Australian Government
Australian Centre for International Agricultural Research

Final report

Small research and development activity

Project	**Development of a cost-benefit assessment framework in support of the State of Land and Water (SOLAW) report 2021**
project number	SLAM/2020/138
date published	November 2022
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approved by	Dr James Quilty
final report number	FR2022-028
ISBN	978-1-922787-48-4
published by	ACIAR GPO Box 1571 Canberra ACT 2601 Australia

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1 Acknowledgments

The team of researchers would like to acknowledge and sincerely thank the large number of technical offices from FAO Rome, and regional offices and country offfices in Asia Pacific, Africa, Near East and North Africa, Latin America and the Caribbean Island with assisted with the expert opinion survey. We are to acknowledge the support of WOCAT, the global network on Sustainable Land Management (SLM) that promotes the documentation, sharing and use of knowledge to support adaptation, innovation and decision-making in SLM.This study would not have been possible without the support of WOCAT. The team also wishes to record their thanks to ACIAR staff for their support and guidance.

2 Executive summary

Sustainable management of land, soil, and water is important to tackle the growing dual challenges of global food insecurity and environmental degradation. Different regions and countries face these challenges differently, some are more vulnerable than others. Various solutions and response strategies have been developed at a national, regional, and global level to sustainably manage these land, soil, and water. However, the institutional, technical, social, and financial capacities of different regions and countries are different, making it hard to find a set of solutions that would be effective in diverse conditions. There is no comprehensive assessment framework that could be used to test and examine different solution strategies. The project contributes to this gap.

This SRA was designed to develop a Comprehensive Framework of Response Assessment (CFRA) for sustainable management of agricultural systems (land, soil, and water) that could be applied to assess different solutions at national, sub-national, and local levels. The main features of the CFRA are its ability for assessing the relative costs, benefits, and effectiveness of different responses; and in identifying the priority and sequence of responses for investment decisions, and in scaling up effective responses. The developed framework and associated analysis contributed to FAO's State of the World's Land and Water Resources for Food and Agriculture (SOLAW) 2021 (SOLAW2021).

The steps undertaken in the SRA are as follows: 1) Develop a theoretical basis based on a DPSIR framework based on existing literature and expert consultations; 2) Extensive consultations with FAO to understand the effectiveness of responses to various challenges at regional levels; 3) development and augmentation of a global repository of response; 4) comprehensive analysis of the effectiveness of different solutions to test the effectiveness of the CFRA. We outline each of these steps below.

DPSIR: The DPSIR (drivers, pressures, state, impact, and responses) framework was developed to generate a picture of the state of the land, vegetation cover, water, and soil resources, the direction, and nature of the changes in the use of these resources. In addition to this, it seeks to develop a better understanding of the effectiveness of technical, institutional, and policy responses to mitigate and adapt to land, soil, and water degradation. The DPSIR framework has been used in SOLAW21 to describe the state of the land, water, and soil and to a better understanding of the different technical, institutional, and policy responses that have direct relevance on the informed decision-making processes; enhancing sustainable management of land and water resources; and achieving multiple goals such as food security, climate change resilience and combating land degradation.

Consultation: Based on existing literature and expert opinion a preliminary list of drivers, pressures, states, impacts, and responses were prepared. The significance and weight of different drivers, pressures, state and impacts, and their interlinkages with the response categories (DPSIR), have been established for selected regions (e.g., the Asia Pacific, Near East and North Africa, Africa, Latin America, and Caribbean Islands) using high-level expert opinion surveys.

Response repository: A synthesis of global databases and literature was carried out for about sixty broad categories of responses refined through the regional consultation process described above. Additional data on response categories or interventions have been collected from existing sources, including the World Overview of Conservation Approaches and Technologies (WOCAT) and published literature, while information on more than eighty DPSIR indicators has been collected from global and regional databases.

Assessment: An Effective Response Index was created to understand the overall impact of an intervention/solution in several key dimensions. Standard econometric and spatial analysis have been carried out to understand/explain the effectiveness of different responses. The predicted ERI index for different regions and solutions have been produced.

The major achievements from the project are as follows:

- Direct contribution to FAO's SOLAW2021 in terms of development of methodology on how to describe the interconnectedness among different components of an agricultural system
- Development of a comprehensive response repository in close collaboration with FAO, WOCAT
- Development of a Comprehensive Framework of Response Assessment (CFRA)
- Assess and predict the effectiveness of selected key interventions/responses based on an assembled and harmonized dataset of global physical, biophysical, socio-economic contextual, and local data

Key findings of the project are as follows:

- Population is the one key drivers influencing the sustainable land, water and soil system in the Asia Pacific, Central Asia, Near East and North Africa, while urbanisation is the key driving factor in Africa. Other important drivers affecting all regions are the uneven rainfall, recurrent flood and drought events which further puts the agricultural system under pressure.

- Loss of agricultural productivity and efficiency, land degradation and reduced water availability and water quality are the major impacts caused by the unsustainable agricultural practices, increasing pressure of over-extraction of groundwater and surface water.

- Conservation practices and agriculture, Community Based natural resource management, Restoration and rehabilitation of degraded lands , Sustainable forest management (both planted and natural) are crucial responses to land degradation and loss of vegetation cover.

- Integrated groundwater and surface water management, modernisation of irrigation system and installation of large-scale dams are a few of the top-rated responses to address water scarcity and groundwater depletion. Statistical analysis also shows that there is about 50% probability that the intervention-Small holder irrigation will have highly positive impacts on benefit-cost ratio.

- Conservation agriculture with minimum soil disturbance, use of smart technologies and integrated plant nutrition and management are the three most effective responses to manage the loss of agricultural productivity. Among these three, smart technology responses are likely to have higher positive impacts on benefit-cost ratios and have overall high effectiveness.

- Emphasis and higher effectiveness are evident for integrated approaches, for instance, to improve productivity in rainfed systems for adaptation to climate change and in crop-livestock management as well as integrated groundwater and surface water management.

Key recommendations from the project include:

- Prioritization of responses are required at local, sub-national, and local levels to tackle the challenges
- Integration of macro, meso, and micro data are required to generate useful predictions
- To learn from the past, we need to keep a record of the failed projects (as well as successful projects). Otherwise, global analyses are often limited by the data availability constraints

3 Introduction

Sustainable management of the land, water, and soils has become a crucial determining factor for global food security through the maintenance and restoration of the ecosystem today more than ever before (FAO 2018, Dinar et al 2019, Pereira 2018, Acevedo 2018). It is a necessary response to climate change impacts (Lal et al., 2011; Rojas-Downing et al., 2017, IPBES, 2018).

Led by FAO, State of the World's Land and Water Resources for Food and Agriculture (SOLAW) is a unique attempt to address the challenge and build awareness of the status of land (including the soil) and water resources, highlight the risks to them, list the identified hotspots, and inform on related opportunities and challenges. In 2021, SOLAW has been published after ten years of its first edition. It compiles and uses diverse sets of global data on land and water and presents a comprehensive and up-to-date global overview of the availability of land and water resources, their use, and management, as well as related trends and current and likely developments.

SOLAW21 highlights the essential policy and institutional responses, institutions, and investments needed in assuring equitable access to resources and their sustainable and productive management while producing desired levels of economic development. It elaborates on options and strategies for addressing evolving issues such as water scarcity and land degradation.

The DPSIR framework (drivers, pressures, State, impact, and responses) has been used in SOLAW21 to describe the state of the land, water, and soil. One of the key objectives of DPSIR in SOLAW21 is towards a better understanding of the different technical, institutional, and policy responses that have direct relevance on the informed decision-making processes; enhancing sustainable management of land and water resources; and achieving multiple goals such as food security, climate change resilience and combating land degradation. However, responses have different influences in terms of impacts (social, environmental, and economic costs), sustainable land productivity, and human well-being. It is essential to know the different perspectives of such responses in terms of impact, and particularly if the responses influence the State and whether they impact directly or indirectly on drivers or pressures through feedback loops in the system. Recognizing such differences among responses under different scenarios is critical in making informed decisions about how to prioritize actions. Some of the responses have co-benefits to land, water, and soil, and understanding such interlinkages (land - water - soil) among responses can help to better understand synergies and the different trade-offs between contrasting actions and inactions. This understanding is essential to prepare appropriate responses for climate change adaptation and mitigation options.

With support from ACIAR, a multidisciplinary team of experts led by Griffith University developed a comprehensive framework of response assessment (CFRA) to compare technical, institutional, and policy responses, or interventions, to address global land, water, and soil degradation. The CFRA aims to offer a standardised methodology for assessing the relative costs, benefits and effectiveness of different responses based on a DPSIR framework. CFRA follows a systems approach and uses a causal framework for describing the interactions between society and the environment. The combination approach of CFRA and DPSIR thus offers a solution-oriented assessment relevant at the local level and design principles to scale up the most effective responses for a broader impact.

The CFRA will aid in identifying the priority and sequence of responses for investment decisions, and in scaling up of effective responses.

The project contributes to the FAO-led SOLAW21 report by providing a strong and comprehensive response framework for better understanding the effectiveness of technical, Institutional and policy responses to mitigate and adapt to land, soil and water degradation.

In the project's current phase, a synthesis of global databases and literature has yielded data for about sixty broad categories of responses. The significance and weight of different drivers, pressures, State and impacts, and their interlinkages with the response categories (DPSIR), have been established for selected regions (e.g., the Asia Pacific, Near East and North Africa, Africa, Latin America and Caribbean Islands) using high-level expert opinion surveys. Additional data on response categories or interventions have been collected from existing sources, including the World Overview of Conservation Approaches and Technologies (WOCAT) and published literature, while information on more than eighty DPSIR indicators has been collected from global and regional databases. The report shares the findings with the following objectives:

- Showcase the methodology developed and demonstrate the functionality, scope and applicability of CFRA using a DPSIR approach.
- Add value to existing works in assessing the effectiveness of responses that can address the degradation of land, water and soil; and
- Understand the limitations of the framework in terms of data availability and potential future scope.

The report is structured as follows. The following two sections describe the background of the SOLAW21 initiative and explain the DPSIR Framework. Section five presents the regional DPSIR Framework based on an expert opinion survey. It shows the different ranking of elements of Drivers, Pressure, State and Impact in three Regions-Asia Pacific, Africa and Near East and North Africa with the relevance of the response given each of the possible sets of driver, pressure, state and impact. Section six presents the CFRA, methodology and data, and section seven presents the selected results. The final section summarizes the results with a description of key lessons learned, and it outlines the future work area of the project.

4 State of the World's Land and Water Resources for Food and Agriculture (SOLAW21)

The first edition of the State of the World's Land and Water Resources for Food and Agriculture (SOLAW) was launched in 2011. The publication presented an objective, up-to-date, and comprehensive information and analyses on the State, trends, and challenges facing land and water. Land and water resources are central to agriculture and rural development and are intrinsically linked to the global challenges of food insecurity and poverty, climate change adaptation and mitigation, as well as degradation and depletion of natural resources.

A major objective of SOLAW 2011 was to build awareness of the status of land and water resources, highlight the risks to them, list the identified hotspots, and inform on related opportunities and challenges. SOLAW 2011 also highlighted the essential but often understated contribution to which appropriate policies, institutions, and investments make in assuring equitable access to resources and their sustainable and productive management while producing desired levels of economic development. It elaborated on options and strategies for addressing evolving issues such as water scarcity and land degradation.

Since the launch of SOLAW in 2011, numerous important developments have taken place, to assess and ensure effective positioning of the new edition of SOLAW (SOLAW 21). Further, SOLAW 21 involves a process of updating the earlier version of SOLAW with a review and update of the challenges, status, and trends in land and water resources in the light of recent global developments and international commitments. It highlights various opportunities to foster a practical shift toward sustainable management of land and water resources and provides recommendations and knowledge about options and actions. This is intended to support decision-makers, practitioners, and the private sector to contribute and lead a transformative process to move from degradation and vulnerability toward sustainability and resilience.

The DPSIR framework (Drivers, Pressures, State, Impact, and Responses) has been used in SOLAW21 to describe the interlinkages and interdependencies between the environment, socioeconomic factors, and sustainable agricultural production systems. While SOLAW (2011) does not explicitly mention the use of DPSIR methodology, its structure broadly follows it. The preparation of SOLAW 21 makes use of this framework in building on (and updating wherever applicable) the various indicators that the first edition of SOLAW established to identify the drivers of change, pressures, impacts and possible response options available to decision-makers.

5 Background of DPSIR

Assessment of agricultural sustainability is complex as it encompasses multifaceted interactions between technology, environment, natural resources, policy, economics, and society. It is even more complex to identify suitable policy strategies to respond to such dynamic interacting systems. It needs an appropriate system framework that can assess sustainable rural livelihoods, can emphasize social and economic dimensions of sustainable development at a relatively smaller (local or micro) scale while assessing the environmental impacts of use and management of critical resources like land, water, and soil at global, regional and local scales; and to propose effective and efficient response options (appropriate to different scales).

The Driver-Pressure-State-Impact-Response (DPSIR) model stemmed from the Pressure-State-Response (PSR) framework which was devised by the Organization for Economic Cooperation and Development (OECD, 1993) to address the problem of systematic identification of indicators for environmental sustainability for the first time. It is based on the stress-response framework developed earlier for ecosystems analysis. The PSR framework relies on the simple concept of causality: human activities exert pressure on the environment and change its State. Society responds to these changes through environmental, economic, and other actions and policies. Activities resulting from these policies, in turn, exert pressure, completing the PSR feedback loop. Later, the DPSIR framework was elaborated and widely adopted by European Environmental Agency to analyse the interacting processes of human-environmental systems and capture the cause-effect relationships between the sectors of social, economic and environmental systems (Burkhard and Müller, 2008; European Environment Agency, 1995; Svarstad et al., 2008).

Land Degradation Assessment in Dryland (LADA) used the DPSIR framework to describe the interaction of society and the environment; the framework has been used in more than 25 countries to analyse the land status and trends at the local and national levels using both scientific and expert knowledge.

The reasons for the wide adoption of DPSIR are its simple structure to capture the complicated relationship and the ability to help in the framing of policy response that can mitigate and adapt to direct and indirect impacts (Bunning et al. 2016). However, there are certain shortcomings of DPSIR; for instance, it ignores temporal and spatial scale issues, overlooks social or political aspects, as well as provides poor connections to ecosystem service approaches. Thus, its application poses difficulties in gathering a complete and consistent picture of the operation mechanism of the causality chain, particularly in agriculture (Kohsaka, 2010; Rao and Rogers 2006, Maxim et al., 2009; Potschin, 2009; Spangenberg et al., 2015; Svarstad et al., 2008). An additional challenge of the application of DPSIR is to develop a common framework that standardizes the causal links between humans, environment, and socioeconomics at the global level on the one hand, and in agroecosystems analysis and sustainable livelihoods assessments at more localized and regional levels on the other. Despite such limitations, DPSIR is a commonly used framework due to its pragmatic structure. In this report, the DPSIR was adopted to enhance the understanding of the cause-effect relationship and to assist in delivering key policy recommendation messages to advance the sustainable management of land and water resources. The framework was slightly modified to overcome some limitations, with particular emphasis on differentiating between global and regional/sub-regional frameworks.

There are several DPSIR models for land, water, and soil, that all address in silos the causal links to understand the State of the resource. Given the explicit linkage of these three resources, the critical question remains; how to integrate and capture the interlinkages and interdependencies between land, water, and soil for agricultural sustainability assessment.

5.1 DPSIR Framework for SOLAW21

The objective of this DPSIR exercise is to create a framework that can generate a picture of the State of the land, vegetation cover, water, and soil resources, the direction, and nature of the changes in the use of these resources. In addition to this, it seeks to develop a better understanding of the effectiveness of technical, institutional and policy responses to mitigate and adapt to land, soil, and water degradation.

In the DPSIR framework, the drivers represent the factors exogenous to the agricultural systems (including land, water, and soil) which puts the system under stress through increased human activities. The pressures are the stresses on the systems due to the human reactions to the exogenous drivers. The State represents the condition of the systems (quality and quantity) over a given period. States of the system change over a period due to the pressures. The impact indicates the influences on flows and services in the ecosystem, agriculture, and economy that is determined by the pressure and State of the systems. The responses variable in the DPSIR represent the efforts/interventions/actions at different levels to sustain services from the natural systems (land, water, and soil) while minimizing the negative externalities.

The components of the DPSIR framework (Figure 1) have been defined in the following manner:

5.2 Driving Forces:

In the context of this work, drivers could be defined as any natural- or human-induced factor that directly or indirectly brings about change in an agricultural system (soil-land-water) (Hazell and Wood, 2008). The driving forces for SOLAW21 encompass market drivers (increasing and changing consumption), natural drivers including climate change, and drivers related to changes in governance, institutions, and policies. The increasing and changing consumption category reflects the evolving needs of society, for instance, the demand for food, shelter, and water, as a result of population growth, changing employment rates and income changes. Other driving force factors include unequal distribution of knowledge and technology application as evidenced by growing knowledge and technology-driven agriculture on the one hand, as well as certain gaps in knowledge and lower levels of technology deployment for farmers on the other.

Other factors include rising inequality in land & water access, all affecting consumption, and poverty, changing consumption habits, increasing obesity, food wastage and changing production technology. Human-induced climate change and natural factors affect the sustainability of the land, water, and soil and include greenhouse gas concentrations, flood and drought events, forest fires, atmospheric transport and deposition and uneven rainfall distribution.

Under the governance and institution category, changing land & water rights, access to support agriculture extension services, different types of governance failure (at different scales) along the value chain leading to postharvest loss are some of the factors (it can lead to losses along the whole food value chain, not only postharvest).

Different international and regional trading agreements facilitated by various organizations such as the World Trade Organization (WTO) affect soil-land-water systems (particularly agricultural productions) around the world. For example, in the agriculture sector international trade has increased by many times over the past few decades. Some countries have taken advantage and increased their exports of non-traditional products, whereas other countries have lost significant market share (Hazell and Wood, 2008).

The drivers in the DPSIR can also be characterized at a local level and explained using a Sustainable livelihood approach. The factors can be classified into different forms of capital-social, human, natural, social, financial, and physical components that interact with numerous policies, governance, and institutions that affect the sustainability of the land, water, and soil use and management.

5.3 Pressures:

The activities provoked by the driving forces create pressures in terms of changing production systems, the level/type of resource use, land-use changes, movement of soil, contaminants and nutrients leading to changes in environmental conditions, among others. These include human-induced as well as natural processes and disasters.

The pressures category includes resource use and management of land, water, and soil exerting pressures on the stock of natural resources. That leads to continuous cultivation, intensification of land, water and soil, over-extraction of groundwater, adoption of land management practices like cultivation on slopes, deforestation, overgrazing, and land abandonment.

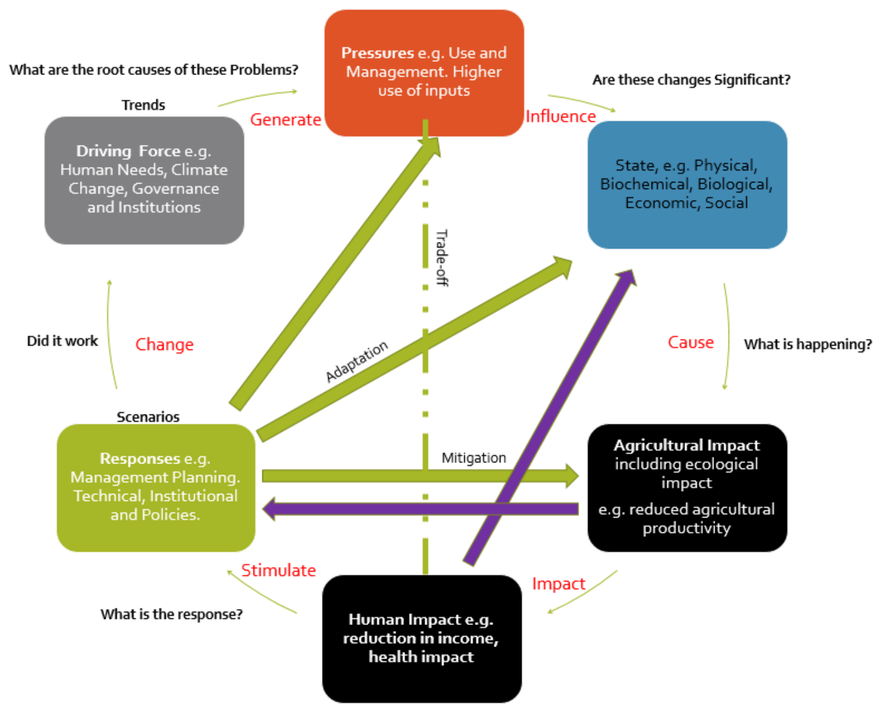

Figure 1: Interactions in DPSIR

Along the agricultural value chain, the pressure manifests in the agricultural input sector, where there is evidence of changing dynamics in input use as a result of price changes in fertilizer and energy prices, cross dependence of the factors, and market concentration.

The pressures also include intensification of resource use, which engenders water pollution through intensive use of agrochemicals, pesticides, and fertilizers, releases contaminated effluents in and near catchments. It also results in irrigation practices using untreated wastewater, and poor-quality livestock waste and an increase in GHG's.

5.4 States:

Pressures affect or lead to changes in the State of the environment (land-water-soil), described by quantity and quality of the resources, flora/fauna, chemical concentrations in water and soil, among others.

The State of agriculture and sustainable use of land, water, and soil has been categorized into

i) physical state

ii) biogeochemical state

iii) biological state

iv) economic state, and

v) social state.

The physical state captures dynamic physical changes in the soil, land, and water, including, for example, the loss of topsoil, salinization, deforestation, loss of vegetation cover, increased fluctuation of surface water, groundwater depletion, and degree of land degradation, desertification, or water scarcity.

The biogeochemical state category includes elements like soil chemical imbalances and nutrient toxicities, inorganic pollutants in the soil, the pollution of surface and groundwater, or the reduction in the quality of the vegetative biomass.

The biological state is defined by the number of fish, animal, and plant species, and the State of native biodiversity.

The economic state includes the changing market value of agricultural goods due to price volatility, as well as upward and downward pressures on prices, including the level of asset holding, inequality, and the income level of small and marginal farmers.

The social state includes conflicts arising from competition for land and water, migration out of agriculture leading to the aging of farmers, and gender inequality.

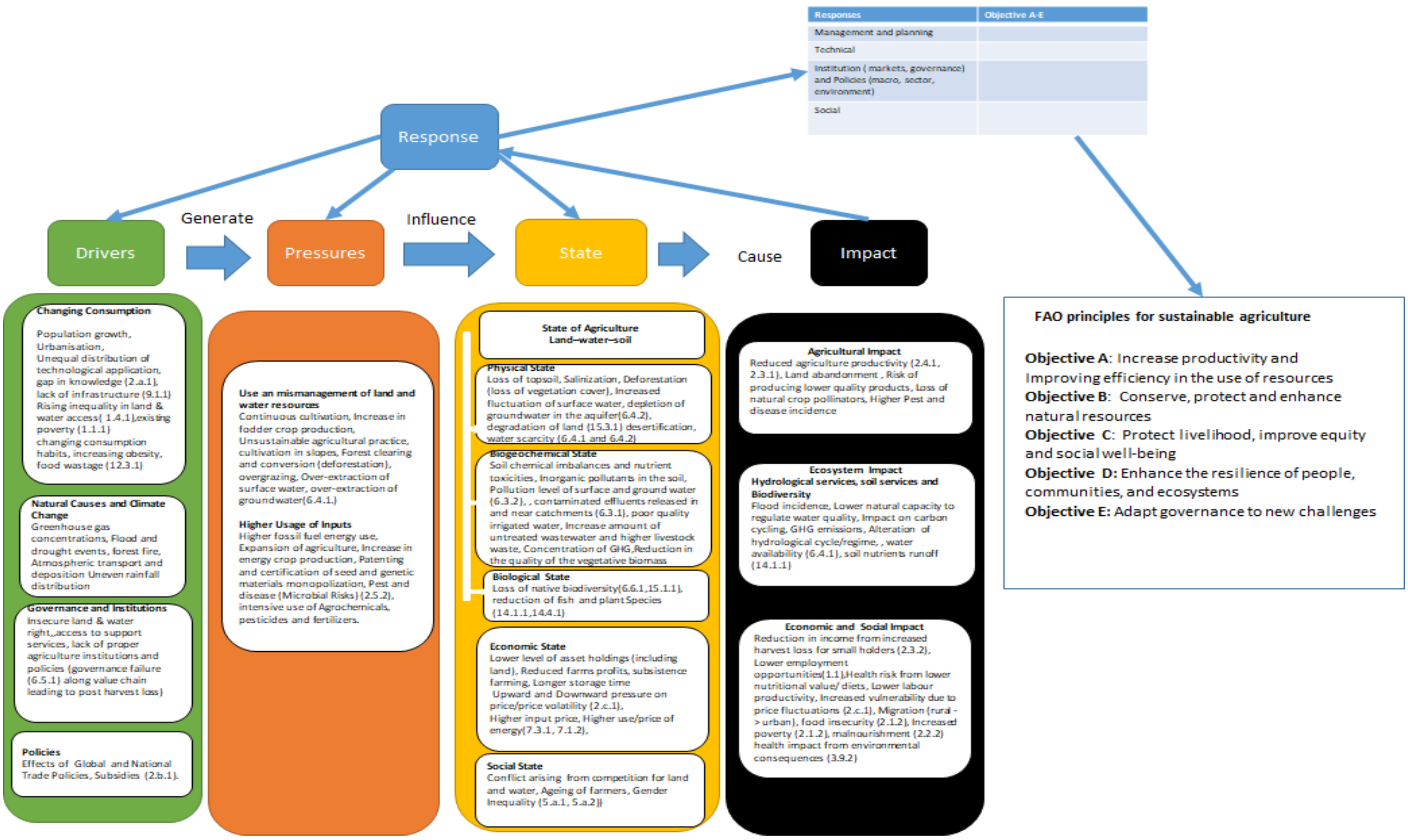

Figure 2: DPSIR framework -Note: Numbers in parenthesis denote the relevant SDG indicator

5.5 Impacts:

Impacts capture the effect on the functions of the biophysical, socio-economic, and environmental systems.

The proposed framework connects the impacts on agricultural productivity, land abandonment, the risk of lower quality products, competition for pollination, higher pest and disease incidence, agricultural efficiency, and sustainability.

In addition to direct agricultural impacts, there are impacts on ecosystem services, which may indirectly affect agricultural productivity. These impacts include flood incidence, lower natural capacity to regulate water quality, impact on carbon cycling, GHG emissions, and alteration of hydrological cycle/regime, water availability, along the decline of soil nutrients runoff. These indirect impacts lead to social and economic effects which may include a reduction in income from increased harvest loss for smallholders, lower employment opportunities, health risk from lower nutritional diets, lower labor productivity, increased vulnerability due to price fluctuations, migration (rural -> urban), increased poverty, malnourishment, and health impacts.

5.6 Responses:

Responses options as means to reach desired objectives linked to the DPSI and a set of actions and strategies available to individuals, groups, communities, businesses, and governments, to prevent, compensate, ameliorate, mitigate or adapt to the likely changes identified.

Responses are classified according to the following categories:

i) management and planning responses

ii) technical responses

iii) institutional (markets, governance) and policy responses (macro, sector, and environment)

iv) social responses, and

v) other options not related to the direct management of land and water management.

The management and planning responses include resource planning to promote sustainable land, soil, and water management. It includes technical and institutional knowledge to understand the potential for enhancing agricultural production (vertical as well as horizontal expansion) and productivity in the future under different climate change projected scenarios, as well as sustainable management options to avoid, reduce and reverse degradation, particularly in unique and fragile landscapes.

The technical response category includes techniques that improve agricultural production sustainably, manage soil health and fertility, appropriately source water for irrigated agriculture, and the technical options to modernize irrigation systems and rainfed agriculture to reduce inefficiency. It also covers water harvesting and techniques in managing wastewater/greywater use and techniques to tackle water pollution in agriculture and to manage pollution-related environmental risks. This category may also explore how the use of digital technology (big data, ICT, and IoT), nature-based solutions, and circular economies can influence the state and impact the agricultural system in the short and long term.

The institutional (markets, governance) and policy (macro, sector, environment) responses include national strategies and policies that shape sustainable management and secure access to soil, land, and water resources. It also includes responses that can strengthen international partnerships and alliances with a regional focus, such as initiatives to foster knowledge sharing, along with policy dialogue on sustainable land and water management.

SDGs, the Paris Agreement, UNCCD (e.g. LDN) and CBD (the Aichi Targets and the post-2020 global biodiversity framework) as well as the Sendai Agreement, are also global responses with a regional and local impact that may influence the sustainable use of resources and may lead to different trade-offs and synergies. Other than the global policy agenda, several national and regional trade policies, for instance, subsidies, act as a driving force.

Other options outside the domain of land and water management may also influence sustainable agriculture. These include improved plant varieties (high-yielding crops, seeds resistant to disease, pests, drought/scarcity/heat, salt-tolerant crops, transgenic crops), crop fortification, as well as responses that can help in increasing efficiency in industrial use (from site selection to manufacturing processes to reduce consumption, pressure on resources and decrease pollution/contamination). Energy plays a key role in determining interdependent factor usage in agriculture. Reducing the cost of energy and promoting the use of renewable sources of energy is considered as one of the important responses in this category.

Pathways to sustainable agriculture depend on a wide range of factors, such as the behaviour of producers and consumers. Social responses, such as dialogues that can induce behavioural change, are another form of response that influences the agriculture system, potentially leading to equitable and participatory sustainable land and water management. From a market perspective, dietary patterns not only reflect consumer needs and preferences but generally reflect complex social behaviours. Sustainable choices such as diets with zero-km products, low water footprint (from the choice of meat to packaging), and gender balance also influence agricultural systems and are regarded as a key part of the response function.

Each category of response aligns aligned with the FAO's five principles for sustainable food and agriculture (FAO, 2014), which were used in framing the actions in the agriculture and food domain to guide policymakers in achieving the Sustainable Development Goals (FAO, 2018). These principles are taken as the objectives of the study.

i) Objective A: Increase productivity and improve efficiency in the use of resources

ii) Objective B: Conserve, protect and enhance natural resources

iii) Objective C: Protect livelihood, improve equity and social well-being

BOX 1 : The purpose of the box is to list some of the responses linked to the objectives listed above and indicate the nature of influence (direct or indirect) of responses on the drivers, pressures, states, and impacts in the DPSIR framework. For instance, R-P indicates that the response influences pressures while (R-P-S-I) shows that the response influences impact indirectly through influences on the pressures, and states. The box also indicates the SDG targets aligned to the specific responses.

Objective A: Increase productivity and Improve efficiency in the use of resources

Improving sustainable agricultural production and facilitate access to productive resources, finance, and services

- Use of improved plant varieties (high-yielding crops, seeds resistant to disease, pests, drought/scarcity/heat, salt-tolerant crops, transgenic crops), fortification, etc. (R-P) SDG 2.5, 12.2, 6.4
- Investing in mechanization and advanced technologies (R-P) SDG 2.3,2a, 7b,9b,9c, 17.6 and 17.7, 6.4
- Increasing on-farm water productivity (R-P) SDG 2.3, SDG 6.4
- Increasing the efficiency of nutrient cycling and applied inputs, to maintain and raise soil fertility (R-P-S) SDG 2.4, SDG 6.5, 9.4, 14.1, 12.2
- Strengthening access to the financial system, risk management instruments and output markets (R-D-P-S-I) SDG 2.a, 2b, 2c, 9a
- Modernizing irrigation systems (R-P-S-I) SDG 6.4

Connect smallholders to markets (R-P-S-I)

- A macro-economic framework, including better infrastructure, public goods, regulations and policy, and legal environments (R-D-P-S-I) SDG 2,7,9-- SDG 2b. 2c,7.1, 7.3, 9.3, 9.1, 17.13
- Improved market information and food safety guidelines, as well as focusing on value-added production and marketing (R-P-S-I) SDG 2, 9c
- Strengthen the infrastructure needed for urban-rural integrated development and agricultural connectivity; (R-P-S-I) SDG 2c, 9.1, 9.3, 11a

Encourage the diversification of production and income (R-P-S-I) & (R-I) SDG 2.3, 10.1, 10.2, 8.2, 8.3

Build producers ´knowledge and develop their capacities (R-D-S)

- Support sustainable land and water management options, participatory land-use planning across sectors, landscape restoration, and management, investment in SLM role of private and public sectors, governance (R-D-S). SDG 2a, 2.3, 6a, 13.1, 13.2
- Balance the Big Data and Smart Analytics approaches, as well as the promotion of skilled farmers and professionals capable of interpreting data streams (R-I). SDG 4.4, 4.7, 13.3

Objective B: Conserve, protect and enhance natural resources

Enhance soil health and restore land (R-S)

- Soil moisture management for rainfed areas, SDG 2.4,12.4, 15.3, 6.4
- harmonize data within a common framework and improve information systems for continuous monitoring of soils. SDG 17.19

Protect water and manage scarcity (R-S)

- Sourcing water for irrigated agriculture, SDG 6.4
- Tackling water pollution from agriculture SDG 3.9, 6.3, 14.1

Mainstream biodiversity conservation and protect ecosystem functions (S-I)

- Managing other environmental risks associated with intensification SDG 2.5, 8,4, 12.4, 15.2

Reduce losses, encourage reuse and recycle, and promote sustainable consumption

- Water harvesting, wastewater/gray water use, nature-based solutions, circular economy in water management SDG 6.3, 6.4, 12.5
- Reducing food loss and waste SDG 12.3
- Marketing and consumer levels: sustainable choices such as sustainable diets, zero-km products, low water footprint (from the choice of meat to choose of packaging) SDG 8.4, 12.2, 12.3
- Reducing the cost of energy and promoting the use of renewable sources of energy. SDG 7.2
- Increasing efficiency in industrial use (from site selection to manufacturing processes to reduce consumption, pressure on resources, decrease pollution/contamination) SDG 9.4

Objective C: Protect livelihood, improve equity and social well-being

- Use social protection tools to enhance productivity and income (R-P) SDG 10.1,10.4, 1.3, 1a
- Promote secure tenure rights (R-D) SDG 1.4
- Improve nutrition and promote balanced diets(R-D-S) SDG 2.2,
- Nutritional productivity of water and soil; nutrition-sensitive water and soil management

Objective D: Enhance the resilience of people, communities, and ecosystems

Prevent and protect against shocks: enhance resilience (R-P-S) SDG-1,2, 9, 11,13,14

- Sustainable soil, land, and water approaches in view of climate change SDG 2.4, 13.1, 6.4

Prepare for and respond to shocks (R-P-S)

- Options for the drylands: soil conservation, SLM, water harvesting, wind erosion and control (sand and dust storms), SDG 15.1
- Drought preparedness and management, SDG 15.3

Address and adapt to climate change (R-D-S)

- Integrated approaches to improving productivity in rainfed systems SDG 2.4, 6.5
- Strengthen ecosystem resilience (R-P-S) SDG 13.1

Objective E: Adapt governance to new challenges

Enhance policy dialogue and coordination (I-R) SDG-1,2, 5,6,7,11 12, 13,14,15,16, 17

- Strengthening international partnerships SDG 17.16
- Social dialogue leading to equitable and participatory sustainable L&W management
- Regional focus and initiatives to foster knowledge sharing, policy dialogue on regional issue
- Global alliance on sustainable land and water management SDG 17.16
- engage with the private sector in making the investments and developing the technologies and best practices needed to enhance productivity, efficiency, and sustainability in food value chains.

Strengthen the Agricultural Market Information System (AMIS) to reduce food price volatility SDG 2 b and c

Strengthen innovation systems (R-P-S)

Adapt and improve investment and finance (R-P-S-I)

Strengthen the enabling environment and reform the institutional framework (R-D) & (R-S)

Integrated land and water planning, conflict resolution among competing sectors (trade-offs)

6 Regional DPSIR

The global DPSIR framework does not capture information about DPSIR linkages within a specific regional context. This has motivated the current study to make suitable modifications and apply the DPSIR framework to regional or national contexts. The regional DPSIR framework provides a quick snapshot of the challenges in the land, water, and soil degradation and identifies a potential priority ranking for responses. The design, understanding of causal linkages between DPSI components, and relevance of potential responses in the regional DPSIR framework are based on an extensive literature survey. Subsequently, the importance of each response within the region in question is determined through an expert opinion survey.

6.1 Data Expert Opinion

Several workshops were organized by FAO HQ, FAO-Regional and country offices, and Griffith University, Australia to develop the regional framework in Africa, Near East and North Africa, Asia Pacific, Latin America, Central Asia, and Caribbean Islands. Table 1 shows the subregion countries covered in the expert opinion survey.

The workshops aimed to conduct an extensive expert opinion survey to rank different elements of Drivers, Pressures, State and Impacts that put stress on the agricultural systems (including land, water, and soil) from increased human activities. The experts were drawn from a range of disciplinary fields, including agriculture water management, land specialists, soil and land planning.

The survey started with the prioritization of the drivers, pressures, states and impacts that stress the agricultural systems (including land, water, and soil) that result from increased human activities. Then, experts were asked about their opinion on the link between responses of different categories (management, technical, institutional and social) to the elements of DPSI and to indicate how important each response would be for their region and/or countries in mitigating drivers and pressures, improving the states and bringing about positive impacts on the flows and services of the agricultural systems. The prioritization ranking scores were then normalized between a score of 0 to 1 so that the top-most element receives a value of 1 and the lowest-scored element receives a value of 0.

Table 1:List of Countries and Region for Expert opinion Survey

Region	Countries
Africa	Cameroon, Central African Republic, Chad, Congo Republic - Brazzaville, Democratic Republic of Congo, Equatorial Guinea, Gabon, São Tomé & Principe.
Near East and North Africa	Algeria, Bahrein, Egypt, Iran, Iraq, Jordan, Kuwait, Lebanon, Libya, Mauritania, Morocco, Oman, Qatar, Saudi Arabia, Sudan, Syria, Tunisia, United Arab Emirates, Yemen.
Asia and Pacific	Bangladesh, Myanmar, Cambodia and the Philippines
Latin America	Bolivia, Chile, Brazil, Guatemala, Suriname
Central Asia	Kazakhstan, Kyrgyzstan, Turkmenistan, Uzbekistan

Caribbean Islands	Barbados, Grenada, Jamaica, Saint Lucia

The second part of the survey requires scoring of the linkage between response and DPSI elements based on the levels of the scales of the importance of the response (1 to 5), where 1 indicates the response is not important or relevant to the DPSI elements, and five means that the response is significant.

- Not important or relevant (1): The Response is not relevant to the element.
- Slightly important (2): The Response may be relevant to consider in addressing the element. However, implementation across countries is challenging due to the context of the region or even difficult to apply within reasonable time limits.
- Moderately important (3): The Response is relevant, and there are indications of application in some countries, but the impact is still in an initial phase/realized. It is possible that with time and more effort, such a response can help address the stress on the system due to that specific element.
- Important (4): The response is important, but its full implementation to address a given element requires considerable effort.
- Very important (5): The Response is very important with demonstrated positive outcomes within the region. It can help to address the specific element within the region's context and within a reasonable timeframe.

6.2 Results-DPSIR:

In this section, we summarise the findings of the expert opinion survey on the Regional DPSIR framework in Africa, Near East and North Africa, Asia Pacific, Latin America, Central Asia and the Caribbean Islands. The results highlight the main challenges related to land, water and soil management and ranked critical responses to mitigate the threats to the physical, economic and social State caused by the degradation of land, water and soil.Table 2 summarises the results of Regional Driver-Pressure -State -Impact based on the expert opinion survey.

Table 2: Regional Key Driver, Pressure, State and Impact

Region	Drivers	Pressure	State	Impact
Africa	Urbanisation	Increase in fodder crop Production	Reduced farm Profits	Reduced Agricultural productivity and efficiency
	Flood and Drought Events	Unsustainable Agricultural Practices	Degradation of Land	Health Impact from Environmental consequences
	Insecure Land and Water Rights	Continuous Cultivation	Upward and Downward pressure on price, price volatility	Food Insecurity
Near East and North Africa	Population	Over extraction of Groundwater	Water Scarcity	Water availability
	Uneven Rainfall	Over Extraction of Surface water	Depletion of Groundwater	Loss of crop pollinators

	Urbanisation	Over Grazing	Increased fluctuation in Surface water	Reduced Agricultural productivity and efficiency
Asia and Pacific	Population	Continuous Cultivation	Water Scarcity	Reduced Agricultural productivity and efficiency
	Flood and Drought Events	Forest Clearing	Upward and Downward pressure on price, price volatility	Food Insecurity
	Uneven Rainfall	Unsustainable Agricultural Practices	Loss of vegetation Cover	Alteration of hydrological Cycle
Latin America	Green House gas Concentration	Cultivation on slopes	Increased amount of Untreated waste	Food Insecurity
	Lack of Infrastructure	Pest and Disease (Microbial Risks)	Loss of vegetation Cover	Flood Incidence
	Uneven Rainfall	Forest Clearing	Upward and Downward pressure on price, price volatility	Health Risk from lower Nutritional Value
Central Asia	Population	Increase in fodder crop Production	Salinisation	Alteration of hydrological Cycle
	Flood and Drought Events	Continuous Cultivation	Desertification	Impact on Carbon Cycle
	Uneven Rainfall	Over Grazing	Degradation of Land	Rural urban Migration
Caribbean Islands	Population	Pest and Disease (Microbial Risks)	Depletion of groundwater	Food Insecurity
	Uneven Rainfall	Cultivation on slopes	Conflicts on land and water	Flood Incidence
	Urbanisation	Intensive use of agrochemicals, pesticides and fertilisers	Water Scarcity	Rural-urban Migration

The results find that loss of agricultural productivity and efficiency, land degradation and reduced water availability and water quality are the major impacts caused by the unsustainable agricultural practices, increasing pressure of over-extraction of groundwater and surface water. There is an increasing pressure to meet the food demand of the rising population and with growing urbanization coupled.

