Measuring environmental impacts of Potato-maize-rice and potato-maize-maize cropping systems of Pakistan using carbon footprint and life cycle assessment approach

Thesis submitted for the award of degree

Master of Science in Agribusiness Management

Submitted by

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I, Irshad Ullah hereby declare that the research work entitled **"Measuring environmental impacts of Potato-maize-rice and potato-maize-maize cropping systems of Pakistan using carbon footprint and life cycle assessment approach"** is entirely my own work. The content of this dissertation is original and has not been submitted in whole or in part for consideration for any other degree or qualification in this or any other University. Any materials or information obtained from external sources have been appropriately acknowledged and referenced.

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DEDICATION

I dedicate this work to my supportive family who always believed in me and supported me in each step during the study period.

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Abstract

To meet the world's food demand agriculture sector must maximize the utilization of resources. However, it has been observed that agriculture sector contributes a substantial amount of GHGs. To mitigate climate change, global agriculture is under the face of huge social and economic challenges. That is why nations must find out the most suitable cropping systems in terms of their environmental impacts and contribution towards food security. Thus, to identify the most efficient and sustainable farming systems in Pakistan, here we used a life cycle assessment (LCA) approach. The Potato-Maize-Rice (PMR) and Potato-Maize-Maize (PMM) cropping systems are prevalent in Punjab Pakistan, however, the studies on their environmental impacts are seldom. Here we measured the environmental impacts of two cropping systems by using Life Cycle Assessment approach. Additionally, the financial aspect is taken into consideration together with the environmental assessment. The assessment reflects the guidelines set forth by the CML baseline, and it uses the OpenLCA software to analyze the data. Global Warming (Kg CO2-eq), Human toxicity (K1, 4-DCB-eq), Ionizing radiation (DALYs), Eutrophication (Kg NO-eq), Photochemical oxidation (kg formed ozone), Ozone depletion (kg CHC-11 eq) and Land use (m2a) are the impact categories to construct the difference between PMR and PMM cropping system. The results signify that PMR has significantly higher negative impacts on the environment than PMM cropping system. The PMM system outperforms the PMR system in terms of economic profitability. The economic viability emphasizes that how crucial it is to choose crops that are sustainable for agricultural systems, while keeping in view the environmental impacts. Overall, this study highlights the importance of using an extensive LCA framework when assessing the effects of agricultural practices on the environment. The findings support the preference for the PMM cropping system compared to PMR cropping system in terms of minimizing environmental impact and increasing economic viability. This study contributes to continuing discussion about sustainable agriculture systems and provides insightful information for farmers, researchers, and policy makers working for environmental sustainability and food security.

Keywords: Life cycle assessment, carbon footprint, potato, maize, rice

Chapter 1: Introduction

One of the most pressing global problems of the twenty-first century is climate change that is being fueled by an enormous rise in anthropogenic greenhouse gas (GHG) emissions (Andress, Nguyen, and Das 2011). The energy sector, as well as operations related to agriculture, forestry, and land use, were significant contributors to the century's enormous rise in GHG emissions (Anshassi, Smallwood, and Townsend 2022). The agriculture industry continues to expand to meet the food security as the world's population rises (Ntiamoah and Afrane 2008). Likewise is growing concern over how agricultural methods affect the environment. In the context of Pakistan's agriculture sector, the carbon footprint of different crops and cropping systems remains to be understudied (Mitchell et al. 2022.). A comprehensive Life Cycle Assessment (LCA) of various crops and cropping systems is urgently required to evaluate their environmental consequences, including resource depletion, effects on human and ecosystem health, and, particularly, carbon emissions. The entire environmental impact of processes, products, or actions can be assessed with the helpful instrument of life cycle assessment.

In Pakistan, there is lack of evidence that the efficient policies exists and in order to make effective policies regarding the carbon emissions and other pollutants of the environment, the database and results and comparisons must be known that which crop and which cropping system emits more carbon emissions into the environment. Pakistan agriculture GHG emissions are not known properly and cannot being found in the literature. To reduce the gap between accurate inventory data base and results, the research must be taken and accurate inventory must be gathered in order to make effective government policies and decision making regarding product life cycle. And to reduce the GHG emission from the unwanted practices through which farmers get their yield in order to create a safer world.

Cropping system include maize, rice and potato crops. Under various agro-climatic conditions, maize is a promising crop in both Asia and the rest of the world. In Asia, 3.55 million hectares of rice and maize are grown as part of the rice-maize cropping system (Lal et al. 2019). Next to maize, rice (*Oryza sativa* L.) is one of the three most significant food crops. Nearly 165 million hectares are used to grow rice worldwide, and 88% of the crop is grown in flooded soil (Fuhrmann et al. 2018). PMR cropping system is practiced in different regions of Pakistan. A common secondary element in many cropping systems in Asia, Africa, and America is the potato. This crop is very appealing to resource-poor farmers due to its ability to produce stable yields in a short growing season, multiple uses as human food, livestock feed, and raw material for starch-based industries, as well as its comparably lower input requirements (Nedunchezhiyan et al. 2012). Potato itself can generate more dry matter per unit area and per unit time. Its function in cropping systems varies from location to location. This crop is a catch crop or a fallow crop in some cropping systems. In some other places, it might be used as a crop for green manure, livestock feed, or even erosion control (Nedunchezhiyan et al. 2012). The opportunity to increase potato acreage and production during the winter months is provided by intercropping potatoes with crops that are compatible with them (Singh et al. 2015). The benefit of maize is that it can be used to feed livestock and poultry. Thus, the paddy rice and maize cropping system is increasingly used in Southeast Asia to produce food and fodder (Singh et al. 2015). The FAO's "Save and Grow" strategy for the sustainable intensification of cereal production has recently used the rotation of maize and paddy rice as an example (Rajaram and Pretty 2016). The most significant new cropping system in South Asia is the double cropping of rice and maize. 3.5 million ha in Asia is currently occupied by rice-maize systems. The rice-fallow-maize-fallow sequence are used to grow the maize and rice crops. Maize can also be grown in the dry season from November to March, while rice can be grown during the monsoon season from July to October (Kadiyala et al. 2015).

Cropping system followed by different crops tend to give benefits in different forms. Farmers tend to make a portfolio in terms of crop diversification and following a certain cropping system to increase nutrients in soil and to have different options for income during the year and to reduce the external risks. Numerous agronomic advantages of intercropping include the diversification of dietary choices, the effective use of nutrients, and barriers against pests and diseases (Ibrahim et al. 2021). The inclusion of more crops in a cropping system can increase productivity and profitability, but this practice frequently leads to rising energy inputs, particularly non-renewable energy, which worsens ecological imbalance (Babu et al. 2020).

Climate change and the disruption of biogeochemical cycles have been brought on by the enormous rise in anthropogenic greenhouse gas (GHG) emissions during the 20th century. The energy sector has been regarded as the primary source of global GHG emissions in 2018, followed by agriculture, forestry, and other land uses (Hemingway, Vigne, and Aubron 2023). The manufacturing of goods and machinery, the transportation of materials, and direct and indirect soil greenhouse gas emissions are just a few of the diverse ways that the agriculture sector significantly contributes to global carbon emissions (Hillier et al. 2009). Pakistan's agriculture industry contributes an important and substantial percentage of the country's GDP (Fatima et al. 2019). Although Pakistan agriculture plays an important role in the gross domestic product, however it also plays a major role in the carbon emission and leave an impact on the environment. Agriculture's scope is expanding to meet the diversity of dietary preferences as human population increases (Yu et al. 2023). Pakistan's percentage of greenhouse gas emissions emitted through different agricultural related activities is not well documented in the literature. Therefore, in order to make effective policies regarding agricultural related activities in Pakistan, the percentage impact of different practices needs to be known.

The most popular vegetable consumed globally is potatoes (Rajaram and Pretty 2016). Potato cultivation may cause soil degradation and water contamination if chemical fertilizers and pesticides are used. Carbon emissions and air pollution can both rise as a result of transporting potatoes and potato products (Uchino et al. 2012). Around the world, rice is a staple food for billions of people (Assefa et al. 2021). However, the production of rice has an impact on the environment because it uses up land and water and emits greenhouse gases (Fuhrmann et al. 2018). Chemical pesticides and fertilizers can also degrade the soil and contaminate the water when used in rice farming (Porpavai et al. 2011). The evidence regarding environmental limitations and effects on smallholder maize production is inconsistent. It has been frequently observed that many environmental issues, such as biodiversity loss, are more generally related to the agro ecology or farming systems in which maize is grown than to the maize crop itself (Cui et al. 2019).

The goal of agricultural policies are to create beneficial, long-term rules for the promotion of effective agricultural practices that will ensure food security, create jobs, supply the raw materials for all agro-based industries, and generate foreign exchange.

As the concentration of greenhouse gases in the atmosphere rises, the environment is disrupted, resulting in severe consequences (Larsen and Hertwich 2010). The measurement of the greenhouse gas emission of various products, bodies, and processes expressed as their carbon footprints takes place globally in accordance with the maxim that only what is measurable is controllable (Ekins and Barker 2001). Although the methods for calculating carbon footprints are still being developed, they are becoming a crucial tool for managing greenhouse gas emissions (Peters 2010). The idea of carbon foot printing has permeated and is currently being commercialized in every aspect of life and the economy, but there is little consistency in the definitions and calculations of carbon footprints across studies (Pandey et al. 2011). With an adequate methodological base, carbon footprints and embodied carbon contribute significantly to the formulation of policies (T. Gao, Liu, and Wang 2014). It is necessary to promote and regulate the widespread application of carbon footprints using currently available knowledge. Carbon footprints at the product level can help consumers influence their own climate-friendly behavior and assist governments in creating policies that do not create unintended incentives (Haines and Dora 2012). Cities and regions can use carbon footprints to implement regional policies that aid in achieving broad national goals (Fenner et al. 2018). Designing fair and effective climate agreements that prevent problems from being transferred to other administrative regions can be aided by knowledge of national carbon footprints (Peters 2010).

A tool called life cycle assessment can be utilized to determine how much of an impact a process, product, or activity has on the environment over the course of its entire life cycle. Today's LCA users are a diverse group of people who want to assess their processes, activities, or products in the context of the life cycle (Roy et al. 2009). Life cycle assessment is now well established, is used to evaluate resource depletion issues as well as the effects that agricultural production has on the environment and human health (van der Werf, Knudsen, and Cederberg 2020). The decision-makers may find the agricultural life cycle assessment to be a useful resource. An important challenge is finding representative and sufficient data to create life cycle inventories at that level (Sinisterra-Solís et al. 2023).

1.1 Objectives

I. To calculate and compare the carbon footprint of potato-maize-rice and potato-maize-maize cropping system.
II. Measurement of overall environmental impacts (resource depletion, human and ecosystem health) of potato-maize-rice and potato-maize-maize cropping systems.

Chapter 2: Literature Review

2.1 Global Climate Change

Global climate change refers to the long-term changes in Earth's climate system, including its temperature (Arnell et al. 2019), precipitation, and weather patterns that have occurred as a result of human activities such as burning fossil fuels and deforestation (Skendžić et al. 2021). Human-induced global climate change is primarily caused by the emission of greenhouse gases (Le Quéré et al. 2019), such as carbon dioxide, methane, and nitrous oxide (Hillier et al. 2011), which trap heat in the Earth's atmosphere and cause the planet to warm up (Al-Ghussain 2019). This warming is leading to a range of impacts on our planet (Hong et al. 2019), including rising sea levels (Short and Neckles 1998), more frequent and severe heatwaves, droughts, and floods, changes in precipitation patterns (Baldos, Hertel, and Moore 2019) , and shifts in ecosystems and wildlife distribution.

