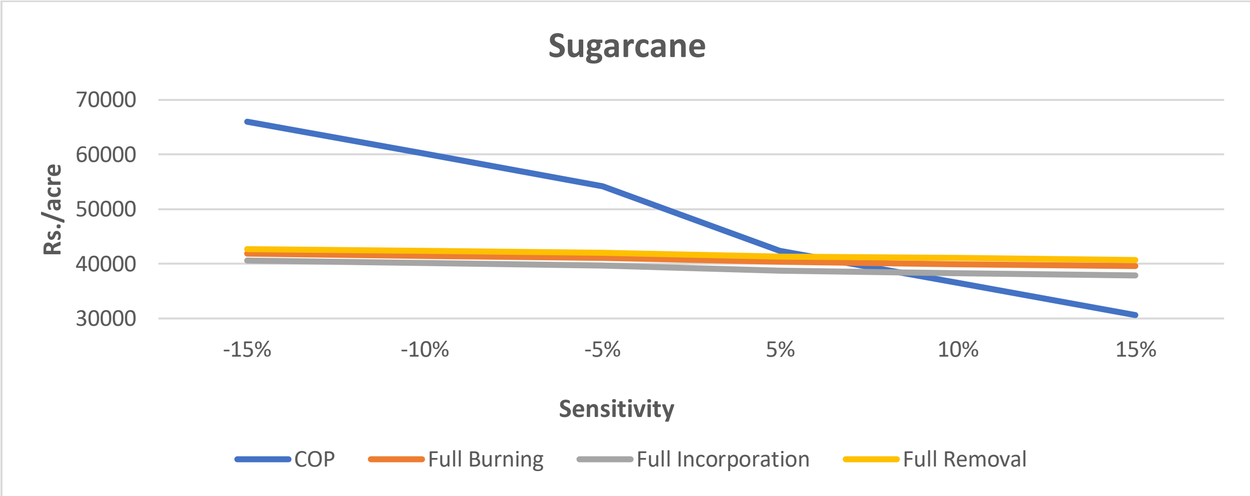

Figure 23: Sensitivity Analysis, Sugarcane- Gross Profit Margin

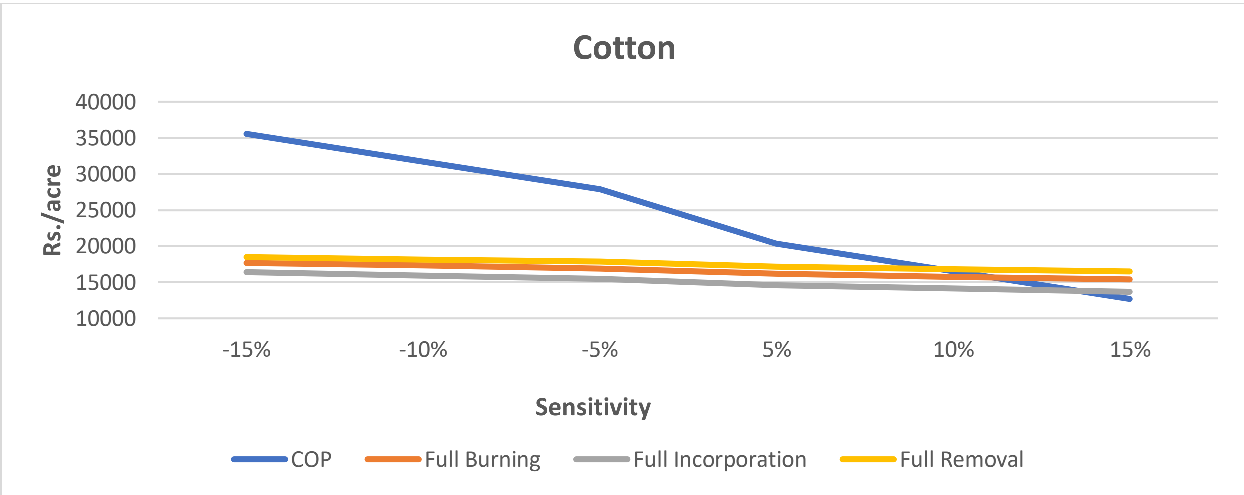

Figure 24: Sensitivity Analysis, Cotton- Gross Profit Margin

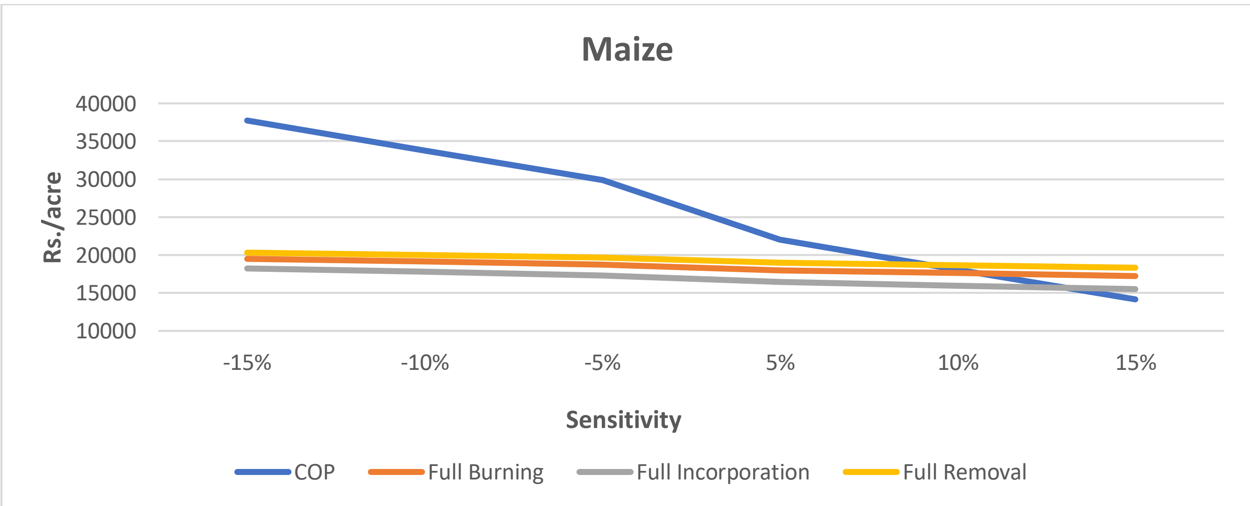

Figure 25: Sensitivity Analysis, Maize- Gross Profit Margin

4.2 Conclusion

In this study, we set out to explore the vital question of whether achieving agricultural sustainability in Pakistan is a luxury or a necessity for smallholder farmers. While existing research has highlighted the significance of agricultural sustainability in terms of environmental benefits, improved agricultural practices, and enhanced food security for consumers, our investigation has delved into a critical dimension often overlooked: the impact on the profitability of smallholder farmers themselves.

Our findings have unveiled a reality. Despite the undeniable advantages of sustainable agricultural practices, such as reduced input costs, enhanced soil health, and diversified income sources, the prevailing conditions in Pakistan's agricultural sector do not readily facilitate the adoption of these practices among smallholder farmers. It has become evident that the major crops cultivated in Pakistan are often not financially rewarding for these farmers, rendering the pursuit of sustainability a difficult challenge rather than a feasible opportunity.

As we reflect on our research, we conclude that achieving agricultural sustainability in Pakistan, particularly for smallholder farmers, is, in essence, a luxury. The complex web of economic constraints, limited access to resources, and market dynamics combine to make it exceedingly difficult for these farmers to prioritize sustainability over immediate financial survival. To address this issue, comprehensive policy reforms, increased access to resources, and market interventions are imperative, as sustainability should not be a privilege but a fundamental necessity for all stakeholders in Pakistan's agricultural landscape.

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