Population is the one key drivers influencing the sustainable land, water and soil system in the Asia Pacific, Central Asia, Near East and North Africa, while urbanisation is the key driving factor in Africa. Other important drivers affecting all regions are uneven rainfall, recurrent flood and drought events which further puts the agricultural system under pressure. The major pressure factors are unsustainable agricultural practices and continuous cultivation in Africa and the Asia Pacific. Over extraction of water is one of the major pressure factors in the Near East and North Africa, while in Latin America and the Caribbean Islands.

Prioritisation of responses is urgently needed today at different levels, particularly when there is a global effort to accelerate the implementation of SDGs, and hence the contribution of this project's contribution is very timely.

Table 3 illustrates the assessment of DPSIR from a range of elements (components) and shows how conservation agriculture with minimum soil disturbance and tillage practices will be effective in addressing the different drivers, pressures, states and impacts. This exercise has been conducted for all other responses, and detailed results are provided in Appendix Table 1.

The elements have been assessed using the mean rankings, ranging from 1 (low) to 4, or 5 (high) as determined by respondents to the study. The higher the mean ranking, the more effective the factor is likely to be in addressing the element in each of the three regions. The total column at the end of each table is the mean score for each of the three regions, with the commentary accompanying the table using this figure as the basis for determining the most effective elements (components) to the response based on a mean score of at least 4.

Table 3:Expert Evaluated Scores of Drivers, Pressures, State and Impacts according to Response - Conservation agriculture with minimum soil disturbance and tillage practices.

Driver

	Africa	Asia and Pacific	Caribbean	Central Asia	Latin America	Near East and North Africa	Total
Access to support services		4			2		3
Atmospheric transport and deposition					2		2
Changing consumption habits					1		1
Effect of global and national trade policies and subsidies					2		2
Existing poverty	3	4	2	3	3	2	3
Flood and drought events		2			2		2
Food wastage					1		1
Forest fire					2		2
Greenhouse gas concentrations					2		2
Increasing obesity					1		1
Insecure land & water right					1		1
Lack of infrastructure			4		1		3
Lack of proper agriculture institutions and policies					2		2
Population growth					1		1
Rising inequality in land & water access		5	4		1		3
Unequal distribution of technological application and gap in knowledge	3	3	3	3	3	2	3
Uneven rainfall distribution					2		2
Urbanisation	1				1		1
Total	3	3	3	3	2	2	3

Pressure

	Africa	Asia and Pacific	Caribbean	Central Asia	Latin America	Near East and North Africa	Total
Continuous cultivation	3	5	4	4	4	3	4
Cultivation in slopes	3	4	4	3	3	3	4
Expansion of agriculture	3	4	4	4	3	4	4
Forest clearing and conversion					2		2
Higher energy use (fossil fuel)	2	4	3	2	2	3	3
Increase in energy crop production	1	3	3	3	2		3
Increase in fodder crop production	3	3	2	4	3	2	3
Intensive use of agrochemicals, pesticides and fertilizers					2		2
Over-extraction of groundwater					2		2
Over-extraction of surface water					2		2
Overgrazing					2		2
Patenting and certification of seed and genetic materials (monopolization)					1		1
Pest and disease (Microbial Risks)					2		2
Unsustainable agricultural practice	4	5	4	3	4	5	4

Total	3	4	4	3	3	3	3

State

	Africa	Asia and Pacific	Caribbean	Central Asia	Latin America	Near East and North Africa	Total
Ageing of farmers	2	3	2	2	3		3
Concentration of GHG	3	3	2	3	3	2	3
Conflict arising from competition for land and water					3		3
Contaminated effluents released in and near catchments					3		3
Degradation of land	4	4	4	5	4	4	4
Depletion of groundwater in the aquifer	2	3	2	3	2	2	3
Desertification	5				4		5
Gender inequality					2		2
Higher input price					3		3
Higher use/price of energy					3		3
Increase amount of untreated wastewater and higher livestock waste					2		2
Increased fluctuation of surface water	4				3		4
Inorganic pollutants in the soil	4				2		3
Longer storage time					3		3
Loss of native biodiversity					3		3
Loss of topsoil	4	5	5	5	4	4	4
Loss of vegetation cover (deforestation)	4		3		3		3
Lower level of asset holdings (including land)					2		2
Pollution level of surface and ground water					3		3
Poor quality irrigated water					3		3
Reduced farms profits, subsistence farming	3	4	3	3	2	2	3
Reduction in the quality of the vegetative biomass					3		3
Reduction of fish and plant Species					3		3
Salinization	3	3	2	4	3	3	3
Soil chemical imbalances and nutrient toxicities	4				2		3
Upward and downward pressure on price/Price volatility					3		3
Water scarcity	4				3		4
Ageing of farmers	2	3	2	2	3		3
Total	3	4	3	4	3	3	3

Impact

	Africa	Asia and Pacific	Caribbean	Central Asia	Latin America	Near East and North Africa	Total
Alteration of hydrological cycle/regime	3	4	3	4	3	3	3
Flood incidence					1		1
Food insecurity					1		1
GHG emissions					4		4
Health impact from environmental consequences					3		3
Health risk from lower nutritional value/ diets					1		1
Higher pest and disease incidence					3		3
Impact on carbon cycling	1				4		3
Increased poverty	3	4	3	2	3	4	3
Increased vulnerability due to price fluctuations					1		1
Land abandonment					4		4
Loss of natural crop pollinators					3		3
Lower employment opportunities					1		1

Lower labour productivity					3		3
Lower natural capacity to regulate water quality	3	4	3	3	4	2	3
Malnourishment		3			1		2
Migration (rural -> urban)					1		1
Reduced agriculture productivity and efficiency	4	4	4	4	4	4	4
Reduction in income from increased harvest loss for small-holders					3		3
Risk of producing lower quality products					2		2
Soil nutrients runoff	3	4	4	4	4	4	4
Water availability	3	4	3	4	3	3	3
Water quality	3	4	3	4	3		3
Total	3	4	3	3	3	3	3

Results from the expert opinion survey indicate that in Africa and Near East and North Africa, as well as central Asia, conservation agriculture can address drivers directly like poverty, and unequal distribution of technological application and gap in knowledge, while in Asia Pacific, the most important driver influenced by conservation agriculture is inequality in land and water rights other than poverty and access to support services. In the Caribbean Islands, conservation agriculture can meet some of the problems arising from lack of infrastructure and at the same time address unequal distribution of technological application and gap in knowledge.

Related to Pressures, conservation agriculture is very effective in addressing the problems related to continuous cultivation, cultivation of slopes and agricultural expansion. It will also address unstainable agricultural practices.

Conservation of Agriculture has multiple benefits related to the different States. We find that it addresses loss of topsoil, land degradation, water scarcity and desertification, particularly in Africa and Latin America.

Conservation agriculture has on average equal impact in addressing reduced agricultural productivity in all the regions and enhancing the capacity to regulate water quality.

This exercise has been conducted for all other responses, and detailed results are provided in Appendix Table 1.

Table 4 summarises the effect of key responses across all the regions. The survey results find that the key response listed in the table ranging from sustainable planted forest management to the use of smart technology in agricultural production could have high positive effects on agricultural productivity and efficiency. Integrated plant nutrition management to enhance soil productivity could have very high impacts on water availability, and quality and higher impacts on good insecurity, land degradation, agricultural productivity, and can address problems related to Soil chemical imbalances and nutrient toxicities.

Table 4:Expert Opinion Based Summary of Response to selected State and Impacts

Response	Food insecurity	Reduced agriculture productivity and efficiency	Water availability	Water quality	Degradation of land	Soil chemical imbalances and nutrient toxicities	Reduced farms profits, subsistence farming
Use of smart technology in agricultural production, selling, and buying of inputs	4	4	3	3	3	3	3
Conservation agriculture with minimum soil disturbance and tillage practice	1	4	3	3	4	3	3
Integrated plant nutrition management to enhance soil productivity	4	4	5	5	4	4	2
Integrated groundwater and surface water management	4	4	4	4	3	2	3
Smallholder irrigation management	4	4	4	4	3	1	3
Conservation practices to reduce soil loss on the sloping and erosion-prone land	3	4	3	1	4	3	3
Restoration and rehabilitation of degraded land	3	3	3	3	4	2	3
Sustainable planted forest management (e.g., agroforestry)	3	4	3	4	4	3	3

Detailed results of the study are provided in appendix A.

The results of the survey find that Conservation practices and agriculture, Community Based natural resource management, Restoration and rehabilitation of degraded lands, and Sustainable forest management (both planted and natural) are crucial responses to land degradation and loss of vegetation cover. Groundwater depletion and water scarcity are issues of increasing concern in all the regions. Integrated groundwater and surface water management, modernisation of irrigation systems and installation of large-scale dames are a few of the top-rated responses to address water scarcity and groundwater depletion. There are multiple technical and economic responses with equal importance rated by the respondents of the survey to address agricultural productivity loss in the region. It ranged from diversification of farm income, government assistance in agricultural inputs to increased efficiency of nutrient cycling and applied inputs to improve soil fertility and yield (e.g., precision agriculture, adequate and balanced use of fertilizers). There is an emphasis on integrated approaches, for instance, to improve productivity in rainfed systems for adaptation to climate change and crop-livestock management as well as integrated groundwater and surface water management. As expected, the best responses vary from region to region and are a function of different drivers, pressure states and impacts. In the Asia Pacific, we see a lot of emphasis on smallholder irrigation management to address water scarcity as well to improve agricultural productivity. In Africa, more emphasis is placed on large-scale dams and reservoirs to address water scarcity and improve agricultural productivity. In Central Asia, the experts identified the importance of improving plant variety to increase yield as a response to reduced agricultural productivity and food insecurity. The findings of these surveys demonstrate important regional differences in regional DPSIR linkages and are an essential contribution to the SOLAW21 report.

7 Comprehensive Framework for Response Assessment

Comprehensive Framework for Response Assessment (CFRA) is a process framework by which interventions and responses to the degradation of land and water resources can be assessed and valued considering future climate scenarios that can help guide the investment of resources. There are several distinct aspects of a CFRA which are described below and provided diagrammatically in figure 3.

Identification of responses: Following a causal systems approach like DPSIR, key responses are identified that are linked to different elements of Pressure, State, and Impact of the agricultural system. The responses are classified according to three major categories: technical, management and planning, social and institutional.

Data mining: CFRA involves extensive data mining on initial biophysical and socio-economic conditions (before the adoption of response) as well as biophysical and socio-economic impacts and costs of responses. Initial biophysical conditions reflect the state of the land, water, and soil as well as other ecological conditions, a significant factor to understand the effectiveness of responses under different enabling conditions as part of the contextual analysis.

Data unification: CFRA unifies different databases and information on land, water, and soil degradation conditions such as soil properties, climate, land use, and topography (from Global database and SDG indicators).

Scoring of responses: The responses are scored in the framework through the construction of an Effective Response Index, that is based on derived conditions. The normalised scores of the Index enable comparison of different responses to address challenge areas in the area of land, water and soil degradation**.**

Analysis: Analytical work within CFRA involves the use of archetype, cluster analysis, and multivariate space analysis methods to systematically classify agro-ecological regions and other physical, biophysical and socio-economic characteristics worldwide on the response implementation. It enables researchers to understand the relationship between response and ecological and biophysical impacts. The analysis will help to conduct geospatial projection of the expected impacts, and trade-off analysis of different responses given different physical, biophysical, and socio-economic contexts.

Key outputs of a CFRA: CFRA allows identifying regions where responses with potential impacts can be implemented. The effectiveness of the key interventions is predicted at the national and regional levels. The application of CFRA in the regional or national context enables understanding of the regional relevance of the responses.

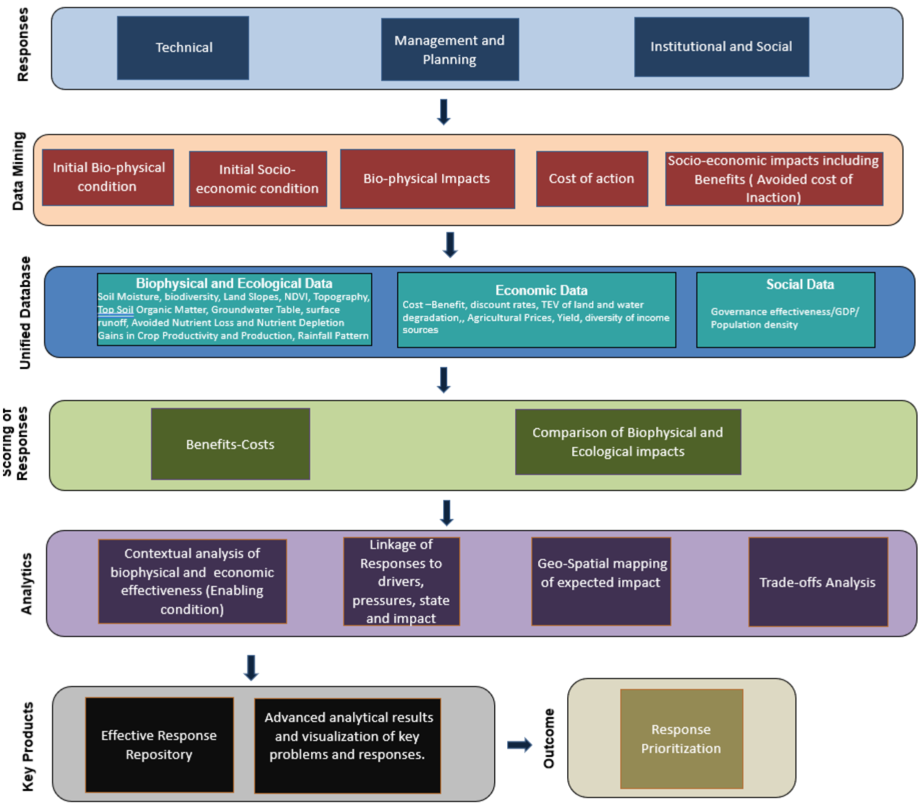

Figure 1: Comprehensive framework of response assessment

7.1 Data and Methodology:

Data: A detailed list of responses was collected from two sources: World Overview of Conservation Approaches and Technologies (WOCAT) and extensive search for peer-reviewed literature.

WOCAT: Data was collected from the World Overview of Conservation Approaches and Technologies (WOCAT). WOCAT is a global Network to compile, document, evaluate, share, disseminate, and apply sustainable land management (SLM) knowledge. SLM are community-based initiatives and have been adopted to improve land management sustainably. WOCAT has documented the knowledge from site-specific field-tested SLM practices. WOCAT has developed a standardised methodology in the form of questionnaires. The community-based SLM initiatives under WOCAT are recorded as SLM technology and/or SLM approach. SLM technology is a physical practice that controls land degradation and/or enhances productivity and consists of one or several measures. SLM approach comprises the ways and means to implement one or several SLM technologies, including technical and material support, and stakeholder engagement.

This study focussed on 1079 SLM technologies with information on resource pre-conditions as well as economic, social and biophysical impacts. It includes data on production impacts, cost-benefit, soil and resource availability conditions. WOCAT provides data on aspects relevant to land degradation, i.e. land use and climatic conditions, the type of degradation they addressed and what land degradation response they pursued, which SLM groups they belonged to and, most importantly, how well they contributed to achieving LDN. The impacts are classified as highly positive (+3), positive (2), slightly positive (1), no impact (0) slightly negative (-1), negative (-2) and highly negative (-3).

WOCAT maintains records of individual interventions implemented at the local level. Each record has been carefully examined and re-coded according to the response categories used in the DPSIR regional surveys. This was done to ensure compatibility in terms of the presentation of results. The most frequent response from the WOCAT data was conservation practices to reduce soil loss on the sloping and erosion-prone land, with a percentage response rate of 22.38, with sustainable planted forest management the second-highest response rate of 14.64%. Organic agricultural practices were the third most frequent response at 10.42%, followed by Sustainable grazing land management at 7.69%. The least frequent response rates included Diversification of agricultural production and income, strengthening road infrastructure, the use of improved information systems and the use of smart technology in agricultural production, selling, and buying of inputs, all with response rates of 0.12%.

The country with the most frequent distribution of case studies using sustainable land management technologies was Tajikistan at 112, with the frequency diminishing after this quite significantly with Kenya the second most frequently cited country at 59. this was closely followed by Ethiopia at 58. Rounding out the top ten most frequent case studies in this category were Uganda at 55, Nepal at 48, Cambodia with 37, the Philippines with 36, Senegal at 32, with Morocco and Spain both at 29. Countries with the lowest frequency of 1, included Angola, Canada, Ecuador, Egypt, Ghana, Indonesia, Iran, Pakistan, Serbia, Sweden, Ukraine and Zimbabwe.

Peer-reviewed literature: The WOCAT data was supplemented by literature review data on sustainable land management technologies. The most frequent response from the literature review was organic agriculture practice management (35.81%), with the second most frequent response category being conservation practices to reduce soil loss on the sloping and erosion-prone land (15.62%). The other three categories that rounded out the top five responses were conservation agriculture with minimum soil disturbance and tillage practice (10.86%), sustainable planted forest management (10.70%) and smallholder irrigation management (9.33%). The data shows that the country with the highest frequency was the United States with 18.13% of the total, followed by India (11.89%), Canada (10.92%), Ethiopia (9.16%) and Bangladesh at 8.77% making up the top 5 countries from the literature review case studies. Using the literature review case studies and data, detailed data on benefits and costs, discount rates, were synthesised, and Net Present Values were calculated for each response type.

WOCAT and literature case studies data were also complemented by the geophysical data and information (e.g. soil properties, climate, land use, water availability topography). From the spatial datasets, 14 explanatory variables were selected as potentially relevant to the benefit-cost ratio of key responses and were extracted from the spatial datasets for the 815 sites. The spatial data were harmonised with WOCAT data and literature review data. We removed the original number of cases in the WOCAT dataset (1079 cases) with missing information of response group membership, or benefit-cost ratio, or geographic location (i.e. longitude and latitude). After the removal, the number of cases was reduced to 806.

Some applications in WOCAT have a rectangular range of coordinates to indicate their geographic location, and we chose the centroid point of the range to represent the application location. The response application groups were prioritised and selected for analysis based on expert opinion scores on their performance.

7.2 Construction of an Effective Response Index:

WOCAT database contained information on assessment scores (-3 to +3) for impacts of an interventions in different dimensions. An Effective Response Index was created to understand the overall impact of an intervention in the following key dimensions: Crop Production, Soil Loss, Surface Runoff Land Management, Land and Water right as well as economic benefit and cost.

The Effective response Index was calculated using the following formula:

$ERI = \frac{\sum(I)+nN}{2nN}$ where I denote the impact on Crop Production, Soil Loss, Surface Runoff Land Management, Land and Water right as well as economic benefit and cost. ERI lies on a scale between 0 and 1. A score of 1 signifies the most effective Response while 0 signifies the least effectiveness.

N denotes the max ranking of the impact variables while n denotes the number of the impact variables.

7.3 Data analysis:

Two different data analysis techniques have been employed: regression models and cluster analysis.

The ordinary least-square regression model has been applied to understand the variation in the overall response effectiveness index score in terms of key bio-physical and socio-demographic factors (see Appendix Tables 10 and 11) for the details of the variables): surface water extraction, disaggregated GDP, Soil conditions slope and the presence of different responses. Based on the results, the predicted Effective Response Index (ERI) was also calculated. Ordered logit regression was performed to understand the relation between different impacts (soil production, benefit-cost, water harvesting and soil loss) and surface water extraction, disaggregated GDP, soil conditions slope and the presence of different responses. The ordinal regression was performed as the dependent variables are at the ordinal level. Based on the regression results, we have computed the anticipated probabilities of impacts and analysed them based on geographic location and responses type.

An alternative prediction model based on cluster analysis has also been tried. Two different techniques have been applied: K-means cluster analysis and Random Forest modelling. We applied K-means clustering analysis to classify the different on-sites into discrete groups based on variation in the 14 explanatory variables (See Appendix Table 10). We then evaluated the concordance of benefit-cost ratings with the cluster groups. If the explanatory variables are strong drivers of benefit-cost ratings, we would expect that each cluster would be dominated by sites with the same benefit cost rating. K-means clustering is a commonly used unsupervised machine learning algorithm for dividing a given dataset into k clusters. Here, k represents the number of clusters and must be provided by the user. We set k = 3 to match the number of benefit-cost ratio ratings (slightly positive, positive, and highly positive). The basic idea behind k-means clustering consists of defining clusters so that the total intra-cluster variation (known as a total within-cluster variation) is minimized. There are several k-means algorithms available. However, the standard algorithm defines the total within-cluster variation as the sum of squared distances Euclidean distances between items and the corresponding centroid.

We applied agglomerative hierarchical cluster analysis to classify the sites into discrete groups based on the Gower dissimilarity values among the 14 explanatory variables. Hierarchical clustering is a method of cluster analysis that seeks to build a hierarchy of clusters. It suits the project objective, particularly if the explanatory variables are strong drivers of benefit-cost ratings, we would expect that each cluster would be dominated by sites with the same benefit cost rating. In the agglomerative hierarchical clustering, initially, each data point is considered as an individual cluster. At each iteration, the similar clusters merge with other clusters until one cluster or k (user-defined) clusters are formed. The result is a tree that can be plotted as a dendrogram. One of the advantages of using the Gower dissimilarity metric is that it can accommodate mixed data types, including categorical, ordinal and numeric. Here, we set k = 3 to match the number of benefit-cost ratio ratings (slightly positive, positive, and highly positive). We then evaluated the concordance of benefit-cost ratio ratings with the cluster groups.

We also developed a machine learning Random Forest (RF) model to predict the benefit-cost ratio rating of each of the application sites based on the 14 explanatory variables. This approach offers greater flexibility than K-Means clustering and if effective, would provide a predictive model to use in applying the patterns in the WOCAT and literature review data more broadly. We applied leave-one-out cross-validation to assess the performance of the RF model and two performance metrics – overall accuracy and Cohen's Kappa - were calculated and a confusion matrix was also generated to show detailed prediction results of the developed RF model. Kappa measures the agreement between two classifications and takes a value between 0 (no agreement) and 1 (complete agreement).

However, the preliminary results from the cluster analysis is inconclusive and we are exploring further. The initial results from the cluster analysis have been presented in Appendix Figures 4 and 5, and Table 19. In the following section, we focus on results from the regression models.

8 Results-CFRA

The result section is divided into two parts; analysis of the effective response index and analysis of key dimensions of impacts.

8.1 Effective Response Index

The Effective Response Index results are shown in Table 7 on a scale from 0-1 with 1 being highly effective and 0 being least effective. The table lists the responses with mean average scores by responses, and it ranges between 0.53 to 0.69. Smart technology is ranked as highly effective with a score of 0.69 while the use of improved information systems for continuous monitoring of soils is least effective. The score of nearly 40 of the listed responses is above the overall average score of 0.63.

Table 5: Effective Response Index Scores by Responses

Responses	Effective response Index
Use of smart technology in agricultural production, selling, and buying of inputs	0.6944
Integrated plant nutrition management to enhance soil productivity	0.6692
Implement soil moisture conservation techniques (e.g. terracing, runoff diversion, and vegetative strips on contours)	0.6497
Diversification of agricultural production and income	0.6389
Strengthen the road infrastructure needed for urban-rural integrated development and agricultural connectivity	0.6389
Sustainable planted forest management (e.g., agroforestry)	0.6387
Modernizing irrigation systems (e.g. implementing drip irrigation)	0.6368
Organic agriculture practice management	0.6339
Conservation practices to reduce soil loss on the sloping and erosion-prone land (e.g. wind erosion and gully erosion control, cross-slope barriers)	0.6321
Increase efficiency of nutrient cycling and applied inputs to improve soil fertility and yield (e.g., precision agriculture, adequate and balanced use of fertilizers)	0.6316
Integrated crop-livestock management (e.g., manage livestock density)	0.6306
Smallholder irrigation management	0.6302
Integrated groundwater and surface water management	0.6271

Responses	Effective response Index
Use of improved plant varieties (high-yielding crops, seeds resistant to disease, pests, drought/scarcity/heat, salt-tolerant crops, transgenic crops, etc.)	0.6265
Integrated approaches to improving productivity in rain-fed systems for adaptation to climate change	0.6250
Community-based natural resource management (CBNRM)	0.6204
Sustainable natural forest management	0.6148
Conservation agriculture with minimum soil disturbance and tillage practice	0.6128
Soil salinity management	0.6111
Rotational agriculture practice management	0.6056
Sustainable grazing land management	0.6048
Increasing efficiency in the value chain of agricultural products (from site selection to manufacturing processes)	0.5926
Installation of buffers between cropland and water body	0.5917
Restoration and rehabilitation of degraded land	0.5858
Reduce the need for and optimize the use of antimicrobials in agriculture	0.5853
Recycling and re-use of stormwater, wastewater and grey water	0.5741
Installation of large-scale dams and reservoirs	0.5694
National strategies and policies that strengthen resilience and adaptive capacity to natural disasters and climate-related impacts	0.5611
Soil acidity control	0.5463
Use of improved information systems for continuous monitoring of soils	0.5278
Total	0.63

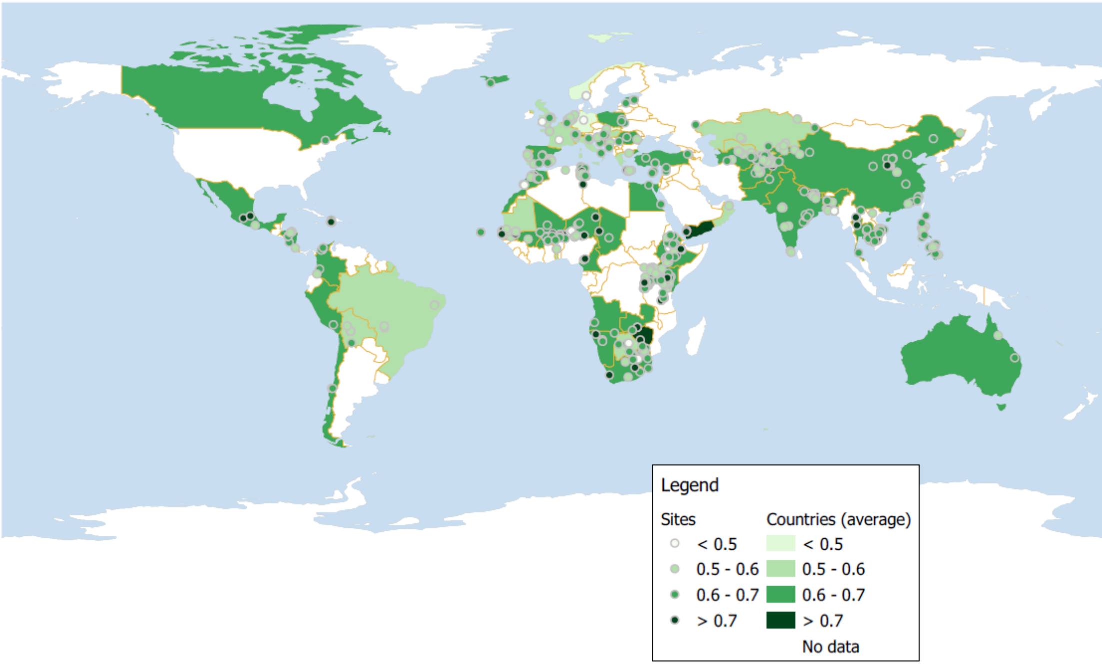

Figure 4: Effective Responses Index Scores by Countries

Figure 4 shows the effective Response Index across the countries. Effective responses are high for Zimbabwe, Rwanda, Yemen with a score above 0.70. Countries with lower scores of 0.5 and below are Indonesia, Madagascar, Ukraine, Germany, Slovakia, Norway. Nearly 10 % of the countries have a score of 0.60 while 8 % of the total number of countries have an ERI score above 0.66.

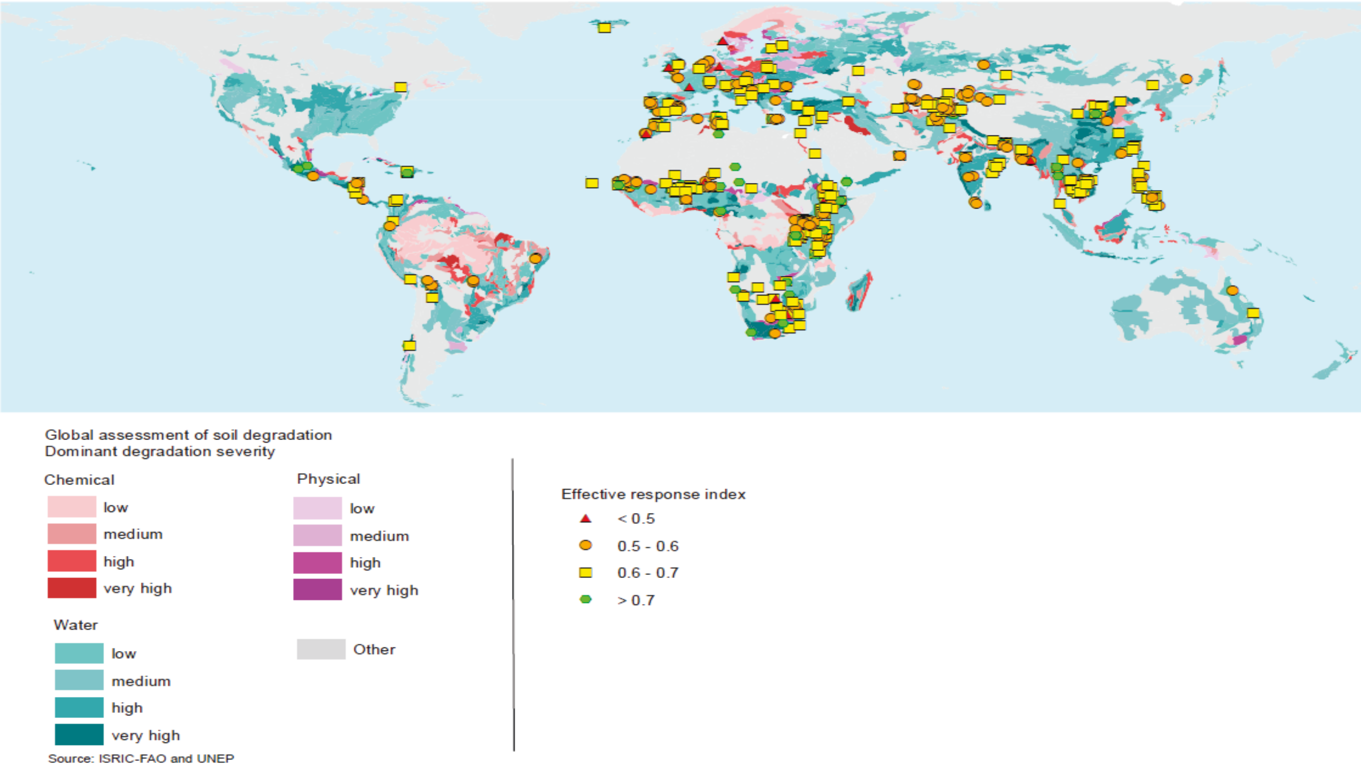

Figure 5: Soil Degradation and Effective Response

Figure 5 shows the effective response index scores according to different categories of soil degradation classified by dominant degradation severity. It includes chemical, physical and water-related soil degradation map points out most of the application or intervention sites are in water-induced soil erosion. Water erosion is caused by the detachment and transport of soil by rainfall, runoff, and irrigation. Excessive erosion can threaten the production of agricultural and forest products. Water-related soil erosion is easily observable and hence could be an inducing factor for intervention compared to other types of soil degradation.

Figure 6 shows the different combinations of crop production and soil loss impacts at a global level. The map shows there are a significant number of interventions in Africa, South Asia and Latin America where both the crop production and soil loss impacts have positive impacts (above the upper quartile). There are limited cases where both are impacts are low impacts (below the lower quartile). Only in Europe, is there evidence where soil loss is high with a lower crop production impact.

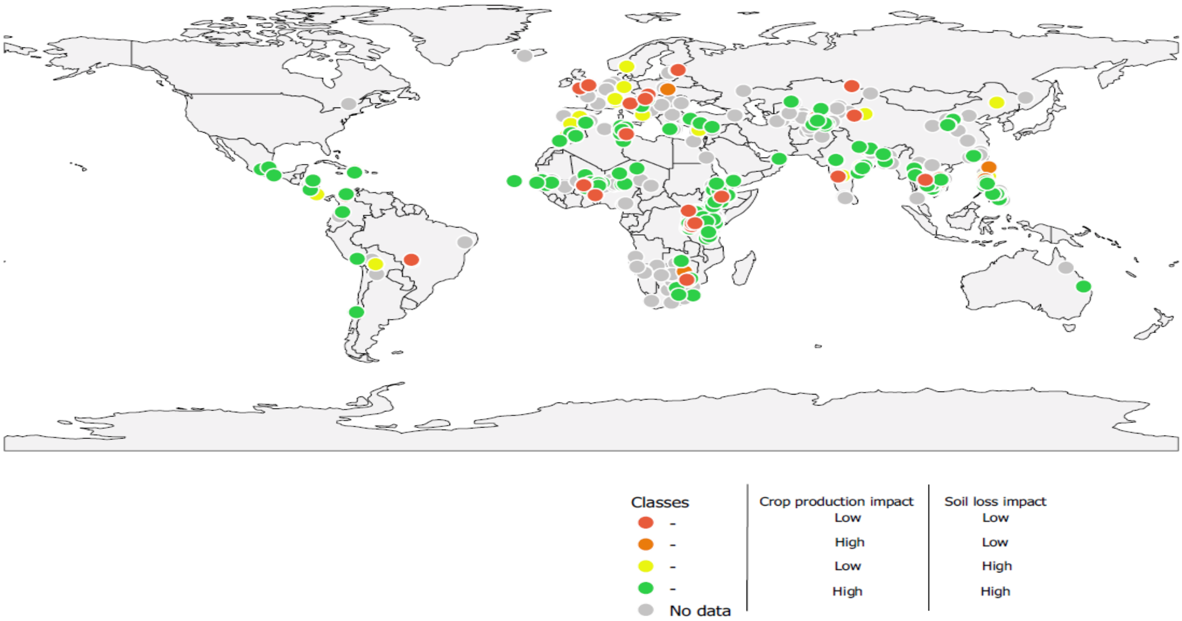

Figure 2: Crop Production and Soil Loss Impact

Regression Results: The ordinary regression result in Table 6 shows that interventions implemented in higher slope areas are likely to have a higher effective response index. Sites located in the areas with gross domestic products, higher rate of groundwater extraction, and moist, moderate soils have a higher significant impact. On the other hand, sites located in areas with a high proportion of land degradation have lower effectiveness. In terms of different response groups, interventions related to soil moisture conservation techniques and plant nutrition management to enhance soil productivity have higher effectiveness scores.

Table 6: Least Square Regression Results

Variable	Effective Response index
Higher Slope (Dummy Variable)	.0160**
Average gross domestic production per capita in a given administrative area unit	.000164***
Higher Proportion of Land Degradation (80%)	-.0118*
Groundwater Extraction	.00065**
Response-Implement Soil Moisture Conservation techniques (Dummy Variable)	.02555*
Response-Integrated plant nutrition management to enhance soil productivity (Dummy Variable)	.04894*
AEZ: Moist, moderate soils (Dummy Variable)	.0859*
AEZ: Arid (Dummy Variable)	-0.0274
AEZ: Sub-humid, moderate soils (Dummy Variable)	0.0244
Constant	.58209643***

legend: * p<.05; ** p<.01; *** p<.001

8.2 Analysis of disaggregated impacts

Table 6 shows the Ordered Logit regression results and the results of the coefficient can be interpreted in terms of log odds ratio. For instance, a unit increase in Surface water extraction will increase the crop production impact. The average gross domestic production per capita in each administrative area unit, will likely have minimal impact on crop production, however, it is positive. The results show that the surface water extraction will have a positive benefit-cost impact, whilst the annual average ratio of precipitation to potential evapotranspiration of a grid has a probability that is slightly negative on its benefit-cost impact. The data for the impact on water harvesting indicates that the intervention probability of human-induced soil degradation rate will be negative, whilst an intervention wealth at a local level would be positive. The results show that the soil loss impact interventions have a positive probability for population density class, however, it will be negative for a higher proportion of land degradation.

Table 2: Ordered Logit Regression Results

Variable	Crop production Impact	Benefit-Cost Impact	Water harvesting Impact	Soil Loss Impact
Surface Water Extraction	0.0434***	0.03719***		
Higher Slope (Dummy Variable)	0.4261*	0.00303*		
lower slope (Dummy Variable)				-0.6425**
AEZ - Dry Soil (Dummy Variable)	-0.4492	-0.4152		
AEZ - hydromorphic soils (Dummy Variable)				-0.6645*
AEZ - Moist, moderate soils (Dummy Variable)				-1.7661
AEZ - Sub-humid, poor soils (Dummy Variable)				-1.0116*
Average gross domestic production per capita in a given administrative area unit	0.00304			0.00493**
Annual average Ratio of precipitation to potential evapotranspiration of a grid		-0.00447***		
Population density class		0.13204*		0.1506
Surface Water Supply			-1.3219**	
Human-induced soil degradation rate			-0.6743**	
Wealth at local level			0.1609**	
Higher Proportion of Land Degradation (80%)				-0.5965**
Response-Sustainable Planted Forestry Management (Dummy Variable)		0.52008*		
Response-Conservation Practice to Reduce Soil Loss (Dummy Variable)				0.7345***
Approximate likelihood-ratio test of proportionality of odds across response categories:				

chi2(19)	45.43	37.31	5.29	
Prob > chi2	0.0006	0.1123	0.8087	

legend: * p<.05; ** p<.01; *** p<.001

Based on the post estimation of the ordered logit regression, we have computed the average predicted probability of interventions on four different categories of impacts-crop production, benefit-cost, soil loss and water harvesting (see Figure 7). The anticipated probability of having a positive outcome (combining highly positive, positive, and slightly positive outcomes) is more than 90 % in terms of benefit-cost ratio, soil loss and harvesting impacts. For the crop production impact, the anticipated probability is higher for positive outcomes compared to highly positive outcomes. For the benefit-cost impact, there is practically zero probability of having any negative impact. However, it should be noted that the results are influenced by the underlying distribution of impact assessment scores which are more skewed towards positive and highly positive scores.

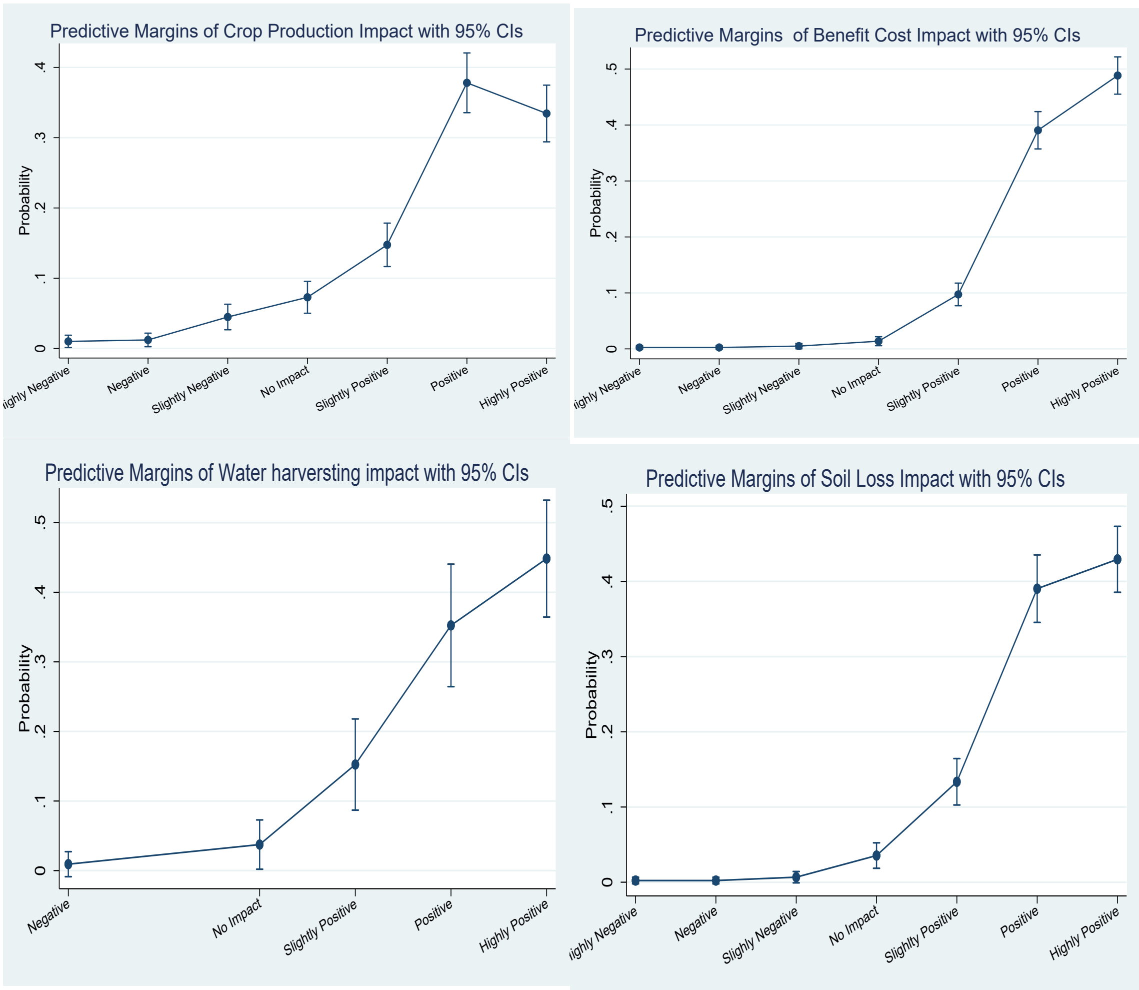

Figure 3:Average Predicted Probabilities of Key Impacts

We have also compared the anticipated probabilities country wise (see Figure 8 and 9). We found that the predicted probabilities of crop production impacts by country are most highly positive in Burundi at 0.57, followed by Colombia at 0.51, Morocco at 0.49, Uganda at 0.47 and Mexico at 0.45. Figure 20 indicates that in all countries, there is a near, or in the case of Burundi 50% chance of an impact on crop production. There were several countries with a less than 10% chance in a highly positive crop production impact including Botswana, Estonia, Germany, Iceland, Oman, and Switzerland.