By establishing carbon emission scenarios with regard to changes in population, economy, technology, energy, and land use, and agriculture, future climate can be predicted (Stewart, Wang, and Nguyen 2012). Global climate change is an issue which is a threat to mankind (Okolie et al. 2023). Climate change affects mankind in many ways, particularly for the most vulnerable regions worldwide, where catastrophic droughts and starvation already drive population relocation. Extreme weather events become more intense due to climate change, which causes migration and displacement. As a consequence, climate refugees are receiving a growing amount of attention worldwide (Berchin et al. 2017).

While addressing the issue of climate change innovative strategies requirement can be seen, mitigating greenhouse gasses (Al-Ghussain 2019), offering sustainable technologies (Huisingh et al. 2015), reducing deforestation (Allen and Barnest 1985), promoting energy efficiency and promoting sustainable ways of transportation(Andress, Nguyen, and Das 2011). The impacts of global climate change are wide-ranging and include both natural and human systems (Yalew et al. 2020). Some of the impacts of climate change include more frequent and severe weather events(Afshar et al. 2020) , rising sea levels, changes in ecosystems and wildlife distribution (Duane, Castellnou, and Brotons 2021), food and water insecurity, health impacts, economic impacts, and social and political impacts (Babu et al. 2020).

Some of the specific solutions that have been proposed to address global climate change include implementing policies and regulations to reduce greenhouse gas emissions (Ekins and Barker 2001), promoting clean energy and energy efficiency (Hanna, Sawyer, and Petersen 2012), investing in low-carbon transportation and infrastructure (Acar and Dincer 2020), protecting forests and other natural systems (Jackson et al. 2008), and supporting international cooperation and collaboration on climate issues(Ortiz et al. 2021). Ultimately, addressing global climate change will require sustained and concerted action on a global scale (Nunez et al. 2019).

2.2 Drivers of Global warming and Climate Change

Global warming and climate change are primarily driven by human activities that release large amounts of greenhouse gases into the atmosphere (J. Gao et al. 2023). Insufficient supplies of energy threaten the world's economy, nevertheless it has become increasingly clear that the main cause of global warming is the ongoing extraction and burning of fossil fuels currently or higher rates (Nel and Cooper 2009). Deforestation and land use changes account for global greenhouse gas emissions (Allen and Barnest 1985). When forests are cut down or burned, the carbon stored in trees and other vegetation is released into the atmosphere (Veldkamp et al. 2020). In addition, deforestation reduces the ability of forests to absorb and store carbon dioxide, further exacerbating the problem (Landholm et al. 2019).

Trees release moisture into the atmosphere through evapotranspiration, which has the effect of cooling the surroundings (Allen and Barnest 1985). This cooling impact is lessened and regional temperatures may rise when big wooded areas are removed. The meteorological systems, particularly the intensity and distribution of rainfall, can be disturbed by the changed patterns of temperature (Veldkamp et al. 2020). For it to maintain the water flow in balance, forests are essential. Their roots aid in the absorption and storage of rainwater, replenishing the supply of groundwater and controlling river and stream movement (Silva et al. 2021). When trees are cut down, fewer gallons of rainwater is intercepted, resulting in greater surface runoff, more soil erosion, and less water availability. Droughts, reduced agricultural output, adverse effects on ecological systems, and adverse impacts on human populations can all result from these shifts throughout the water cycle (Landholm et al. 2019).

Loss of biodiversity as a consequence of deforestation has an impact on climate change. There are countless different plant and animal species found in forests. Ecosystems are less resistant to adapt to changing climatic circumstances as a result of biodiversity loss (Nunez et al. 2019). In addition, an array of organisms, including plants and insects, are found in forests and play a vital role in processes including nitrogen cycling and pollination. Another impact of these structures being disturbed on climate regulation (Gabel et al. 2016).

Agriculture is mainly responsible for higher percentage of global greenhouse gas emissions (Ortiz et al. 2021). The main sources of emissions in agriculture are the production of livestock and the use of synthetic fertilizers (El Chami, Daccache, and El Moujabber 2020). Livestock produce large amounts of methane, a potent greenhouse gas, through their digestive processes (Hemingway, Vigne, and Aubron 2023). Synthetic fertilizers, meanwhile, release nitrous oxide, another potent greenhouse gas (Hao et al. 2020).

Agriculture produces a significant amount of greenhouse gas emissions. Methane (CH_4) and nitrous oxide (N_2O), which are strong greenhouse gases, are released as a result of the production of livestock (especially cattle), the growing of rice paddies, livestock production, with the use of synthetic fertilizers (Fuhrmann et al. 2018). Methane is a result of enteric fermentation in animals that ruminate as well as the anaerobic breakdown of organic waste in flooded rice fields. Utilizing nitrogen-based fertilizers and managing animal manure both produce nitrous oxide. Both of these gases have a lot more potential for warming that carbon dioxide (Hao et al. 2020). Deforestation is frequently needed in order to create more agricultural land, especially in places like Southeast Asia and the Amazon rainforest. Huge amounts of carbon dioxide held in trees are let out when forests are cut down for agriculture, raising atmospheric CO_2 levels (Landholm et al. 2019). Additionally, the loss of forests affects the vital ecosystem services that that they offer and reduces the planet's ability to absorb CO_2 (Veldkamp et al. 2020).

Soil deterioration and can be attributed to unsustainable agricultural practices such extensive mono and excessive tilling. Erosion causes soil to release stored carbon as carbon dioxide to the atmosphere (Musafiri et al. 2020). Soils that have been damaged also have less organic matter, which further decreases their capacity for storing carbon. The depletion of fertile topsoil due to soil erosion lowers agricultural output and forces the expansion of agricultural land into other areas (Wang et al. 2021).

Water resources are extensively utilized by agriculture, and poor water management practices can hasten global warming. Fossil fuels are frequently used to power large-scale agriculture, which produces greenhouse gas emissions (Gleick 2014). Furthermore, ineffective irrigation methods might waste water, aggravating the problem of water scarcity. Agricultural fields which are flooded or have poor drainage may release methane, a powerful greenhouse gas (Allan et al. 2020).

Contemporary farming frequently uses synthetic fertilizers, which release nitrous oxide into the atmosphere and promote global warming. Pollution of nitrogen in bodies of water can result from the excessive application and ineffective usage of fertilizers (Lv et al. 2020). Eutrophication, which results in depleted in oxygen "dead zones" where aquatic life cannot thrive, can be brought on by nitrogen runoff into rivers and oceans. Nitrous oxide emissions may be produced in these areas by the microbial decomposition of extra nitrogen (Fuhrmann et al. 2018). Development of farming frequently ends in the creation of massive concentrated from various natural ecosystems. The shift in land use decreases biodiversity, disrupts biological processes, and deteriorates the natural environments of many species. Ecosystems become less resilient as a result of biodiversity loss, thereby raising their susceptibility to the impacts of climate change (Banerjee and Punekar 2020).

Transportation causes emissions that directly comes from the use of cars, trucks, and airplanes (Acar and Dincer 2020). As the global population continues to grow and become more urbanized (Benis and Ferrão 2017), demand for transportation is expected to increase (Acar and Dincer 2020), leading to even greater greenhouse gas emissions (Andress, Nguyen, and Das 2011). Petroleum-based fuels like petrol, diesel and aviation gasoline are used extensively by the majority of autos, including automobiles, trucks, vessels, aero planes and trains. Carbon dioxide (CO_2) and other greenhouse gases are released in the environment during the burning of these fossil fuels. Due to the greenhouse effect it produces and the way it retains heat, CO_2 is an important driver in global warming (Andress, Nguyen, and Das 2011).

Compared to other economic sectors, the transport industry has a comparatively high carbon footprint. Engines with internal combustion (ICEs) are frequently seen in fossil fuel-powered cars, which is mostly to blame for this (Gulnora Mardievna 2021). Although the efficiency of fuel has increased, these advantages are countered by the sheer number of cars on the road and the increasing demand for transport (Acar and Dincer 2020). Higher emissions are due to of an increasing amount of automobiles on the road, particularly in urban areas. Congestion and longer travel dimensions as a result of the quick increase in vehicle ownership and use have increased energy consumption and greenhouse gas emissions (Andress, Nguyen, and Das 2011).

Land authorization is frequently necessary for the creation of transport infrastructure, such as roads, highways, and airports, which results in deforestation. Deforestation allows carbon that has been stored in trees to be released, and exacerbates climate change. In addition, it causes ecosystem services that help regulate the climate to be disrupted for biodiversity to be lost (Ding, Steubing, and Achten 2023). A substantial amount of the world's trade is carried out by maritime shipping, which is primarily reliant on heavy fuel oils with high Sulphur contents (Gissi et al. 2021). These fuels cause pollution in the atmosphere and climate change by releasing significant volumes of Sulphur dioxide, or SO2, and nitrogen oxides. Furthermore, the marine sector's reliance on fossil fuels increases CO2 emissions (Cabral et al. 2019).

Planet is warmed up due to the above mentioned human activities, which leads to cause a lot of risks in our planet. In order to mitigate the problem of climate change, primarily the need to reduce the greenhouse gas emissions is necessary.

2.3 Impacts of Climate Change

Global emergencies such as extreme weather, air pollution, decreased food supply, rising sea levels, or the spread of epidemics brought by climate change have turned become key tests for nations attempting to expand their economies in an environmentally friendly manner. The substantial quantity of carbon emissions generated by human activity is an element in this occurrence (Shi and Yin 2021). Climate change has created global impacts on our planet, affecting many things such as ecosystem (Zheng et al. 2019). Global temperatures are rising due to climate change, which are leading to leading to heat waves, droughts, and more frequent and intense wildfires (Duane, Castellnou, and Brotons 2021). As temperatures rise, glaciers and ice sheets are melting, causing sea levels to rise (Allan et al. 2020). This is the threat to coastal communities and ecosystems, and can lead to more catastrophic events such as floods (Courchamp et al. 2014).

According to the annual study of Weather, Climate and Catastrophe Insight, natural catastrophes alone cost the global economy USD 225 billion in losses in 2018 and since 2016 the costs from natural calamities have exceeded USD 200 billion annually (Weather, Climate and Catastrophe Insight 2023). Incidences connected to the weather are responsible for almost 95% of these losses;

cyclones, floods, and droughts are the main culprits and are directly related to climate change (Arora 2019).

Climate change is causing changes to ecosystems around the world, with some species moving to new areas as temperatures shift, and others becoming endangered or extinct (Román-Palacios and Wiens 2020). Climate change is having a range of impacts on human societies, including food and water scarcity (Armengot et al. 2021), increased disease transmission (Woodward and Samet 2018), displacement of people due to sea level rise or extreme weather events, and damage to infrastructure and property (Stewart, Wang, and Nguyen 2012).

Climate change tend to have high costs for repairing the infrastructure and have an impact on economy. (Schweikert et al. 2014) , yield loss due to fluctuations in weather patterns (Kjellstrom, Holmer, and Lemke 2009). Climate change is the reason why people are migrating from harsh weather affected areas and it is a security threat for people. (Kaczan and Orgill-Meyer 2020).

Climate change and human health are directly proportional to each other and the problem of climate change has major consequences on human health (Hong et al. 2019). Greenhouse gas emissions are the major cause behind climate change and all the activities driven that emits GHGs are directly responsible for human health, ecosystem health and resource depletion and to mitigate climate change transitions of operations are required (Zhang 2010). In order to create a huge impact, the thinking needs to come from all over the world either it is a small business or individual or government (Stewart, Wang, and Nguyen 2012).