The country with the most highly positive probability of a benefit-cost impact was Egypt at 0.67, closely followed by Burkina Faso at 0.65 and Morocco at 0.64. The predicted probability also ranked highly positive in Mali, Niger, and Tajikistan all with a 63% chance, whilst Syria 0.62, Colombia and Turkmenistan (0.61), and Mauritania 0.60 rounded out the top 10 countries in the highly positive classification. Estonia and Iceland were the only two countries with a highly positive probability of less than 0.20.

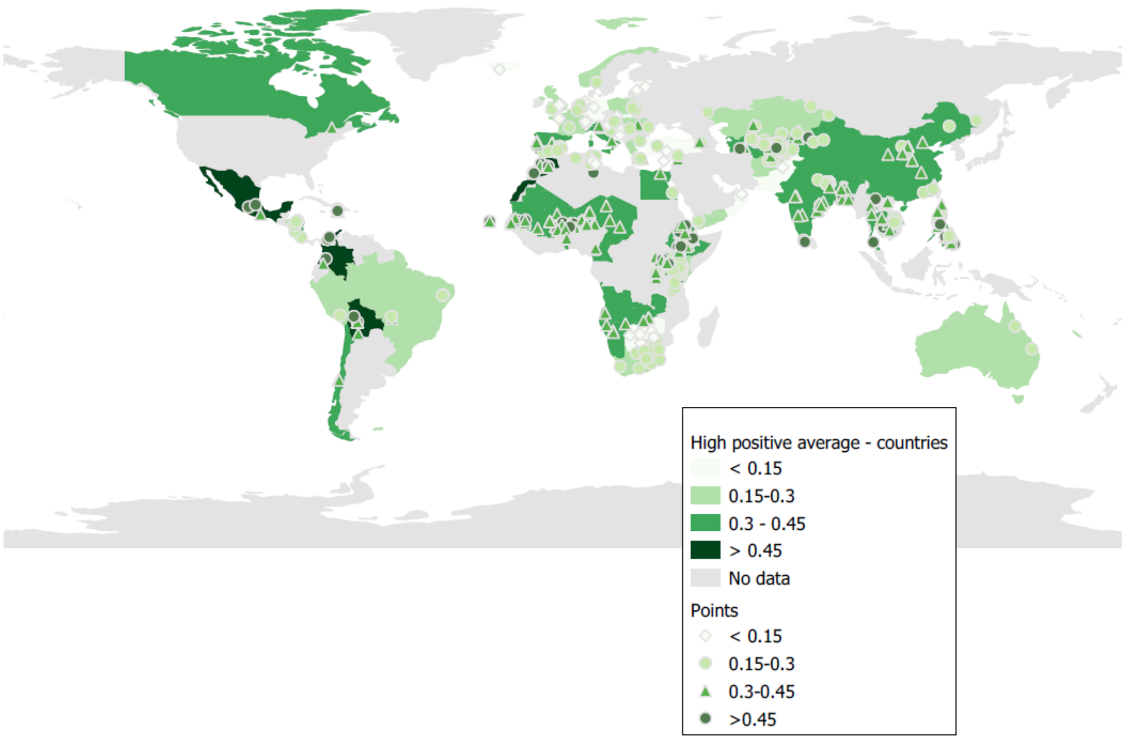

Figure 4: Predicted Crop Production Impact

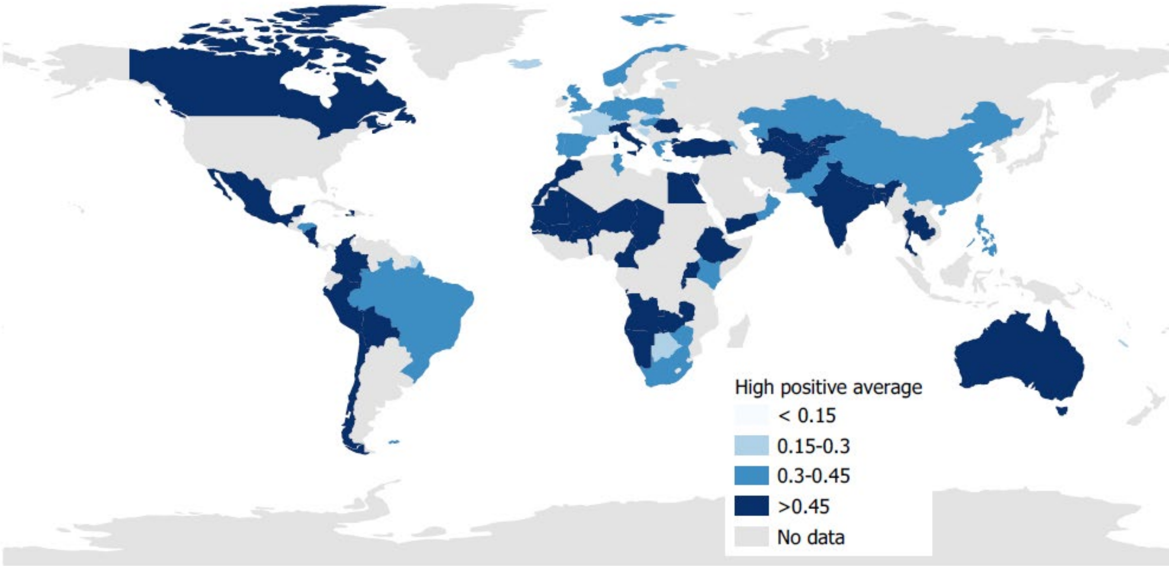

Figure 5: Predicted Benefit Cost Impact

We have also analysed response categories according to different responses (see Table 6 in Appendix). The response categories with the most highly positive probability related to crop production impacts were integrated plant nutrition management to enhance soil productivity and sustainable planted forest management (e.g., agroforestry) both with a 50% chance. The next highest response categories in this classification included implementing soil moisture conservation techniques (e.g. terracing, runoff diversion, and vegetative strips on contours) at 0.42 and community-based natural resource management with a 33% chance. There were several response categories with a high positive probability of 0.41 including; diversification of agricultural production and income, increasing efficiency in the value chain of agricultural products (from site selection to manufacturing processes), integrated approaches to improving productivity in rain-fed systems for adaptation to climate change. It also included national strategies and policies that strengthen resilience and adaptive capacity to natural disasters and climate-related impacts, strengthening the road infrastructure needed for urban-rural integrated development and agricultural connectivity, and the use of smart technology in agricultural production, selling, and buying of inputs.

The responses with the highest probability of benefit-cost impacts were the use of smart technology in agricultural production, selling, and buying of inputs with a 63% probability. Sustainable planted forest management (e.g., agroforestry) also had a high probability ranking of 0.60, followed by community-based natural resource management of 0.53. The other two highly positive responses with a probability ranking above 0.50 were diversification of agricultural production and income 0.52 and smallholder irrigation management at 0.51.

9 Discussions

There are various ways the results of this could be synthesised and processed. In Figures 10 - 12, we have presented the three most effective responses to tackle the three most important issues identified through expert consultations: land degradation, water scarcity and loss of agricultural productivity. To manage land degradation, the three most effective responses include conservation practices to reduce soil loss on the sloping erosion-prone areas, sustainable planted forest management and restoration and rehabilitation of degraded soils. All three responses have been identified to be highly effective in all three regions according to the expert's survey. The statistical analysis also reveals that the probability of having a highly positive impact on the benefit-cost ratio and crop production is more than 30% with sustainable forest management more effective than the other two interventions. The overall effectiveness score is also slightly higher for this intervention.

Integrated groundwater and surface water management, installation of large dams and reservoirs, and smallholder irrigations are the top three responses to manage water scarcity that the experts have identified to be highly effective (receiving a score of 4 or more). Statistical analysis also shows that there is about a 50% probability that the intervention-Small holder irrigation will have highly positive impacts on the benefit-cost ratio. As expected, the overall Effective Response Index (ERI) is slightly lower for large-scale dams and reservoirs, given their single-purpose approach.

Our analysis reveals that conservation agriculture with minimum soil disturbance, use of smart technologies, and integrated plant nutrition and management are the three most effective responses to manage the loss of agricultural productivity. Among these three, smart technology responses are likely to have higher positive impacts on benefit-cost ratios and have overall high ERI.

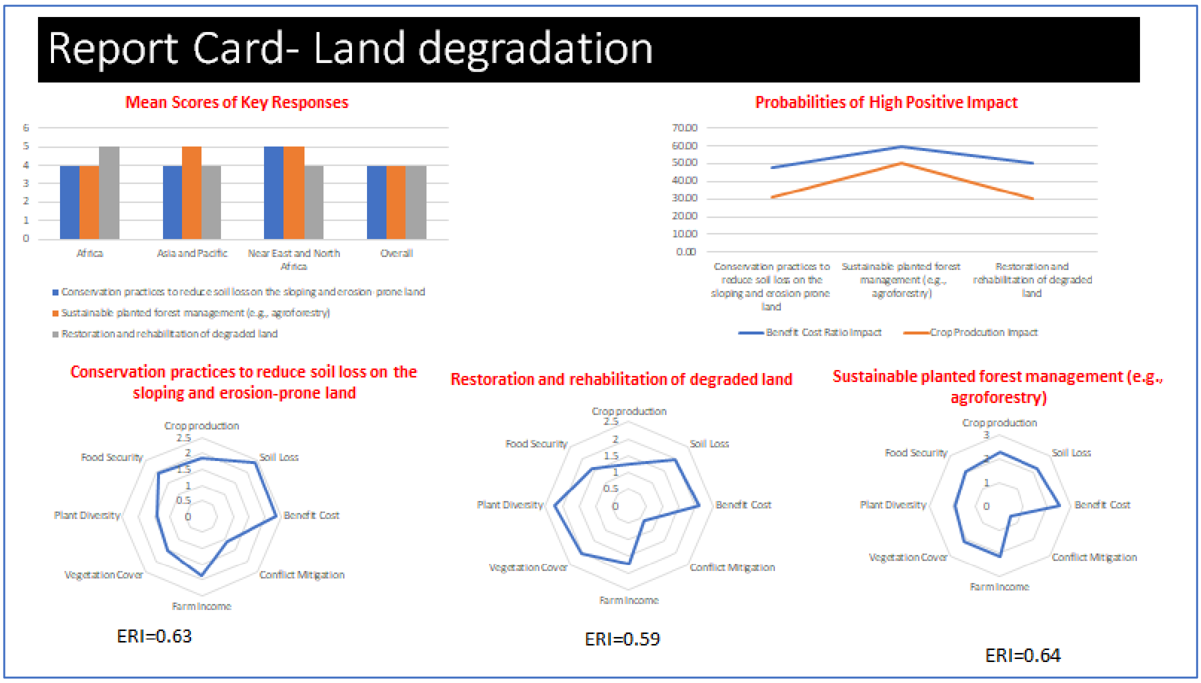

Figure 6: Summary of response to address land degradation

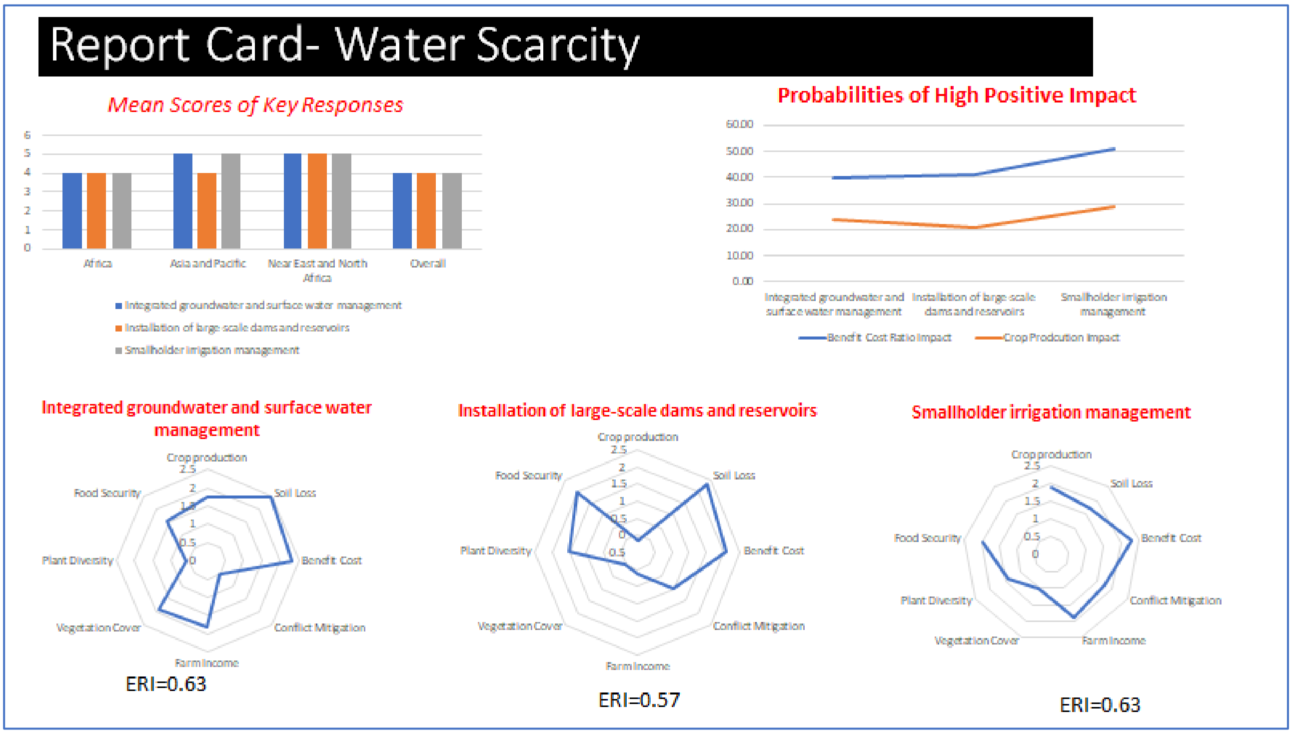

Figure 7: Summary of response to address water scarcity

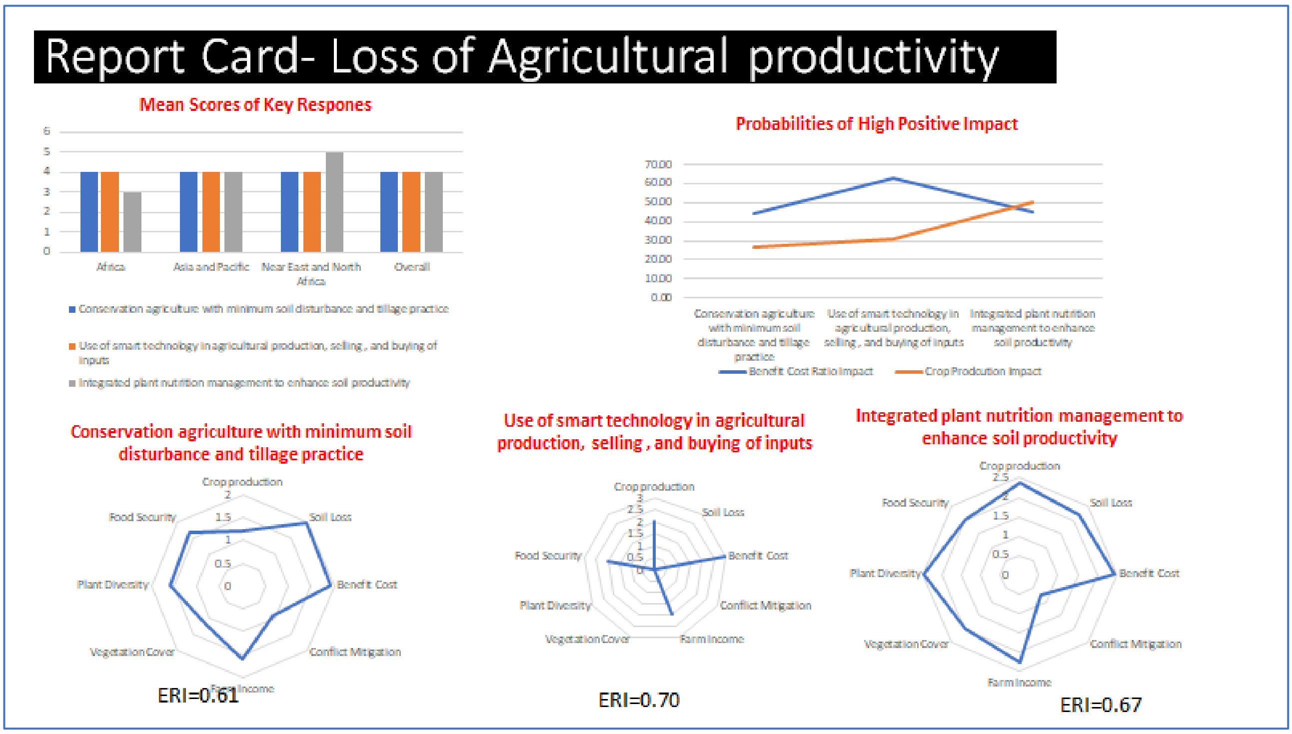

Figure 8: Summary of response to address loss of agricultural productivity

10 Conclusion and Recommendation

Several lessons were learned from the SRA project to prioritize responses to mitigate land, water, and soil degradation. Prioritisation of responses is urgently needed today at different levels, particularly at a time when there is a global effort to accelerate the implementation of SDGs, and hence the contribution of this project is very timely. This project attempts to compare different responses to mitigate land, water and soil degradation using three different kinds of data sets: expert opinion, WOCAT data related to post and pre-impacts of onsite application of SLM technologies as well as data extracted from peer revived research papers. As impacts of the responses vary from site to site and depend on so many physical, biophysical, socio-economic factors, it was necessary to compare the results from three data sources to improve the efficacy of the methodology. The expert option survey on the drivers and the relation between responses and import drivers gave us the overall picture of the relative importance of responses; it helped us to preselect the data variables in the analysis, as well as in the validation of the results.

We have also assembled global data on the state of the land, water, and soil as well as disaggregated socio-economic data and harmonised this with the response dataset. The additional contextual information provides us with an additional opportunity to validate the impacts analysis results. The project is a unique attempt to compare different responses using an assembled and harmonised dataset of global physical, biophysical, socio-economic contextual and local data on response impacts using a causal system approach of DPSIR. The framework promises the opportunity to tailor the applicability of the framework to assist policy and decision-makers at a regional and local level.

Some of the key results are the following-

- Population is the one key drivers influencing the sustainable land, water and soil system in the Asia Pacific, Central Asia, Near East and North Africa, while urbanisation is the key driving factor in Africa. Other important drivers affecting all regions are the uneven rainfall, recurrent flood and drought events which further puts the agricultural system under pressure.
- Loss of agricultural productivity and efficiency, land degradation and reduced water availability and water quality are the major impacts caused by the unsustainable agricultural practices, increasing pressure of over-extraction of groundwater and surface water.
- Conservation practices and agriculture, Community Based natural resource management, Restoration and rehabilitation of degraded lands , Sustainable forest management (both planted and natural) are crucial responses to land degradation and loss of vegetation cover.
- Integrated groundwater and surface water management, modernisation of irrigation system and installation of large-scale dams are a few of the top-rated responses to address water scarcity and groundwater depletion. Statistical analysis also shows that there is about 50% probability that the intervention-Small holder irrigation will have highly positive impacts on benefit-cost ratio.
- Conservation agriculture with minimum soil disturbance, use of smart technologies and integrated plant nutrition and management are the three most effective responses to

manage the loss of agricultural productivity. Among these three, smart technology responses are likely to have higher positive impacts on benefit-cost ratios and have overall high ERI.

- Emphasis and higher effectiveness are evident for integrated approaches, for instance, to improve productivity in rainfed systems for adaptation to climate change and in crop-livestock management as well as integrated groundwater and surface water management.

Limitations: There are certain limitations of the data that we have realised from our analysis. WOCAT data set is a very comprehensive data set on responses and intervention of SLM without the support of WOCAT we could not have completed this study in such a timely manner. However, it was also realised from the analysis of the WOCAT data set that there is an upward bias in the selection of the application sites with high positive and positive outcomes as best-case studies. The provision of fewer cases on negative outcomes meant it was difficult to classify the data and extrapolate to non-applied areas statistically. The skewness towards very high positive outcomes leads to classification error of higher-margin for other groups of impacts with slightly positive and positive impacts. This could also be related to an unbalanced number of observations in each category of impacts. In our future work, we will attempt to do the classification grouping of highly positive, positive and slightly positive impacts as one group, but this may lead to a loss of information and may result in smaller variation among different response categories.

As the impacts are evaluated by expert opinion in the WOCAT database, there is subjectiveness in impact assessment. Hence, we have complemented it with data from research papers. The literature dataset provided detailed benefit-cost impacts, for example, in terms of ordinal ranking. It has improved the robustness of the data; however, the literature dataset does not have information on other important factors, such as other biophysical impacts. It could be due to the disciplinary focus of the research papers. Further, only three primary responses comprise more than 50% of the observations, whilst we were able to gather data on all 59 responses.

The following question emerges from our study: how global data on responses will help the prioritisation of responses. We have learnt that the global data on responses and land, water and soil state is vital to create a Comprehensive Response Assessment Framework and understand the scope and functionality with the power to compare different response effectiveness. However, it will not be sufficient for decision-making at a local level to forecast response effectiveness in non-applied areas. To make it operational with a high confidence level, we require more in-depth farm-level survey data with actual values on key impacts and more elaborate data on unsuccessful cases. We may not need a wide spectrum of different kinds of impacts at a farm level, but actual values of impacts are required to achieve more robust results. This will enable the research to successfully employ different classification models to systematically understand the relationship between response and ecological and biophysical impacts and make projections based on contextual information.

Further spatial analysis is needed for a better understanding the linkage between global and local data. It includes geospatial mapping of expected impacts of responses. Further work will also involve a more detailed trade-off analysis between different responses and to understand if a response is counterproductive to other responses when applied together.

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12 Appendixes

12.1 Appendix 1: The list of Drivers, States, Pressure, Impact, and Responses used in the survey

Table A1.1: List of Drivers

Sequence	Drivers	Examples
1	Population growth	Annual population growth of the region over the last decade
2	Urbanization	Urban development and intensification over time
3	Unequal distribution of technological application and gap in knowledge	Lack of equitable distribution of technological applications and awareness of such action unable by intended users
4	Lack of infrastructure	Inadequate in-built infrastructure such as roads or markets in support of rural economic development
5	Rising inequality in land & water access	Lack of equity or fair shares in access and formal entitlements to land and water and benefits from land and water use
6	Existing poverty	Poverty level by headcount ratio (international)
7	Changing consumption habits	Humans dietary changes including both quantitative and qualitative in the diet composition (e.g. a shift to a higher energy density diet or protein intake)
8	Increasing obesity	A condition of overweight than a standard healthy weight for a given height as measured by adult Body Mass Index (BMI)
9	Food wastage	Postharvest food loss of unconsumed food products from decisions and actions by retailers, food service providers, and consumers
10	Greenhouse gas concentrations	Accumulation of atmospheric greenhouse gases from various economic activities (e.g. industries, agriculture emissions)
11	Flood and drought events	Occurrence of flood and drought over a period of time nationally and/or globally
12	Forest fire	Forest fire incidences due to natural causes
13	Atmospheric transport and deposition	Deposition of atmospheric pollutants such as gases and droplets in the form of dust or in precipitation, that will ultimately enter freshwater systems causing acidification and eutrophication
14	Uneven rainfall distribution	Trends in seasonal precipitation and reliability of rainfall
15	Insecure land & water right	Lack of secured rights and ownership to land and water to support rural livelihoods
16	Access to support services	Official flows of development assistance (e.g. financial, technical, and training) to economic sectors
17	Lack of proper agriculture institutions and policies	Lack of appropriate governments' policies for postharvest loss reduction along the supply chain, starting from harvest until its consumption or others end use
18	Effect of global and national trade policies and subsidies	Trade policies and export subsidies by countries that might distort world agricultural markets and contribute to unsustainable use of natural resources

Table A1.2: List of Pressures

Sequence	Pressures	Examples
1	Continuous cultivation	Land area under continuous agricultural production (e.g., lack of crop rotation)
2	Increase in fodder crop production	Agricultural area for fodder production
3	Unsustainable agricultural practice	Conventional tillage
4	Cultivation in slopes	Cultivation on steep land that is prone to erosion
5	Forest clearing and conversion	Loss of natural vegetation cover and land use change
6	Overgrazing	Excessive use of pastureland for livestock grazing
7	Over-extraction of groundwater	Unsustainable extraction of groundwater
8	Over-extraction of surface water	Unsustainable extraction of surface water
9	Higher energy use (fossil fuel)	Use of fossil fuel
10	Expansion of agriculture	Agricultural expansion and conversion of natural systems due to mechanization
11	Increase in energy crop production	Production of biofuels (monoculture)

12	Patenting and certification of seed and genetic materials (monopolization)	Genetic resources and traditional knowledge
13	Pest and disease (Microbial Risks)	Crop pests/animal diseases that threaten agricultural production
14	Intensive use of agrochemicals, pesticides and fertilizers	Continued of use of chemical fertilizers and pesticides

Table A1.3: List of States

Sequence	States	Examples
1	Loss of topsoil	Loss of topsoil through erosion due to unsustainable agricultural land use
2	Salinization	Irrigated land area affected by salinization
3	Loss of vegetation cover (deforestation)	Loss of natural vegetation cover and land use change
4	Increased fluctuation of surface water	Surface water level changes over time
5	Depletion of groundwater in the aquifer	Over-extraction of groundwater that leads to reduction of the groundwater table
6	Degradation of land	Productive land converted to barren land due to unsustainable land use and management practices
7	Desertification	Land area changed to desert due to drought and deforestation
8	Water scarcity	Water stress due to unsustainable soil and water resource management
9	Soil chemical imbalances and nutrient toxicities	Soil chemical imbalances and nutrient toxicities due to the application of inappropriate quantities of chemical fertilizers
10	Inorganic pollutants in the soil	Inorganic pollutants released due to human activities such as agriculture and industries that enter the soil
11	Pollution level of surface and ground water	Pollutants released due to human activities such as agriculture and industries that enter the water
12	Contaminated effluents released in and near catchments	Changes in water quality due to farming practices (e.g. input use) leading to pollution of surface and ground waters
13	Poor quality irrigated water	Application of untreated water for irrigation
14	Increase amount of untreated wastewater and higher livestock waste	Increase in the quantity of untreated wastewater discharged without any prior treatment
15	Concentration of GHG	Concentration of GHG
16	Reduction in the quality of the vegetative biomass	The density of vegetation cover on a patch of land in declining
17	Loss of native biodiversity	Increase in loss of native species triggering biodiversity conservation efforts
18	Reduction of fish and plant Species	Decline in the number of fish and plant species due to overfishing
19	Lower level of asset holdings (including land)	Reduced landholding size by small holder farmers
20	Reduced farms profits, subsistence farming	Decline in agricultural production levels and the economic returns for producers
21	Longer storage time	Loss in agricultural product (e.g., vegetables) quality and quantity
22	Upward and downward pressure on price/Price volatility	Lack of proper functioning of food commodity markets and erratic market prices
23	Higher input price	Higher input price
24	Higher use/price of energy	Higher use/price of energy
25	Conflict arising from competition for land and water	Trans-boundary / trans-regional conflicts
26	Ageing of farmers	Productive age group of society
27	Gender inequality	Access to productive resources including formal ownership and use rights of land by women

Table A1.4: List of Impacts

Sequence	Impacts	Examples
1	Reduced agriculture productivity and efficiency	Agricultural crop yield is reduced
2	Land abandonment	Land abandoned due to continuous production and loss of fertility
3	Risk of producing lower quality products	Agricultural production from lower quality production systems
4	Loss of natural crop pollinators	Decreased crop pollination services by pollinators
5	Higher pest and disease incidence	Higher pest and disease incidence
6	Flood incidence	Number of floods observed in the past
7	Lower natural capacity to regulate water quality	Reduced water quality regulation service by watershed ecosystems
8	Impact on carbon cycling	Forest carbon stocks
9	GHG emissions	GHG emissions from industries
10	Alteration of hydrological cycle/regime	Changes in natural water cycle in mountain areas
11	Water availability	Changes in quantity of water available for abstraction
12	Water quality	Increased pollution level of surface and groundwater
13	Soil nutrients runoff	Nutrient loads in waterbodies
14	Reduction in income from increased harvest loss for small holders	Reduction in income from post-harvest grain losses due to storage pests of staple food crops like maize
15	Lower employment opportunities	Lack of access to high-income jobs
16	Lower labour productivity	Lower marginal value of farm labour
17	Health risk from lower nutritional value/ diets	Health issues due to unbalanced diet consumption/calorie intake
18	Increased vulnerability due to price fluctuations	Increased vulnerability due to price fluctuations
19	Migration (rural -> urban)	Increased migration of individuals from rural to urban areas for employment opportunity
20	Food insecurity	Lack of self-sufficient food production and reliable employment
21	Increased poverty	Widespread poverty and food insecurity
22	Malnourishment	Population with insufficient calories required for an active and healthy growth
23	Health impact from environmental consequences	Communicable diseases due to lack of safe drinking water, sanitation, etc

Table A1.5: List of Responses

Sequence	Responses
1	Participatory land-use planning across sectors (e.g. forestry, fishery etc) (PLUP)
2	Organic agriculture practice management
3	Rotational agriculture practice management
4	Sustainable grazing land management
5	Sustainable planted forest management (e.g., agroforestry)
6	Sustainable natural forest management
7	Smallholder irrigation management
8	Promoting farmer innovation and participatory innovation development
9	Integrated groundwater and surface water management
10	Community-based natural resource management (CBNRM)
11	Private sector investment in sustainable forest management
12	Public sector investment in conservation agriculture (CA)
13	Integrated plant nutrition management to enhance soil productivity
14	National strategies and policies that strengthen resilience and adaptive capacity to natural disasters and climate-related impacts
15	Efforts to combat desertification and land degradation at national level
16	Integrated crop-livestock management (e.g., manage livestock density)
17	Implementation of payment for ecosystem services programs (e.g., REDD+)
18	Integrated approaches to improving productivity in rain-fed systems for adaptation to climate change
19	Soil salinity management
20	Restoration and rehabilitation of degraded land
21	Modernizing irrigation systems (e.g. implementing drip irrigation)
22	Use of smart technology in agricultural production, selling, and buying of inputs
23	Use of improved information systems for continuous monitoring of soils
24	Conservation practices to reduce soil loss on the sloping and erosion-prone land (e.g. wind erosion and gully erosion control, cross-slope barriers)
25	Increase efficiency of nutrient cycling and applied inputs to improve soil fertility and yield (e.g., precision agriculture, adequate and balanced use of fertilizers)
26	Conservation agriculture with minimum soil disturbance and tillage practice
27	Installation of buffers between cropland and water body
28	Installation of large-scale dams and reservoirs

29	Soil acidity control (e.g., liming)
30	Training skilled farmers and professionals in information technology and data analytics
31	Recycling and re-use of stormwater, wastewater and grey water
32	Implement soil moisture conservation techniques (e.g. terracing, runoff diversion, and vegetative strips on contours)
33	Use of improved plant varieties (high-yielding crops, seeds resistant to disease, pests, drought/scarcity/heat, salt-tolerant crops, transgenic crops, etc.)
34	Agricultural biotechnology options
35	Diversification of agricultural production and income
36	Reduce the need for and optimize the use of antimicrobials in agriculture
37	Reducing the cost of energy and promoting the use of renewable sources of energy
38	Increasing efficiency in the value chain of agricultural products (from site selection to manufacturing processes)
39	A macro-economic framework with a reliable access to modern energy sources (e.g. electricity)
40	A macro-economic framework with regulations and measures to ensure the proper functioning of food commodity markets and food safety
41	Improved market information through information technology (e.g., strengthening Agricultural Market Information System)
42	Government assistance in agriculture inputs
43	Government assistance in agriculture outputs
44	Strengthen the road infrastructure needed for urban-rural integrated development and agricultural connectivity
45	Greater investment to ensure conservation of biodiversity and genetic resources are mainstreamed in development sectors
46	Adopt national legislation, regulations and policy frameworks to ensure fair and equitable sharing of benefits of genetic resources for food and agriculture
47	Promote secured and formal systems of tenure and rights to land and water resources
48	Social dialogue leading to equitable and participatory sustainable forest management
49	Social dialogue leading to equitable and participatory sustainable land and water management
50	Protect natural habitats and rehabilitate degraded habitats, in particular in mountain, forests, freshwater and coastal environments
51	Strengthening international partnerships on sustainable soil, land and water management (e.g., global alliance on sustainable land and water management)
52	Regional focus and initiatives to foster knowledge sharing, policy dialogue on regional issue
53	Engage with the private sector in making the investments and developing the technologies and best practices needed to enhance productivity, efficiency, and sustainability in food value chains
54	Public investments for primary agriculture product storage and processing infrastructure
55	Strengthen the enabling environment and reform the institutional framework (e.g., national, regional)
56	Sustainable choices such as sustainable diets with low environmental impacts
57	Marketing consumer level sustainable choices such as zero-km products and low water footprint (from the choice of meat to the packaging)
58	Use of nationally appropriate social protection systems (e.g. government safety net or food security programs) to enhance income of poor vulnerable group of society
59	Improve nutrition and balanced diets addressing undernourishment and obesity

12.2 Appendix 2: Relative Ranking Drivers

Figure A2: Relative ranking of Drivers

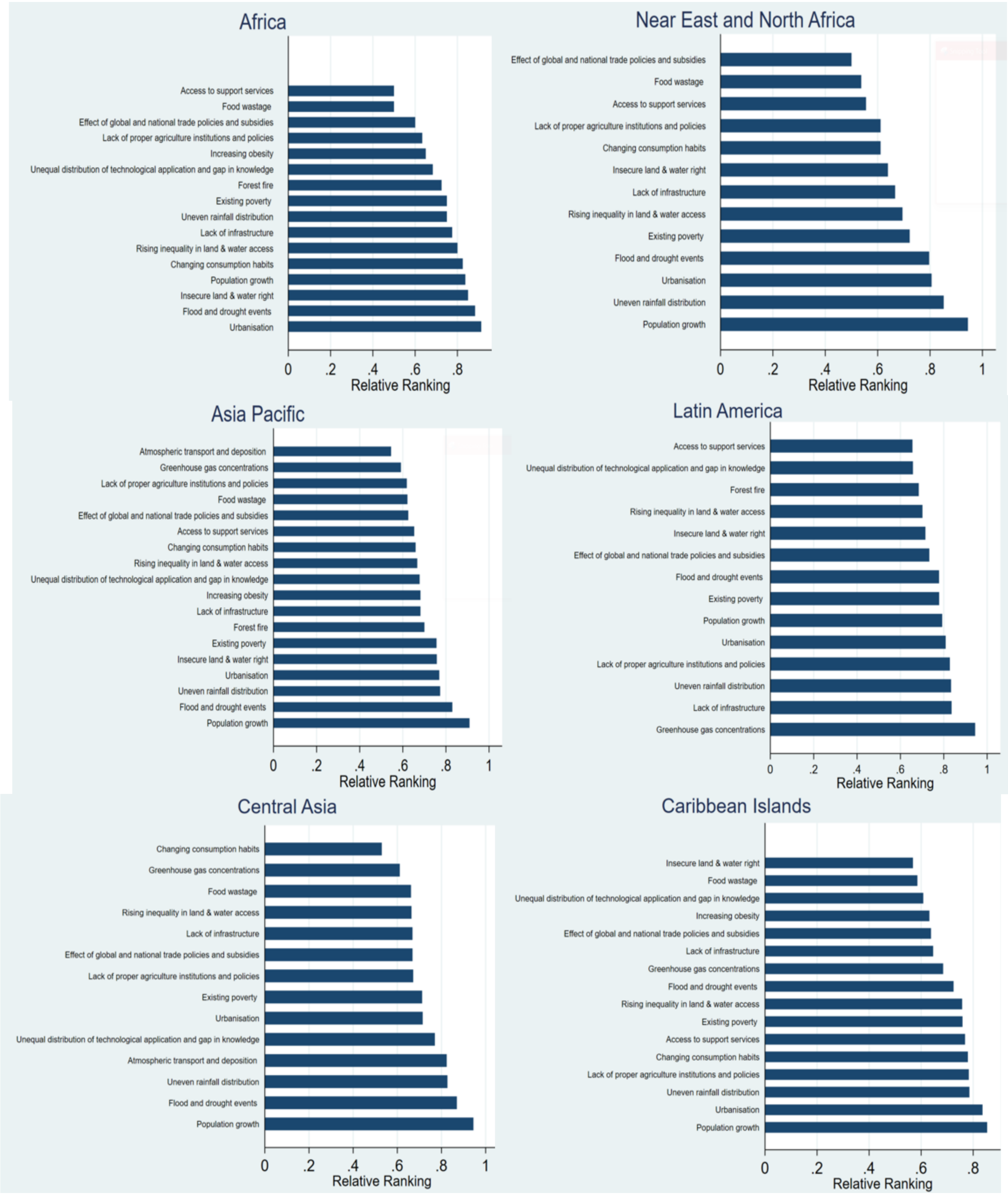


Figure A2.1 indicates that there are several drivers in **Africa** that are impacting sustainable agriculture across Africa. The driver with the largest impact is urbanization, resulting in a reduced availability of land for cropping and grazing, affecting the livelihoods of formerly agrarian-based communities now affected by urban encroachment, which is also affected by population growth across numerous countries in Africa. The other main driver in Africa is weather-related events such as extreme floods and drought, perennial problems on the continent that have been exacerbated by more intense weather events associated with changing climates. In addition to this, uneven rainfall patterns cause further problems for agriculture across Africa, resulting in continual water shortages across several countries.

The **Near-East and North Africa** comprise a range of diverse countries located in some of the most arid and warm sections of the Mediterranean, the Red Sea and the Persian Gulf. The key driver affecting agriculture in the region is population growth (0.94) which has been accompanied by increased urbanization (0.81) that have disrupted traditional agricultural practices and lifestyles in many of the region's countries. The survey data indicates that the regions' weather patterns are major drivers that affect farming, most notably the regions uneven rainfall distribution (0.85), with drought and flood (0.80) and key drivers in a region characterized by extreme heat long periods of dry weather.

Other drivers that impact the region include trade policies and subsidies (0.50) and access to support services. Their relevance to the region's farmers should not be underestimated as free trade, for example, provides opportunities for the sector in those areas of production where it has a comparative advantage. Changing consumption habits (0.61) with a move away from processed foods have the potential to be key drivers for farmers in the region, particularly in fruit and vegetables, where the region's climate enables a wide range of food products to be grown.

The **Asia-Pacific** region is one of the fastest-growing regions globally, both economically and in terms of population growth. This has impacted agricultural production across the region, which has been accompanied by increased urbanization and a subsequent loss of agricultural land. This is reflective of the data, which shows that two of the largest drivers of change in the region are population growth (0.91) and urbanization (0.77) which are problems that face many countries across the developing world. The other main drivers in this region are weather-related, uneven rainfall patterns and flood and drought events both key issues facing the Asia-Pacific region, much of which are influenced by monsoonal weather patterns that impact agricultural practices across the region.

Atmospheric transport and deposition, along with Greenhouse Gas concentrations and agricultural policies and institutions, have received lower ranking in the region. However, this may be associated with different levels of development across the Asia-Pacific region. Other drivers of change across the Asia-Pacific include rising land and water access inequality (0.67) and insecure land and water rights (0.76) that suggest regulatory and policy changes are required to assist in overcoming these barriers for the sector. In addition to this, the findings from the survey indicate that investment in infrastructure is required to overcome the barriers that this is causing, with a lack of infrastructure (0.68) recognized as one of the key drivers in the region.

The driver with the largest impact in **Latin America** is greenhouse gas concentrations which has resulted in a reduction in air quality and affected weather patterns across the region. The changes in weather patterns have increased the severity of weather-related events such as uneven rainfall distribution, floods and drought, and forest fires that have been exacerbated by more intense weather events associated with changing climates. In addition to this, uneven rainfall distribution causes further problems for agriculture across Latin America, resulting in continual water shortages across several countries. Rapid urbanization across Latin America associated with population growth were two key drivers affecting the region's primary industries sector, which, when coupled with a lack of infrastructure, place further pressure on farmers across the region. Two of the lower ranked drivers were access to support services and issues associated with the application of technology and knowledge gaps, however, this suggests that policies need to be implemented that aid knowledge and skill development for people in rural areas to assist them in overcoming these gaps and equip them with the resources that enable them to implement best practice methods across the primary industries sector.

In **Central Asia,** the driver with the largest impact is population growth which has resulted in increased urbanization placing pressure on agricultural land as urban encroachment reduces the amount of land available for primary industries. Changes in weather patterns across Central Asia have increased the severity of weather-related events such as floods and drought, which have increased due to uneven rainfall distribution, both of which have been exacerbated by more intense weather events associated with changing climates. Trade policies and subsidies both globally and at the national level are a key driver in the Central Asia region that has been intensified by a lack of proper agricultural institutions and policies in countries across the area. Two of the smallest drivers were changing consumption habits, along with greenhouse gas concentrations. However, both have detrimental effects on the primary industries sector across Central Asia that will need to be addressed to prevent further pressure on the primary industries sector.

Population growth is the major driving force in the **Caribbean Islands** which has resulted in increased urbanization, in turn further worsened by the geography of the region, namely small island nations with limited land use availability. Changes in weather patterns across the Caribbean have increased the severity of weather-related events, leading to uneven rainfall distribution. Trade policies and subsidies both globally and at the national level are a key driver in the Caribbean region, with a lack of proper agricultural institutions and policies, along with access to support services in the region failing to assist primary industry producers in the region impacted by aggressive trade policies of other countries. Insecure land and water rights and food wastage were two lower ranked drivers in the Caribbean Islands, however, they are still substantial drivers, with little difference separating them in the mean rank scores from the top-ranked driver of population growth, indicating how the regions geographical constraints place considerable pressure on the primary industry sector.

12.3 Appendix 3: Relative Ranking Pressures

Figure A3: Relative ranking of Pressures

Figure A3 shows that there are several pressures **Africa** face that are adversely affecting the system in the region. The survey found that the highest-ranking pressure in the region is the production of fodder crops that reduces land to produce crops for human consumption. Overgrazing, which is related to the production of fodder crops, is also an issue for farmers in Africa, with a mean ranking of 0.82. The continent is also facing other pressures that have detrimental impacts on agriculture with the survey data showing that the over extraction of both surface and groundwater (0.56 and 0.59, respectively) limits potential agricultural production. Other pressures the continent's farmers are facing include greater use of fossil fuels associated with more intensive farming practices (0.74), which has also increased the use of agrochemicals, pesticides and fertilizers (0.78).

Figure A3 shows that there are several pressures **Near East and North Africa** face that are adversely affecting farmers in the region. Farmers in the Near East and North Africa face slightly different pressures to their counterparts in the Asia-Pacific region and Africa, with data indicating that water extraction, both surface (0.79) and groundwater (0.88) having the largest impact on farming practices, which is unsurprising given the arid landscape that characterizes much of the region. Agriculture in the region also faces pressure from overgrazing (0.75) and more intensive agrochemical, pesticide and fertilizer usage (0.68), along with unsustainable agricultural practices (0.74), from forest clearing and continuous cultivation that will require addressing from policymakers and farmers themselves if the region is to avoid long-term damage to soil, water stores and the regions natural resources. The region is also facing pressures from pests and disease (0.50) that threaten the fragile ecosystem and is associated with climate-related changes and increased urban encroachment on the region's rural areas, placing further burdens on farmers across the zone.

The agricultural sector in the **Asia-Pacific** region faces a range of pressures with continuous cultivation (0.84), forest clearing and cultivation (0.81) and unsustainable agricultural practices (0.80) being the leading pressure indicators faced by the region. The expansion of agriculture in the region (0.72), particularly more intensive agriculture, has impacted both surface and groundwater extraction (both 0.76) with the potential to adversely affect farming practices in the future unless there are significant changes to farming practices. The region’s changing agricultural practices have resulted in higher energy usage (0.53) and the production of higher energy-producing crops which affects the costs of production for the region’s farmers. The findings from the data also indicate that the region’s agriculture sector is facing other external cost pressures from seed and genetic material makers whose market monopolization increases prices for farmers further increasing production costs (0.53).

In **Latin America**, the highest-ranking pressure in the region is the cultivation in slopes. This is closely followed by pest and disease, forest clearing and conversion, and continuous cultivation, all of which increase environmental degradation associated with soil loss. Pests and disease (microbial risks) is placing pressure across Latin America and is the second highest ranked pressure, this has, in turn, increased the use of agrochemicals, pesticides and fertilizers in the region to combat the risks of disease. The region is also facing other pressures that have detrimental impacts on agriculture with the research data showing that the over extraction of surface water limits agricultural production's potential. Higher energy use, unsustainable agricultural practices and overgrazing have been identified by the research as further pressures faced by primary producers in Latin America.

In **Central Asia** faces, there are pressures to increase fodder crop production this is closely followed by continuous cultivation. Overgrazing, the monopolization of agricultural inputs and the over-extraction of surface water all ranked with equal rating in terms of the pressures they are placing on the region's primary producers. Central Asia is also facing other pressures that are having negative impacts on agriculture, for instance, microbial risks are a major pressure, which has in turn increased the use of agrochemicals, pesticides and fertilizers. Higher energy use, groundwater over-extraction and forest clearing, and conversion have been identified by the survey as further pressures faced by primary producers in Central Asia.

Caribbean Islands also face the threat of pest and disease, which is closely related to an increase in the intensive use of agrochemicals, pesticides and fertilizers. The region also faces pressures leading to unsustainable agricultural practices and forest clearing and conversion and impacting future land use practices for the region's producers.

12.4 Appendix 4: Relative Ranking State

Figure A4: Relative ranking of States

The mean ranking of different state elements show that in **Africa** the most impact is causing reduced farm profits and impacting on subsistence farming, with a mean score ranking of 0.97. The farming practices are causing a loss of farming land through degradation that is impacting on farming livelihoods with this being the second-highest ranking at 0.94. In addition to these issues, farmers across Africa also face volatility in crop prices, which impacts family and community life and further erodes living standards for farmers, with this ranking just behind land degradation with a mean score of 0.93. The survey indicates that farmers across Africa face problems associated with poor irrigated water (0.80) and salinity issues (0.80). The survey found that African farmers are facing numerous other important concerns that have implications for agricultural output over the coming years, which includes surface and groundwater pollution (0.83), deforestation (0.88) and desertification (0.91), along with an ageing farmer population (0.90) and gender imbalances (0.90) all of which will require addressing from policymakers across the continent to mitigate potential social and economic failure among agricultural communities.

In the **Near East and North Africa**, the survey found that water scarcity had the highest mean score ranking of 0.96, which is unsurprising given that many countries across the region are characterized by arid and semi-arid landscapes with low and sporadic rainfall rates. Water-related issues rounded out the top three rankings across this region, with data indicating that groundwater depletion (0.91), and surface water fluctuations (0.88) scored high among concerns with farming practices. The lower order rankings were still dominated by water, as poor-quality irrigated water with a mean score of 0.57 causing problems for farming practices in this region. The region also faces increased urbanization as once rural areas become subsumed by growing urban centres forcing competition for land and water resources (0.57) between urban and rural populations and a subsequent reduction in the land available for agriculture. The data also indicates that other problems facing the regions farmers include soil pollution from inorganic materials (0.59), price volatility for agricultural products (0.63) and higher input prices forcing up the costs of agricultural products (0.67). Farmers in the region are also facing vegetation loss (0.70), loss of topsoil (0.73) and desertification (0.80), with the data showing that these problems are causing increased land degradation (0.84) which has the potential to impact on future agricultural production.

Across the **Asia-Pacific region**, the survey found that the largest issue currently facing the region was the scarcity of water, with a mean score of 0.90. The survey data also indicates that farmers across the area are also impacted by price volatility for their products (0.90), deforestation (0.90) and salinity problems (0.89), which is exacerbated by the loss of vegetation. Lower-ranking issues facing agricultural communities across the nations of the Asia-Pacific region include soil pollutants associated with inorganic materials (0.73), poor irrigated water quality (0.73) and higher prices associated with increased energy costs (0.75). The regions' farmers also face pollution of surface and groundwater (0.75), with the survey findings also concluding that associated with this was increased conflict accompanying competition for both land and water (0.81) as the countries across the region increasingly urbanize. The study has also identified an ageing farming population across the region (0.83) as one of the problems facing the sector currently, which is associated with urbanization as younger generations leave rural communities for better livelihoods in the regions burgeoning cities.

The survey data in relation to the state for farming currently across **Latin America** shows that the largest impact results from an increase in the amount of untreated wastewater and waste from livestock. The farming practices across Latin America are causing an increase in deforestation, which is the second-highest-ranking, with volatility associated with prices the next highest ranking. In addition to these issues, farmers across Latin America also face issues associated with water scarcity, land degradation, increased salinity and topsoil loss which further erodes living standards for farmers in the region. The research indicates that farmers across Latin America face problems associated with contaminated effluents in catchment areas, ground and surface water pollution, groundwater depletion and fluctuating surface water, all of which had similar mean scores indicating the seriousness of the issues faced by farmers across the region. The research found that there are numerous other important concerns facing Latin American farmers that have implications for agricultural output over the coming years, which include ageing farmer population, higher input prices, a reduction in farm profits and subsistence farming, along with gender inequality all of which will require addressing from policymakers across the region to mitigate social and economic problems among agricultural communities.

Across the **Central Asia region**, the survey found that the largest issue currently facing the region was salinity, with a mean score close to 1.0. The data also indicates that farmers across the area are also impacted by closely related issues such as desertification, land degradation, fish and plant species reduction and water scarcity. Lower-ranking issues facing agricultural communities across the nations of the Central Asia region are water-related and include ground and surface water pollution, aquifer groundwater depletion and surface water fluctuation, impacting the ability of rural communities to access freshwater supplies for irrigation and potable water. The survey found that primary producers in Central Asia face increased vegetation cover loss, along with competition for land and water as the countries across the region increasingly urbanize. The ageing farming population across the region (0.83) is one of the problems facing the sector currently, which is associated with urbanization as younger generations leave rural communities for better livelihoods in the regions growing cities.

In the **Caribbean Islands**, the survey found that the depletion of groundwater in the aquifer had the highest mean score, whilst other water-related issues rounded out the top three rankings, including conflicts arising from land and water access and water scarcity. Higher input prices, price volatility issues, along with higher energy usage and prices scored high among concerns for primary producers in the Caribbean Islands. The lower order rankings were dominated by soil-related problems, including inorganic pollutants in the soil and soil chemical imbalances and nutrient toxicities, causing difficulties for farming practices in this region. The region also faces increased reduced farm profits and subsistence farming, lower land asset holdings, and ageing farmers leading to a subsequent reduction in the resources available for agriculture. The data also indicates that primary producers in the region are also facing a reduction in the quality of the vegetative biomass, a reduction in fish and plant species, and deforestation, with the data showing that these problems can impact future agricultural production across the Caribbean.

12.5 Appendix 5: Relative Ranking Impact

Figure A5: Relative ranking of Impacts

In Africa reduced agricultural productivity and efficiency has been ranked as the most pronounced problem with the highest mean score of 0.95. The health impact from environmental issues (0.88) and food insecurity (0.84) are the next two highest-ranking problems facing the continent, along with the abandonment of land (0.83), with implications for food production if this trend continues. The survey data also identified that water quality issues are having an impact across the region with a mean score of 0.64. The region is facing a range of social issues in the primary industries sector from increased malnourishment (0.72), rural-urban migration (0.76) and increased poverty (0.77) in rural communities which has been exacerbated by other social issues resulting in a perpetuating cycle that policymakers need to address to prevent systemic loss of people and food production in the agricultural sector across Africa.

In the Near East and North Africa, the survey identified that the issue that contributed to the largest impact facing the region was water availability, with a mean score ranking of 0.96. There was also a range of other problems that are impacting the region, which includes the loss of natural crop pollinators (0.87) and reduced productivity and efficiency in the agricultural sector (0.86), which is followed by problems of food insecurity (0.81) that will impact on the ability of the region to be self-sufficient in farming. At the lower end of the rankings scale, the survey data indicate that farmers are facing issues with alteration of hydrology cycles (0.59), there are reduced employment opportunities for rural people in the sector (0.59), and price fluctuations are increasing the vulnerability of farmers (0.63) as they become dependent on outside markets for their products and move away from traditional subsistence farming practices. There are also numerous social impacts that were identified in the survey, including malnourishment (0.65), the continued migration from rural to urban areas (0.76) and the increase in poverty that is associated with increased urbanization in rural areas as small landholders find it increasingly difficult to maintain profitable enterprises (0.70).

In the **Asia-Pacific region**, reduced agricultural productivity has been identified as having the highest impact on the agricultural sector, with a mean score ranking of 0.89. This was closely followed by food insecurity (0.84), issues with hydrology cycles associated with changes to farming practices (0.82) and lower nutritional value diets that are causing health risks among rural populations (0.77). The survey data indicates that issues with lower impact on the Asia-Pacific region include carbon cycling (0.50) and health issues associated with environmental problems (0.63), which enjoyed the same mean ranking as lower labour productivity. The region is also facing several other water-related issues that are impacting on agricultural production, including lower water quality (0.70), and less capacity to regulate water quality (0.71), along with problems with water availability (0.77) that affect the productive capacity of rural landholders.

In **Latin America** food insecurity has been ranking as the most pronounced problem with the highest mean score above 0.8. Flood incidence and health risks from lower nutritional diets are the next two highest-ranking problems facing Latin America, along with increased poverty with implications for the health of those involved in primary production if these trends continue. The issues with the lower impact on Latin America include lower labour productivity, health impacts associated with environmental consequences, along soil nutrient runoff. The data also indicates that the region is facing a range of social issues in the primary industries sector from rural-urban migration, land abandonment, lower employment opportunities and malnourishment in rural communities which has been exacerbated by economic and environmental problems resulting in a perpetuating cycle that policymakers need to address to prevent systemic loss of people and food production in the agricultural sector across Latin America.

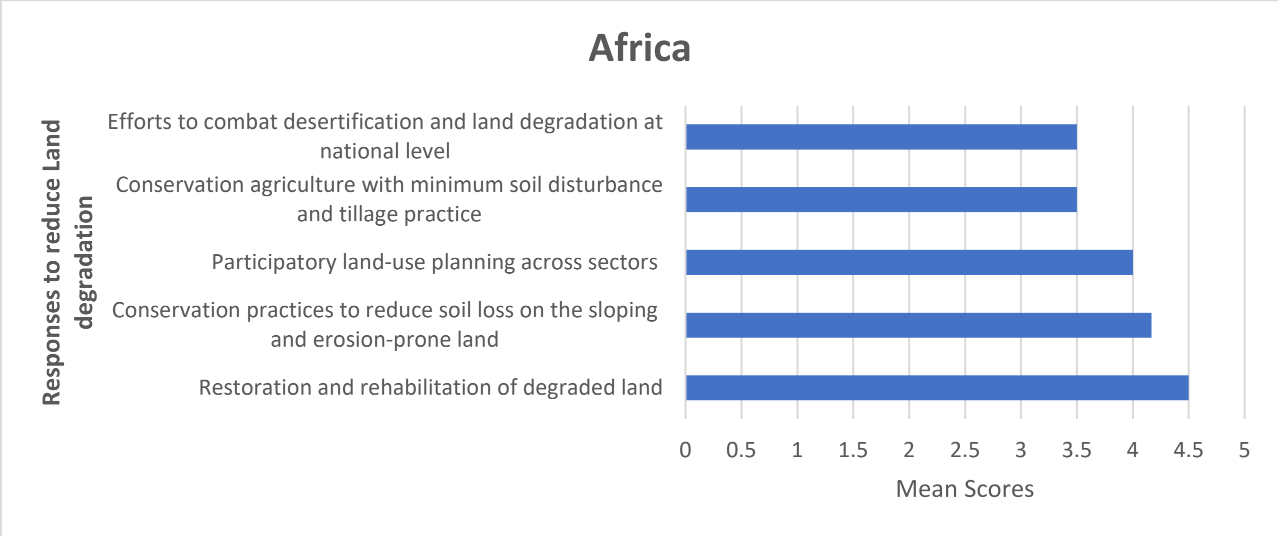
In **Central Asia** hydrological cycle has been top-ranked. The impact on carbon cycling and increased migration from rural to urban areas are the next highest-ranked impacts on Central Asia, with implications for primary sector production across Central Asia if this trend continues. The data also indicates that the region is facing a range of social issues in the primary industries sector, including malnourishment, health issues associated with environmental problems, increased poverty and land abandonment, all of which result in a perpetuating cycle that policymakers need to address to prevent systemic loss of people and food production in the agricultural sector across Central Asia. The issue with the least impact on Central Asia was soil nutrient runoff. However, the data also identified that water quality issues and the loss of natural crop pollinators are having an impact on primary production across the region.

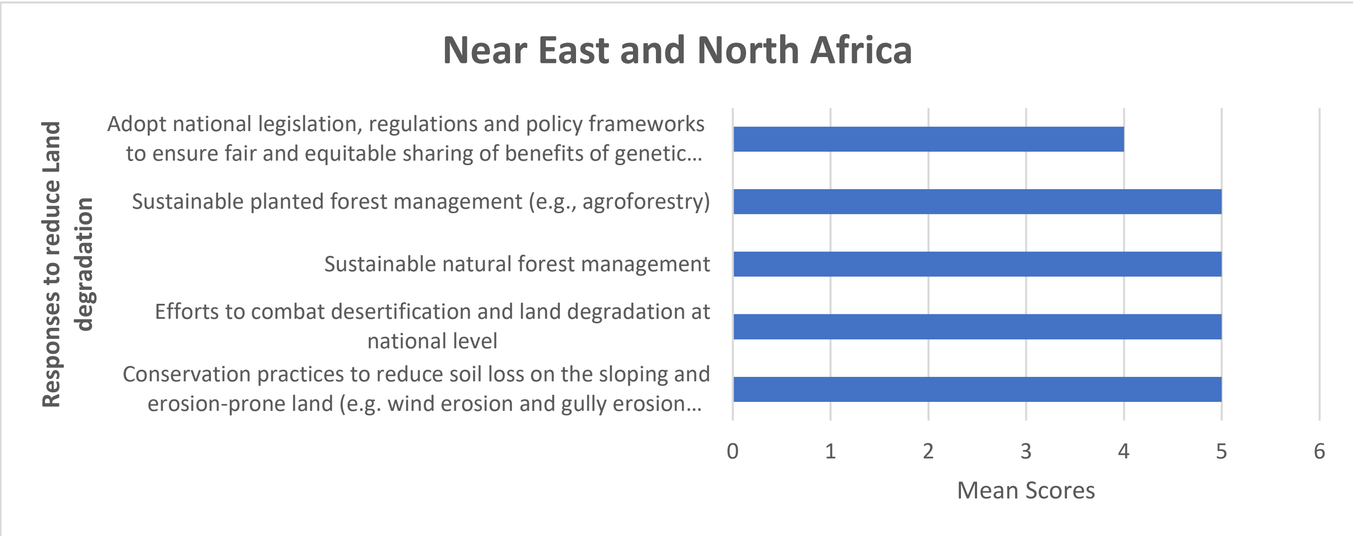
The impact on primary producers in the **Caribbean Islands** has been quite significant, with food insecurity ranking as the most pronounced problem with the highest mean score, just over 1.0. The impact of flood incidence and increased migration from rural to urban areas are the next highest-ranked impacts on the Caribbean, with implications for primary sector production across the Island nations of the region if this trend continues. The data also indicates that the region is facing several social issues in the primary industries sector, including health issues associated with environmental problems, land abandonment, malnourishment and increased poverty, issues that policymakers need to address to prevent further loss of domestic food production in the agricultural sector across the Caribbean. The issues with the least impact on the Caribbean Islands included the lower natural capacity to regulate water quality, health impacts from environmental issues and income loss from lower harvests for small landholders, all of which are having an impact on primary production across the region, decreasing the ability of the region to be self-sufficient in agricultural production.

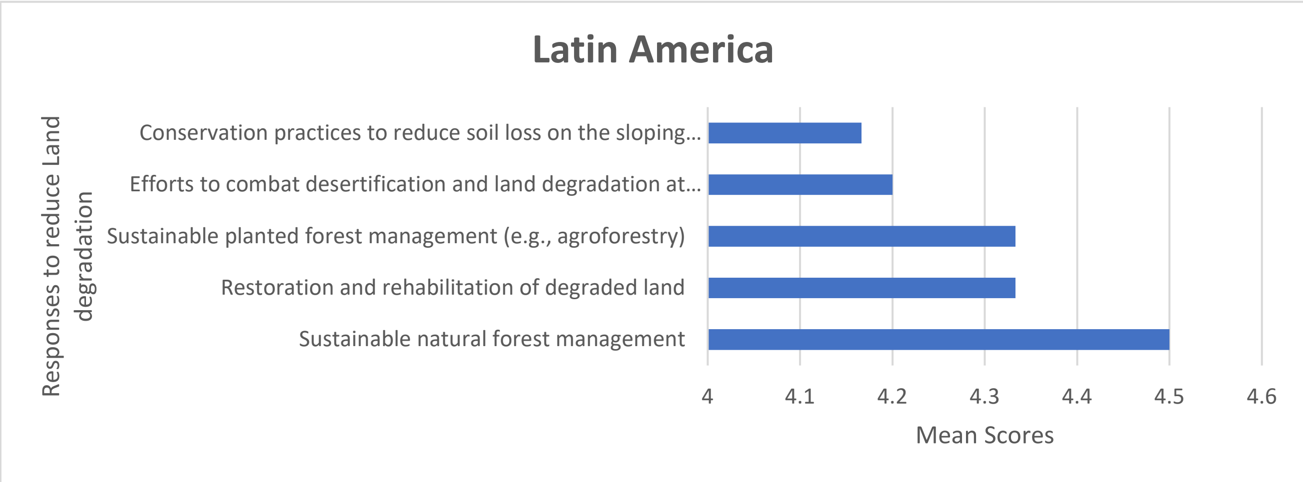
12.6 Appendix 6: Relative Ranking -Response

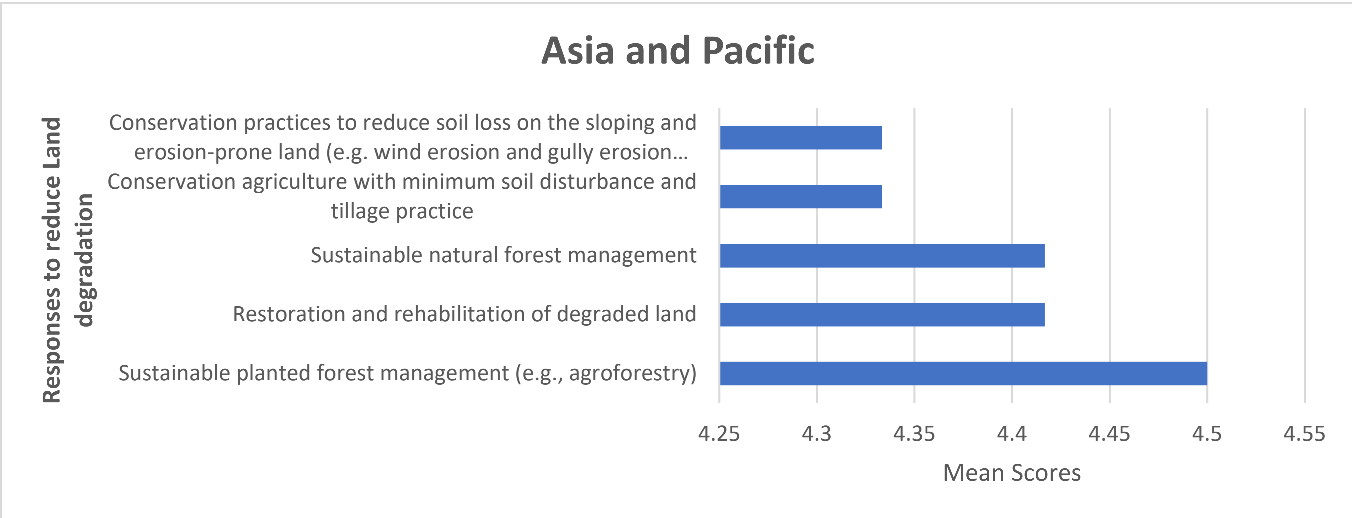
We demonstrate some most effective responses identified in different regions to tackle six key issues: land degradation, loss of vegetation cover, water scarcity, groundwater depletion, price volatility and how to increase farm income.

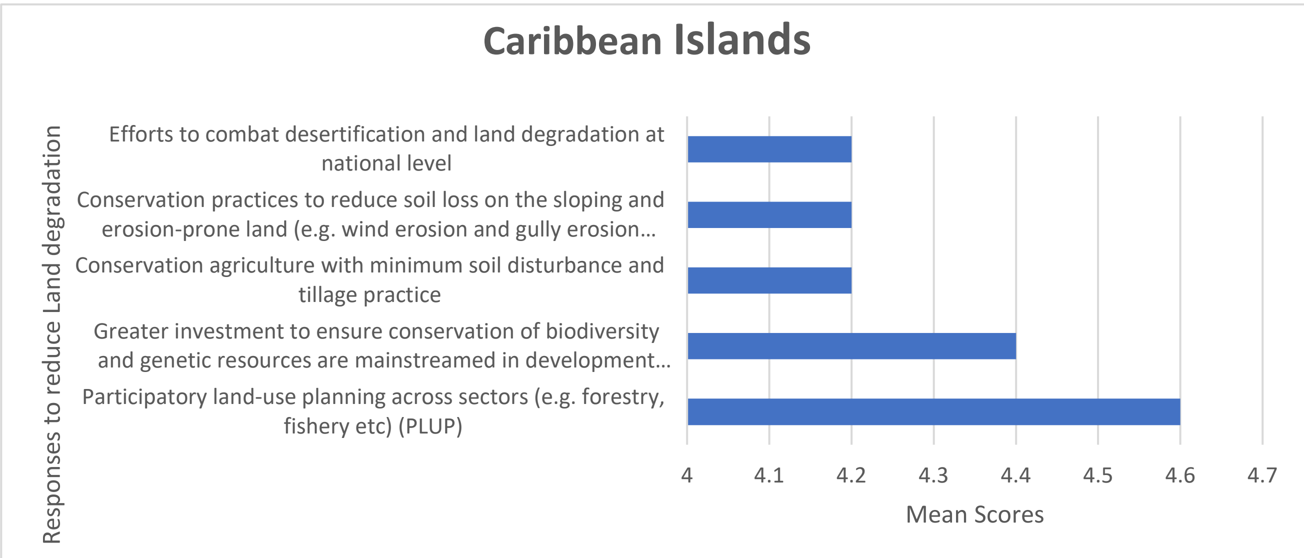
Figures A.6.1: Ranking of key responses to combat land degradation



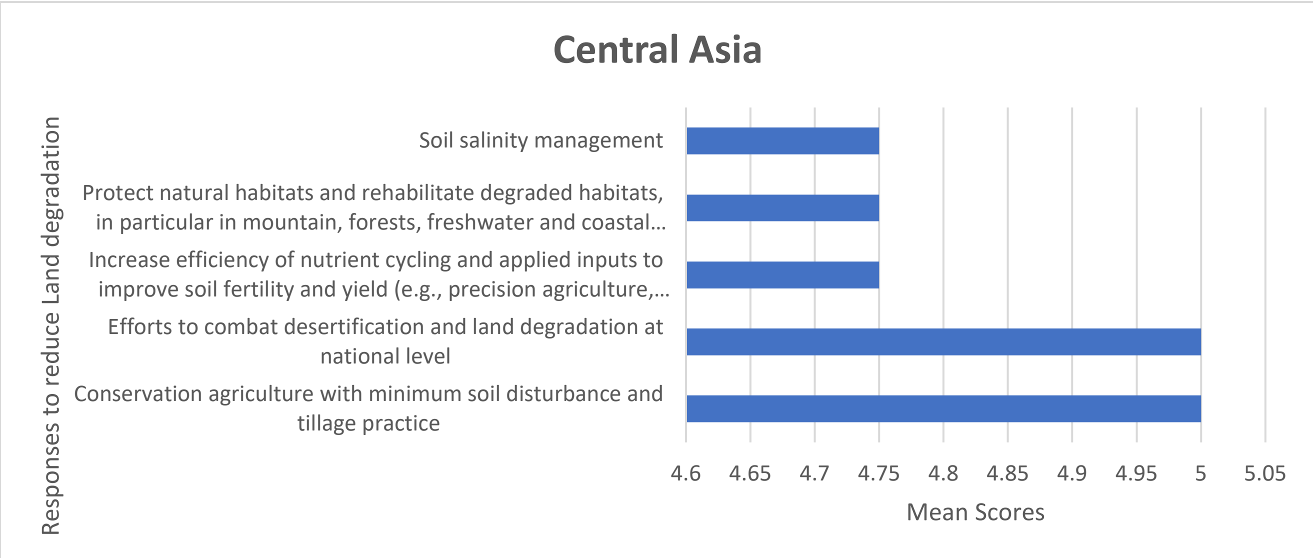



Latin America
Responses to reduce Land degradation
Conservation practices to reduce soil loss on the sloping...
Efforts to combat desertification and land degradation at...
Sustainable planted forest management (e.g., agroforestry)
Restoration and rehabilitation of degraded land
Sustainable natural forest management
4
4.1
4.2
4.3
4.4
4.5
4.6
Mean Scores


Asia and Pacific
Responses to reduce Land degradation
Conservation practices to reduce soil loss on the sloping and erosion-prone land (e.g. wind erosion and gully erosion...
Conservation agriculture with minimum soil disturbance and tillage practice
Sustainable natural forest management
Restoration and rehabilitation of degraded land
Sustainable planted forest management (e.g., agroforestry)
4.25
4.3
4.35
4.4
4.45
4.5
4.55
Mean Scores


Caribbean Islands
Responses to reduce Land degradation
Efforts to combat desertification and land degradation at national level
Conservation practices to reduce soil loss on the sloping and erosion-prone land (e.g. wind erosion and gully erosion...
Conservation agriculture with minimum soil disturbance and tillage practice
Greater investment to ensure conservation of biodiversity and genetic resources are mainstreamed in development...
Participatory land-use planning across sectors (e.g. forestry, fishery etc) (PLUP)
4
4.1
4.2
4.3
4.4
4.5
4.6
4.7
Mean Scores

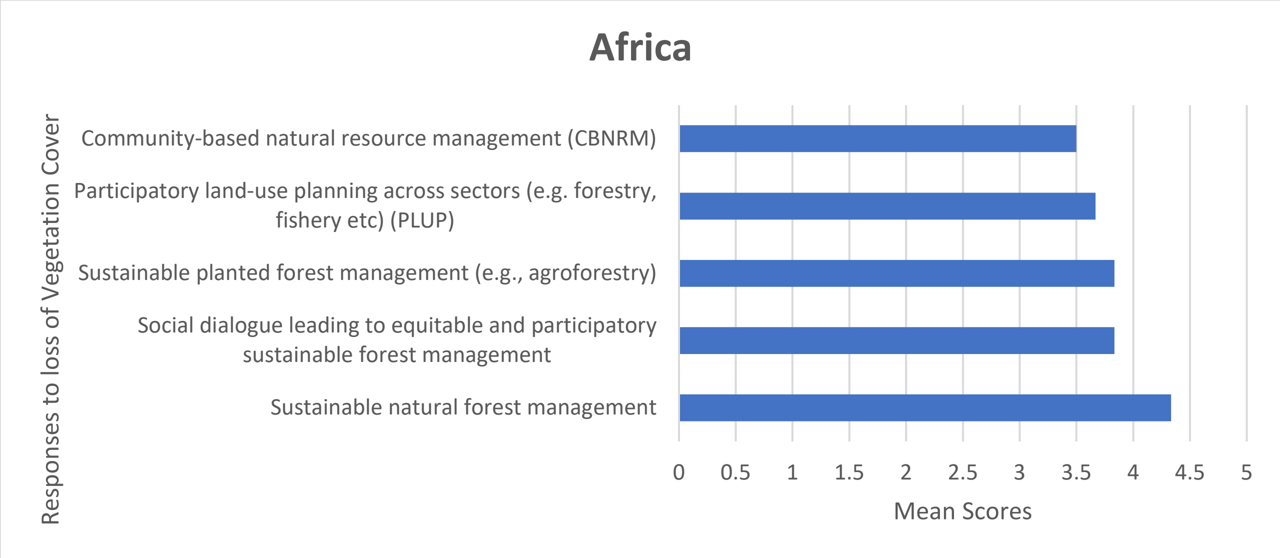
The survey identified a range of responses from farmers across the regions to reduce land degradation. In Africa, respondents indicated that the restoration and rehabilitation of degraded land with a mean score ranking of 4.5 was the most effective choice to restore land value. In the Asia-Pacific region, respondents identified that sustainable forest plantations would reduce land degradation (4.5), whilst in the more arid Near East and North Africa regions, respondents identified that practices aimed at reducing soil loss on erosion-prone land would assist in mitigating land degradation. The survey found that in the Near East and Africa, respondents believed that a national policy and regulated frameworks were important in assisting with the prevention of land degradation, with a mean score of 4. In Africa, the survey found that efforts aimed at reducing desertification and land degradation at a national level were important, with a mean score of 3.5 from respondents. In contrast, in the Asia-

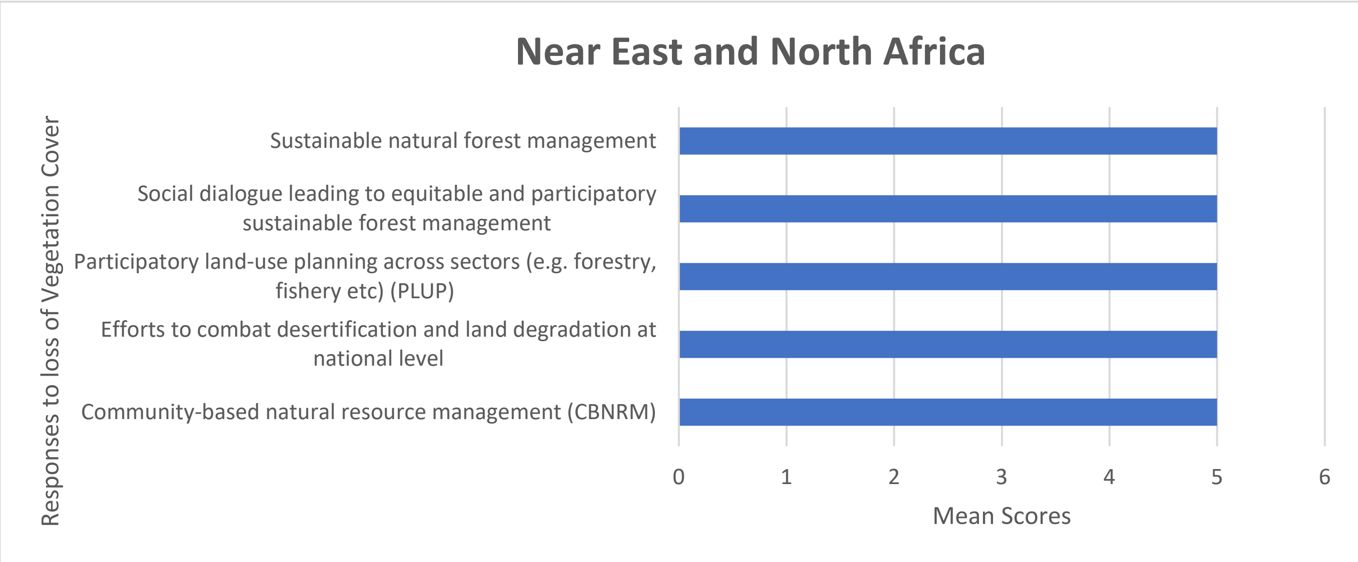


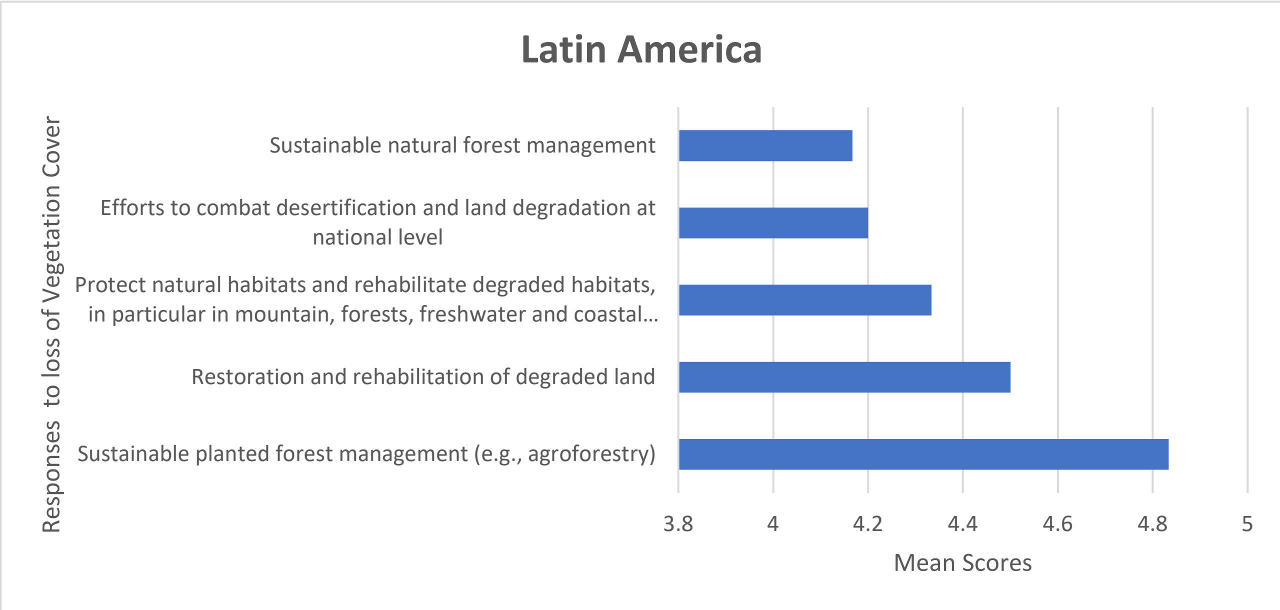
Pacific region, respondents believed that one of the optimal ways to reduce land degradation in the region is through conservation practices aimed at reducing soil erosion, particularly on sloping land (4.3). In Africa, the respondents also identified that a more participatory land-use planning approach across a range of sectors, would be beneficial in reducing land degradation (4). Respondents in the Asia-Pacific region identified more sustainable forest management practices would help reduce land degradation, with a mean score ranking of 4.4. In the Near East and Africa, with its arid environment, the survey respondents wanted increased national efforts to combat desertification and land degradation, with a mean score rating of 5.

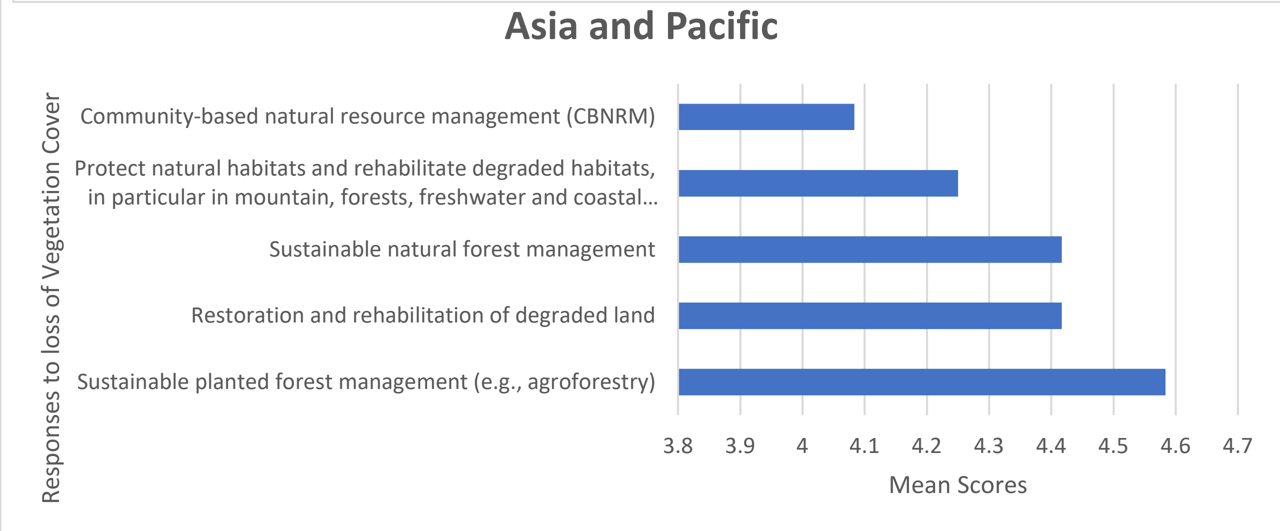
In Latin America, respondents indicated that sustainable natural forest management with a mean score ranking of 5.5 was the optimal choice to restore land value. In the Central Asia region, respondents identified that conservation agriculture with minimal disturbance, along with efforts to combat desertification and land degradation, both at 6.0 were the highest ranked responses. In the smaller island nations of the Caribbean, respondents identified that participatory land-use planning across the primary industry sectors would assist in mitigating land degradation. The research found that Latin America respondents believed that restoration and rehabilitation of degraded land and sustainable planted forest management were important in assisting with the prevention of land degradation with mean scores 4.3. In Central Asia the research found that soil salinity management, the protection of habitats, and increased efficiency in nutrient cycling and efforts to improve soil fertility were critical to reducing land degradation. In the Caribbean Islands region by contrast, respondents believed that the optimal ways to reduce land degradation in the region is through efforts to combat desertification and land degradation, conservation practices to reduce soil loss, along with conservation agriculture with minimal soil disturbance all rating mean scores of 4.2.