Globally, there are wide-ranging and intricate effects of climate change on environmental systems, human communities, and the economy (Roson 2012). It will take a coordinated global effort to solve this problem, with the participation of all stakeholders in lowering greenhouse gas emissions and adjusting to the changes now under progress (Gössling, Scott, and Hall 2013)

2.4 The drivers of global warming and climate change

Climate change and the disruption of biogeochemical cycles are results of the 20th century's enormous rise in anthropogenic GHG emissions.(Hemingway, Vigne, and Aubron 2023). Over 14% of the world's GHG emissions are solely attributable to agricultural operations. Over the past 50 years, GHG emissions from "agricultural, forestry, and other land use" have almost doubled, and forecasts show that they will increase even more by 2050 (Shabir et al. 2023). Extreme weather and climate change are already warning signs of the imbalances generated by global warming in natural systems. Mountainous snow cover, permafrost, and glaciers are melting, and the ice sheets in Greenland, Antarctica, and the Arctic are suffering a negative mass balance, which is driving the sea level to rise at a rate of 3 mm per year (Pandey, Agrawal, and Pandey 2011). Moreover, the use of scarce natural and energy resources in intensive agriculture has a negative impact on the environment, as does the rising release of GHGs (Andress, Nguyen, and Das 2011). The production of crops for human use is thought to be responsible for roughly 21% of all GHG emissions, or about 2.8 Gt of CO2eq (Rana, Bux, and Lombardi 2023). In 2018, it is believed that the world's second-largest source of greenhouse gas emissions, after the energy industry, comes from agriculture, forestry, and other land uses (Hemingway, Vigne, and Aubron 2023). The total amount of key food crops produced globally increased by 22.5% from 1996 to 2018, while use of chemical fertilizer, pesticides, and power climbed by 17.6%, 54.1%, and 86.3%, respectively (Xian et al. 2023).

The CO_2 gets released into the atmosphere when fossil fuels are burned for transportation, energy, and manufacturing (Andress, Nguyen, and Das 2011). According to projections, this factor is responsible for 65-70% of the world's greenhouse gas emissions (Acar and Dincer 2020). Methane is released through an array of human endeavors, such as rearing animals, growing rice, mining coal, and generating oil and gas (Weller et al. 2015). It is responsible for 15–25% of the world's greenhouse gas emissions. When forests are cut down or burned, the carbon dioxide that has been deposited there gets released into the atmosphere, causing climate change. Around 10-15% of the world's greenhouse gas emissions are brought about by deforestation and changes in land use (Jackson et al. 2008).

Hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and Sulphur hexafluoride (SF6) belong to the powerful greenhouse gases released by specific industrial operations. These gases have a great potential for warming regardless of whether they are present in lesser quantities. 5–10% of the world's emissions of greenhouse gases come from manufacturing operations (Anshassi, Smallwood, and Townsend 2022). The primary sources of nitrous oxide emissions include industrial and agricultural processes, as well as the combustion of fossil fuels and solid waste. About 5% of the world's greenhouse gas emissions are caused by it (Wang et al. 2021).

2.5 Approaches of impact assessment

There are several approaches to impact assessment of drivers of global warming and climate change such as quantitative modeling, risk assessment and life cycle assessment approach (Amirahmadi et al. 2022). Life cycle assessment approach is widely used around the world when doing environmental impact assessment (Ding, Steubing, and Achten 2023). Impact assessment approaches can be useful for evaluating the potential impacts of climate change and reaching to a end result (Schmidt 2008). Life cycle assessment involves assessing the environmental impacts of a product, service, or process throughout its entire life cycle, from raw materials, production and to disposal (Vázquez-Rowe et al. 2013). Life cycle assessment can be beneficial in identifying greenhouse emissions and later for reducing greenhouse gas emissions and other environmental impacts (Anshassi, Sackles, and Townsend 2021).

2.6 Life cycle assessment (LCA) methodology

Although the idea of LCA started in the 1960s and many attempts to create LCA methodology have been undertaken since the 1970s, it has received significant attention from those working in the field of research on the environment since the 1990s (Roy et al. 2009). LCA is a helpful instrument for measuring the environmental impacts caused by production while developing processes, products, and policies. As a consequence, LCA has become known as the most widely used technique for achieving these objectives. It might additionally act as a helpful guide for choosing the right combination of production inputs to lessen the effect of production systems on the environment (Nikkhah et al. 2019). Life cycle assessment (LCA), also referred to as a "from cradle to grave" analysis, is an instrument that can be used to analyses the environmental impact of a product, process, or activity throughout the duration of its life cycle or lifetime (Roy et al. 2009).

LCA includes system boundary and that is recognizing of what is and what is not included in the process of life cycle assessment (Costa et al. 2020). For example, the production of raw materials, manufacturing of products, transportation, use and disposal of the products (Berton et al. 2021). The second step of LCA involves collecting data on all inputs (e.g., raw materials, energy usage, and water, methods etc.) and outputs (e.g., the emissions/carbon footprints) associated with the product or process being studied (Jacquemin, Pontalier, and Sablayrolles 2012). Impact assessment is third step in life cycle assessment and this steps elaborates the data collected in the inventory analysis is then used to calculate the environmental impact of the product, service or activity. This is typically done by assigning environmental impacts in terms ecosystem health, human health and resources depletion due to different categories of services provided, activities performed or the final product (Fan et al. 2022). Lastly, the results of the impact assessment are interpreted and evaluated to determine the overall environmental impact of the product or process (Roy et al. 2009). Various industries prefer using Life cycle assessment methodology because it quantifies large amount of regularities in order to evaluate the environmental impact of products. (Schmidt 2008).

According to ISO 14040:2006, the LCA study should go through four phases. In defining goals and the scope of the undertaking, the functional unit (FU) looked at system boundaries and level the Life Cycle Assessment (LCA) is defined in detail (Costa et al. 2020). In order to achieve the objectives for this specific study, the life cycle inventory (LCI) analysis phase entails gathering the necessary input/output data with regard to the investigated system (Vázquez-Rowe et al. 2013). The life cycle analysis and interpreting phase, at which the results of the inventory and impact assessment phase are summarized and discussed, and recommendations and conclusions are formed in line with the objective and scope, is intended to offer information for the life cycle impact assessment phase (LCIA) results of a product's system through assessing the impacts in order to comprehend their environmental importance (Armengot et al. 2021).

Agricultural LCA could determine possible compromises and the most environmentally friendly system solutions while evaluating the full impact on the environment of agricultural operations and products over its complete life cycles (Ding, Steubing, and Achten 2023). LCA is a useful tool for measuring the environmental effects of manufacturing while developing procedures, goods, and policies. As a result, LCA emerged as the approach most commonly employed for these goals. It might also serve as a helpful guide to choose the right mix of producing inputs to reduce the manufacturing system's environmental impact (Armengot et al. 2021).

Production systems can be examined with LCA in terms of several repercussions, like eutrophication, acidification, and global warming. LCA technique has been used up to this point to assess and control the environmental effects of diverse production industries (Anshassi, Sackles, and Townsend 2021). To measure and research the environmental effects on any product or service through its life cycle, the LCA method is often utilized. The study's objectives, the functional unit, the system boundaries, and the method used to evaluate the study's impact must all be specified (Santolini et al. 2023a).

Then, life cycle inventory analysis (LCIA) takes into account each unitary process's relevant inputs and outputs. The impact assessment then assigns the LCI results to the impact categories by quantifying any potential environmental effects and potential effects on human health based on the impact categories chosen and the related characterization models. The results of the analysis are finally evaluated and used as a decision-making tool to grade each of the products (Santolini et al. 2023b). LCA has become widely used in agriculture during the past few years to assess various farm management practices, and it has generated a significant level of consensus for the evaluation of the environmental effects of agro-food products (Rouault et al. 2020).

Chapter 3: Materials and Methods

3.1 Modelling approach

Life cycle assessment approach is used for conducting the environmental impact of PMR and PMM cropping system. Impact analysis can be accomplished by employing a number of software programs, including SimaPro, OpenLCA, Gabi, Umberto, and others. In order to process the questionnaire data OpenLCA software is used (Iswara et al. 2020). Eclipse, a Java-based Integrated Development Environment by IBM which is additionally open source, is employed to create the openLCA framework (Ciroth 2007).

3.1.1 Goal and scope definition

An LCA must have a specific purpose and adhere to parameters that are appropriate for the intended application. The scope of the study may need to be adjusted because LCA is iterative in nature (ISO 14044). The study is aimed at performing life cycle assessment and environmental impact assessment for the comparisons of two cropping system (PMR and PMM). The PMR and PMM cropping system are selected in order to better create understanding of how cropping system tend to contribute towards the greenhouse gas emissions in Pakistan. In order to mitigate such greenhouse gas emissions, the process of these cropping systems must be known and it must be clear through which systems the crops harvests and transported through. Pakistan's main problem is the lack of database available of these systems and processes.

Primary source of data is selected for this research. Questionnaire was developed for the farmers to elaborate the methods and processes they follow while processing these crops in these two cropping systems. Farmers are working under the cropping system of PMR and potato maize-maize in okara district Pakistan. The data is extracted through questionnaires from the farmers that are practicing PMR and PMM cropping system.

3.1.2 Functional unit

The functions (performance attributes) of the system under study shall be clearly specified in the LCA's scope. The functional unit must be in line with the objective and domain of the research. Providing a reference point for the input and output data to be normalized (in a mathematical sense) is one of the main functions of a functional unit. The functional unit must therefore be precisely defined and quantifiable (ISO 14044 Environmental management-Life cycle assessment).

Functional unit of PMR and PMM cropping system is 1 hectare land used for growing the crops which comes under the system of these two cropping system (Roy et al. 2009).1 hectare of land justifies and creates a comparison better than using 1 kg of product for comparison. 1 kg of product might create a better comparison of two crops final yield are compared with each other but when two cropping system are compared than 1 hectare of land as a functional unit justifies even more (Tricase et al. 2018).

1.1.3 System boundary

The unit processes that must be included in the LCA are determined by the system boundary. The study's objective must be consistent with the system boundary choice. The system boundary's establishing criteria must be named and described (ISO 14044). System boundary includes processes that life cycle assessment has to include for the assessment of environmental impacts (Schmidt 2008).

The PMR cropping system's life cycle stages, such as cultivation, harvesting and transportation from farm to market are all covered by the LCA analysis. The process for PMR and PMM involves production and sourcing of seeds, preparing and cultivating the land. Application of fertilizer, water and irrigation management, control of pests, harvesting and transportation.

The investigated the carbon footprint of PMR and PMM cropping systems, a questionnaire is developed and certain components have been set according to the process. Fig 03 shows the system boundary of objective 1 and 2 interconnected and explained according to the cropping system. Developing the questionnaire is a crucial step which includes uncertainties regarding which information is necessary and prioritize in terms of necessary information.

The system boundary for the comparisons of PMR and PMM cropping system is cradle to gate which include the database from seed bed preparations to harvesting and later transported to the marker. The research is limited to the market stage of the life cycle assessment and not to the disposal stage of the life cycle assessment stage.

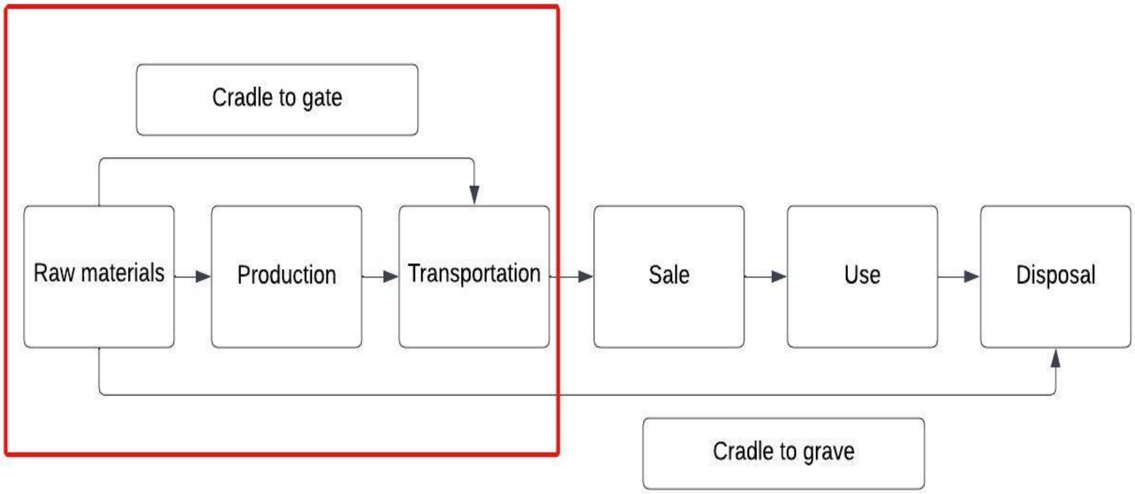

Figure.1: System boundary diagram for potato-maize-rice and potato-maize-maize cropping systems.