Figure A6.2: Ranking of key responses to address the loss of vegetation cover



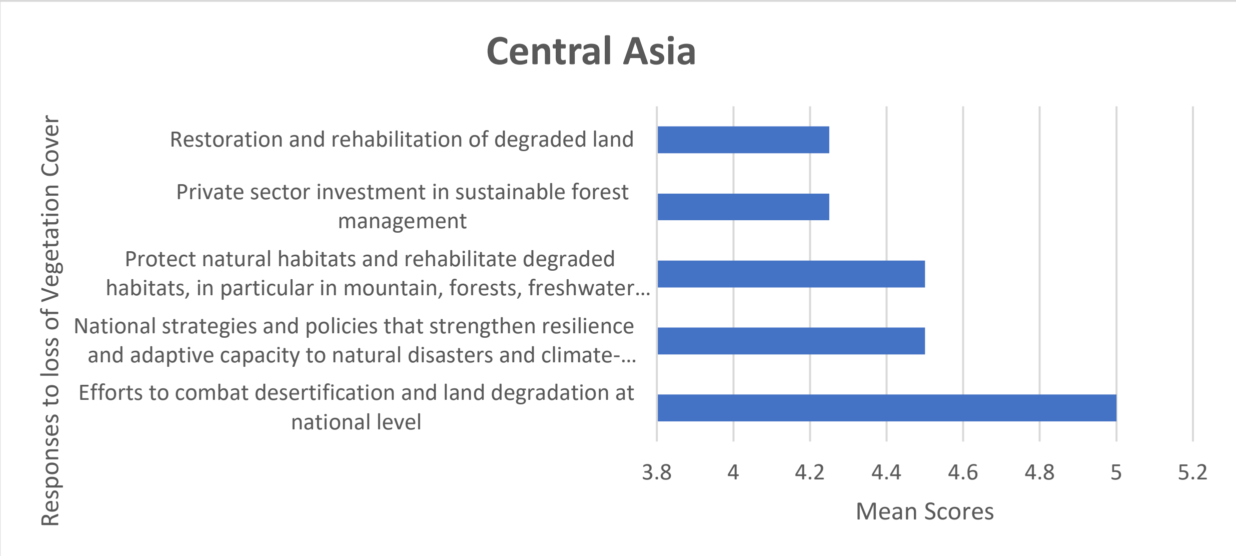


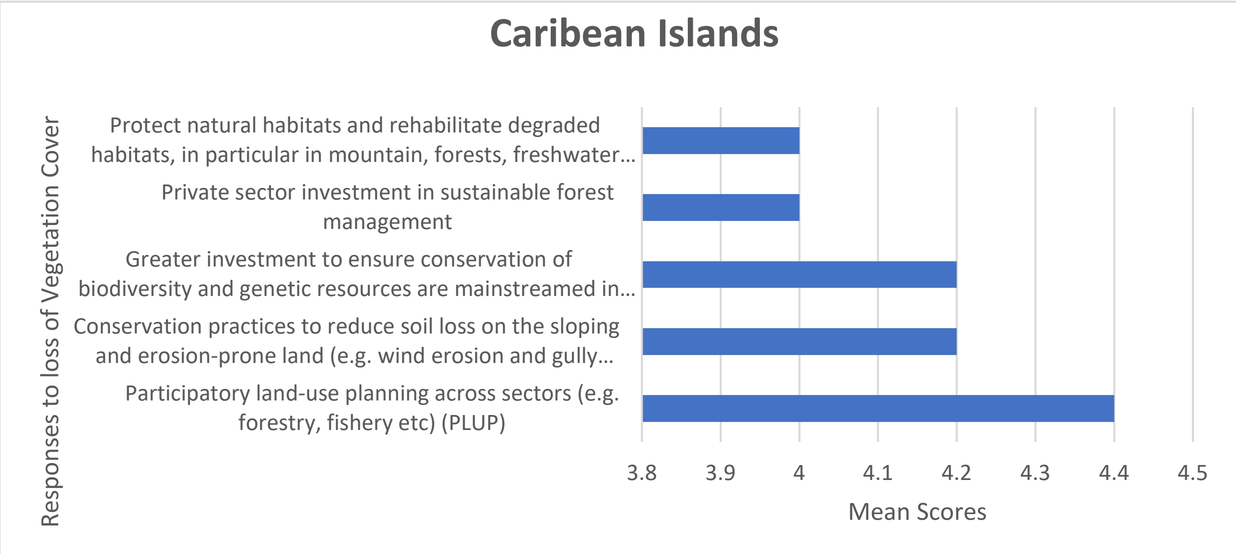

Latin America
Responses to loss of Vegetation Cover
Sustainable natural forest management
Efforts to combat desertification and land degradation at national level
Protect natural habitats and rehabilitate degraded habitats, in particular in mountain, forests, freshwater and coastal...
Restoration and rehabilitation of degraded land
Sustainable planted forest management (e.g., agroforestry)
3.8
4
4.2
4.4
4.6
4.8
5
Mean Scores


Asia and Pacific
Responses to loss of Vegetation Cover
Community-based natural resource management (CBNRM)
Protect natural habitats and rehabilitate degraded habitats, in particular in mountain, forests, freshwater and coastal...
Sustainable natural forest management
Restoration and rehabilitation of degraded land
Sustainable planted forest management (e.g., agroforestry)
3.8
3.9
4
4.1
4.2
4.3
4.4
4.5
4.6
4.7
Mean Scores

One of the major impacts on-farm sustainability identified in the survey was the loss of vegetation cover, which increases erosion associated with increased runoff and dried out soil in times of low rainfall. In responding to ways to reduce this loss of vegetation cover, respondents in the Asia-Pacific region rated sustainable forest management as the best way to reduce vegetation loss (4.6). In Africa, sustainable forest management was recognised as the most favoured approach to reduce losses of vegetation cover (4).

In the Near East and North Africa, survey participants gave equal weighting to five different options for managing vegetation loss, ranging from community-based natural resource management to sustainable natural forest management and participatory land-use management practices across a range of primary industries. In Africa, the data indicates that almost equal importance is given to the remaining four categories with community-based resource management and participatory land-use planning, both given almost identical weightings by participants. Sustainable forest management and equitable and





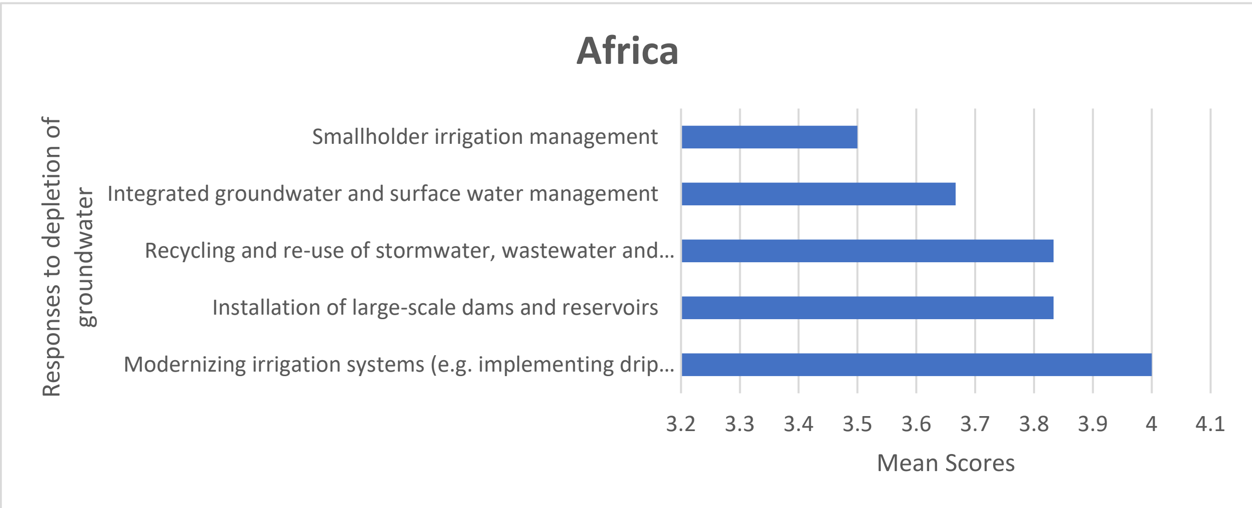
participatory sustainable forest management practices were of equal importance with a mean ranking score of 4.

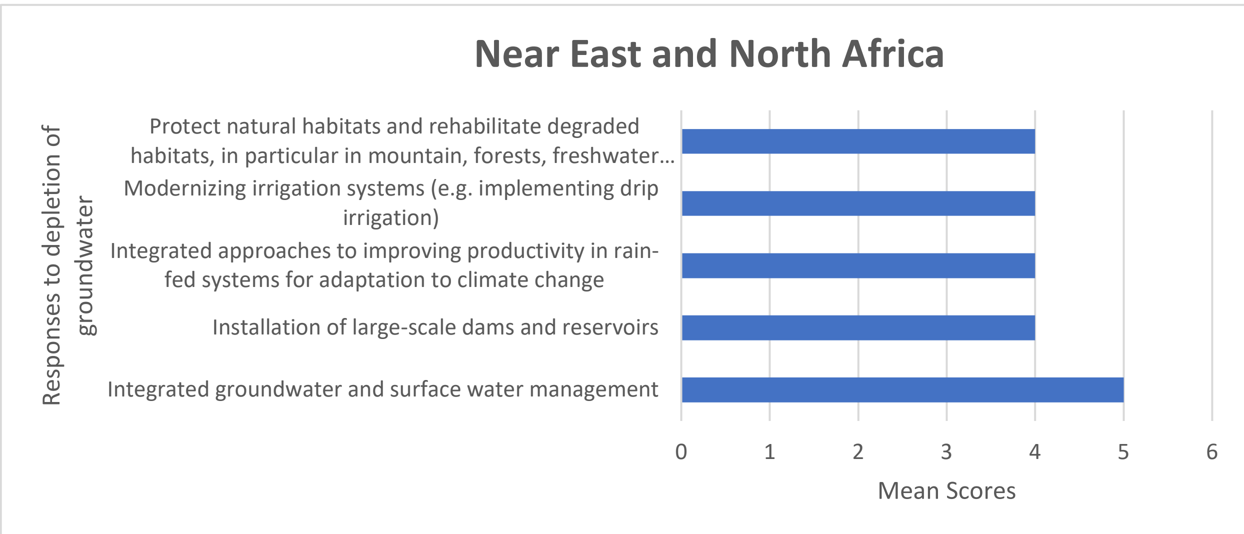
In the Asia-Pacific region, the survey data showed that the least important was given to community-based natural resource management (4.1), whilst sustainable forest management and restoring and rehabilitating degraded land were both equal second as the most important factors in restoring vegetation loss (4.4). One of the major impacts on farm sustainability identified in the research was the loss of vegetation cover which increases erosion associated with increased runoff and dries out soil in times of low rainfall. In responding to ways to reduce this loss of vegetation cover respondents in Latin America rated sustainable forest management as the best way to reduce vegetation loss (4.8).

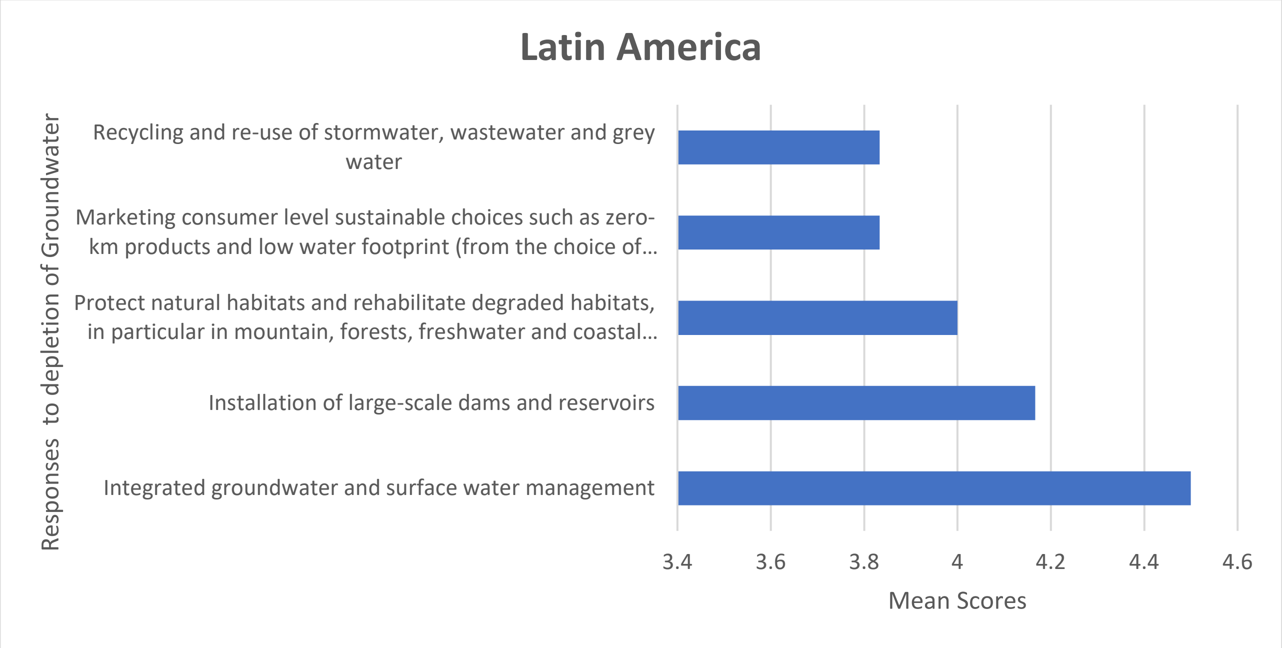
In Central Asia, efforts to combat desertification and land degradation was recognised as the most favoured approach to reduce losses of vegetation cover 5). In the Caribbean Islands, survey participants stated that participatory land-use planning in the primary industry sector as the best way to manage vegetation loss (4.4). In Latin America the data indicates that the next most important way to reduce vegetation cover loss was through the restoration and rehabilitation of degraded land, whilst sustainable natural forest management was given the lowest mean score by respondents to the survey.

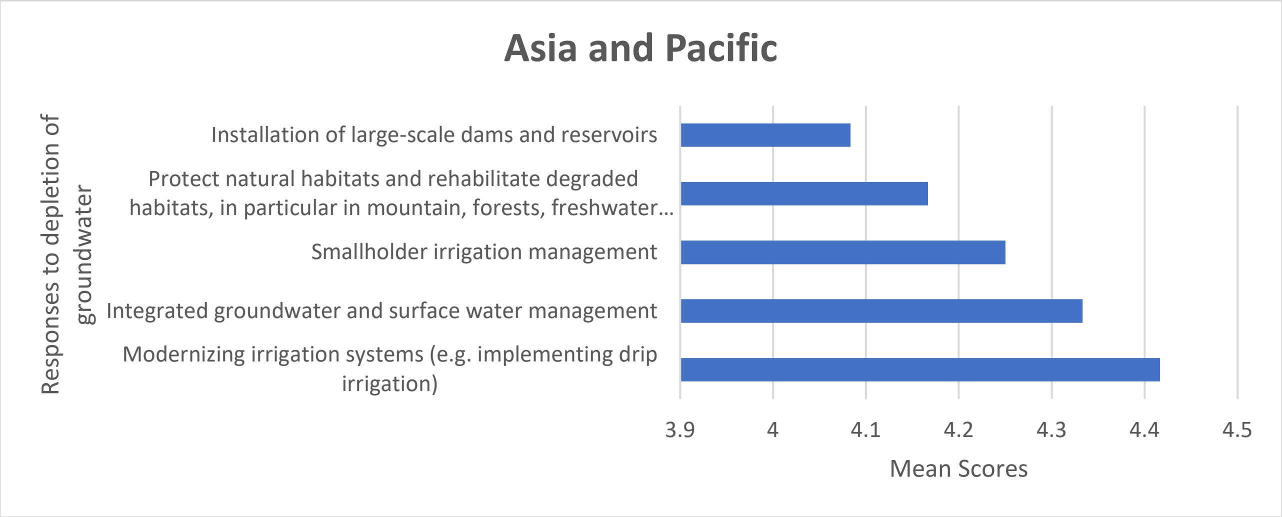
In the Central Asia region, the survey data showed that importance was given to the restoration and rehabilitation of degraded land, along with private sector investment in sustainable forest management, both with mean rankings of 4.2. Whilst in the Caribbean Islands, the lowest rankings were given to protecting natural habitats and private sector investment in sustainable forest management, both scoring 5 by respondents.

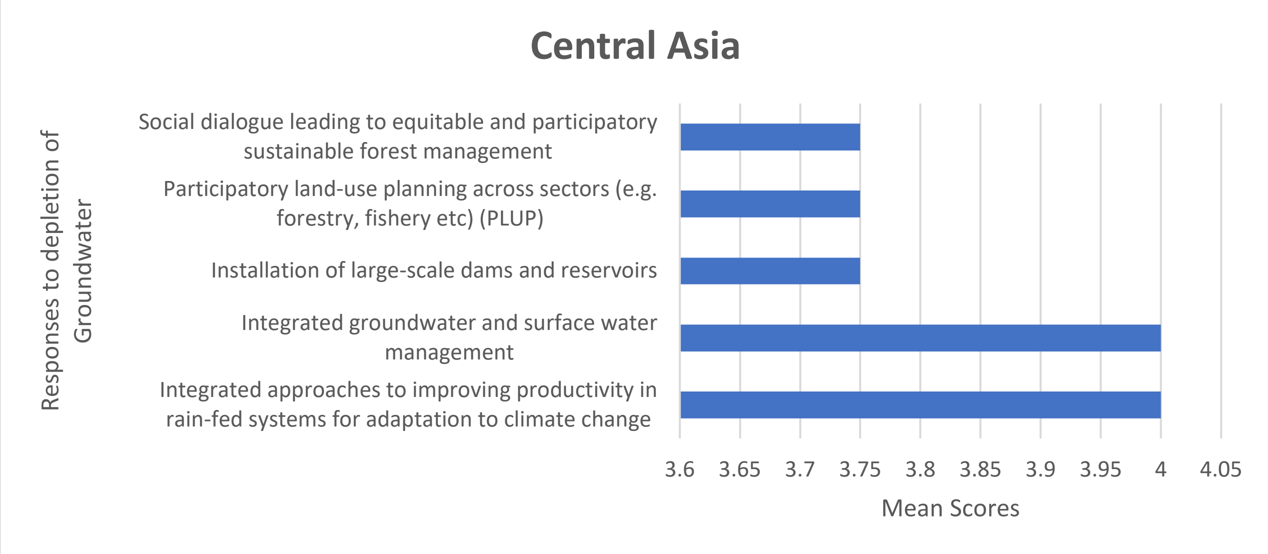
Figure A6.3: Ranking of key responses to address groundwater depletion

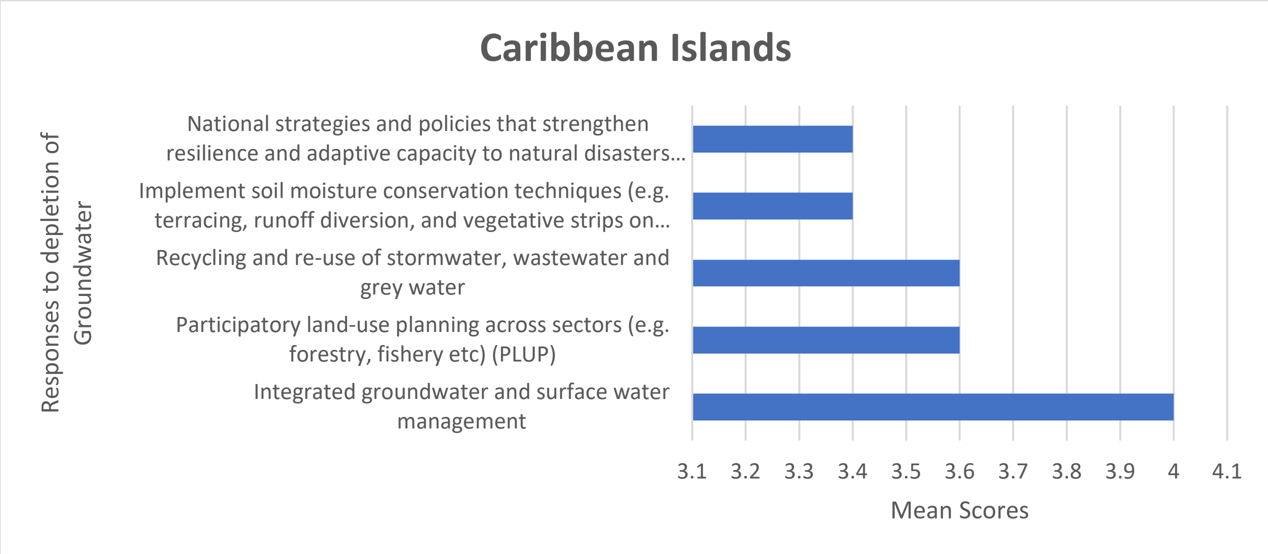





Latin America
Responses to depletion of Groundwater
Recycling and re-use of stormwater, wastewater and grey water
Marketing consumer level sustainable choices such as zero-km products and low water footprint (from the choice of...
Protect natural habitats and rehabilitate degraded habitats, in particular in mountain, forests, freshwater and coastal...
Installation of large-scale dams and reservoirs
Integrated groundwater and surface water management
3.4
3.6
3.8
4
4.2
4.4
4.6
Mean Scores


Asia and Pacific
Responses to depletion of groundwater
Installation of large-scale dams and reservoirs
Protect natural habitats and rehabilitate degraded habitats, in particular in mountain, forests, freshwater...
Smallholder irrigation management
Integrated groundwater and surface water management
Modernizing irrigation systems (e.g. implementing drip irrigation)
3.9
4
4.1
4.2
4.3
4.4
4.5
Mean Scores



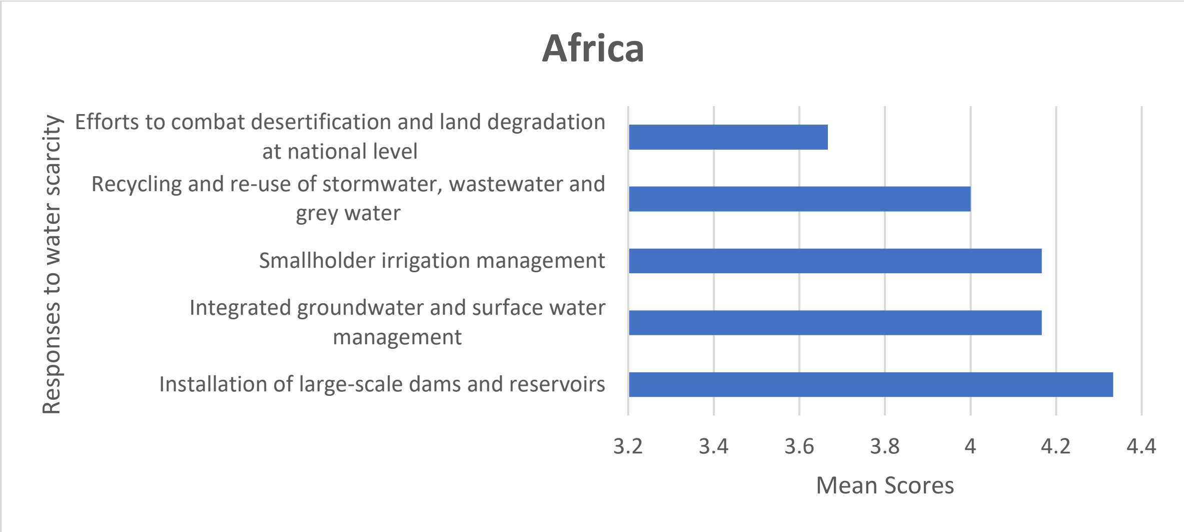


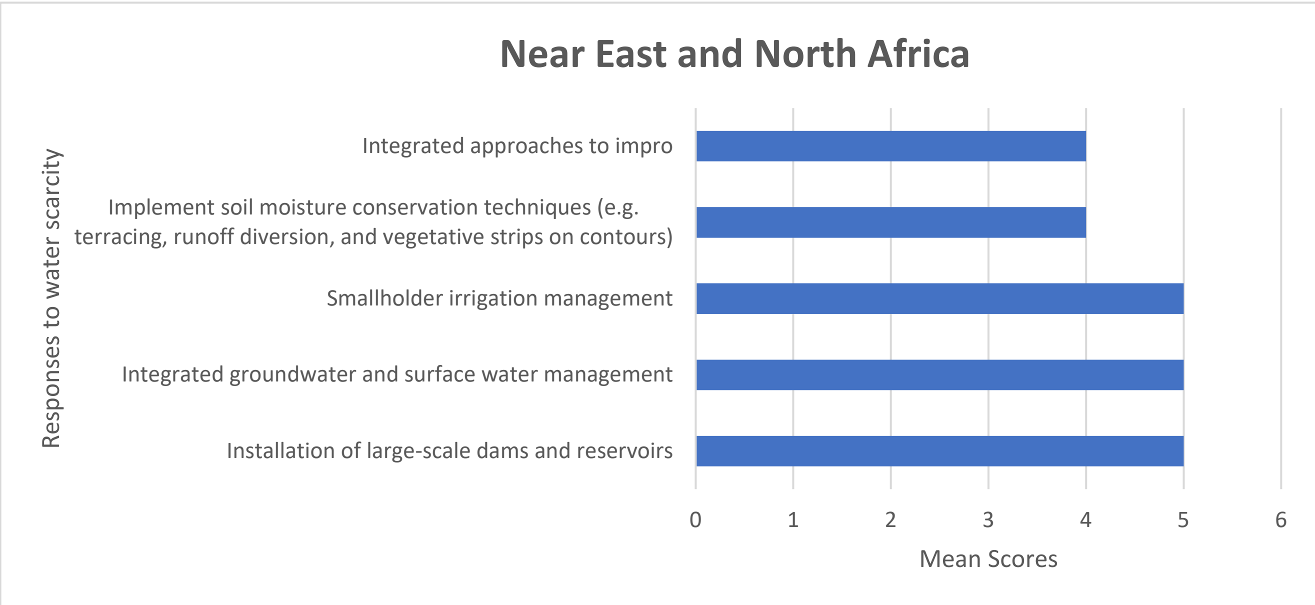
The depletion of groundwater was identified as a major inhibitor to agricultural development across all three regions, and this section identifies what can be done to assist in mitigating the effects of groundwater depletion. In Africa and the Asia-Pacific regions, the single best way to prevent the depletion of groundwater was seen to be the modernisation of irrigation systems, with a move towards drip-fed systems, with rankings of 4 and 4.4, respectively. In the Near East and North Africa, the most important way to mitigate groundwater depletion was identified as a more integrated approach to groundwater and surface management with respondents providing it a rating of 5.

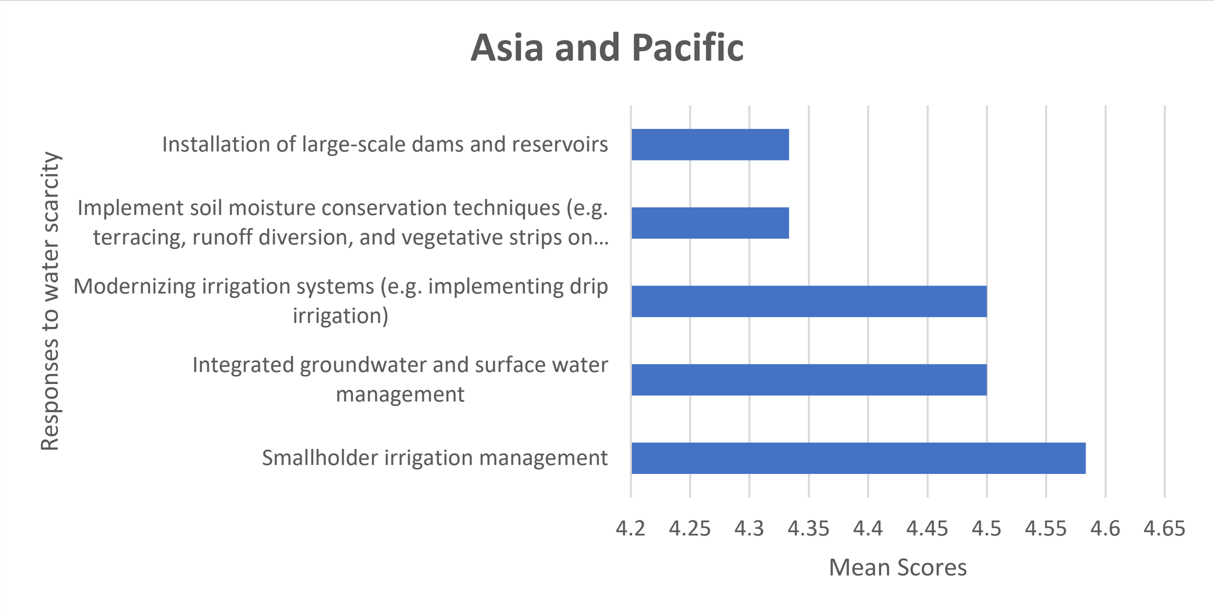
The Near East and North Africa respondents gave equal ranking to a range of other options to preventing groundwater depletion, including protecting and rehabilitating natural habitats, improving productivity in rain-fed irrigation systems and the installation of large scale water sources, all with a ranking of 4. In the Asia-Pacific region, respondents identified an integrated approach to ground and surface water management as the second most appropriate way to mitigate groundwater depletion. In Africa, equal rating was given to the installation of water storage systems and water recycling treatments (3.8 each) as the second most important ways to ensure more sustainable use of groundwater across the continent. The depletion of groundwater was identified as a major inhibitor to agricultural development across all three regions and this section identifies what can be done to assist in mitigating the effects of groundwater depletion.

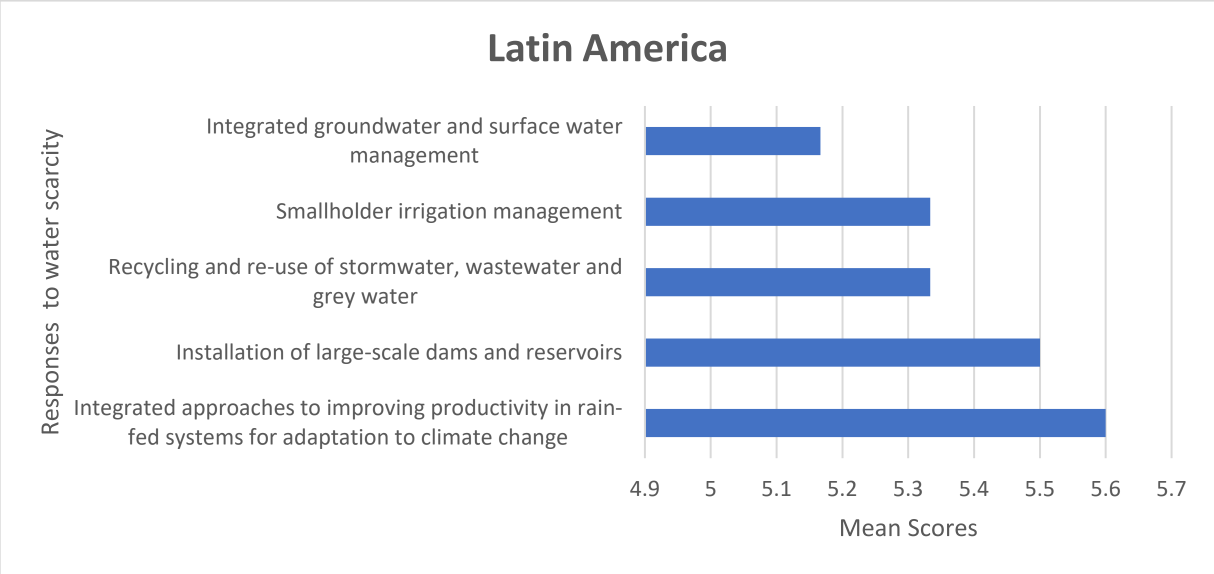
In Latin America, Central Asia and in the Caribbean Islands, the best way to prevent groundwater depletion was through the integrated ground and surface water management. In Central Asia, adoption of integrated approaches to improving productivity in rain fed systems were given by respondents as another best way to prevent groundwater depletion. In the Caribbean Islands, the respondents identified participatory land use planning as another optimal way to address groundwater reduction (3.6). In the Caribbean Islands, respondents also highlighted the importance of recycling and reuse of stormwater, wastewater and greywater.

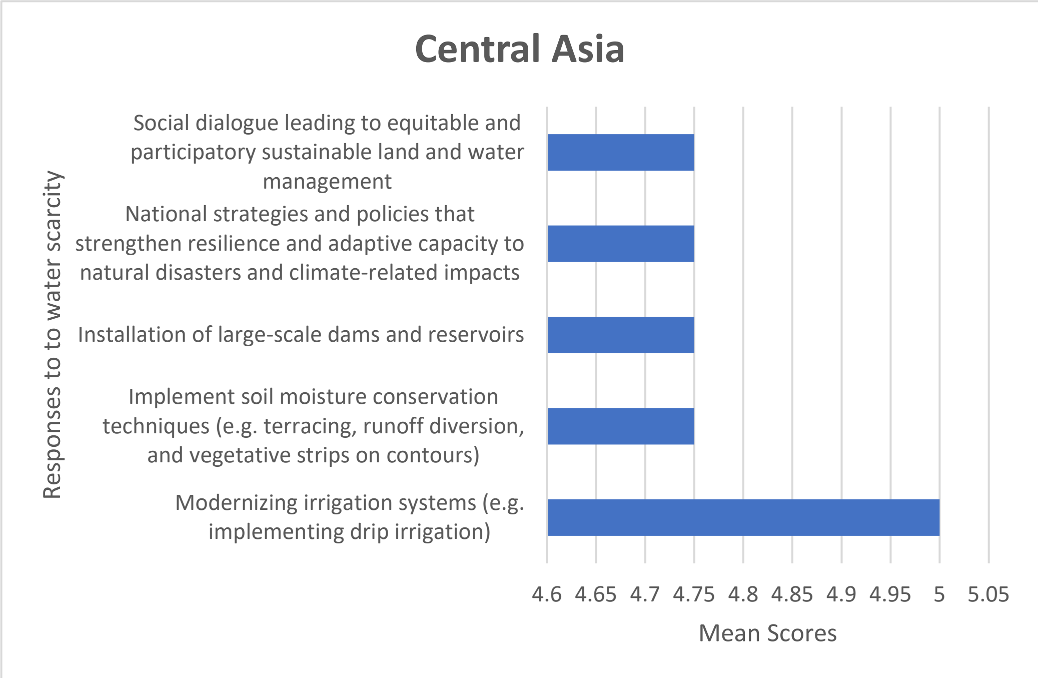
Figure A6.4: Ranking of key responses to water scarcity

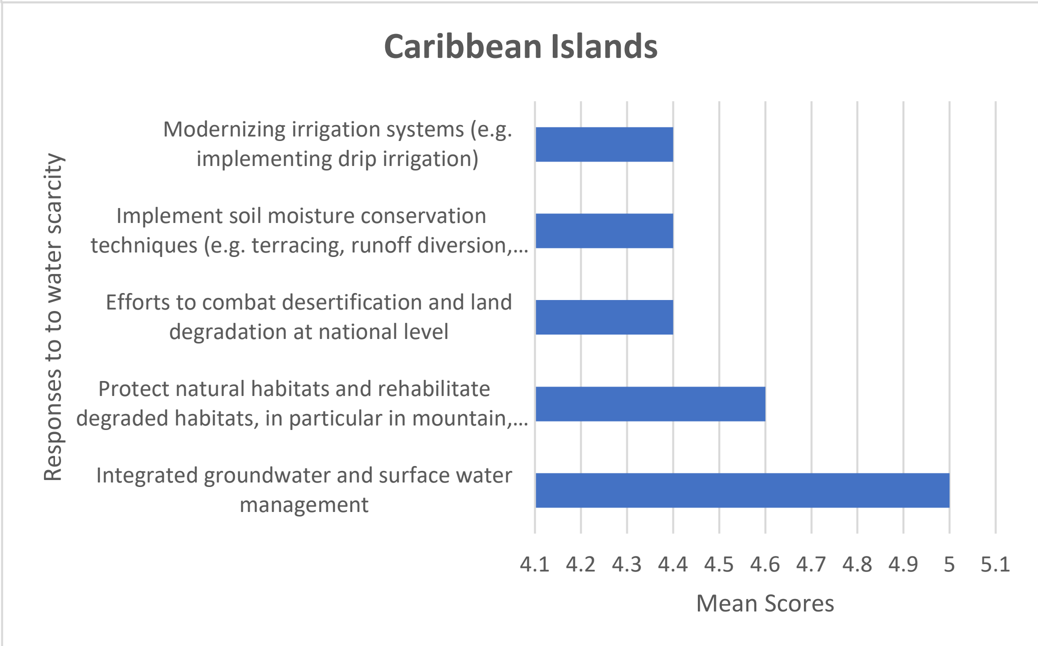





Asia and Pacific
Responses to water scarcity
Installation of large-scale dams and reservoirs
Implement soil moisture conservation techniques (e.g. terracing, runoff diversion, and vegetative strips on...
Modernizing irrigation systems (e.g. implementing drip irrigation)
Integrated groundwater and surface water management
Smallholder irrigation management
4.2 4.25 4.3 4.35 4.4 4.45 4.5 4.55 4.6 4.65
Mean Scores


Latin America
Responses to water scarcity
Integrated groundwater and surface water management
Smallholder irrigation management
Recycling and re-use of stormwater, wastewater and grey water
Installation of large-scale dams and reservoirs
Integrated approaches to improving productivity in rain-fed systems for adaptation to climate change
4.9 5 5.1 5.2 5.3 5.4 5.5 5.6 5.7
Mean Scores

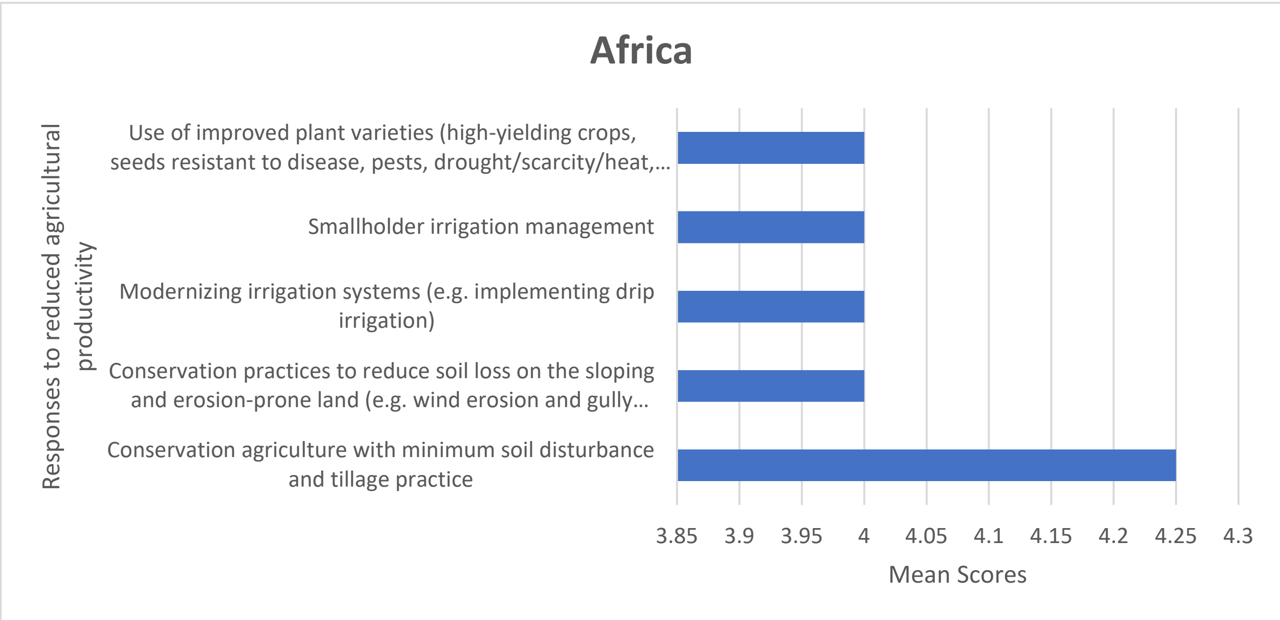


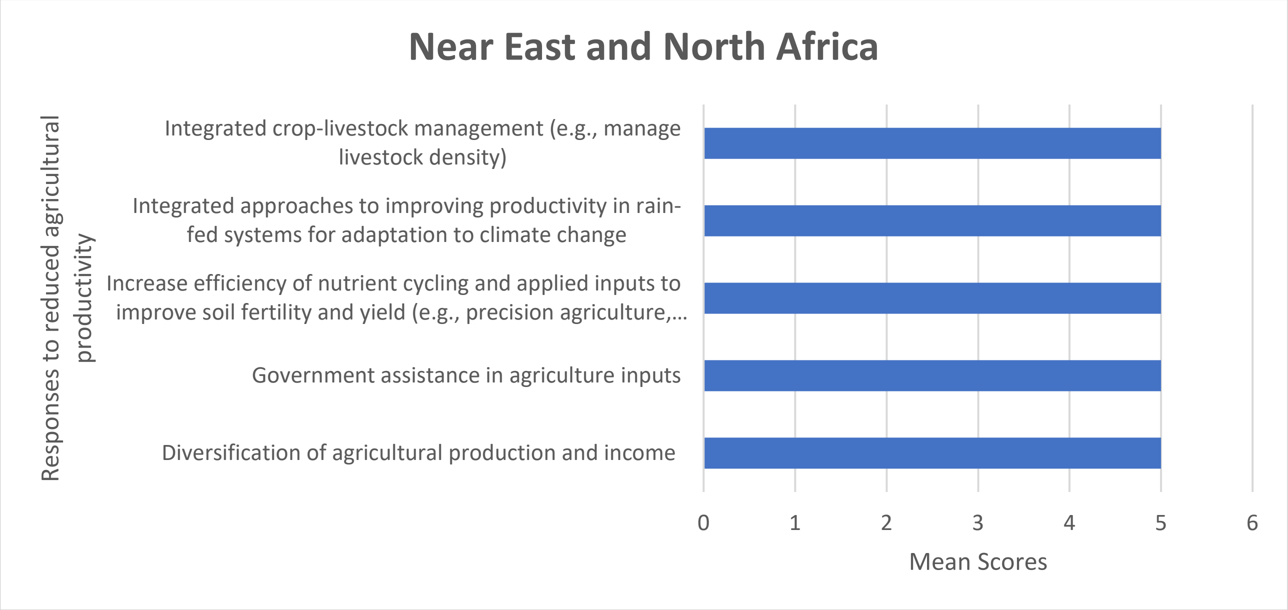


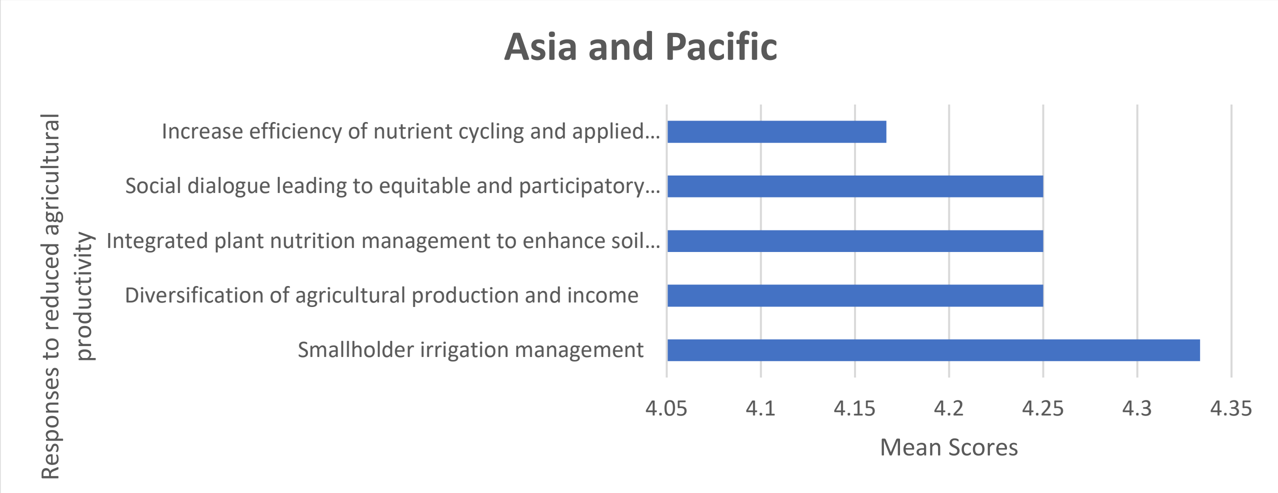
Water scarcity is an issue that has impacted on farming practices over many years, with the issue becoming more prevalent with climate-related changes that are causing more widespread and frequent droughts. The survey identified a range of options available to farmers to mitigate water scarcity problems, given that in some country's drought has always been a continuous weather pattern cycle. The Near East and North Africa have some of the driest areas in the three regions and as such, water scarcity is a problem that does not recognise national boundaries. The data demonstrate that in this region, there were three equally weighted factors that can assist in overcoming water scarcity, including installing large scale water storage systems, ensuring that ground and surface water are managed in an integrated fashion, and that small landholder embrace better irrigation management practices (rating of 5 across each category). In Africa (4.2) and the Asia-Pacific region (4.5) an integrated approach to ground and surface water management was also ranked as the second most important option for mitigating groundwater depletion. In the Asia-Pacific region, the lowest ranking was given to the installation of large-scale dams and the installation of water conservation systems both equally weighted at 4.35. In Africa, programs aimed at reducing desertification and land degradation on a national scale were given the lowest weighting (3.6) in relation to reducing water scarcity across the continent.

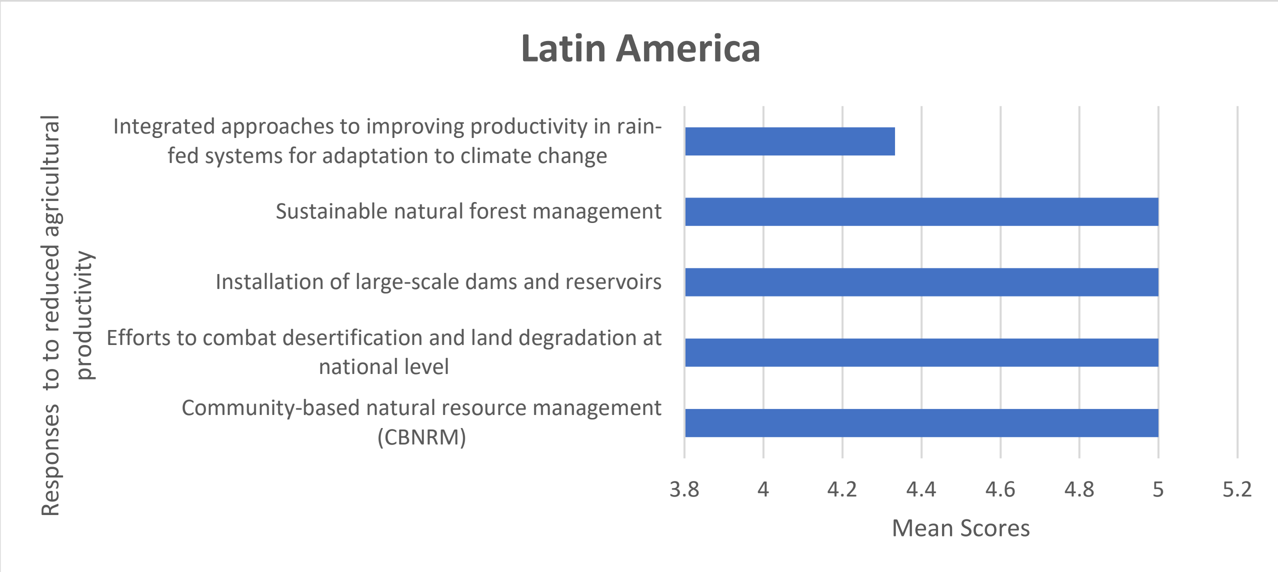
In Latin America, an integrated approach to improving productivity through rain-fed systems along with installation of large scale dams and reservoirs was the best response chosen by the respondents. In Central Asia, modernising irrigation systems was seen as the optimal way to address water scarcity with a mean score of 5, whilst in the Caribbean Islands, integrated ground and surface water management was considered the best way to address water scarcity along with the protection and rehabilitation of natural habitats. In Central Asia, respondents gave an equal weighting to four options for addressing water scarcity, including recycling of water, implementing soil moisture conservation, installing large scale dams and national strategies and policies that strengthen resilience (4.75). In the Caribbean Islands, respondents gave equal weighing to three measures to address water scarcity, including modernising irrigation systems, implementing moisture conservation techniques and combatting desertification and land degradation at a national level (4.4).

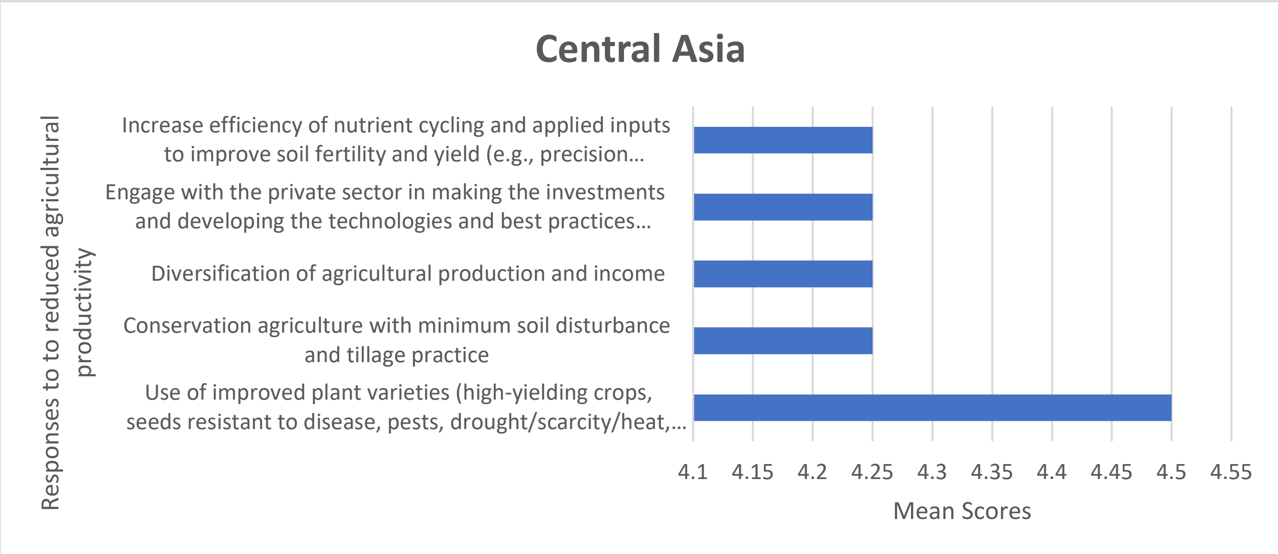
Figure A6.5: Ranking of key responses to address reduced agricultural productivity

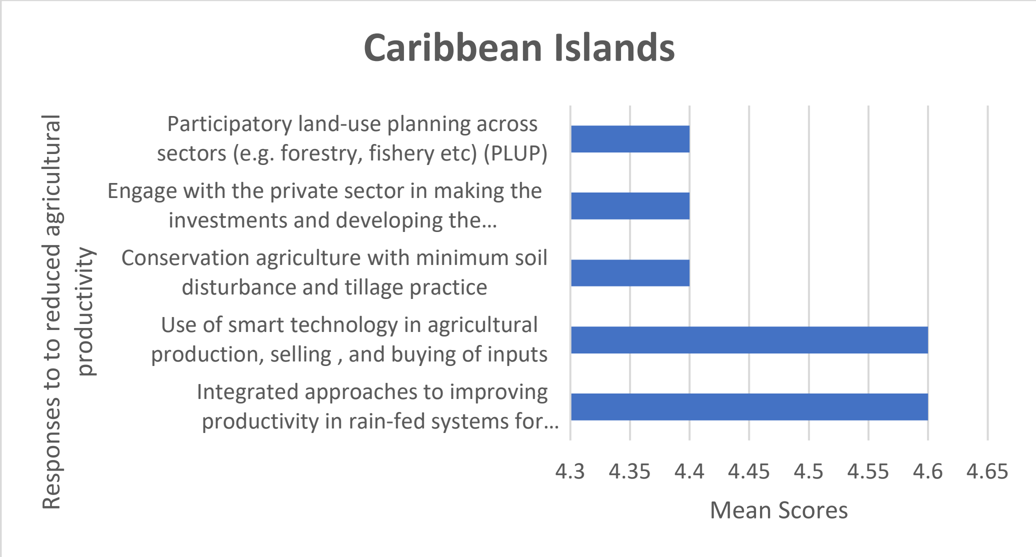



Near East and North Africa
Responses to reduced agricultural productivity
Integrated crop-livestock management (e.g., manage livestock density)
Integrated approaches to improving productivity in rain-fed systems for adaptation to climate change
Increase efficiency of nutrient cycling and applied inputs to improve soil fertility and yield (e.g., precision agriculture,...
Government assistance in agriculture inputs
Diversification of agricultural production and income
0
1
2
3
4
5
6
Mean Scores


Asia and Pacific
Responses to reduced agricultural productivity
Increase efficiency of nutrient cycling and applied...
Social dialogue leading to equitable and participatory...
Integrated plant nutrition management to enhance soil...
Diversification of agricultural production and income
Smallholder irrigation management
4.05
4.1
4.15
4.2
4.25
4.3
4.35
Mean Scores


Latin America
Responses to to reduced agricultural productivity
Integrated approaches to improving productivity in rain-fed systems for adaptation to climate change
Sustainable natural forest management
Installation of large-scale dams and reservoirs
Efforts to combat desertification and land degradation at national level
Community-based natural resource management (CBNRM)
3.8
4
4.2
4.4
4.6
4.8
5
5.2
Mean Scores

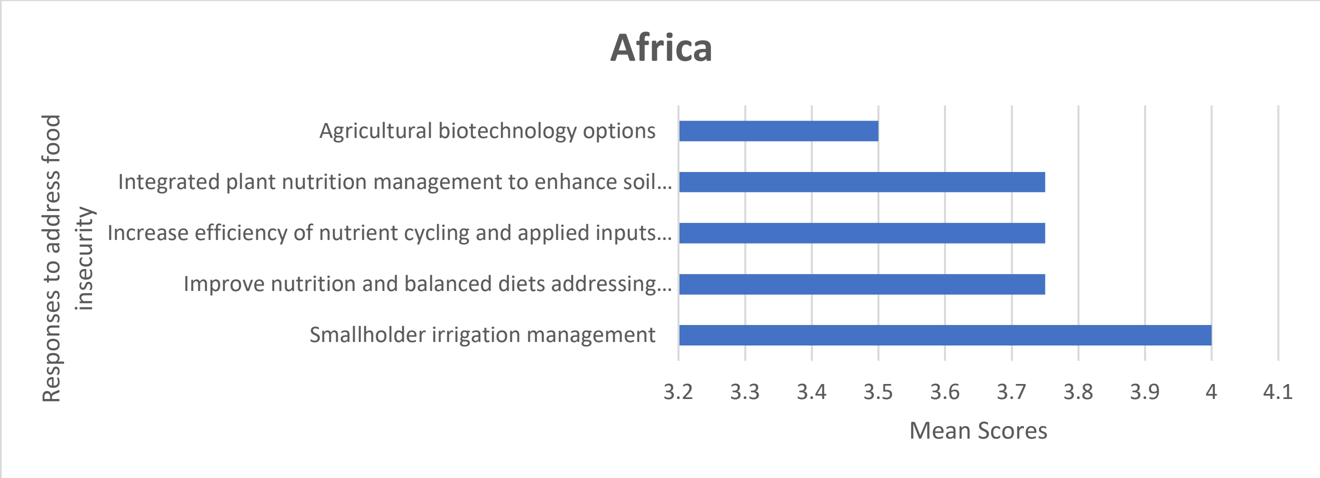

Central Asia
Responses to to reduced agricultural productivity
Increase efficiency of nutrient cycling and applied inputs to improve soil fertility and yield (e.g., precision...
Engage with the private sector in making the investments and developing the technologies and best practices...
Diversification of agricultural production and income
Conservation agriculture with minimum soil disturbance and tillage practice
Use of improved plant varieties (high-yielding crops, seeds resistant to disease, pests, drought/scarcity/heat,...
4.1
4.15
4.2
4.25
4.3
4.35
4.4
4.45
4.5
4.55
Mean Scores

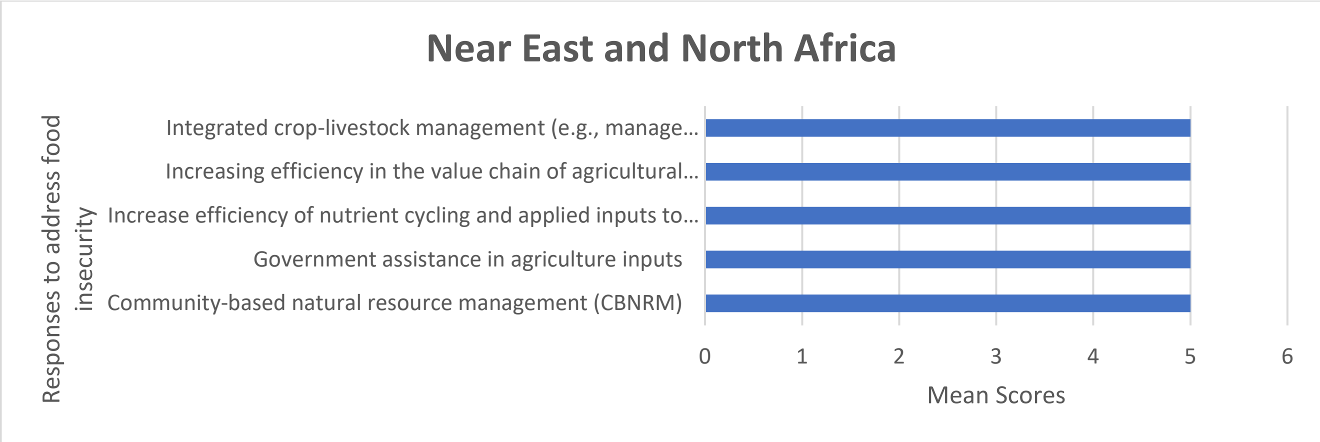


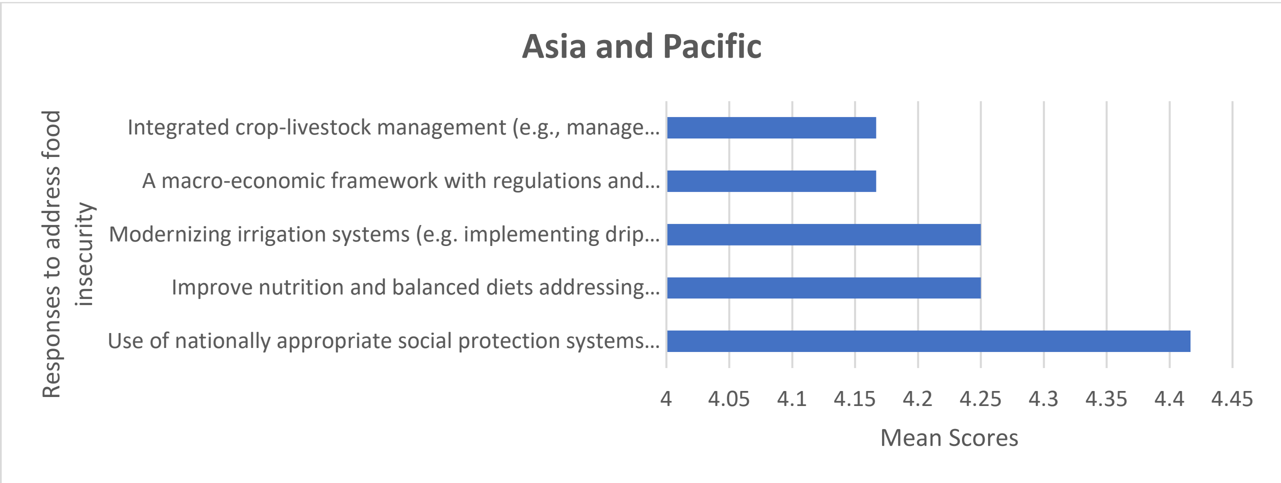
The survey data indicated that reduced agricultural productivity is a key factor affecting farming livelihoods. To boost productivity in the sector, the survey participants recognised several options available to farmers to improve output. In the Asia-Pacific region, small landholder irrigation management was identified as the best option for boosting productivity in the sector. In Africa, a more sustainable approach to farming with minimal soil tillage and disturbance was seen as a more appropriate way to boost output for the regions, farmers, particularly given the poor soil nutrition that characterises many countries on the continent. In the Near East and North Africa, equal classification was given to all options identified as boosting the productivity of farmers and included diversifying farm output, managing livestock density and improving soil fertility through better nutrient cycling, all rating 5. In Africa, an equal rating of 4 was given to a range of options to increase farm productivity, including more efficient small landholder irrigation practices, modernising irrigation systems and undertaking better conservation practices to reduce erosion. In the Asia-Pacific region, improving soil fertility through better nutrient cycling was given the lowest weighting by respondents of 4.15, with farm diversification, greater equity and participation by farmers in adopting sustainable land management practices and boosting soil productivity all given an equal ranking of 4.25 by participants. In Latin American countries, there are serval responses with equal importance that addresses the problem of reduced agricultural productivity. As agricultural productivity is caused by interconnected problems of land degradation and water scarcity, the survey suggests responses like large scale dams and reservoirs and national efforts to combat desertification, particularly in Bolivia, and complimented by community-based natural resources management, including forest management.

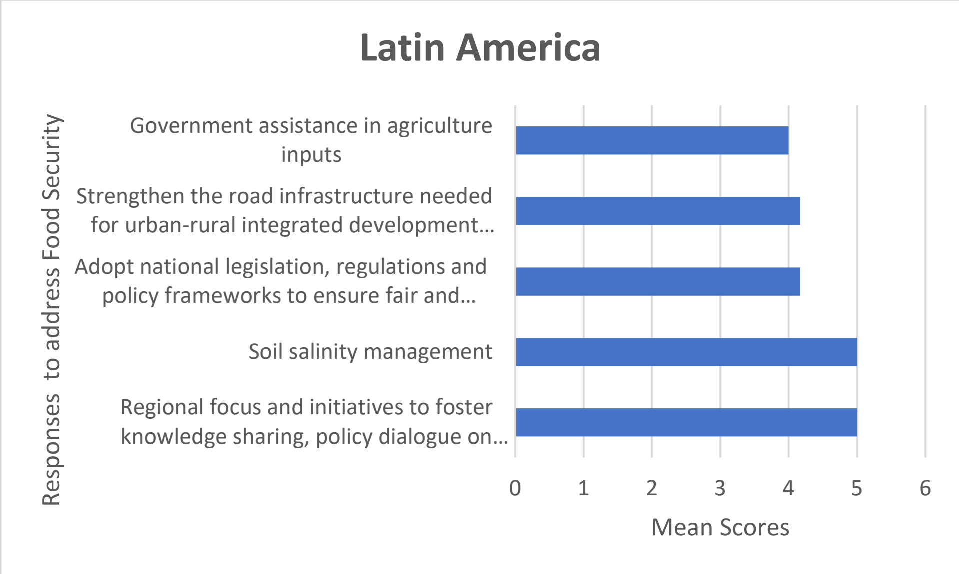
In Central Asia, use of improved plant varieties is ranked as the most significant response compared to other relevant responses like conservation agriculture. In the Caribbean Islands, the emphasis was placed on Integrated approaches to improving productivity in rain-fed systems for adaptation to climate change to increase agricultural productivity due to the dominance of rainfed agriculture in the region.

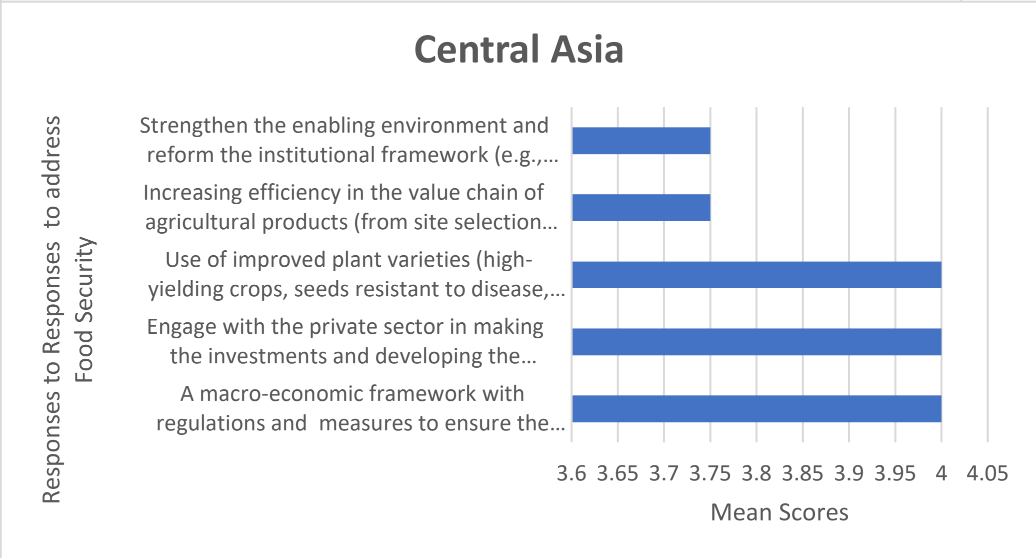
Figure A6.6: Ranking of key responses to address food insecurity

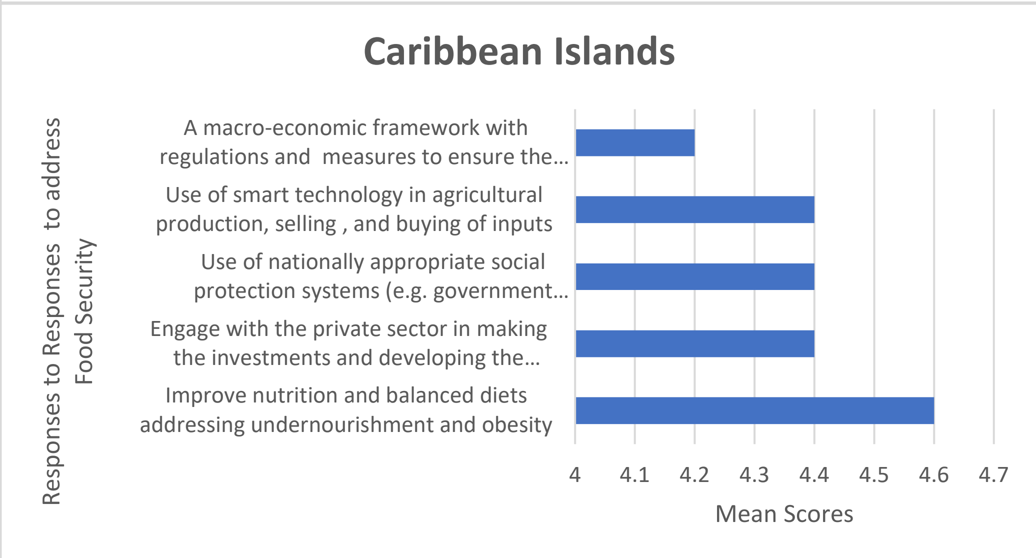

Africa
Responses to address food insecurity
Agricultural biotechnology options
Integrated plant nutrition management to enhance soil...
Increase efficiency of nutrient cycling and applied inputs...
Improve nutrition and balanced diets addressing...
Smallholder irrigation management
3.2
3.3
3.4
3.5
3.6
3.7
3.8
3.9
4
4.1
Mean Scores


Near East and North Africa
Responses to address food insecurity
Integrated crop-livestock management (e.g., manage...
Increasing efficiency in the value chain of agricultural...
Increase efficiency of nutrient cycling and applied inputs to...
Government assistance in agriculture inputs
Community-based natural resource management (CBNRM)
0
1
2
3
4
5
6
Mean Scores


Asia and Pacific
Responses to address food insecurity
Integrated crop-livestock management (e.g., manage...
A macro-economic framework with regulations and...
Modernizing irrigation systems (e.g. implementing drip...
Improve nutrition and balanced diets addressing...
Use of nationally appropriate social protection systems...
4
4.05
4.1
4.15
4.2
4.25
4.3
4.35
4.4
4.45
Mean Scores







Food insecurity is related to unsustainable agricultural practices was a problem identified in the survey across all regions. In Africa, smallholder irrigation management (4) was identified as the most appropriate response to reducing food insecurity, whilst in the Asia-Pacific region, it was the use of government safety protection systems (4.4) that were seen as providing the best option for addressing the region's food security issues. In the Near

East and North Africa, there was a range of options equally identified as increasing food security, including community-based resource management, better management of livestock and improved supply chain management in the sector including the selection of sites identified for farming. In the Asia-Pacific region, respondents identified both modernised irrigation systems and improving nutrition and diets equally for the role they can play in reducing food insecurity, with each ranking at 4.5. Likewise, in Africa, improving nutrition and balanced diets was the second-highest ranked option (3.7) for improving food security for farmers across the continent. However, it rated of equal importance with enhancing soil efficiency and improving soil fertility through better nutrient cycling. In the Asia-Pacific region, better management of livestock density and a regulated macro-economic framework to ensure better approaches to land management were given the lowest mean score rankings in the survey.

In Latin America, food insecurity is one of the growing issues and entails cooperation and initiatives at different levels, and survey ranked several key responses to address it. The responses are policy and technical at different levels. The experts focused on soil salinity management and government assistance in agricultural inputs with better road infrastructure. Such efforts also need robust policies- Legislation, regulations and policy frameworks to ensure fair and equitable sharing of benefits of genetic resources for food and agriculture. Knowledge and solutions exist in the regional, and the experts view that regional focus and initiatives to foster knowledge sharing and policy dialogue is most important to address food insecurity.

In Central Asia, we see both supply and demand management to address food insecurity. Alongside macroeconomic policies to ensure the proper functioning of food commodity markets and food safety, and higher engagement with the private sector, equal importance has been given by experts to use to the improved plant varieties to increase yield.

In the Caribbean Islands, the experts highlighted higher food consumption, obesity as well as undernourishment and calls for improving nutrition and balanced diet to address food security Engage with the private sector in making the investments and developing the technologies and best practices needed to enhance productivity, efficiency, was given importance alongside the use of national level food security program. Experts view use of smart technology in agricultural production, selling and buying of inputs at the farm level could help farmers optimise agricultural production system better.

12.7 Appendix 7: List of Responses from WOCAT data

The most frequent response from the WOCAT data was conservation practices to reduce soil loss on the sloping and erosion-prone land, with a percentage response rate of 22.38, with sustainable planted forest management the second highest response rate of 14.64%. Organic agricultural practices were the third most frequent response at 10.42%, followed by Sustainable grazing land management at 7.69%. The least frequent response rates included diversification of agricultural production and income, strengthening road infrastructure, the use of improved information systems and the use of smart technology in agricultural production, selling , and buying of inputs, all with response rates of 0.12%.

Response	Freq.	Percent
Community-based natural resource management (CBNRM)	3	0.37
Conservation agriculture with minimum soil disturbance and tillage practice	49	6.08
Conservation practices to reduce soil loss on the sloping and erosion-prone land	180	22.33
Diversification of agricultural production and income	1	0.12
Implement soil moisture conservation techniques (e.g. terracing, runoff diversion, and vegetative strips on contours)	36	4.47
Increase efficiency of nutrient cycling and applied inputs to improve soil fertility and yield (e.g., precision agriculture, adequate and balanced use of fertilizers)	23	2.85
Increasing efficiency in the value chain of agricultural products (from site selection to manufacturing processes)	3	0.37
Installation of buffers between cropland and water body	10	1.24
Integrated approaches to improving productivity in rain-fed systems for adaptation to climate change	2	0.25
Integrated crop-livestock management (e.g., manage livestock density)	30	3.72
Integrated groundwater and surface water management	26	3.23
Integrated plant nutrition management to enhance soil productivity	11	1.36
Modernizing irrigation systems (e.g. implementing drip irrigation)	13	1.61
National strategies and policies that strengthen resilience and adaptive capacity to natural disasters and climate-related impacts	5	0.62
Organic agriculture practice management	84	10.42
Recycling and re-use of stormwater, wastewater and grey water	3	0.37
Reducing the cost of energy and promoting the use of renewable sources of energy	14	1.74
Restoration and rehabilitation of degraded land	34	4.22
Rotational agriculture practice management	5	0.62
Smallholder irrigation management	51	6.33

Soil acidity control	3	0.25
Soil salinity management	3	0.37
Strengthen the road infrastructure need	1	0.12
Sustainable grazing land management	62	7.69
Sustainable natural forest management	15	1.86
Sustainable planted forest management (	118	14.64
Use of improved information systems for	1	0.12
Use of improved plant varieties (high-yielding crops, seeds resistant to disease, pests, drought/scarcity/heat, salt-tolerant crops, transgenic crops, etc.)	9	1.12
Use of smart technology in agricultural production, selling, and buying of inputs	1	0.12
Total	**806**	**100**

12.8 Appendix 8: Distribution of Case Study Countries of SLM technologies in WOCAT Database

The country with the most frequent distribution of case studies using sustainable land management technologies was Tajikistan at 112, with the frequency diminishing after this quite significantly with Kenya the second most frequently cited country at 59. This was closely followed by Ethiopia at 58. Rounding out the top ten most frequent case studies in this category were Uganda at 55, Nepal at 48, Cambodia with 37, the Philippines with 36, Senegal at 32, with Morocco and Spain both at 29. Countries with the lowest frequency of 1, included Angola, Canada, Ecuador, Egypt, Ghana, Indonesia, Iran, Pakistan, Serbia, Sweden, Ukraine and Zimbabwe.

Country	Freq
Afghanistan	18
Angola	1
Argentina	4
Armenia	2
Australia	3
Bangladesh	12
Belgium	2
Bolivia	12
Bosnia and Herzegovina	3
Botswana	5
Brazil	5

Burkina Faso	17
Burundi	6
Cambodia	37
Cameroon	3
Canada	1
Cape Verde	6
Chad	2
Chile	8
China	26
Colombia	8
Costa Rica	2
Cyprus	3
Ecuador	1
Egypt	1
Eritrea	2
Estonia	3
Ethiopia	58
France	8
Germany	8
Ghana	1
Greece	13
Haiti	10
Honduras	12
Hungary	4
Iceland	3
India	18
Indonesia	1
Iran, Islamic Republic of	1
Italy	19
Kazakhstan	9
Kenya	59
Kyrgyzstan	7

Lao People's Democratic Republic	19
Madagascar	2
Mali	21
Mauritania	2
Mexico	4
Morocco	29
Namibia	4
Nepal	48
Netherlands	9
Nicaragua	13
Niger	32
Norway	2
Oman	5
Pakistan	1
Peru	2
Philippines	36
Poland	4
Portugal	7
Romania	4
Russian Federation	8
Rwanda	4
Senegal	32
Serbia	1
Slovakia	3
Slovenia	4
South Africa	27
Spain	29
Sudan	2
Sweden	1
Switzerland	17
Syrian Arab Republic	5
Tajikistan	112

Tanzania, United Republic of	32
Thailand	9
Togo	8
Tunisia	19
Turkey	5
Turkmenistan	3
Uganda	55
Ukraine	1
United Kingdom	7
Uzbekistan	16
Viet Nam	2
Yemen	4
Zambia	4
Zimbabwe	1
Total	**1079**

12.9 Appendix 9: List of Responses from Literature review

In the table below the most frequent response by a wide margin from the literature review was organic agriculture practice management (35.81%), with the second most frequent response category being conservation practices to reduce soil loss on the sloping and erosion-prone land (15.62%). The other three categories that rounded out the top five responses were conservation agriculture with minimum soil disturbance and tillage practice

(10.86%), sustainable planted forest management (10.70%) and smallholder irrigation management (9.33%).

Response category	Freq.	Percent
Community-based natural resource management (CBNRM)	5	0.95
Conservation agriculture with minimum soil disturbance and tillage practice	57	10.86
Conservation practices to reduce soil loss on the sloping and erosion-prone land	82	15.62
Integrated plant nutrition management to enhance soil productivity	2	0.38
Modernizing irrigation systems (e.g. implementing drip irrigation)	47	8.95
Organic agriculture practice management	188	35.81
Restoration and rehabilitation of degraded land	20	3.81
Smallholder irrigation management	49	9.33
Sustainable grazing land management	1	0.19
Sustainable natural forest management	16	3.05
Sustainable planted forest management	56	10.70
Total	523	100

12.10 Appendix 10: Distribution of Case Study Countries of SLM technologies (Literature review)

The table below provides an overview by country of the number of literature review case studies looking at sustainable land management technologies. The data shows that the country with the highest frequency was the United States with 18.13% of the total, followed by India (11.89%), Canada (10.92%), Ethiopia (9.16%) and Bangladesh at 8.77% making up the top 5 countries from the literature review case studies.

Country	Freq.	Percent
Argentina	1	0.19
Australia	16	3.12
Bangladesh	45	8.77
Bhutan	20	3.9
Brazil	12	2.34
Bulgaria	1	0.19
Burkina Faso	3	0.58
Canada	56	10.92
China	34	6.63
Costa Rica	2	0.39
Croatia	2	0.39
Ethiopia	47	9.16
Europe	6	1.17
Greece	2	0.39
India	61	11.89
Ireland	12	2.34
Italy	9	1.75
Kyrgyzstan	2	0.39
Mozambique	1	0.19
Nepal	4	0.78
New Zealand	6	1.17
Nicaragua	2	0.39
Norway	4	0.78
Pakistan	6	1.17
Peru	6	1.17
Philippines	2	0.39
South Africa	3	0.58
Spain	5	0.97
Sri Lanka	1	0.19
Sudan	6	1.17

Tanzania	13	2.53
Turkey	20	3.9
UK	2	0.39
USA	93	18.13
Viet Nam	3	0.58
Zambia	3	0.58
Zimbabwe	2	0.39
Total	513	100

12.1 Appendix 11: Explanatory variables extracted from the spatial datasets and used for the statistical analyses

The table below provides an overview of the explanatory variables used in the study, with column providing the detail of the explanatory variable and where relevant the unit of measurement used.

No.	Explanatory variable	Detail	Unit
1	Air temperature	Mean annual temperature for year 2000	°C

2	Altitude	Median altitude of a grid (0.083° × 0.083°)	m
3	Argo Ecological Zone	Global Agro-Ecological Zones for assessing agricultural resources and potential and values range from 1 - 18	-
4	GDP per capita	Average gross domestic production per capita across the 26-year period of 1990-2015 in a given administrative area unit	USD
5	Human Development Index	Average achievement in key dimensions of human development across 1990-2015 in a given administrative area unit. Values range from 0 - 1	-
6	N fertiliser application	Global nitrogen fertiliser use for agriculture production in 2011	g N/m2 cropland/yr
7	P fertiliser application	Global phosphorus fertiliser use for agriculture production in 2011	g P/m2 cropland/yr
8	Population density class	Population density class in 2000 ranging from 1 - 6	-
9	Rainfall	Annual average precipitation of a grid (0.083° × 0.083°) across 1961-1990	mm
10	Ratio_P_PET	Annual average Ratio of precipitation to potential evapotranspiration of a grid (0.083° × 0.083°) across 1961-1990	-
11	Slope class	Median terrain slope class ranging from 1 - 9	-
12	Soil biodiversity	An index describing the potential level of diversity living in soils.	-
13	Soil degradation	Human-induced soil degradation rate ranging from 0 - 3	-
14	Water risk	Global water risk class (1-5, low - high)	-

12.2 Appendix 12: The new categories of variable Agro-Ecological zones

Original Agri-Ecological Zones Classification	Original group	Regrouped Agri-Ecological Zones Classification for Analysis	New group
Steep terrain	1	Steep terrain	1
Arctic/cold	2	Arctic/cold	2
Desert/arid	3	Desert/arid	3
Irrigated soils	4	Irrigated soils	4

Hydromorphic soils	5	Hydromorphic soils	5
Dry, good soils	6	Dry	6
Dry, moderate soils	7	Dry	6
Dry, poor soils	8	Dry	6
Moist, good soils	9	Moist	7
Moist, moderate soils	10	Moist	7
Moist, poor soils	11	Moist	7
Sub-humid, good soils	12	Sub-humid	8
Sub-humid, moderate soils	13	Sub-humid	8
Sub-humid, poor soils	14	Sub-humid	8
Humid, good soils	15	Humid	9
Humid, moderate soils	16	Humid	9
Humid, poor soils	17	Humid	9
Water	18	Water	10

12.3 Appendix 13: Metadata: Global Spatial Data

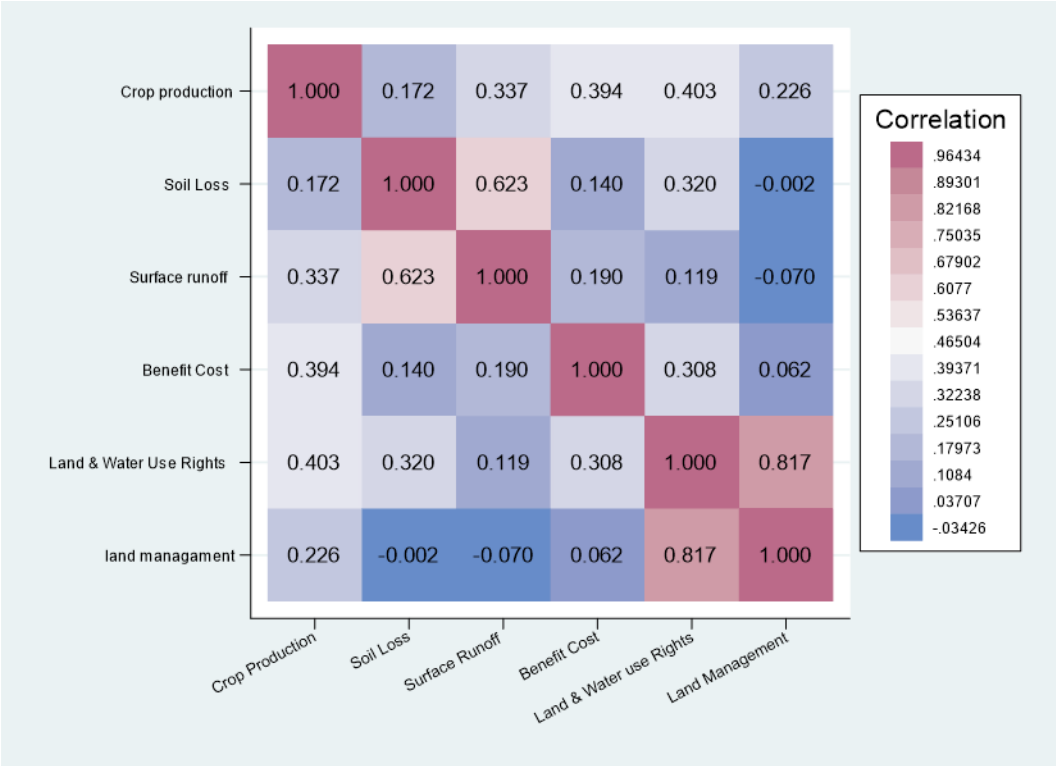
The table below provides an overview of the metadata within this project, which is the global spatial data that overlays the data sets within the project. It provides an overview of the data and the sources of that data specific to this analysis.

No.	Data and Sources
1	AQUEDUCT 2.1 and 3.0: Indicators of water quantity, water variability, water quality, public awareness of water issues, access to water, and ecosystem vulnerability.
2	ESA CCI-Land Cover: Land cover data - including projected biome change rasters by country for 2005-2011; 2005-2015; and 2011-2015.
3	FAO Global Administrative Unit Layers, 2014:
4	GDP and HDI 1990-2015 (Kummu et al., 2018): Gridded global datasets for Gross Domestic Product and Human Development Index.