Cradle to gate for the potato-maize-rice and potato-maize-maize cropping system include raw materials (seeds, fertilizers, pesticides, machinery, water, diesel, petrol and electricity), processing, harvesting and crop residue management. The flow of the steps for the life cycle assessment of potato-maize-rice and potato-maize-maize cropping system will be:

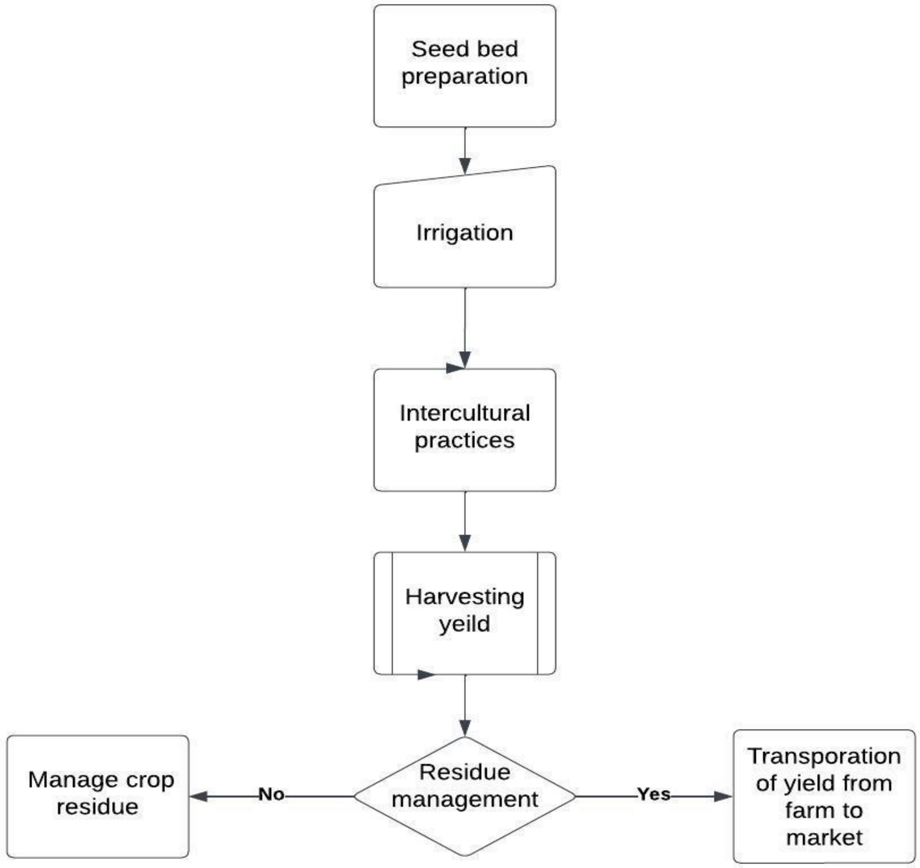

Figure. 2: Flowchart for LCA of potato-maize-rice and potato-maize-maize cropping system

3.2 Life cycle inventory analysis

The LCI was carried out in accordance with all ISO 14040-44 procedures (ISO 14044 STANDARD PREVIEW 1404). Compared to the other phases of an LCA, this phase demands the most work and time, mainly because of data collection. If accurate databases are available and customers and suppliers are willing to cooperate, data collection could take less time. There are numerous LCA databases that are often bought along with LCA software. An LCA database typically contains information on transportation, raw material extraction and processing, production of frequently utilized goods like cardboard and plastic, and disposal. Databases can be utilized for obtaining general information about the production of coal, electricity, or packaging, among other non-product specific processes. Site-specific data is required for specific to the product data. Primary data about the elementary flows of the preparation and processing of aggregates phases, have been calculated starting from the gathering of raw materials to harvesting and later transportation of yield from farm to market. Parameters and parameters were selected for data collection in the form of questionnaire and the required data was filled in by the progressive farmers of Okara district Pakistan. The diesel used by the farmers for maize, potato and rice were of amount 45, 37.7 and 46.5 liter respectively. Electricity consumption for the purpose of irrigation is 22 kWh in a day. The fertilizer used for the crops of maize, potato and rice include urea, di ammonia phosphate, calcium ammonium nitrate (Table 1). Pesticides were composed of thiamethoxam, imidacloprid. Spirotetramat, gramoxone, difenoconazole etc.

Table 01: Fertilizer application rate kg/hectare for maize, potato, and rice.

Fertilizer application rate (kg/hectare**)**	**Maize**	**Potato**	**Rice**
Nitrogen	280	172	115
Potassium	93.75	93.7	62.5
Phosphorus	142.5	200	85
Magnesium			
Calcium	6.625	6.625	6.625
Sulphur	4	4	4
Zinc	4	4	4

3.3 Life cycle impact assessment

Based on already established midpoints related to human health, ecosystem quality, natural resources, and other variables, LCA has been used to estimate a wide range of impacts (Fenner et al. 2018). Within the constraints of the study's objective and scope, the life cycle impact assessment (LCIA) requires to understand and assess environmental impacts based on the inventory analysis (Roy et al. 2009). Impact assessment is used to characterize, normalize, and weight the LCI data in order to further analyze it (Liang et al. 2019).

Table 02: Environment effects (impact categories for human health)

Impact categories	Methodology	Unit	References
Global Warming	CML 2001	kg CO2-eq	
Human toxicity	CML 2001	K 1,4-DCB-eq	
Ionizing radiation	CML 2001	DALYs	

Table 03: Environment effects (impact categories for ecosystem health)

Impact categories	Methodology	Unit	References
Climate change	CML 2001	kg CO2-eq/kg	
Eutrophication	CML 2001	Kg NO-eq	
Photochemical oxidation	CML 2001	kg formed ozone	
Ozone depletion	CML 2001	kg CHC-11 eq	

Table 04: Environment effects (impact categories for resource depletion)

Impact categories	Methodology	Unit	References
Land use	CML 2001	m2a	

3.4 Life cycle interpretation

The LCA study's interpretation of the life cycle is its last step (Ding, Steubing, and Achten 2023). The outcomes of phases 1-3 are now gathered and examined, and additional research will be carried out to achieve good LCA performance (Costa et al. 2020). To enhance results, the procedure is repeated. The outcomes of the inventory evaluation and the LCIA will all be identified, quantified, checked, and reviewed during the analysis and interpretation step (Armengot et al. 2021). In the interpretation stage, the results of the inventory analysis and effect assessment are assembled (Anshassi, Sackles, and Townsend 2021).

3.5 Economic analysis of potato, maize and rice

To conduct the economic analysis of potato, maize and rice the cost benefit analysis will be calculated. The data will be required by conducting a survey from farmers from okara district in Pakistan and that data will be calculated under the circumstances of cost benefit analysis in order to know which costs are incurring in the process of cultivating potato, maize and rice crops.

Chapter 4: Results

4.1 Global warming

Diesel consumption increases the potential for global warming in both cropping systems. Compared to the PMM cropping system, that has a percentage of 70%, the PMR cropping system offers a percentage of 73.70%. Both cropping systems have the same figures for the global warming potential of seed bed preparation (5.10% for PMR and 5% for PMM), that is a relatively small percentage in both cases.

Petrol usage has a noticeable effect on the potential of global warming, with the PMM system providing much more (24.60%) than the PMR system (18.10%).Both cropping systems use very little electricity, resulting in the PMR system contributing 0.40% and the PMM system contributing 0%.Both systems have relatively small potential global warming implications through the use of fertilizers and pesticides. However, relative to the PMM system (0.03%), the PMR system uses fertilizer at a significantly higher rate (0.87%). In the PMR-Potato system, the production of raw materials—which might involve land clearing and cultivation—contributes 1.01% to the potential for global warming, whereas it is insignificant (0%) in the PMM system.

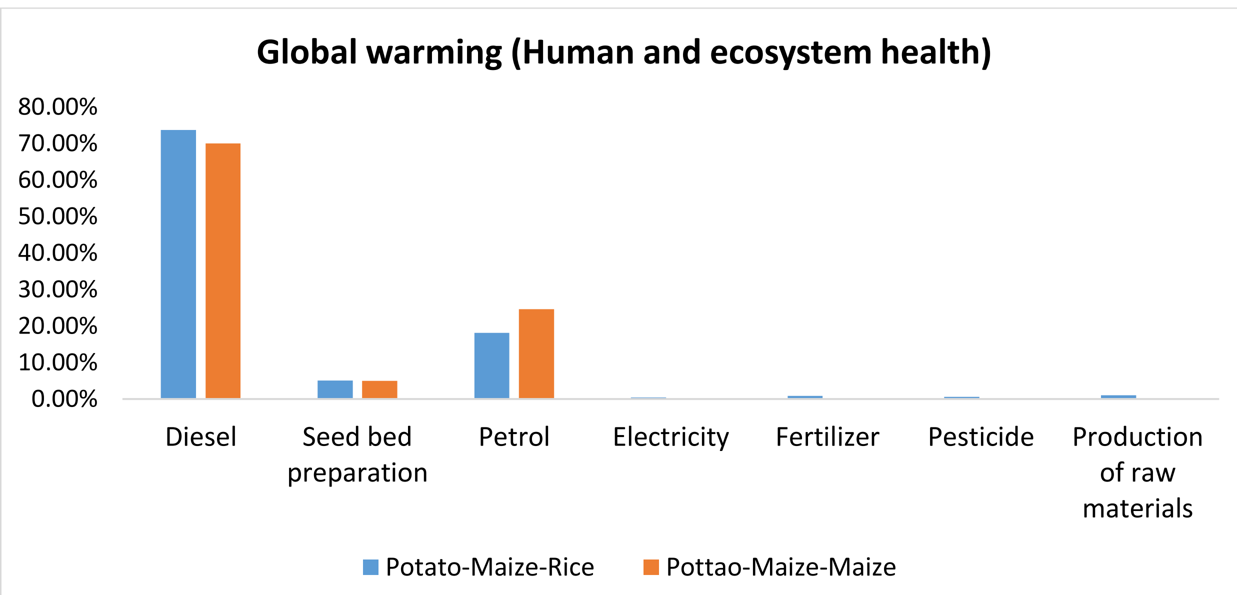

Figure 3: Climate change impact of potato-maize-rice and potato-maize-maize cropping system

4.2 Human toxicity

The obtained results seem to be linked with multiple elements or aspects that contribute to human toxicity in two separate scenarios: "PMR" and "PMM." These percentages reflect the relative influence or contribution of each element to human toxicity in each situation. The burning of diesel fuel is known to produce toxic fumes that are bad for human health. Diesel makes up 4.30% of the total human toxicity in the PMR cropping system, but only 1.40% in the PMM cropping system. This shows that in the first situation relative to the second, the consumption of diesel has a bigger influence on human toxicity. Considering the two cropping systems (both marked as 0%), it appears that seed bed preparation has no effect on human toxicity. This imply that the toxicity of this specific process does not have a major effect on human health. Another fossil fuel that poses a risk to public health, particularly in terms of air pollution and related pollutants, is petrol. Petrol has a major impact on human toxicity in both scenarios, but it adds more to the PMM cropping system (98%) than to the PMR cropping system (83%). Similar to seed bed preparation, electricity seems to have no impact to either cropping system's human toxicity (both are rated as 0%). It demonstrates that, at least under the conditions that have been stated, using electricity has little to no negative effects on people's health. The use of fertilizers causes the emission of a number of toxins into the atmosphere. Fertilizer has a relatively small 0.02% contribution to the PMR cropping system's human toxicity. In contrast, in the PMM cropping system, it has no effect (0%) at all. This shows that the use of fertilizer has a negligible effect on the toxicity of humans, and that this effect is much more insignificant in the additional case. Chemicals used in agriculture to control pests but with possible adverse effects to people. Chemicals such as pest have no effect (0% in the PMM cropping system) but do contribute to 1.26% of the human toxicity in the PMR cropping system. It demonstrates that in the first scenario, pesticide use is more damaging to humans. Production of raw materials is an extensive region, however in the "PMR" scenario it provides 11% of human toxicity and has no effect (0%) in the "PMM" scenario. This shows that the PMR cropping system's raw material production method has a major effect on human toxicity, whereas the PMM cropping system's raw material production process has no significance.