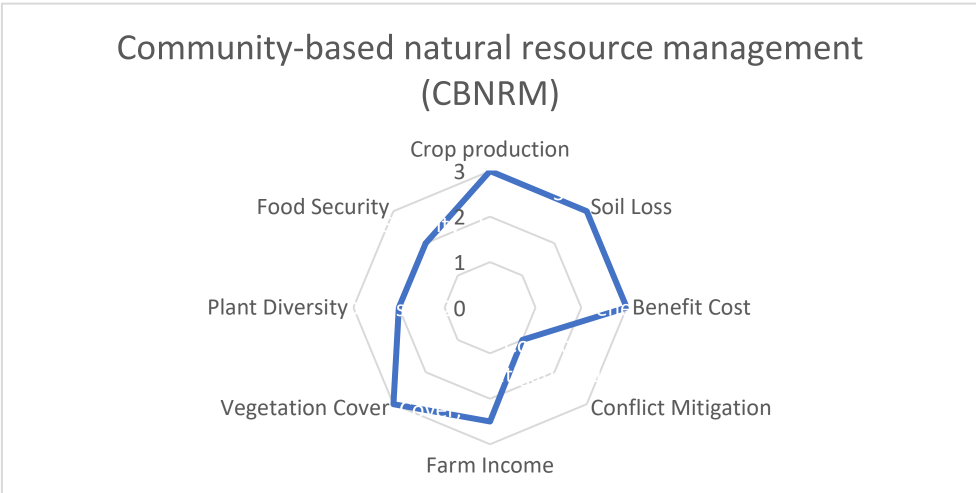
5	Global Agro-ecological Zones (GAEZ): Global Agro-Ecological Zones for assessing agricultural resources and potential -includes soil, terrain and water resource data, climate data, and agricultural production data.
6	Global Assessment of Soil Degradation (GLASOD): a world map of human-induced soil degradation.
7	Global Forest Change 2000-2019 (Hanesn et al., 2013): Annual forest loss 2000-2019 and tree cover in the year 2000.
8	Global Gridded Geo-based Economic Data (Nordhaus, 2005): One-degree cells of GDP data for the years 1990, 1995, 2000 and 2005.
9	Global N and P fertilizer use (Lu & Tian, 2016): Global nitrogen and phosphorus fertilizer use for agriculture production 1900-2013 (470MB on disk).
10	Global Soil Biodiversity Atlas (ESDAC): Soil biodiversity map and soil biodiversity threats map.
11	Global Soil Organic Carbon map (FAO): GSOCmap v1.5.0.
12	Global Surface Water (Pekel et al., 2016): High-resolution mapping of global surface water and its long-term changes 1984-2019 - includes all six sub-datasets.
13	Groundwater stress TABULAR DATA (IGRAC): GRACE-derived groundwater depletion; Groundwater withdrawal statistics; Global groundwater stress.
14	Harmonized World Soil Database: HWSD v1.2.
15	River Threat (Vorosmarty et al., 2010): Driver data for global threats to human water security and river biodiversity.
16	World Inventory of Soil Emissions (ISRIC): Harmonized global soil profile dataset – TABULAR DATABASE (Microsoft Access database) with sample sites geo-referenced with lats + longs; WISE derived soil properties 30 arc second grid MAP; Global distribution of soil phosphorus retention potential 5 arc minute grid MAP.
17	World Resource Base Map: General digital map of the world's soils.

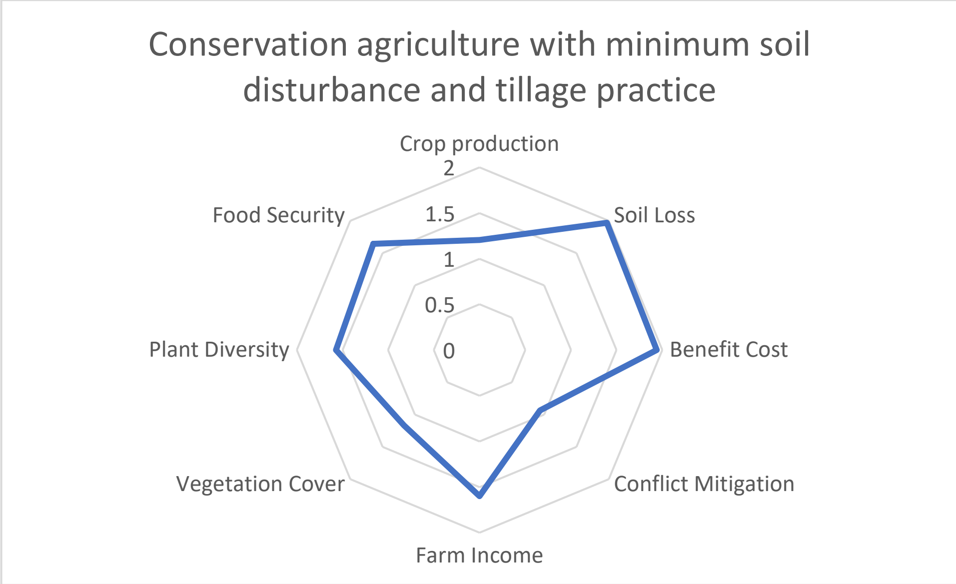
12.4 Appendix 14: Correlation Matrix of Different Impact Variables

The correlation matrix below shows a strong positive correlation between crop production and land and water use rights. There was also a strong correlation between soil loss and surface runoff, which would be expected given their close association. The strongest correlation with benefit cost was with crop production, however there was also a close positive correlation between benefit cost and land and water use rights. The strongest association with land and water use rights was with land management, where there was a near perfectly linear relationship of 0.817.

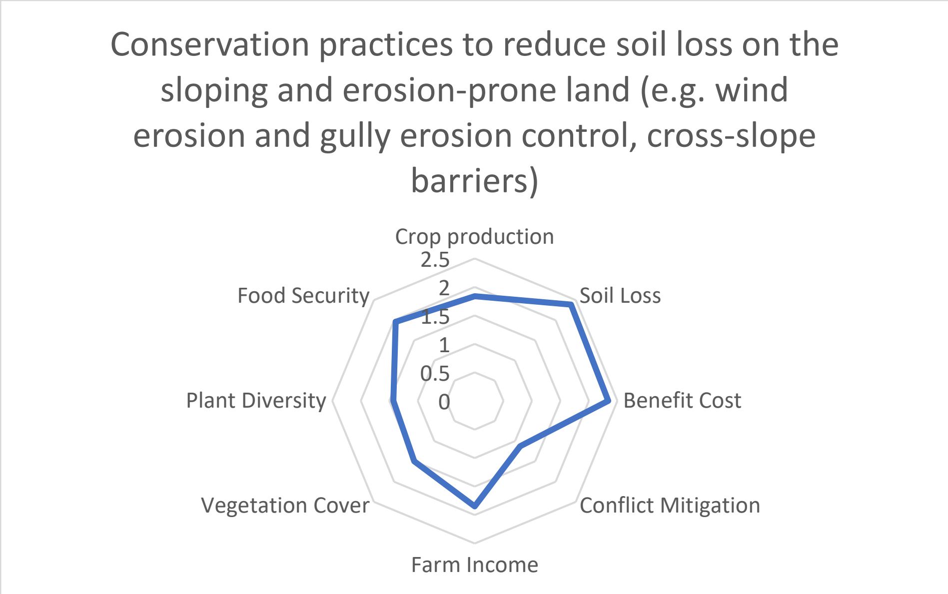


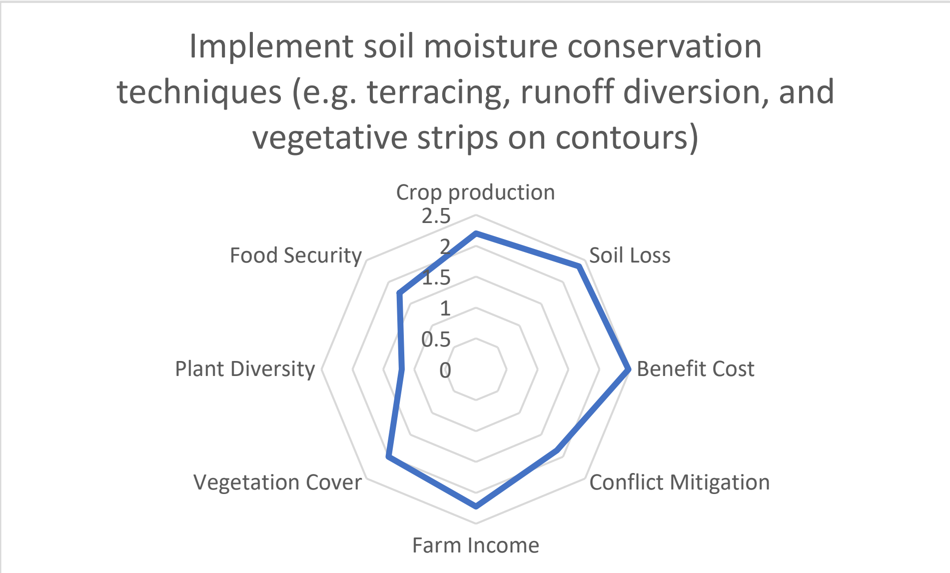
12.5 Appendix 15: Comparison of Different Impacts by Responses



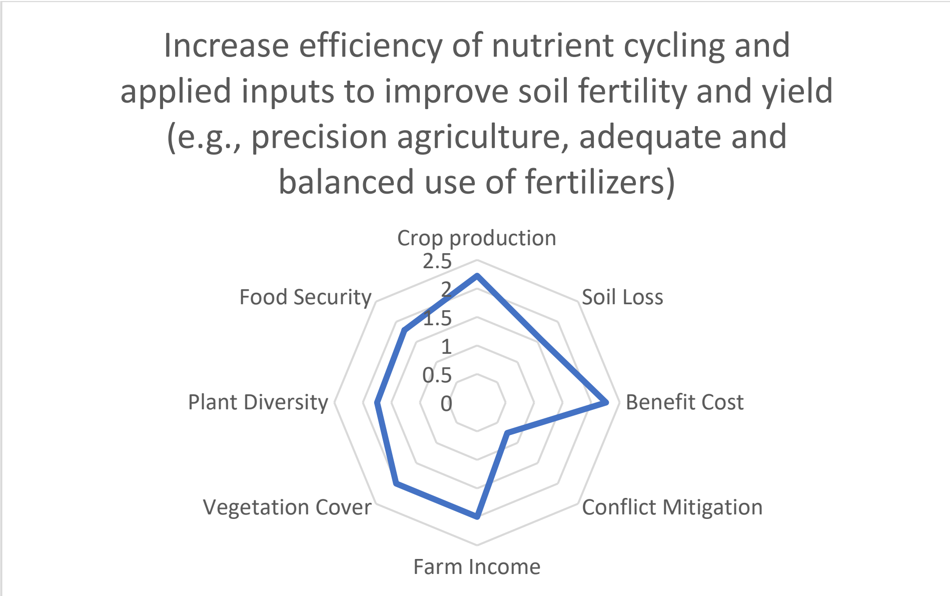


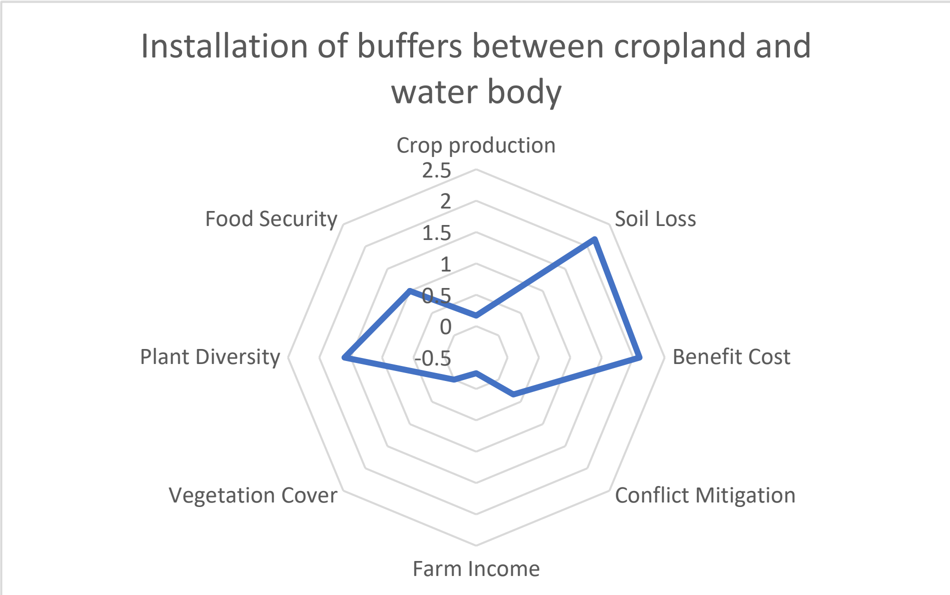
In the two figures above the data shows that for both community based natural resource management (CBNRM) and conservation agriculture with minimum soil disturbance and tillage practice (conservation agriculture) benefit cost and soil loss ranked as highly positive (2 and 3 for the respective response categories). Vegetation cover and crop cover also scored 3 for CBNRM indicating their importance for this response category. In both response categories, plant diversity and food security scored as positive by respondents at 2 for CBNRM and 1.5 for conservation agriculture. At zero there is no impact, with anything above 0.5 indicating a slightly positive impact in the response category.



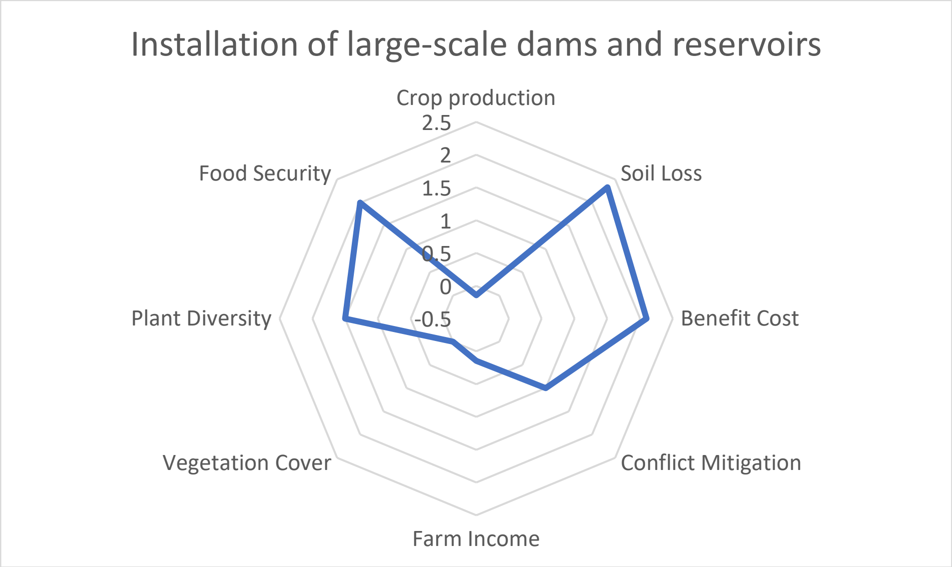


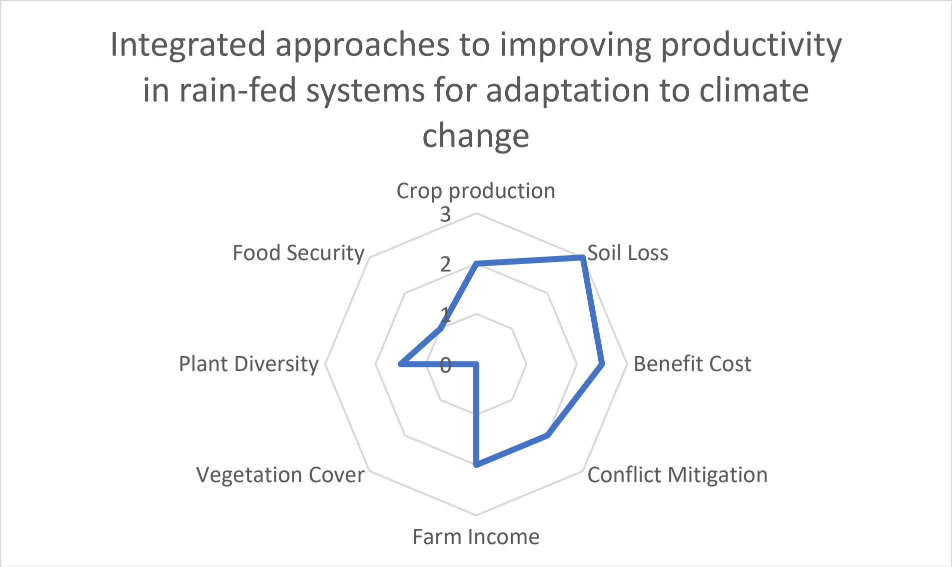
In both response categories, benefit cost and soil loss rated as highly positive, whilst farm income also scored highly positive for implementing soil conservation techniques. The remaining impacts for both response categories scored as either slightly positive, or positive by respondents.



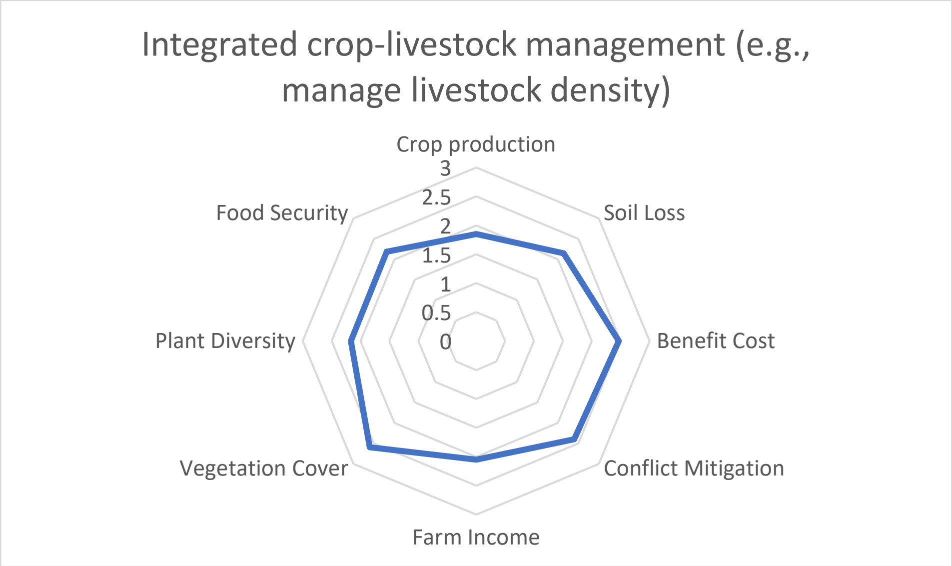


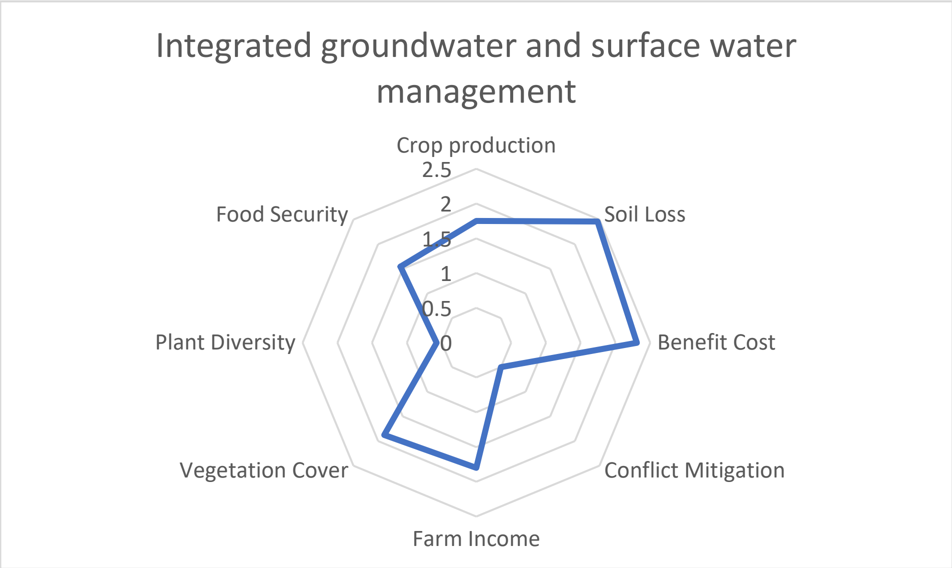
In the two categories above, benefit cost impact was rated as highly positive, or positive, with crop production also scoring as highly positive for the increase efficiency of nutrient cycling and applied inputs to improve soil fertility and yield response. The installation of buffers between cropland and water body response rated farm income as slightly negative, whilst crop production scored 0 indicating no impact.



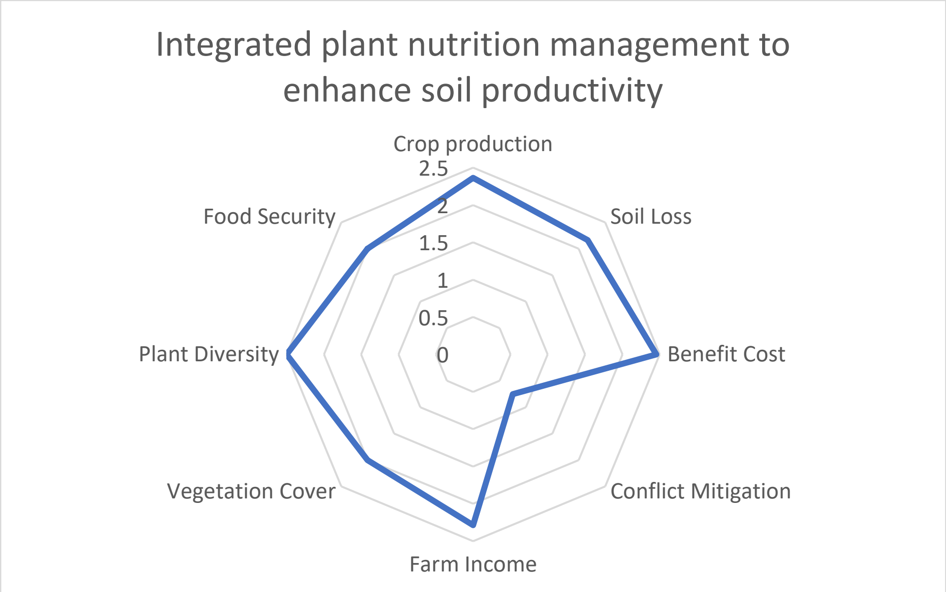


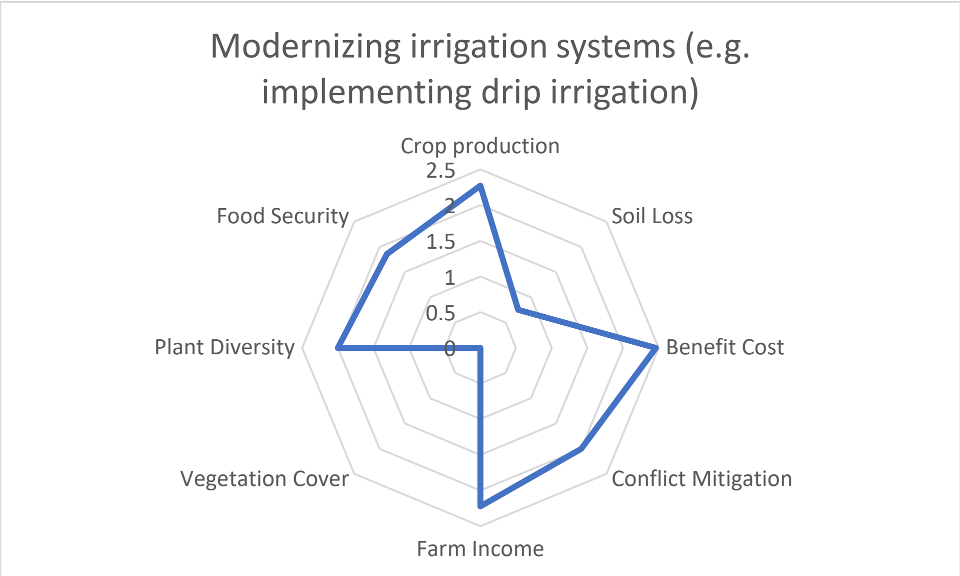
These two response categories show soil loss and benefit cost ranking as highly positive in terms of their impacts. Food security was rated as positive for installation of large-scale dams and reservoirs, with farm income, conflict management and crop production being classed as having a positive impact for the integrated approaches to improving productivity in rain-fed systems for adaptation to climate change response category.



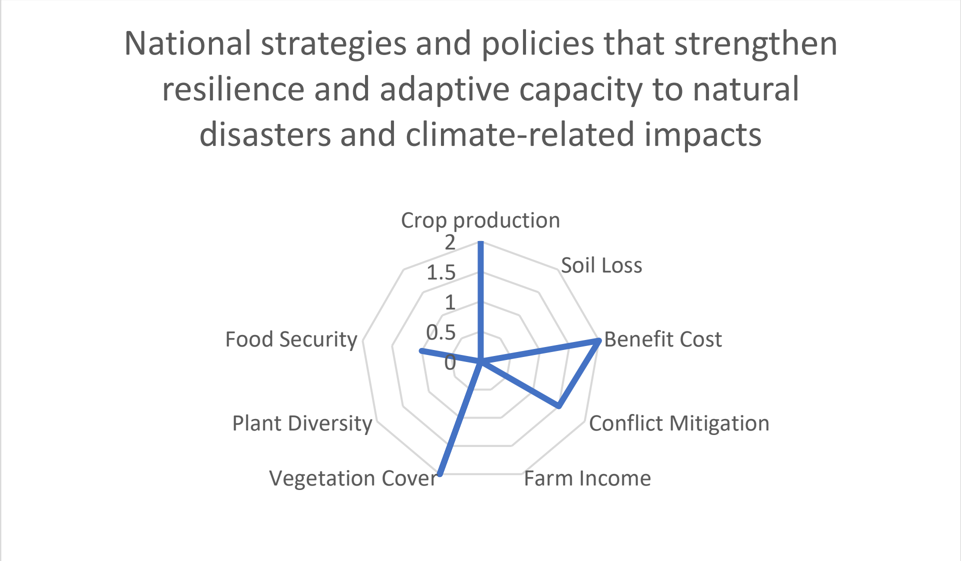


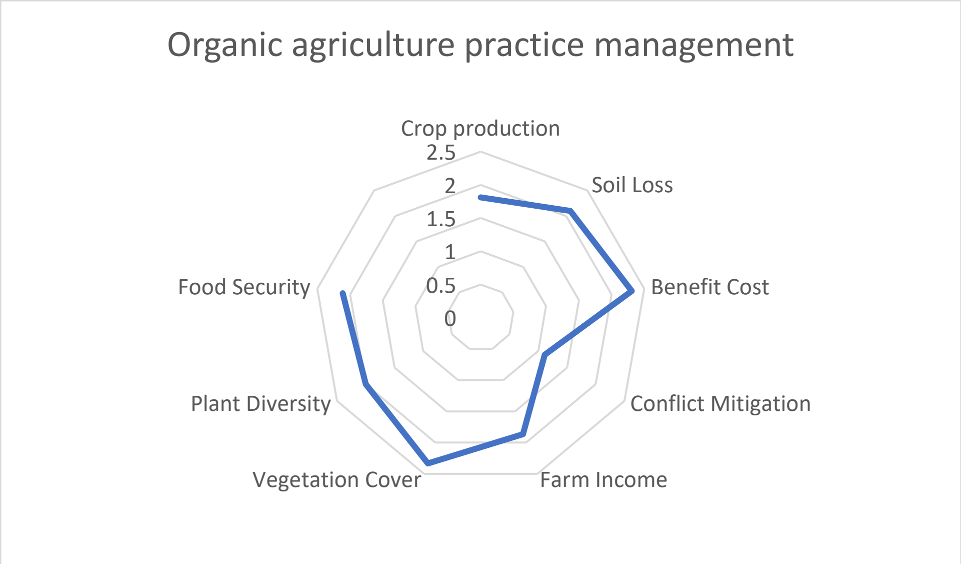
Benefit cost, vegetation cover and conflict management were rated as having positive to highly positive impacts on Integrated crop livestock management. All other impact in this category rated as either positive, or slightly positive. For the response category integrated groundwater and surface water management, soil loss and benefit cost were rated as highly positive impacts, with plant diversity essentially scoring 0 with no impact.

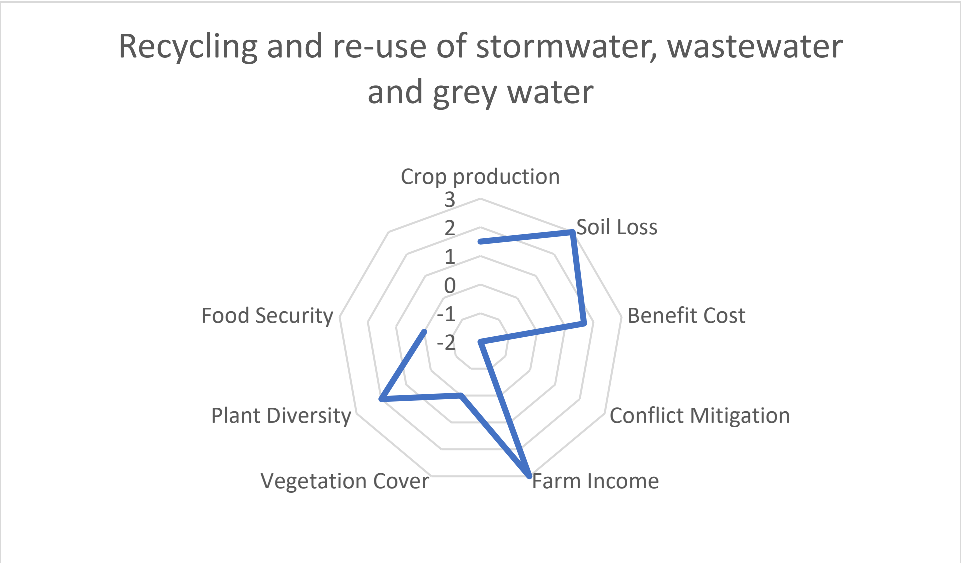


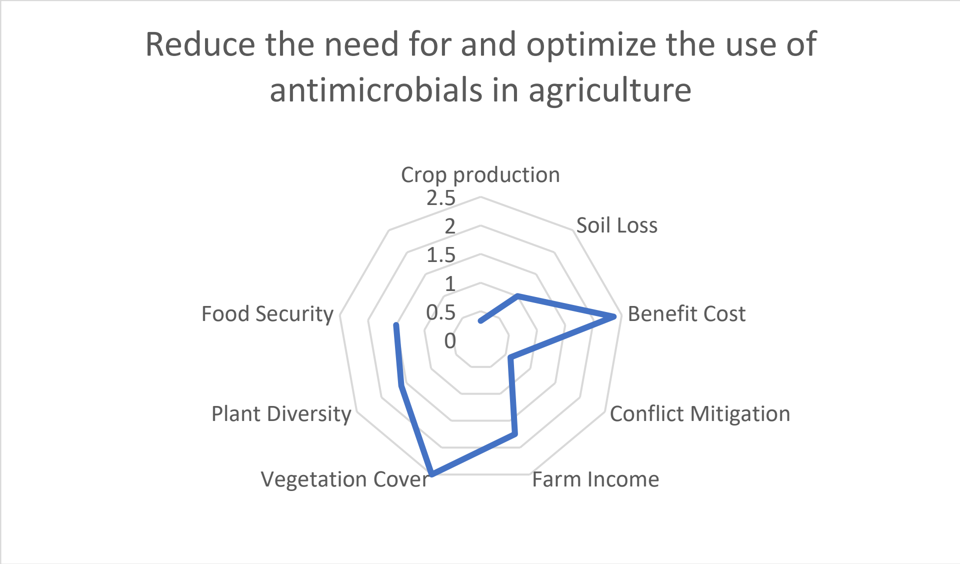


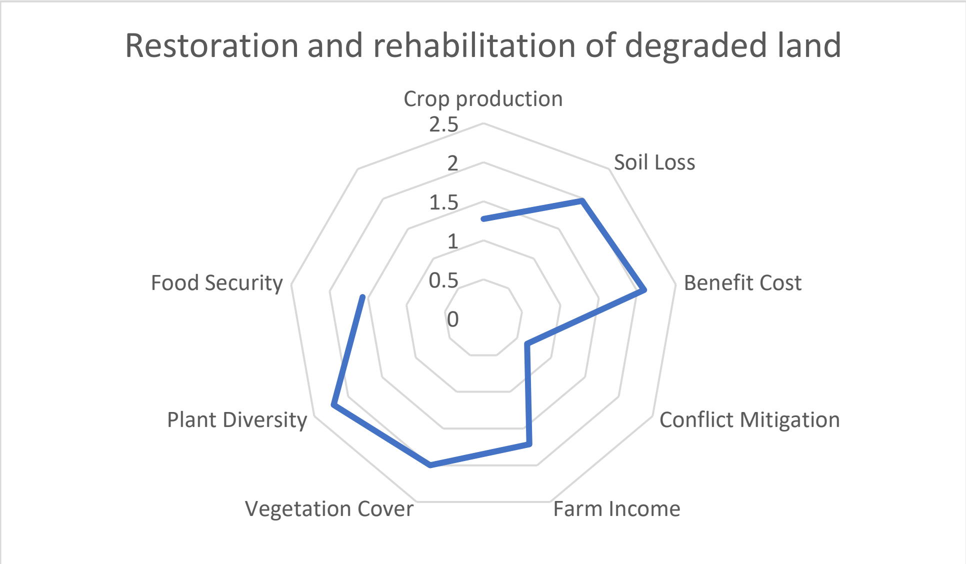
In both response categories, benefit cost, farm income and crop production rated as having highly positive impacts. In the category of integrated plant nutrition management to enhance soil productivity, plant diversity and soil loss rated as highly positive and positive in terms of their impacts. In modernizing irrigation systems vegetation cover rated 0 indicating no impact on this response category.


National strategies and policies that strengthen resilience and adaptive capacity to natural disasters and climate-related impacts
Crop production
Soil Loss
Benefit Cost
Conflict Mitigation
Farm Income
Vegetation Cover
Plant Diversity
Food Security
2
1.5
1
0.5
0

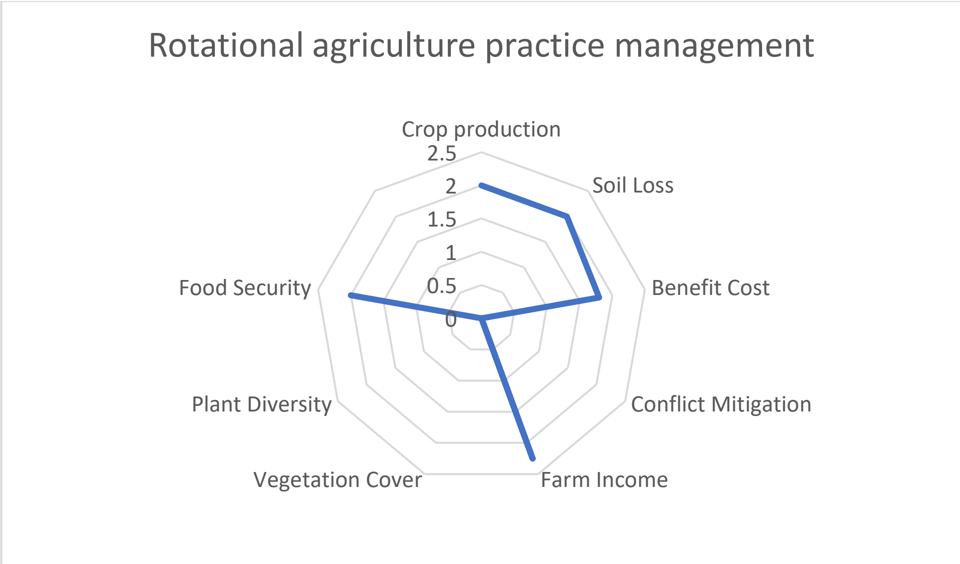

Organic agriculture practice management
Crop production
Soil Loss
Benefit Cost
Conflict Mitigation
Farm Income
Vegetation Cover
Plant Diversity
Food Security
2.5
2
1.5
1
0.5
0

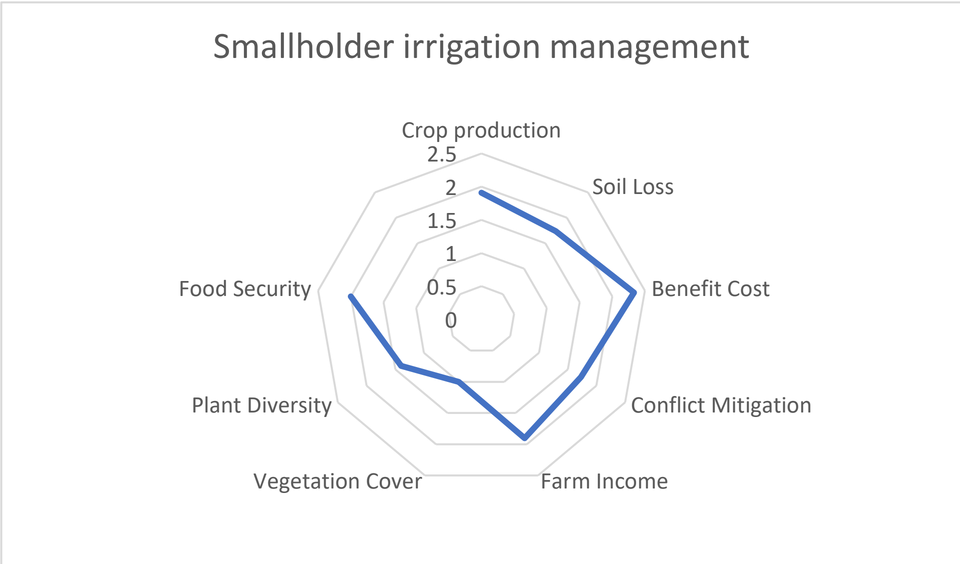

Recycling and re-use of stormwater, wastewater and grey water
Crop production
Soil Loss
Benefit Cost
Conflict Mitigation
Farm Income
Vegetation Cover
Plant Diversity
Food Security
3
2
1
0
-1
-2



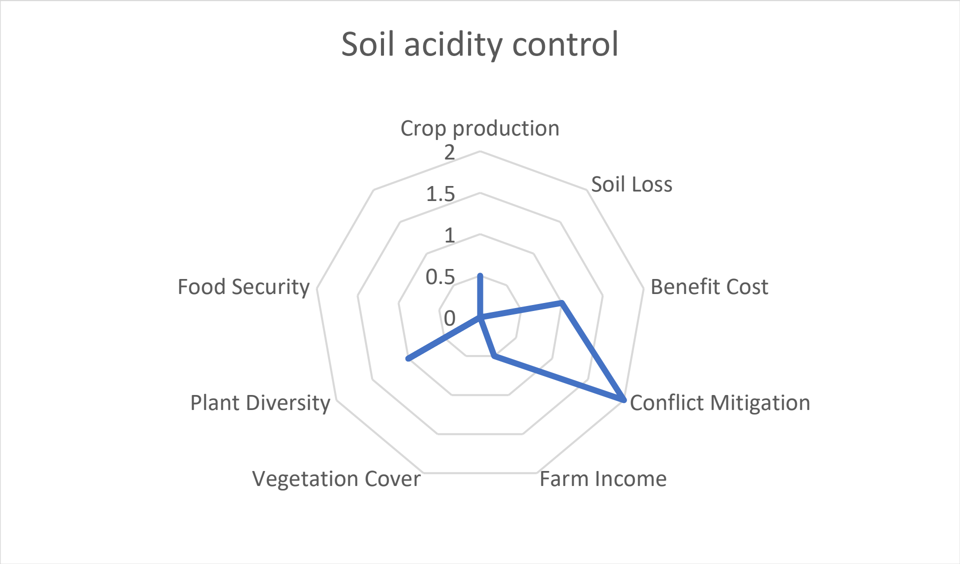


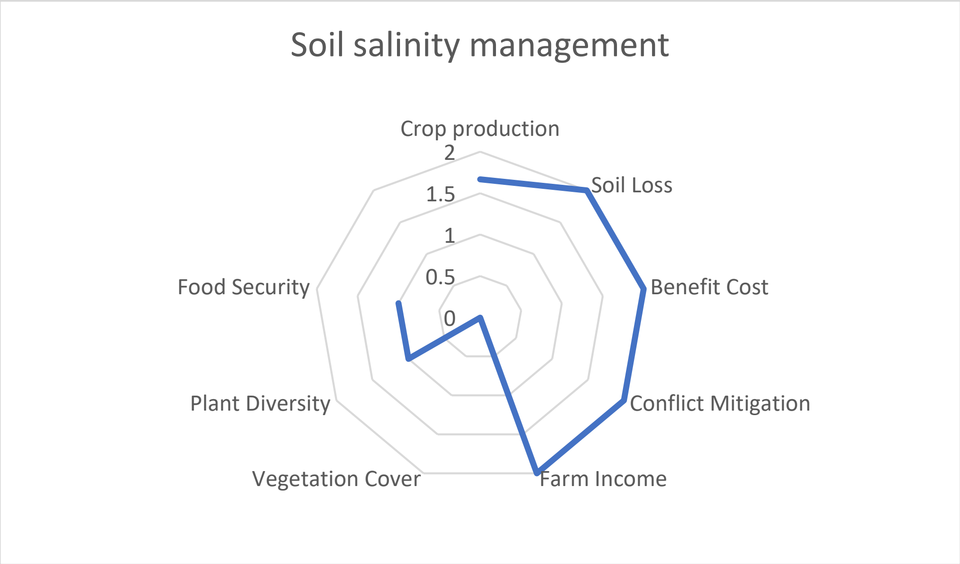
In these five responses vegetation cover scored as positive to highly positive in all categories, aside from recycling and re-use of stormwater, wastewater and grey water where it was rated as having no real impact. In all five categories, benefit cost also scored a positive, or highly positive impact again aside from recycling and re-use of stormwater, wastewater and grey water. Recycling and re-use of stormwater, wastewater and grey water was the only response category in this group where a range of impacts rated negative, including conflict management, plant diversity and vegetation cover.