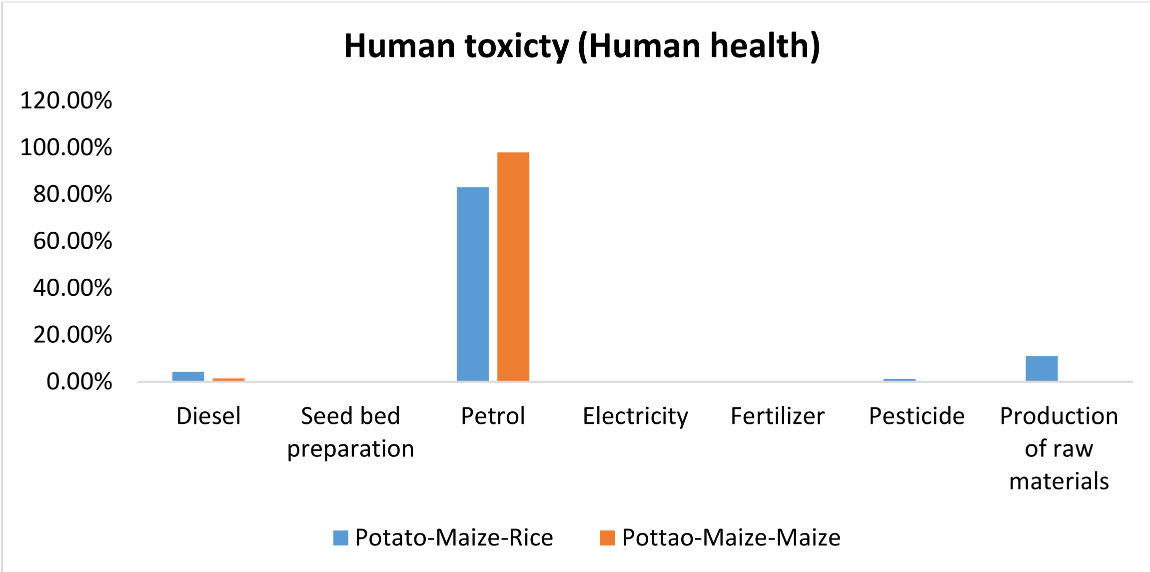

Figure 4: Human health impact of potato-maize-rice and potato-maize-maize cropping system

4.3 Ionizing radiation

In PMM cropping system, diesel consumption is significantly higher (12.60%) than in the PMR cropping system (5.10%). This points to a higher reliance on diesel-powered equipment and trucks compared to PMR cropping system. Preparing the seed bed contributes for 0.69% of energy consumption in PMR cropping system yet not at all in the PMM cropping system. This implies that in the second scenario, seed bed preparation is either unnecessary or not performed. The consumption of petrol in both instances is limited or negligible, suggesting that these agricultural not process significantly influenced by machinery or vehicles that use petrol. The PMR cropping system is heavily dependent on power, accounting for 83% of all energy use. The PMM cropping scheme, in contrast, consumes less electricity (47.46%). This can be because the two farming systems use distinct irrigation techniques, machinery, or infrastructure. The two scenarios include relatively little fertilizer usage, however it's important to note that in the PMR cropping system (0.94%) it is slightly more than in the PMM cropping system (0%). Both cropping systems used minimal pesticides. The PMR cropping system used 1.18%, while the PMM cropping system used no pesticides.

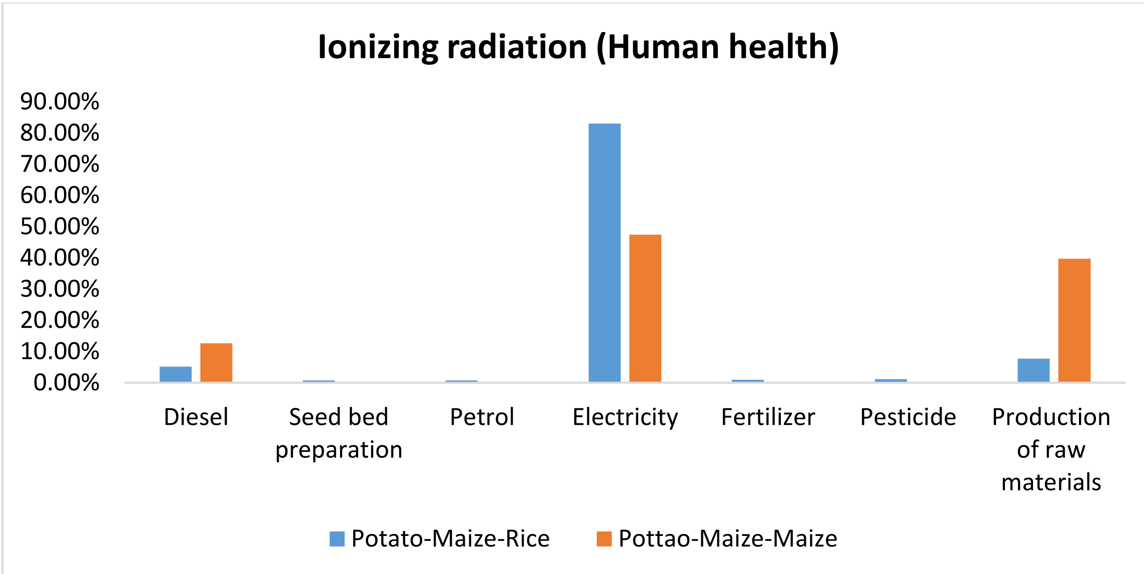

Figure 5: Ionizing radiation impact of potato-maize-rice and potato-maize-maize cropping system

4.4 Photochemical oxidation formation

Relative to the PMM cropping system (1.70%), photochemical oxidation generation from diesel use is slightly greater in the PMR cropping system (2.50%). It indicates that because of operations involving diesel-powered equipment, the PMR system have a slightly stronger effect on photochemical oxidation. Both cropping systems report that seed bed preparation has no impact on the production of photochemical oxidation (both 0%). This suggests that neither system's seed bed preparation procedures significantly encourage photochemical oxidation. The use of petrol is high in both cropping systems, with the PMR system having a photochemical oxidation formation rate of 95.80% and the PMM system having a rate of 98%. This suggests that both cropping systems rely extensively on activities involving petrol, such as transportation or irrigation, which considerably add to the development of photochemical oxidation. Neither cropping system (both 0%) reports any contribution to the development of photochemical oxidation. This shows that photochemical oxidation is not promoted by electricity-related procedures in these systems. Both cropping systems indicate zero contributions from fertilizer use to the growth of photochemical oxidation. This shows that neither the type of fertilizer used nor how it was used significantly affected photochemical oxidation in either system. In the PMR system, photochemical oxidation generation from pesticide use is high (34%), whereas it is stated to be 0% in the PMM system. This suggests that the administration of pesticides in the PMR system have a significant effect on the production of photochemical oxidation. Relative to the PMM system, the production of raw materials results in somewhat more photochemical oxidation generation (1.01% vs. 0%). This shows that activities involving raw material production or changes in land use have a greater impact on photochemical oxidation in the PMR system.

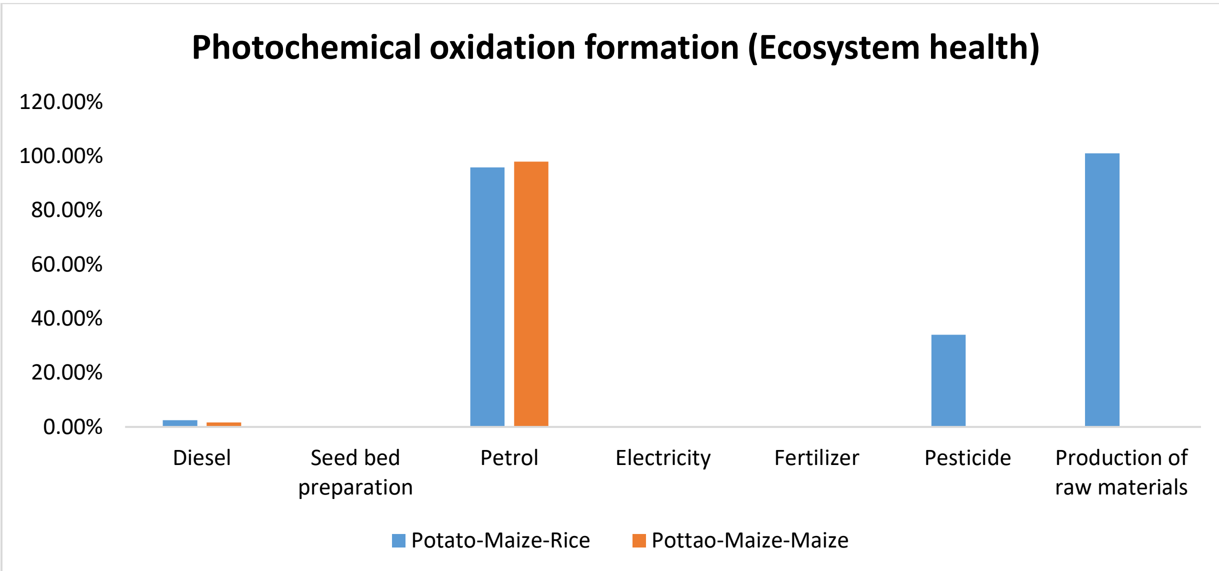

Figure 6: Photochemical oxidation formation impact from potato-maize-rice and potato-maize-maize cropping system

4.5 Eutrophication

Both cropping systems have a comparable chance for eutrophication due to diesel use, with the PMR cropping system having a 42.80% potential and the PMM system having a 42% potential. This implies that the eutrophication potential of diesel-powered equipment is same in both systems. Both cropping systems have a comparable propensity for eutrophication (46 percent for the PMR cropping system and 46.4 percent for the PMM cropping system). This shows that the methods used to prepare seed beds consistently affect the likelihood of eutrophication in both systems. The PMM cropping system has a greater chance for eutrophication due to fuel use (11.30%) than the PMR system (4%). The potential for eutrophication from the use of power is rather minimal for both cropping systems, with the PMR cropping system contributing 0.80% and the PMM cropping system 0.27%, respectively. This shows that the potential for eutrophication in these systems is not greatly increased by electricity-related activities. While the PMM cropping system reports no contribution to eutrophication potential (0.00%), the PMR cropping system reports a large contribution to eutrophication potential (3.20%). Neither cropping system (0.00%) reports any danger for eutrophication due to the use of pesticides. This shows that the use of pesticides in these ecosystems is not raising the risk of eutrophication. Both cropping systems (both 0.00%) claim that the production of raw materials has no impact on the potential for eutrophication. This shows that neither system's eutrophication capacity is boosted by activities related to the production of raw materials.

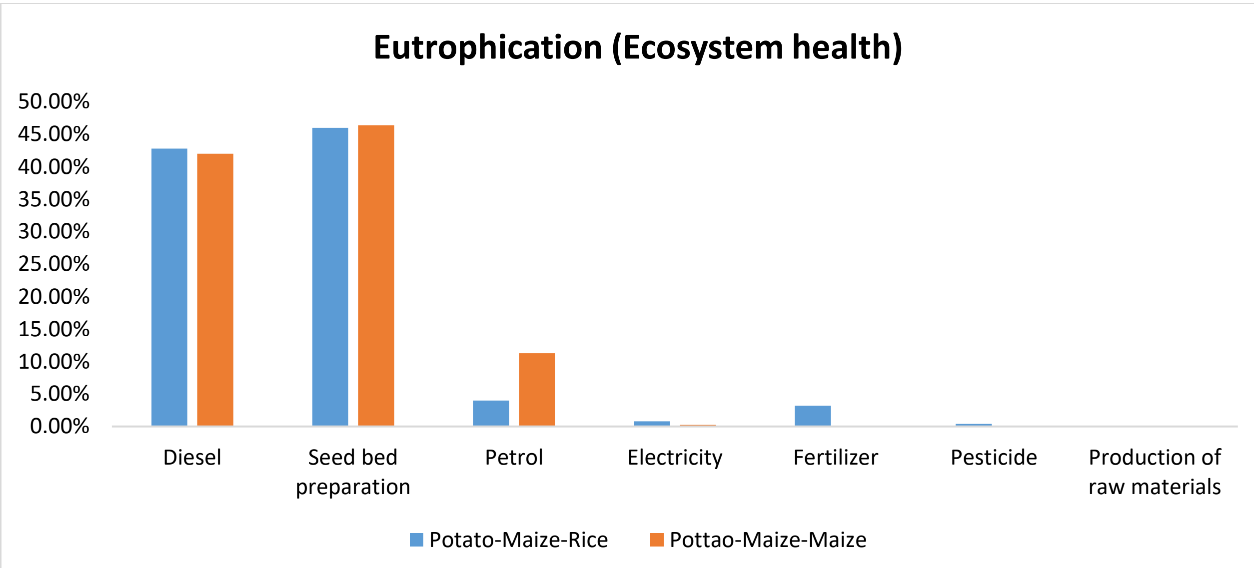

Figure 7: Eutrophication impact from potato-maize-rice and potato-maize-maize cropping system

4.6 Ozone depletion

Relative to the PMR cropping system (12%), the Ozone Depletion Potential from Diesel Use is higher in the PMM cropping System (17.80%). This shows that because of activities involving diesel-powered machinery, the PMM system have a little more effect on ozone depletion. Both cropping systems claim that seed bed preparation has no potential to contribute to ozone depletion (both 0%). This proves that neither system's seed bed preparation procedures have a major negative impact on ozone levels. According to both cropping systems, there is zero potential for petrol use to contribute to ozone depletion. The PMM cropping system has more potential for ozone depletion from electricity use (17%) than the PMR system (10.60%). This implies that there is a higher ozone depletion potential in the energy supply for the PMM system. That caused by the energy mix utilized to generate electricity in various places or the effectiveness of the processes employed to produce electricity. The PMR cropping system has a larger potential for ozone depletion due to fertilizer use (2.96%) than the PMM system (0%). This suggests that fertilizer use in the PMR system have a greater potential to cause ozone depletion.

As compared to the PMM system, the Ozone Depletion Potential from Pesticide Use is higher in the PMR-System (3.58%). This shows that the potential for the destruction of ozone has more significantly impacted by pesticide use in the PMR cropping system. Compared to the PMM cropping system, the PMR cropping system has a greater likelihood to deplete the ozone layer (70.60%) than the PMR system (65.60%). This suggests that the PMR system is more susceptible to ozone depletion due to activities involving land-use change and the production of raw materials.

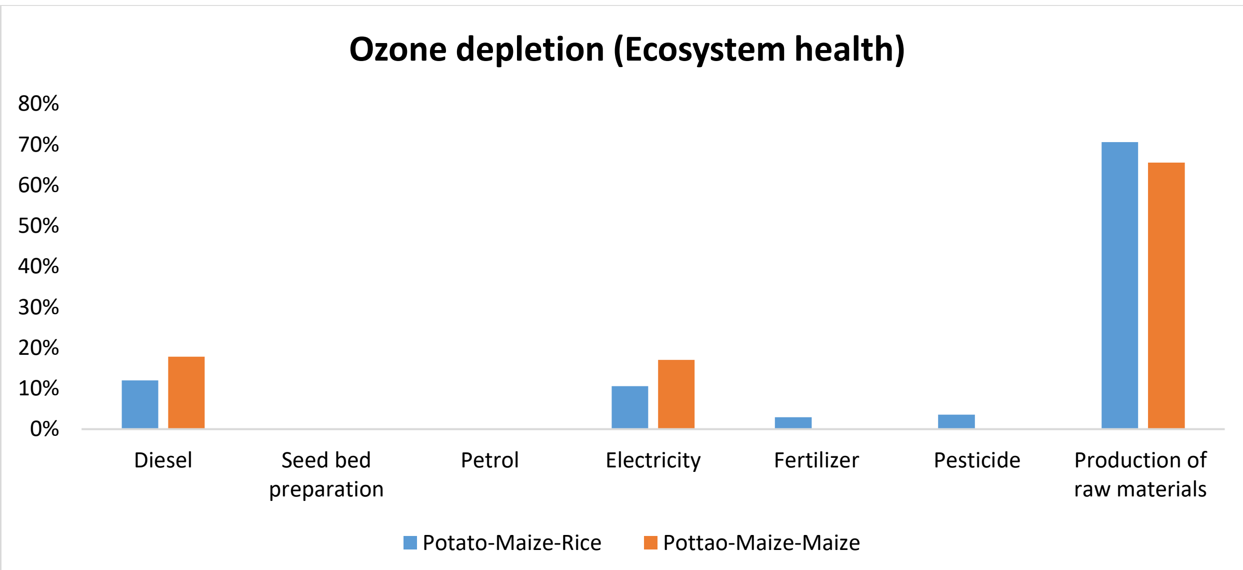

Figure 8: Ozone depletion impact from potato-maize-rice and potato-maize-maize cropping system

4.7 Land use

Diesel use has an extensive effect on land use in the PMM system (99%), but no documented impact is seen in the PMR system (0%). It demonstrates that the PMM system makes substantial use of land for activities involving diesel-powered machinery, like irrigation or agriculture. In the PMR cropping system, seed bed preparation has a significant impact on land use (96%) but not in the PMM cropping system (0%). This shows that the preparation of the seed bed for the PMR system depends extensively on land use, necessitating more extensive tillage practices. Both cropping systems claim that utilizing petrol has no effect on land use (both 0%). This implies that petrol-related activities like transportation and irrigation do not significantly affect the amount of land is used in either system. In both cropping systems, the effect of electricity use on land use is insignificant, with the PMR system having a 0.05% impact and the PMM system having a 0% impact. The impact of fertilizer in land use in PMR and PMM cropping is scored low and the pesticide impact in both cropping systems is relatively low than diesel and seed bed impact. This shows that the PMR system has a greater impact on land use change and the amount of land needed for the production of raw materials.

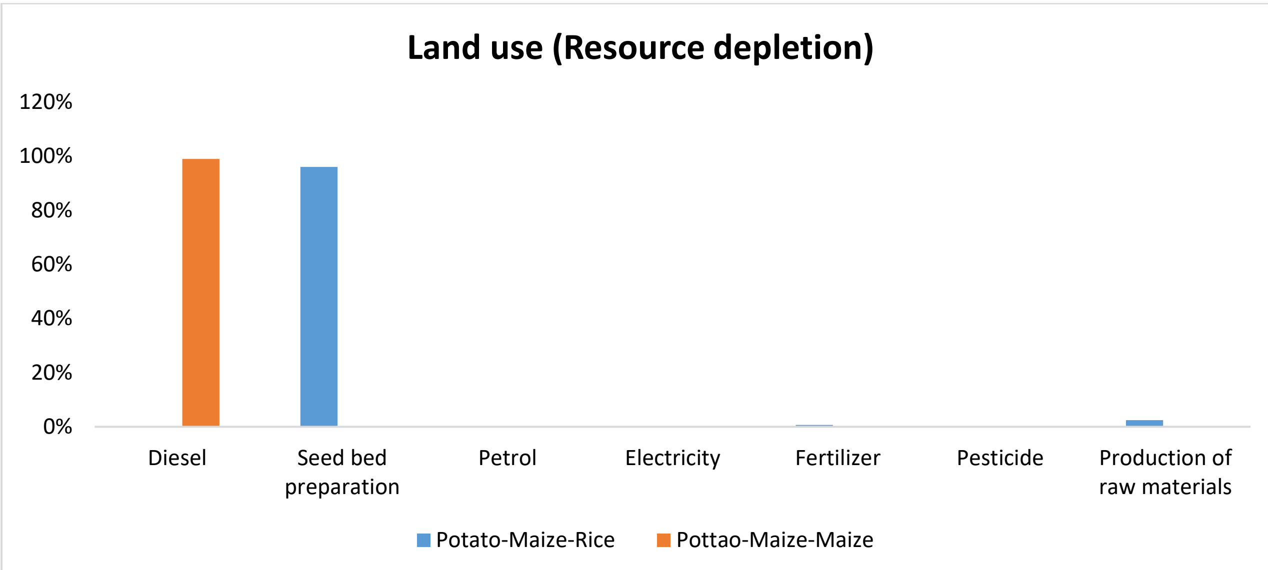

Figure 9: Land use impact from potato-maize-rice and potato-maize-maize cropping system

4.8 Potato-Maize-Rice overall impacts

The findings indicate an array of environmental effects related to various inputs and processes in agricultural production. Diesel and petrol substantially contribute to eutrophication, ionizing radiation, global warming, and human toxicity. While it has some less negative effects than other forms of energy, electricity nonetheless has effects on ionizing radiation and land use. Agriculture's input and activity selection can have a major effect on how environmentally sustainable it is overall, which emphasizes the need for careful thought and potential mitigation methods to lessen unfavorable environmental effects.

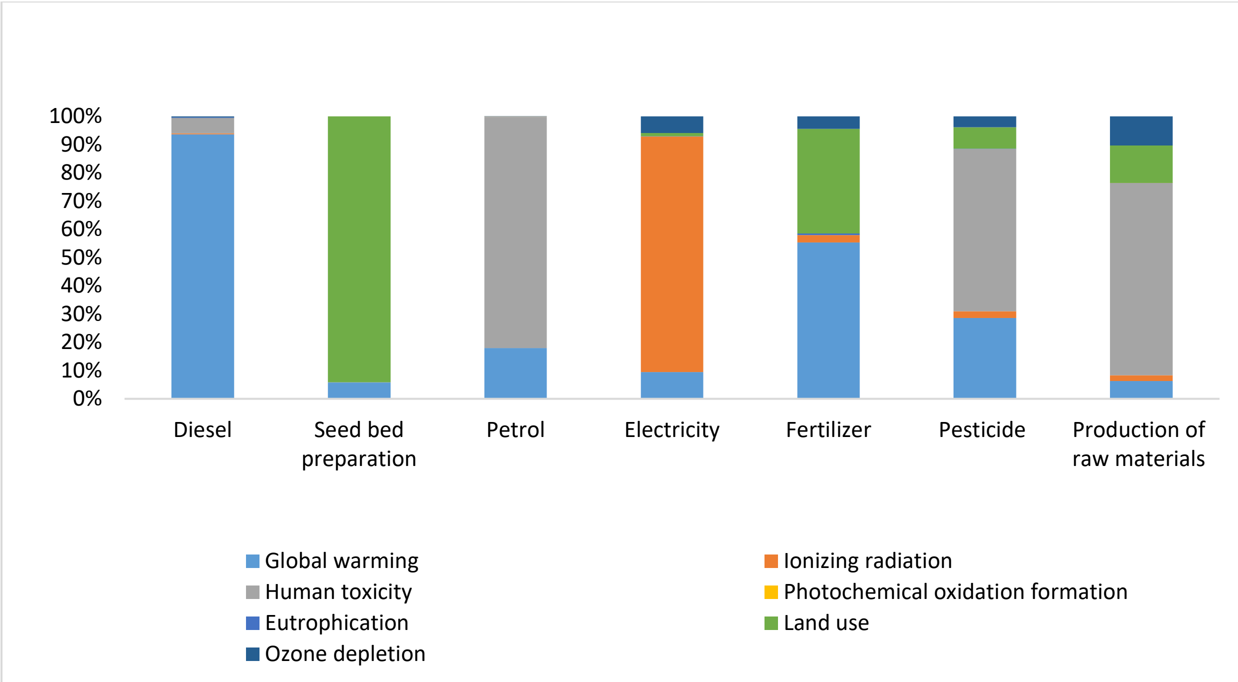

Figure 10: Overall impact of potato-maize-rice cropping system on environment.

4.9 Potato-Maize-Rice overall impacts

Results indicate that the choice of materials and procedures used in agricultural production can have a variety of effects on the environment. Petrol and diesel continue to stand out as major contributors to environmental indicators such as human toxicity and global warming. In this instance, electricity has a negligible effect on global warming but has significant effects on ionizing radiation and ozone depletion, emphasizing the importance of taking into account the energy sources utilized in agriculture. Adopting greener practices and technology that take into account every phase of the life cycle of inputs and activities constitute typical ways to reduce the environmental impact of agriculture.

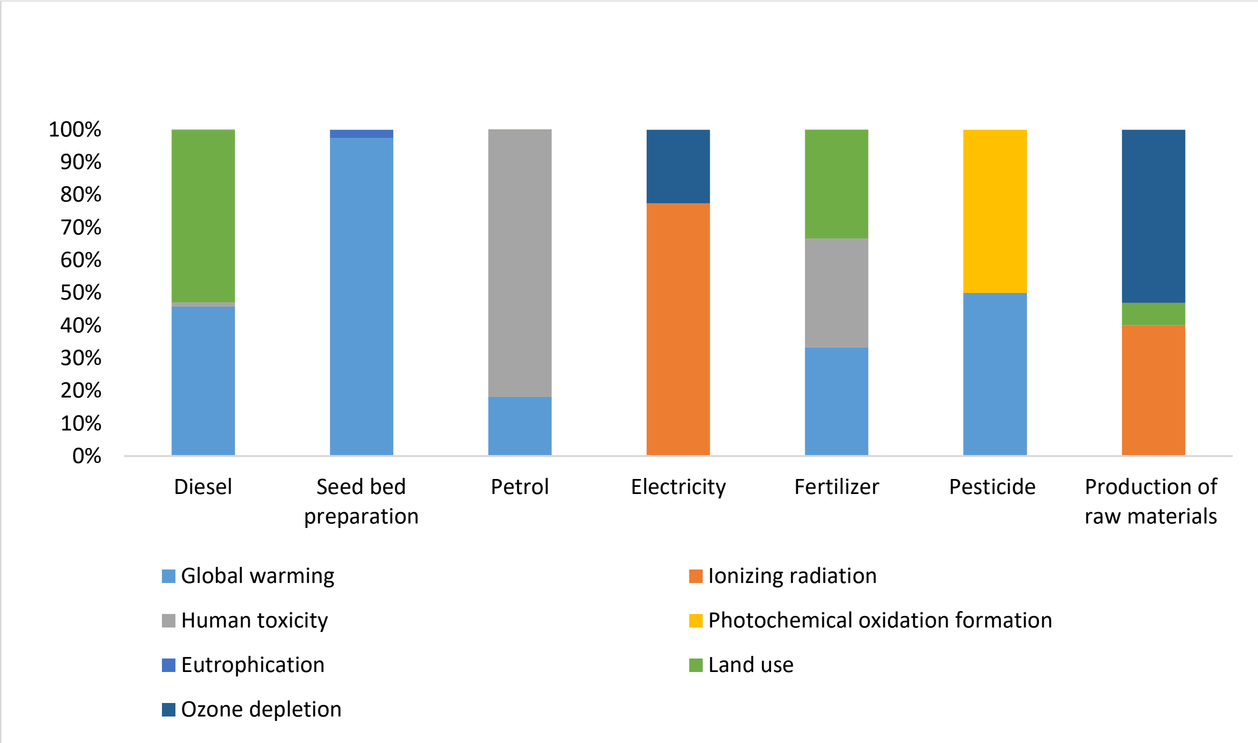

Figure 11: Overall impact of potato-maize-maize cropping system on environment.

4.10 Comparison of potato-maize-rice and potato-maize-maize cropping system

The findings indicate that, across an array of environmental factors, the two agricultural systems have varying environmental effects. Comparing the PMR system to the PMM system, it usually turns out that the former has slightly higher global warming potential, slightly lower eutrophication potential, slightly higher human toxicity, slightly lower ionizing radiation, higher land use, lower photochemical oxidation potential, and slightly lower ozone depletion potential. The complicated nature of environmental evaluations and the need to take into account a variety of environmental indicators when evaluating the sustainability of agricultural production systems are both emphasized by these findings.

Figure 12: Comparison of potato-maize-rice and potato-maize-maize cropping system in terms of impact category.

4.11 Economic analysis of potato-maize-rice

Table 05: Cost calculations of potato-maize-rice

cropping system**Cost**	**Potato**	**Maize**	**Rice**
fertilizer	70000	44000	36000
pesticides	20000	10000	8000
Land rent	50000	50000	45000
Land preparation	28000	14000	10000
Labor cost	19000	23000	25000
Water cost	9000	11000	18000
Total cost (sum all costs)	196000	152000	142000

Table 6: Profit calculations of potato

Revenue	Rs
Rate of product	29.5/Kg
Quantity of potato produced	9000Kg
Total revenue (R*QP)	(9000)*29.5 = 265500
Profit (TR-TC)	69500

Table 7: Profit calculations of maize

Revenue	Rs
Rate of product	100/Kg
Quantity of maize produced	3359.179
Total revenue (R*QP)	(3359.179)*100= 335917.9
Profit (TR-TC)	183917.9

Table 8: Profit calculations of rice

Revenue	Rs
Rate of product	76.34/Kg
Quantity of rice produced	3172.557
Total revenue (R*QP)	(3172.557)*76.34= 242193.001
Profit (TR-TC)	100193

Table 9: Total profit of potato-maize-rice cropping system

Total revenue of potato-maize-rice	843610.901
Total cost of potato-maize-rice	490,000
Total profit (TR-TC)	353610.901

4.12 Economic analysis of potato-maize-maize

Table 10: Cost calculations of potato-maize-maize cropping system

Cost	Potato	Maize	Maize
fertilizer	70000	44000	44000
pesticides	20000	10000	10000
Land rent	50000	50000	50000
Land preparation	28000	14000	14000
Labor cost	19000	23000	23000
Water cost	9000	11000	11000
Total cost (sum all costs)	196000	152000	152000

Table 11: Profit calculations of potato

Revenue	Rs
Rate of product	29.5/Kg
Quantity of potato produced	9000Kg
Total revenue (R*QP)	(9000)*29.5 = 265500
Profit (TR-TC)	69500

Table 12: Profit calculations of maize

Revenue	Rs
Rate of product	100/Kg
Quantity of maize produced	3359.179
Total revenue (R*QP)	(3359.179)*100= 335917.9
Profit (TR-TC)	183917.9

Table 13: Total profit of potato-maize-maize cropping system

Total revenue of potato-maize-maize	937335.8
Total cost of potato-maize-maize	500000
Total profit (TR-TC)	437335.8

According to the comparison, the PMM cropping system has higher net profit compared to the PMR cropping system. Profits from the PMM and PMR cropping systems reached Rs 437,335.8 and Rs 353,610.901, accordingly.

Chapter 5: Discussion

Agriculture's role in global warming through GHG emissions has been an important factor influencing agricultural sustainability (Cui et al. 2019). The results provide insightful information about the environmental effects of Pakistan's two separate cropping systems. The impact of agriculture on the environment in two distinct cropping systems, PMR and PMM. The research shows that differed agricultural operations have significant effects on GHGs emissions, which is important in terms of climate change. These effects are evaluated using a range of environmental indicators, including the potential for global warming, human toxicity, and the development of photochemical oxidation, eutrophication, land usage, ozone depletion, and diverse input sources. The research recommends using sustainable farming methods and alternative sources of energy to tackle climate change (Pathak 2023).

Emissions of greenhouse gases cause climate change, which affects the ecosystem health, human health. GWP are expressed as kg CO2 (Carbon dioxide) equivalents for a period of 500 years (Ozturk and Dincer 2019). The rise in global temperature carried on by the greenhouse effect produced by human activity's production of "greenhouse gases" is known as climate change (Acero, Rodríguez, and Changelog 2017). Both systems' diesel use has a major impact on the potential for global warming, with somewhat larger emissions in the PMR system. This suggests that initiatives to cut back on diesel use or adopt more fuel-efficient habits could help lessen the impact on the environment. Petrol use has a significant impact on the potential for global warming, particularly in the PMM system. It might be advantageous to use less gasoline or switch to renewable energy sources for transportation and irrigation.

The diesel consumption in ionizing radiation indicates the two situations might have utilized different soil types, equipment configurations, and operational scales. The substantial disparity in electricity use could also be due to different irrigation needs, with rice farming often requiring more water. Ionizing radiation is directly caused by electricity (Frischknecht and Rebitzer 2005). In addition, the lack of energy used to prepare the seed bed and the sparse use of fertilizer and pesticides suggest alternative farming methods. Whatever stands out the most is the dramatic disagreement in raw material production, which shows how drastically distinct these two scenarios are in terms of how energy-intensive agriculture is. These findings highlight the need for specialized and sustainable agriculture practices that take into account crop types, regional variables, & technology uptake to maximize energy efficiency and environmental effect.

Within this field, the harmful chemical impacts on human health are assessed. A hazardous substance indicator is defined as an emission of 1.4 DCB (Dichlorobenzene) equivalents per kilogram (Ozturk and Dincer 2019). Environmental toxins' effects on human health are referred to as human toxicity (Hospido et al. 2010). Based on both a compound's inherent toxicity and a possible dose, the Human Toxicity Potential is a calculated index which represents the potential damage of a unit of chemical discharged into the environment (Acero, Rodríguez, and Changelog 2017). Human toxicity is caused by petrol (Andersson, Ohlsson, and Olsson 1998).The consumption of diesel and petrol, particularly in the PMM system, increases human toxicity. This underlines the need to minimize exposure to these fuels' hazardous emissions in agricultural activities. In the PMR system, pesticide use has an important effect on human toxicity, stressing the necessity for responsible pesticide management and possibly looking into alternatives or integrated pest management techniques.

The main causes of photochemical oxidation are transportation and the extraction of oil. Although nitrous oxide and methane are the primary photochemical oxidation contributors, the influence of photochemical oxidation changes greatly depending on the methane emission (Castanheira and Freire 2017). In PMR and PMM cropping system, the development of photochemical oxidation is significantly influenced by the use of petrol. This environmental impact can be lessened by employing strategies to consume less petrol or switch to cleaner alternatives. When petrol use is higher, the photochemical oxidation potential is bigger (Oliveira et al. 2021). The use of energy for irrigation systems and agricultural machinery also significantly contributes to the photochemical oxidation formation (Halberg et al. 2003) . The formation of photochemical oxidants was similar to that of GWPs (Dekamin, Barmaki, and kanooni 2018). Type of a weather pollution is photochemical oxidation, which is often referred to as summer smog (Ghasempour and Ahmadi 2016). As contrasted with the other combinations, it exhibited the highest photochemical oxidation. By introducing unwanted ozone molecules into the atmosphere, the formation of photochemical oxidants has a negative impact on environment (Imtiaz et al. 2021). The fact that using diesel contributes to photochemical oxidation highlights the significance of maximizing diesel-related activities for environmental sustainability.

The improper use of nutrients and associated eutrophication issues are one of the main global environmental difficulties (Uusitalo et al. 2018). Eutrophication potential in both systems is significantly affected by the preparation of the seed bed. This effect might be minimized through the use of conservation tillage techniques or reducing the intensity of field preparation measures. Fertilizer are the main contributing factors towards eutrophication (Smetana 2023). The decomposition of ammonia that comes directly from fertilizers leads to eutrophication (Wowra, Zeller, and Schebek 2021). Eutrophication is more affected by fertilizer use in the PMR system. Reduced nutrient discharge and eutrophication potential can be accomplished by using accurate and efficient fertilization techniques. A major issue on a global scale, freshwater eutrophication is brought on by phosphorus (P) flows from human activities, mainly agricultural usage of P fertiliser(Ortiz-Reyes and Anex 2018). CML methodology used to calculate and CML is a commonly employed approach that includes a category for eutrophication. Eutrophication impacts are calculated using CML methods' eutrophication characterization variables differ (Uusitalo et al. 2018). Eutrophication is higher in diesel use due to high use of diesel in all the agricultural activities (Krzyżaniak and Stolarski 2019).

In life cycle assessment (LCA), land use has drawn a growing amount of focus (Lindeijer 2000). Impact on land use varies greatly across the two regimes. In contrast to the PMR system, which focuses mostly on seed bed preparation and raw material production, the PMM system uses diesel and land use. These variations imply that each system might need different approaches to resource control and land use.

The stratospheric ozone per chlorofluorocarbon created is used as the measurement compare for the depletion of ozone category (Esparham et al. 2023). Additionally, diesel is mostly responsible for the possible stratospheric ozone depletion (ODP) contribution (Halberg et al. 2003). Both systems' diesel use raises the risk of ozone depletion, with somewhat larger emissions in the PMM system. This highlights the need of controlling diesel-related emissions. Additionally, diesel is mostly responsible for the possible stratospheric ozone depletion (ODP) contribution. Electricity use also affects the risk of ozone depletion. This impact can be lessened by switching to less polluting energy sources for the production of electricity. The use of energy for irrigation systems and agricultural machinery also significantly contributes to the ozone depletion (Halberg et al. 2003). The findings show how complex the environmental effects of various agricultural practices are. It's important to take an integrated approach to mitigating these effects, which includes maximizing fuel efficiency, using environmentally friendly agricultural techniques, lowering pesticide and fertilizer use, and shifting to cleaner energy sources. Adapting these methods to the particular needs of each agricultural system might help Pakistani agriculture become more ecologically friendly and sustainable.

The research's findings has significant implications for sustainable agriculture and environmental management. Policymakers, farmers, and researchers can make informed choices to reduce climate change and lower potential health risks related to carcinogenicity by comprehending the ecological effects of various cropping systems, such as PMR and PMM. In an effort to reduce the health hazards related with cancer and agricultural practices, the study emphasizes the importance of switching to cleaner and less damaging energy sources (Clayson, Krewski, and Munro 1983).

The results emphasize how crucial it is for controlling greenhouse gas emissions in agriculture. Encouraging the use of less polluted, more fuel-efficient technology might greatly lower the carbon footprint of farming operations since diesel combustion is an important contributor of emissions (Amirahmadi et al. 2022). In addition, the analysis of the two cropping systems shows the emissions produced by the PMM system are often lower than those generated by the PMR system. Stakeholders may design strategies that facilitate the transition to more environmentally friendly and sustainable agricultural systems by comprehending these distinctions.

The study emphasizes how petrol combustion has a significant impact on its capacity to cause cancer. Farmers and policymakers should think about adopting action to reduce the use of petrol-powered equipment in agriculture. A large reduction in the cancer risk linked with farming practices could be achieved by exploring alternate energy sources, such as electric or renewable energy-powered machinery. Additional study into the possible health effects of these inputs or the efficacy of their regulation and oversight is indicated by the absence of significant contributions from the usage of fertilizer and pesticides in the findings.

If compared the PMR and PMM cropping system in the category of fertilizer and pesticides results, the latter cropping system emits less that the first one. Which indicates that PMM cropping creates an opportunity for farmer to be more sustainable. In terms of electricity category the PMM again reflects the lesser impact than PMR cropping system except land use category. While seed bed preparations results show that it is slightly similar in both cropping systems except in land use where PMM cropping system has more impact than PMR cropping system. The results of diesel and petrol combustion has almost similar impacts except in eco toxicity where PMR has more emissions than PMM. Overall PMM cropping system efficiency exhibits that it is more sustainable than PMR cropping system.

Chapter 6: Conclusion

The comprehensive analysis of the PMR and PMM cropping systems reveals that environmental impacts, and economic factors are interconnected. The results of this study highlight the crucial role that sustainable agriculture plays in tackling major global issues like climate change, environmental degradation, and threats to human health. The major findings showed that PMR and PMM has negative impact on environment. Cropping systems have important effects on a number of environmental indicators, including global warming, ionizing radiation, human toxicity, photochemical oxidation production, eutrophication, land use, and ozone depletion. PMR and PMM produced equal global warming impact however, PMR caused 9% greater eutrophication, 20% more photochemical oxidation, and 10% higher ozone depletion impact than PMM. PMR and PMM are equal in land use impact. Environmental impact of PMR cropping system is more than PMM cropping system. Net Profit of PMM cropping system was 10.5% more than PMR cropping system. However, PMM cropping system also cause 7% more human toxicity impact is than PMR cropping system.

These environmental impacts are caused by agricultural operations, especially the usage of diesel, petrol, electricity, pesticides, fertilizers, and land management techniques. The results shows the importance of a diverse approach to lessen agriculture's negative environmental effects. This entails using cleaner energy sources along with more fuel-efficient technology to lessen reliance on diesel and petrol. For it to reduce human toxicity and eutrophication potential, responsible pesticide and fertilizer management is vital, as is the investigation of alternative farming practices.

The research additionally emphasizes the value of specialized approaches based on crop types, specific circumstances, and advances in technology. For each cropping system, processes should be modified to maximize energy savings and environmental sustainability. There is not one signified strategy that is suitable for all situations. The results highlight that sustainable practices can also be financially successful through demonstrating the possibility for profitability in both cropping systems. This emphasizes how crucial it is for farmers and decision-makers to take into consideration both environmental and economic issues.

Future research on the life cycle of cropping systems and the impact of particular agricultural practices is provided for by this study. To lower and greenhouse gas emissions while preserving production, sustainable practices such as no-till farming, cover crops, and organic agriculture should be further investigated.

The results can be used by decision-makers in government, agriculture, and research to minimize health hazards associated with agricultural practices, promote a more environmentally and economically sustainable agriculture sector, and mitigate climate change. We can work towards a more harmonious coexistence between agriculture and the environment by implementing these steps and promoting their implementation, assuring a healthier planet for future generations.

6.1 Future implications

Understanding of the environmental effects of different agricultural practices and inputs can be gained by conducting comprehensive life cycle evaluations. Future studies should take into account the entire life cycle of various cropping systems, including cradle to grave. Sustainable agriculture can benefit from studying how particular crop management techniques, such as no-till farming, cover cropping, and organic farming, influence reducing cancer risks and greenhouse gas emissions.

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Appendices

Questionnaire

General information

Sr No	Data	Information	Remarks
1	Year		
2	Crop		
3	Seed (Type)		
4	Seed rate kg / ha		
5	Crop area (ac/ha)		
6	Biological yield kg / ha		
7	Yield kg / ha		
8	Soil textural class		
9	Soil organic matter content		
10	Soil drainage / Bulk density		
11	Soil pH		

Machinery used

Sr No	Machine Used	Yes	No	Machine Type	Hours per hectare	Fuel Type (Diesel, Petrol, CNG)	Fuel used per hour	No of operat ions	Remarks
1	**Seed bed preparation**								

1.1	Machine type 1								
1.2	Machine type 2								
1.3	Machine type 3								
2	**Intercultural practices**								
2.2	Fertilizer machinery								
2.2.1	Machine type 1								
2.2.2	Machine type 2								
2.2.3	Machine type 3								
2.3	Herbicide machinery								
2.3.1	Machine type 1								
2.3.2	Machine type 2								
2.3.3	Machine type 3								
2.4	Pesticide machinery								
2.4.1	Machine type 1								
2.4.2	Machine type 2								
2.4.3	Machine type 3								
3	**Harvesting machinery**								

3.1	Machine name 2								
3.2	Machine name 3								
3.3	Machine name 4								
4	**Residue management**								
4.1	Removed								
4.2	Burned								
4.3	Soil incorporated								
4.4	Left on field								
4.5	Mulch								

Irrigation

Sr No	Water source	Yes	No	Fuel	Fuel / hour	No. of hours	Cost/ month/ ha	Amount(mm /ha/ operation	Irrigation method	Remarks
1	Canal irrigation									
2	Tube well (electricity motor) (HP)									
	Tube well (peter engine)									

	Tube well (tractor)									
3	Solar tube well									
4	Pre sowing irrigation									
	Water applied sowing to harvesting (total mm)									

Fertilizer used

Sr No	**Type of fertilizer**	**Yes**	**No**	**Product name**	**Purchased / Own farm**	**How much Kg / ha**	**Method of application**	**Remarks**
1	**Nitrogen**							
1.1	Product 1							
1.2	Product 2							
1.3	Product 3							
2	**Potassium**							
2.1	Product 1							
2.2	Product 2							
2.3	Product 3							
3	**Phosphorus**							

3.1	Product 1						
3.2	Product 2						
3.3	Product 3						
4	**Magnesium**						
4.1	Product 1						
4.2	Product 2						
4.3	Product 3						
5	**Calcium**						
5.1	Product 1						
5.2	Product 2						
5.3	Product 3						
6	**Sulphur**						
6.1	Product 1						
6.2	Product 2						
6.3	Product 3						
7	**Iron**						
7.1	Product 1						
7.2	Product 2						
7.3	Product 3						
8	**Zinc**						
8.1	Product 1						
8.2	Product 2						
8.3	Product 3						

9	Farm yard manure							
10	Compost							
11	Vermi compost							

Pesticides applied

Sr No	Pesticide (type)	Yes	No	Product name	Quantity	Method of application	Remarks
1	**Insecticides**						
1.1	Product 1						
1.2	Product 2						
1.3	Product 3						
2	**Herbicides**						
2.1	Product 1						
2.2	Product 2						
2.3	Product 3						
3	**Fungicides**						
3.1	Product 1						
3.2	Product 2						
3.3	Product 3						
4	**Rodenticides**						
4.1	Product 1						

4.2	Product 2						
4.3	Product 3						
5	**Nematicides**						
5.1	Product 1						
5.2	Product 2						
5.3	Product 3						

Transportation of yield from farm to market

Sr No	**Transport mode**	**Yes/No**	**Fuel type (Diesel, Petrol)**	**Hours of travel from field to market**	**Transport name (e.g.), 22 wheeler, 4 wheeler,**	**Farm to destination distance?**	**Remarks**
1	Road						
2	Rail						
3	Air						
4	Sea						

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