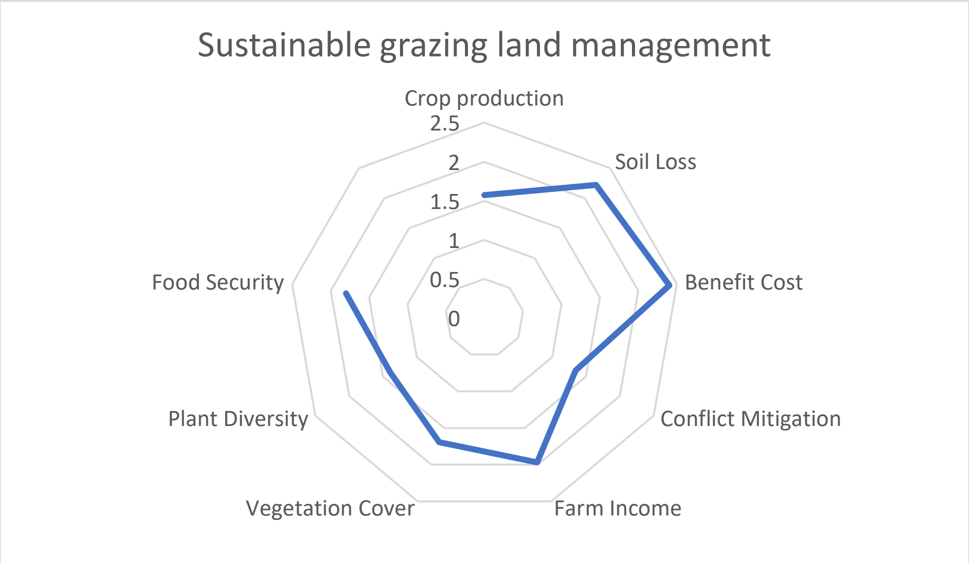


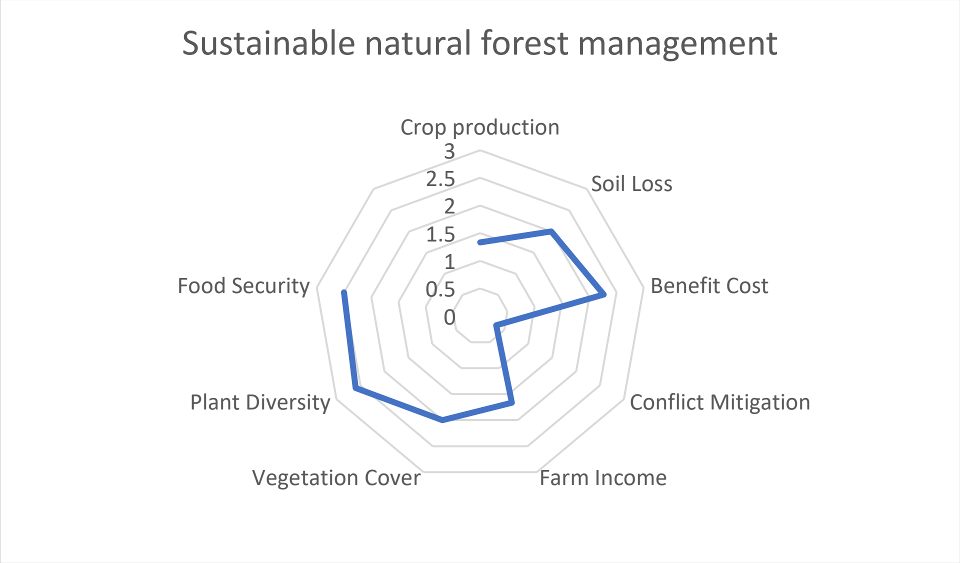


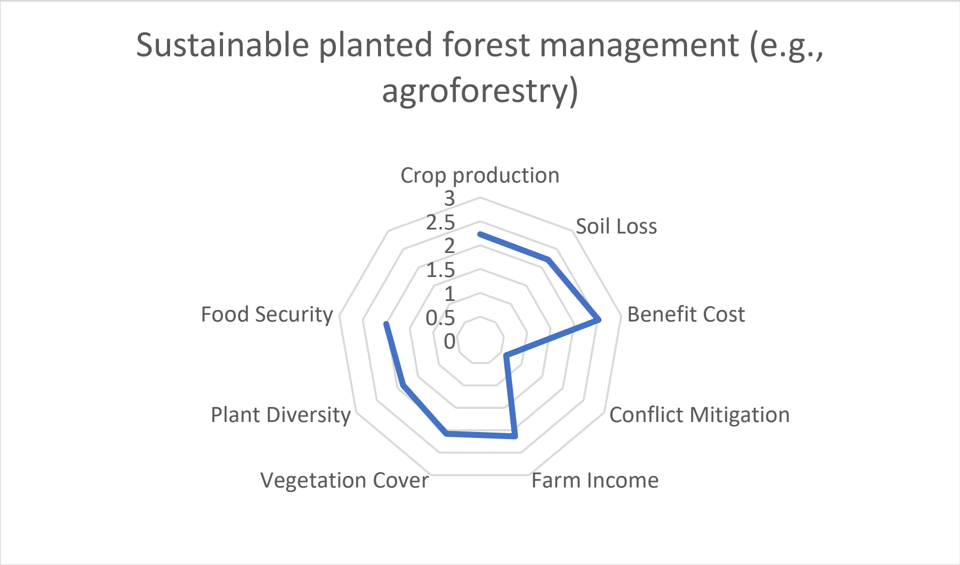
In these two response categories, the impacts with either highly positive scores included farm income for the rotational agriculture practice management response and benefit cost for smallholder irrigation management. In rotational agriculture practice management plant diversity, vegetation cover and conflict management were rated as having no impact. In smallholder irrigation management, all other impacts, aside from the two mentioned were rated from slightly positive to positive.


Soil acidity control
Crop production
Soil Loss
Benefit Cost
Conflict Mitigation
Farm Income
Vegetation Cover
Plant Diversity
Food Security
2
1.5
1
0.5
0

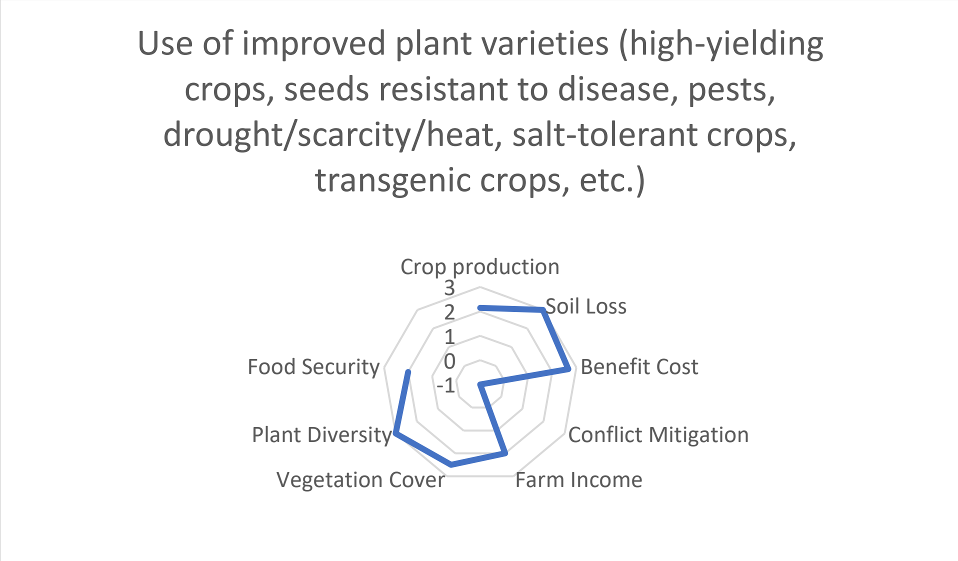

Soil salinity management
Crop production
Soil Loss
Benefit Cost
Conflict Mitigation
Farm Income
Vegetation Cover
Plant Diversity
Food Security
2
1.5
1
0.5
0

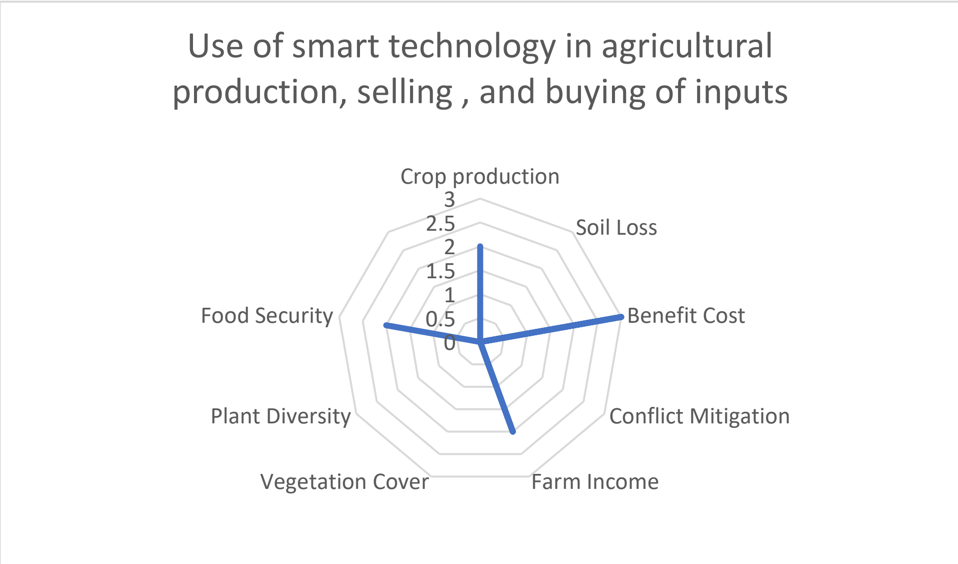

Sustainable grazing land management
Crop production
Soil Loss
Benefit Cost
Conflict Mitigation
Farm Income
Vegetation Cover
Plant Diversity
Food Security
2.5
2
1.5
1
0.5
0





In the five response categories above, aside from soil acidity control, benefit cost impacts were rated as either positive, or highly positive. In the soil salinity management response category, soil loss, conflict mitigation and farm income all rated as highly positive impacts. Conflict mitigation rated as no impact for sustainable planted forest management and sustainable natural forest management. Whilst vegetation cover scored 0 (no impact) for the soil salinity response and soil acidity control categories.

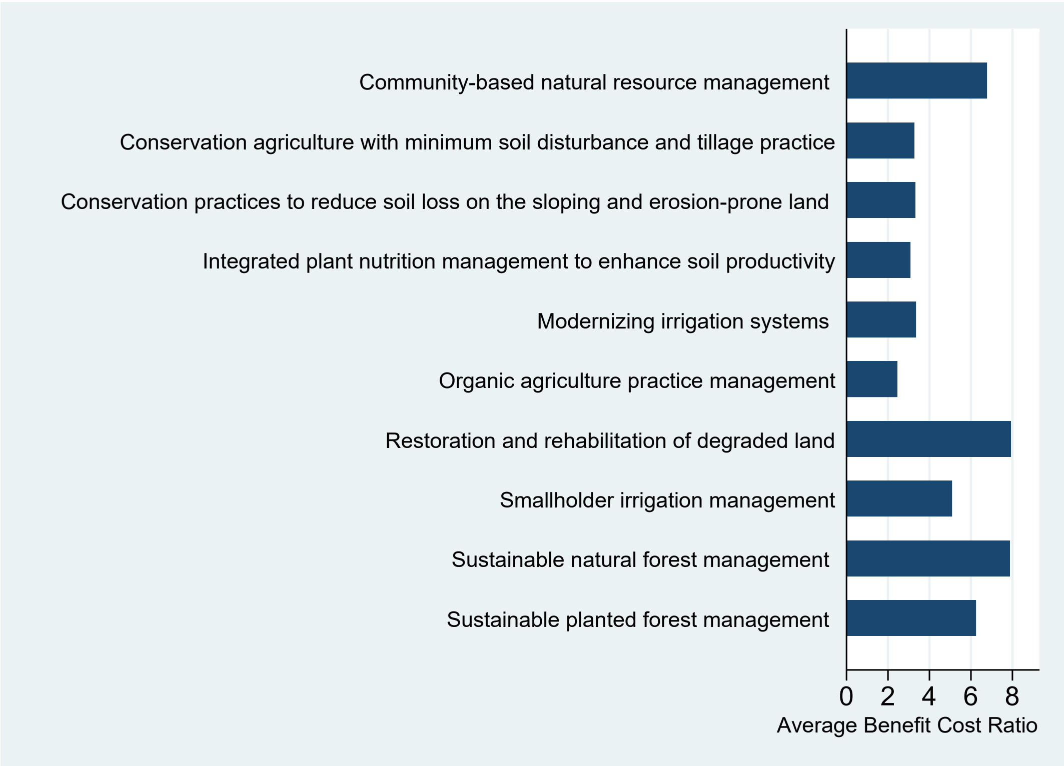




In these two response categories benefit cost impacts were rated as highly positive, with soil loss, plant diversity and vegetation cover scoring highly positive impacts in the use of improved plant varieties response. Conflict management was the only impact to rate a negative impact (-1) in the improved plant varieties category, whereas in the use of smart technology in agricultural production, selling, and buying of inputs response, it was rated as no impact (0).

12.6 Appendix 16: Average Benefit Cost ratio by Responses (From Literature review)

The figure below shows the average benefit cost ratios based on the literature review responses. The ratios for all response categories was higher than 1 indicating in all cases the benefits outweighed the costs. The ratio was highest for restoration and rehabilitation of degraded land and sustainable natural forest management with both responses scoring a ration of 8 (highly beneficial). The response category with the lowest ratio was organic agriculture practice management with a ratio of close to 3, however this still indicates the benefits far exceed the cost associated with it.



12.7 Appendix 17: Predicted probabilities of Crop production Impacts by countries

In the table below, the predicted probabilities of crop production impacts by country is most highly positive in Burundi at 0.57, followed by Colombia at 0.51, Morocco at 0.49, Uganda at 0.47 and Mexico at 0.45. The figures indicate that in all these countries there is a near, or in the case of Burundi 50% chance of an impact on crop production. There were several countries with a less than 10% chance in the highly positive crop production impact including Botswana, Estonia, Germany, Iceland, Oman and Switzerland.

Country	Highly Positive	Positive	Slightly positive	No Impact	Slightly Negative	Negative	Highly Negative
Afghanistan	0.29	0.41	0.16	0.08	0.04	0.01	0.01
Angola	0.42	0.38	0.11	0.05	0.02	0.01	0.01
Armenia	0.26	0.39	0.18	0.09	0.06	0.02	0.01
Australia	0.17	0.37	0.22	0.12	0.08	0.02	0.02
Bangladesh	0.38	0.39	0.13	0.06	0.03	0.01	0.01
Belgium	0.26	0.41	0.18	0.09	0.05	0.01	0.01
Bolivia	0.47	0.36	0.10	0.04	0.02	0.01	0.00
Bosnia and Herze	0.18	0.36	0.21	0.12	0.08	0.02	0.02
Botswana	0.09	0.27	0.24	0.18	0.14	0.04	0.04
Brazil	0.26	0.40	0.17	0.08	0.05	0.01	0.01
Burkina Faso	0.34	0.40	0.14	0.06	0.04	0.01	0.01
Burundi	0.57	0.31	0.07	0.03	0.02	0.00	0.00
Cambodia	0.41	0.38	0.12	0.05	0.03	0.01	0.01
Cameroon	0.37	0.40	0.13	0.06	0.03	0.01	0.01
Canada	0.35	0.41	0.14	0.06	0.03	0.01	0.01
Cape Verde	0.39	0.39	0.13	0.05	0.03	0.01	0.01
Chad	0.31	0.41	0.15	0.07	0.04	0.01	0.01
Chile	0.31	0.41	0.15	0.07	0.04	0.01	0.01
China	0.31	0.40	0.16	0.07	0.04	0.01	0.01
Colombia	0.51	0.34	0.09	0.03	0.02	0.00	0.00
Costa Rica	0.24	0.40	0.18	0.09	0.05	0.01	0.01
Cyprus	0.12	0.32	0.24	0.15	0.11	0.03	0.03
Egypt	0.31	0.41	0.15	0.07	0.04	0.01	0.01

Estonia	0.07	0.22	0.23	0.20	0.18	0.06	0.05
Ethiopia	0.45	0.37	0.10	0.04	0.02	0.01	0.00
France	0.16	0.36	0.22	0.13	0.09	0.02	0.02
Germany	0.08	0.24	0.23	0.19	0.16	0.05	0.04
Greece	0.30	0.40	0.16	0.07	0.04	0.01	0.01
Haiti	0.33	0.40	0.15	0.07	0.04	0.01	0.01
Honduras	0.30	0.41	0.16	0.07	0.04	0.01	0.01
Hungary	0.20	0.38	0.20	0.11	0.07	0.02	0.02
Iceland	0.06	0.21	0.22	0.20	0.19	0.07	0.06
India	0.35	0.40	0.14	0.06	0.04	0.01	0.01
Italy	0.36	0.40	0.13	0.06	0.03	0.01	0.01
Kazakhstan	0.23	0.39	0.19	0.10	0.06	0.02	0.01
Kenya	0.25	0.39	0.18	0.09	0.06	0.02	0.01
Kyrgyzstan	0.42	0.37	0.12	0.05	0.03	0.01	0.01
Lao People's Dem	0.29	0.39	0.16	0.08	0.05	0.01	0.01
Mali	0.39	0.39	0.12	0.05	0.03	0.01	0.01
Mauritania	0.41	0.38	0.12	0.05	0.03	0.01	0.01
Mexico	0.45	0.36	0.10	0.04	0.02	0.01	0.01
Morocco	0.49	0.35	0.09	0.04	0.02	0.01	0.00
Namibia	0.40	0.39	0.12	0.05	0.03	0.01	0.01
Nepal	0.26	0.40	0.18	0.09	0.05	0.01	0.01
Netherlands	0.17	0.36	0.22	0.13	0.08	0.02	0.02
Nicaragua	0.35	0.39	0.14	0.06	0.04	0.01	0.01
Niger	0.35	0.39	0.14	0.06	0.04	0.01	0.01
Norway	0.18	0.38	0.21	0.12	0.07	0.02	0.02
Oman	0.09	0.27	0.24	0.18	0.14	0.04	0.04
Pakistan	0.12	0.32	0.24	0.16	0.11	0.03	0.03
Peru	0.18	0.38	0.21	0.12	0.07	0.02	0.02
Philippines	0.43	0.37	0.11	0.05	0.03	0.01	0.01
Poland	0.28	0.41	0.17	0.08	0.05	0.01	0.01
Portugal	0.42	0.38	0.11	0.05	0.02	0.01	0.01
Romania	0.28	0.41	0.17	0.08	0.05	0.01	0.01

Russian Federation	0.23	0.40	0.19	0.10	0.06	0.02	0.01
Rwanda	0.42	0.38	0.11	0.05	0.02	0.01	0.01
Senegal	0.34	0.40	0.14	0.06	0.04	0.01	0.01
Serbia	0.19	0.38	0.21	0.11	0.07	0.02	0.02
Slovakia	0.14	0.34	0.23	0.14	0.09	0.03	0.02
Slovenia	0.14	0.33	0.23	0.15	0.10	0.03	0.02
South Africa	0.20	0.38	0.20	0.11	0.07	0.02	0.02
Spain	0.30	0.40	0.16	0.08	0.04	0.01	0.01
Switzerland	0.08	0.26	0.24	0.18	0.15	0.05	0.04
Syrian Arab Repu	0.32	0.40	0.15	0.07	0.04	0.01	0.01
Tajikistan	0.32	0.39	0.15	0.07	0.04	0.01	0.01
Tanzania	0.30	0.39	0.16	0.08	0.05	0.01	0.01
Thailand	0.43	0.38	0.11	0.04	0.02	0.01	0.00
Togo	0.31	0.41	0.15	0.07	0.04	0.01	0.01
Tunisia	0.15	0.34	0.22	0.14	0.10	0.03	0.02
Turkey	0.13	0.32	0.23	0.15	0.11	0.03	0.03
Turkmenistan	0.42	0.36	0.12	0.05	0.03	0.01	0.01
Uganda	0.47	0.36	0.10	0.04	0.02	0.01	0.00
United Kingdom	0.17	0.36	0.22	0.12	0.08	0.02	0.02
Uzbekistan	0.25	0.40	0.18	0.09	0.05	0.01	0.01
Viet Nam	0.37	0.40	0.13	0.06	0.03	0.01	0.01
Yemen	0.27	0.41	0.17	0.08	0.05	0.01	0.01
Zambia	0.31	0.41	0.15	0.07	0.04	0.01	0.01
Zimbabwe	0.13	0.34	0.23	0.15	0.10	0.03	0.02
Total	0.33	0.38	0.15	0.07	0.05	0.01	0.01

12.8 Appendix 18: Predicted probabilities of Crop production Impacts by Response

The response categories with the most highly positive probability related to crop production impacts were integrated plant nutrition management to enhance soil productivity and sustainable planted forest management (e.g., agroforestry) both with a 50% chance. The next highest response categories in this classification included implement soil moisture conservation techniques (e.g. terracing, runoff diversion, and vegetative strips on contours) at 0.42 and community-based natural resource management with a 33% chance. There were a number of response categories with the high positive probability of 0.41 including; diversification of agricultural production and income, increasing efficiency in the value chain of agricultural products (from site selection to manufacturing processes), integrated approaches to improving productivity in rain-fed systems for adaptation to climate change. It also included national strategies and policies that strengthen resilience and adaptive capacity to natural disasters and climate-related impacts, strengthening the road infrastructure needed for urban-rural integrated development and agricultural connectivity and the use of smart technology in agricultural production, selling, and buying of inputs.

Response	Highly Positive	Positive	Slightly positive	No Impact	Slightly Negative	Negative	Highly Negative
Community-based natural resource management (CBNRM)	0.33	0.40	0.15	0.07	0.04	0.01	0.01
Conservation agriculture with minimum soil disturbance and tillage practice	0.24	0.38	0.18	0.10	0.06	0.02	0.01
Conservation practices to reduce soil loss on the sloping and erosion-prone land (e.g. wind erosion and gully erosion control, cross-slope barriers)	0.31	0.39	0.16	0.08	0.05	0.01	0.01
Diversification of agricultural production and income	0.27	0.41	0.17	0.08	0.05	0.01	0.01
Implement soil moisture conservation techniques (e.g. terracing, runoff diversion, and vegetative strips on contours)	0.42	0.37	0.11	0.05	0.03	0.01	0.01
Increase efficiency of nutrient cycling and applied inputs to improve soil fertility and yield (e.g., precision agriculture, adequate and balanced use of fertilizers)	0.25	0.39	0.18	0.09	0.06	0.02	0.01
Increasing efficiency in the value chain of agricultural products (from site selection to manufacturing processes)	0.30	0.41	0.16	0.07	0.04	0.01	0.01
Installation of buffers between cropland and water body	0.24	0.39	0.18	0.10	0.06	0.02	0.01
Installation of large-scale dams and reservoirs	0.21	0.34	0.19	0.12	0.09	0.03	0.02

Integrated approaches to improving productivity in rain-fed systems for adaptation to climate change	0.27	0.41	0.17	0.08	0.05	0.01	0.01
Integrated crop-livestock management (e.g., manage livestock density)	0.31	0.39	0.16	0.08	0.05	0.01	0.01
Integrated groundwater and surface water management	0.27	0.37	0.17	0.10	0.06	0.02	0.02
Integrated plant nutrition management to enhance soil productivity	0.50	0.34	0.09	0.04	0.02	0.01	0.00
Modernizing irrigation systems (e.g. implementing drip irrigation)	0.28	0.40	0.17	0.08	0.05	0.01	0.01
National strategies and policies that strengthen resilience and adaptive capacity to natural disasters and climate-related impacts	0.27	0.41	0.17	0.08	0.05	0.01	0.01
Organic agriculture practice management	0.29	0.39	0.16	0.08	0.05	0.01	0.01
Recycling and re-use of stormwater, wastewater and grey water	0.29	0.40	0.16	0.08	0.05	0.01	0.01
Reduce the need for and optimize the use of antimicrobials in agriculture	0.28	0.38	0.16	0.09	0.06	0.02	0.01
Restoration and rehabilitation of degraded land	0.30	0.38	0.16	0.08	0.05	0.01	0.01
Rotational agriculture practice management	0.27	0.40	0.17	0.08	0.05	0.01	0.01
Smallholder irrigation management	0.29	0.39	0.16	0.08	0.05	0.01	0.01
Soil acidity control	0.15	0.35	0.23	0.13	0.09	0.03	0.02
Soil salinity management	0.13	0.30	0.23	0.16	0.12	0.04	0.03
Strengthen the road infrastructure needed for urban-rural integrated development and agricultural connectivity	0.31	0.41	0.15	0.07	0.04	0.01	0.01
Sustainable grazing land management	0.27	0.39	0.17	0.09	0.05	0.01	0.01
Sustainable natural forest management		0.40	0.15	0.07	0.04	0.01	0.01
Sustainable planted forest management (e.g., agroforestry)	0.50	0.34	0.09	0.04	0.02	0.01	0.00
Use of improved information systems for continuous monitoring of soils	0.28	0.40	0.17	0.08	0.05	0.01	0.01
Use of improved plant varieties (high-yielding crops, seeds resistant to disease, pests, drought/scarcity/heat, salt-tolerant crops, transgenic crops, etc.)	0.15	0.35	0.23	0.13	0.09	0.02	0.02

Use of smart technology in agricultural production, selling, and buying of inputs	0.31	0.41	0.15	0.07	0.04	0.01	0.01
Total	0.33	0.38	0.15	0.07	0.05	0.01	0.01

12.9 Appendix 19: Predicted probabilities of Benefit Cost Impacts by countries

The country with the most highly positive probability of benefit cost impact was Egypt at 0.67, closely followed by Burkina Faso at 0.65 and Morocco at 0.64. The predicted probability also ranked highly positive in Mali, Niger and Tajikistan all with a 63% chance, whilst Syria 0.62, Colombia and Turkmenistan (0.61), and Mauritania 0.60 rounded out the top 10 countries in the highly positive classification. Estonia and Iceland were the only two countries with a highly positive probability of less than 0.20.

Country	Highly Positive	Positive	Slightly positive	No Impact	Slightly Negative	Negative	Highly Negative
Afghanistan	0.54	0.37	0.07	0.01	0.00	0.00	0.00
Angola	0.52	0.38	0.08	0.01	0.00	0.00	0.00
Armenia	0.41	0.44	0.12	0.02	0.01	0.00	0.00
Australia	0.46	0.42	0.10	0.01	0.00	0.00	0.00
Bangladesh	0.45	0.42	0.10	0.01	0.01	0.00	0.00
Belgium	0.39	0.46	0.13	0.02	0.01	0.00	0.00
Bolivia	0.54	0.37	0.07	0.01	0.00	0.00	0.00
Bosnia and Herze	0.28	0.48	0.19	0.03	0.01	0.01	0.01
Botswana	0.24	0.49	0.21	0.03	0.01	0.01	0.01
Brazil	0.41	0.44	0.12	0.02	0.01	0.00	0.00
Burkina Faso	0.65	0.29	0.05	0.01	0.00	0.00	0.00
Burundi	0.53	0.37	0.08	0.01	0.00	0.00	0.00
Cambodia	0.49	0.40	0.09	0.01	0.00	0.00	0.00
Cameroon	0.47	0.41	0.09	0.01	0.00	0.00	0.00
Canada	0.56	0.36	0.07	0.01	0.00	0.00	0.00
Cape Verde	0.48	0.40	0.09	0.01	0.00	0.00	0.00
Chad	0.55	0.36	0.07	0.01	0.00	0.00	0.00
Chile	0.49	0.40	0.09	0.01	0.00	0.00	0.00
China	0.39	0.45	0.13	0.02	0.01	0.00	0.00
Colombia	0.61	0.32	0.06	0.01	0.00	0.00	0.00
Costa Rica	0.46	0.42	0.10	0.01	0.00	0.00	0.00
Cyprus	0.22	0.49	0.23	0.04	0.01	0.01	0.01

Egypt	0.67	0.28	0.05	0.01	0.00	0.00	0.00
Estonia	0.17	0.46	0.28	0.05	0.02	0.01	0.01
Ethiopia	0.58	0.34	0.06	0.01	0.00	0.00	0.00
France	0.27	0.49	0.19	0.03	0.01	0.01	0.01
Germany	0.31	0.48	0.17	0.02	0.01	0.00	0.00
Greece	0.38	0.46	0.13	0.02	0.01	0.00	0.00
Haiti	0.55	0.36	0.07	0.01	0.00	0.00	0.00
Honduras	0.43	0.43	0.11	0.02	0.01	0.00	0.00
Hungary	0.37	0.46	0.13	0.02	0.01	0.00	0.00
Iceland	0.15	0.45	0.30	0.06	0.02	0.01	0.01
India	0.53	0.37	0.08	0.01	0.00	0.00	0.00
Italy	0.56	0.36	0.07	0.01	0.00	0.00	0.00
Kazakhstan	0.36	0.46	0.15	0.02	0.01	0.00	0.00
Kenya	0.38	0.46	0.13	0.02	0.01	0.00	0.00
Kyrgyzstan	0.59	0.33	0.06	0.01	0.00	0.00	0.00
Lao People's Dem	0.38	0.46	0.13	0.02	0.01	0.00	0.00
Mali	0.63	0.31	0.05	0.01	0.00	0.00	0.00
Mauritania	0.60	0.32	0.06	0.01	0.00	0.00	0.00
Mexico	0.50	0.38	0.10	0.01	0.00	0.00	0.00
Morocco	0.64	0.30	0.05	0.01	0.00	0.00	0.00
Namibia	0.55	0.36	0.07	0.01	0.00	0.00	0.00
Nepal	0.47	0.41	0.10	0.01	0.00	0.00	0.00
Netherlands	0.45	0.43	0.10	0.01	0.01	0.00	0.00
Nicaragua	0.54	0.37	0.07	0.01	0.00	0.00	0.00
Niger	0.63	0.30	0.05	0.01	0.00	0.00	0.00
Norway	0.37	0.47	0.14	0.02	0.01	0.00	0.00
Oman	0.34	0.47	0.15	0.02	0.01	0.00	0.00
Pakistan	0.38	0.46	0.13	0.02	0.01	0.00	0.00
Peru	0.48	0.41	0.09	0.01	0.00	0.00	0.00
Philippines	0.38	0.45	0.13	0.02	0.01	0.00	0.00
Poland	0.44	0.43	0.11	0.01	0.01	0.00	0.00

Portugal	0.44	0.43	0.10	0.01	0.01	0.00	0.00
Romania	0.54	0.37	0.08	0.01	0.00	0.00	0.00
Russian Federati	0.46	0.42	0.10	0.01	0.00	0.00	0.00
Rwanda	0.60	0.33	0.06	0.01	0.00	0.00	0.00
Senegal	0.57	0.35	0.07	0.01	0.00	0.00	0.00
Serbia	0.38	0.46	0.13	0.02	0.01	0.00	0.00
Slovakia	0.26	0.49	0.20	0.03	0.01	0.01	0.01
Slovenia	0.20	0.48	0.25	0.04	0.02	0.01	0.01
South Africa	0.31	0.48	0.17	0.03	0.01	0.00	0.00
Spain	0.42	0.44	0.11	0.02	0.01	0.00	0.00
Switzerland	0.20	0.48	0.24	0.04	0.02	0.01	0.01
Syrian Arab Repu	0.62	0.31	0.06	0.01	0.00	0.00	0.00
Tajikistan	0.63	0.31	0.05	0.01	0.00	0.00	0.00
Tanzania	0.46	0.41	0.10	0.01	0.01	0.00	0.00
Thailand	0.51	0.39	0.08	0.01	0.00	0.00	0.00
Togo	0.51	0.39	0.08	0.01	0.00	0.00	0.00
Tunisia	0.39	0.45	0.13	0.02	0.01	0.00	0.00
Turkey	0.50	0.39	0.08	0.01	0.00	0.00	0.00
Turkmenistan	0.61	0.32	0.06	0.01	0.00	0.00	0.00
Uganda	0.57	0.35	0.07	0.01	0.00	0.00	0.00
United Kingdom	0.33	0.48	0.15	0.02	0.01	0.00	0.00
Uzbekistan	0.54	0.37	0.08	0.01	0.00	0.00	0.00
Viet Nam	0.39	0.45	0.12	0.02	0.01	0.00	0.00
Yemen	0.56	0.36	0.07	0.01	0.00	0.00	0.00
Zambia	0.52	0.39	0.08	0.01	0.00	0.00	0.00
Zimbabwe	0.37	0.46	0.13	0.02	0.01	0.00	0.00
Total	0.49	0.39	0.10	0.01	0.00	0.00	0.00

12.10 Appendix 20: Predicted probabilities of Benefit Cost Impacts by Response

In the table below the responses with the highest probability of benefit cost impacts was the use of smart technology in agricultural production, selling, and buying of inputs with a 63% probability. Sustainable planted forest management (e.g., agroforestry) also had a high probability ranking of 0.60, followed by community-based natural resource management of 0.53. The other two highly positive responses with a probability ranking above 0.50 were diversification of agricultural production and income 0.52 and smallholder irrigation management at 0.51.

Response	Highly Positive	Positive	Slightly positive	No Impact	Slightly Negative	Negative	Highly Negative
Community-based natural resource management (CBNRM)	0.53	0.36	0.08	0.01	0.00	0.00	0.00
Conservation agriculture with minimum soil disturbance and tillage practice	0.40	0.44	0.13	0.02	0.01	0.00	0.00
Conservation practices to reduce soil loss on the sloping and erosion-prone land (e.g. wind erosion and gully erosion control, cross-slope barriers)	0.48	0.40	0.10	0.01	0.01	0.00	0.00
Diversification of agricultural production and income	0.52	0.39	0.08	0.01	0.00	0.00	0.00
Implement soil moisture conservation techniques (e.g. terracing, runoff diversion, and vegetative strips on contours)	0.49	0.39	0.09	0.01	0.00	0.00	0.00
Increase efficiency of nutrient cycling and applied inputs to improve soil fertility and yield (e.g., precision agriculture, adequate and balanced use of fertilizers)	0.48	0.40	0.10	0.01	0.00	0.00	0.00
Increasing efficiency in the value chain of agricultural products (from site selection to manufacturing processes)	0.46	0.42	0.10	0.01	0.00	0.00	0.00
Installation of buffers between cropland and water body	0.42	0.44	0.12	0.02	0.01	0.00	0.00
Installation of large-scale dams and reservoirs	0.41	0.44	0.13	0.02	0.01	0.00	0.00

Integrated approaches to improving productivity in rain-fed systems for adaptation to climate change	0.37	0.47	0.14	0.02	0.01	0.00	0.00
Integrated crop-livestock management (e.g., manage livestock density)	0.50	0.39	0.09	0.01	0.00	0.00	0.00
Integrated groundwater and surface water management	0.44	0.42	0.12	0.02	0.01	0.00	0.00
Integrated plant nutrition management to enhance soil productivity	0.45	0.42	0.11	0.01	0.01	0.00	0.00
Modernizing irrigation systems (e.g. implementing drip irrigation)	0.50	0.39	0.09	0.01	0.00	0.00	0.00
National strategies and policies that strengthen resilience and adaptive capacity to natural disasters and climate-related impacts	0.50	0.39	0.09	0.01	0.00	0.00	0.00
Organic agriculture practice management	0.46	0.41	0.10	0.01	0.01	0.00	0.00
Recycling and re-use of stormwater, wastewater and grey water	0.41	0.44	0.12	0.02	0.01	0.00	0.00
Reduce the need for and optimize the use of antimicrobials in agriculture	0.44	0.42	0.11	0.02	0.01	0.00	0.00
Restoration and rehabilitation of degraded land	0.50	0.38	0.10	0.01	0.01	0.00	0.00
Rotational agriculture practice management	0.42	0.44	0.12	0.02	0.01	0.00	0.00
Smallholder irrigation management	0.51	0.38	0.09	0.01	0.00	0.00	0.00
Soil acidity control	0.32	0.46	0.17	0.03	0.01	0.00	0.00
Soil salinity management	0.37	0.46	0.13	0.02	0.01	0.00	0.00

Strengthen the road infrastructure needed for urban-rural integrated development and agricultural connectivity	0.43	0.44	0.11	0.02	0.01	0.00	0.00
Sustainable grazing land management	0.47	0.40	0.10	0.01	0.01	0.00	0.00
Sustainable natural forest management	0.49	0.39	0.09	0.01	0.00	0.00	0.00
Sustainable planted forest management (e.g., agroforestry)	0.60	0.32	0.06	0.01	0.00	0.00	0.00
Use of improved information systems for continuous monitoring of soils	0.41	0.44	0.11	0.02	0.01	0.00	0.00
Use of improved plant varieties (high-yielding crops, seeds resistant to disease, pests, drought/scarcity/heat, salt-tolerant crops, transgenic crops, etc.)	0.50	0.38	0.10	0.01	0.01	0.00	0.00
Use of smart technology in agricultural production, selling, and buying of inputs	0.63	0.30	0.05	0.01	0.00	0.00	0.00
Total	0.49	0.39	0.10	0.01	0.00	0.00	0.00

12.11 Appendix 21: Estimated Effective Response Index by Responses

The effective response index for all responses was high with a mean total of 63% across the response categories. The lowest effective response rate was soil acidity control, with an effective response index of 0.60, all other responses ranged between 0.61 and 0.63.

Responses	Effective response Index
Community-based natural resource management (CBNRM)	0.63
Conservation agriculture with minimum soil disturbance and tillage practice	0.62
Conservation practices to reduce soil loss on the sloping and erosion-prone land (e.g. wind erosion and gully erosion control, cross-slope barriers)	0.63
Diversification of agricultural production and income	0.62
Implement soil moisture conservation techniques (e.g. terracing, runoff diversion, and vegetative strips on contours)	0.65
Increase efficiency of nutrient cycling and applied inputs to improve soil fertility and yield (e.g., precision agriculture, adequate and balanced use of fertilizers)	0.62
Increasing efficiency in the value chain of agricultural products (from site selection to manufacturing processes)	0.62
Installation of buffers between cropland and water body	0.61
Installation of large-scale dams and reservoirs	0.62
Integrated approaches to improving productivity in rain-fed systems for adaptation to climate change	0.63
Integrated crop-livestock management (e.g., manage livestock density)	0.63
Integrated groundwater and surface water management	0.62
Integrated plant nutrition management to enhance soil productivity	0.67
Modernizing irrigation systems (e.g. implementing drip irrigation)	0.62
National strategies and policies that strengthen resilience and adaptive capacity to natural disasters and climate-related impacts	0.62
Organic agriculture practice management	0.62
Recycling and re-use of stormwater, wastewater and grey water	0.63
Reduce the need for and optimize the use of antimicrobials in agriculture	0.62
Restoration and rehabilitation of degraded land	0.63
Rotational agriculture practice management	0.62
Smallholder irrigation management	0.62
Soil acidity control	0.60

Soil salinity management	0.61
Strengthen the road infrastructure needed for urban-rural integrated development and agricultural connectivity	0.61
Sustainable grazing land management	0.62
Sustainable natural forest management	0.63
Sustainable planted forest management (e.g., agroforestry)	0.62
Use of improved information systems for continuous monitoring of soils	0.62
Use of improved plant varieties (high-yielding crops, seeds resistant to disease, pests, drought/scarcity/heat, salt-tolerant crops, transgenic crops, etc.)	0.63
Use of smart technology in agricultural production, selling, and buying of inputs	0.63
Total	0.63

12.12 Appendix 22: Least Squares Result

The ordinary regression result shows how different interventions can improve impacts on crop production, benefit cost, water harvest, soil loss. It shows for example that for surface water extraction, overall response interventions have positive significance for crop production, and benefit cost. Higher slope areas also have significant influence on impacts, particularly on crop production impacts.

Results show that with increase in average Ratio of precipitation to potential evapotranspiration of a grid variable, responses will have a significant negative impact on benefit cost. Also, interventions in dry soil area have negative significant impact on benefit cost.

Increasing surface water supply or the presence of large water infrastructure has negative significant relation with respect to harvesting water impact. It suggests a trade-off between large and small scale water projects. In the category of higher proportion of land degradation (80%), the impact of an intervention on soil loss will be highly negative. There are several responses which positively influence the impacts like soil moisture conservation techniques and integrated plant nutrition management on soil loss impacts.

Variable	Crop production	Benefit cost	Water harvest	Soil Loss
Surface Water Extraction	.0319***	.0170***		
Higher Slope (Dummy Variable)	.2951**			
Average gross domestic production per capita in a given administrative area unit	.0021*	0.0009		.0022**
Dry Soil (Dummy Variable)	-0.2679	-.2080*		
Annual average Ratio of precipitation to potential evapotranspiration of a grid		-.0017**		
Population density class		0.0380		0.0540
Response-Sustainable Planted Forestry Management (Dummy Variable)		.1944*		
Surface Water Supply			-.3880**	
Human-induced soil degradation rate			-.2351**	
wealth at local level			.0523**	
Response-Installation of Large-Scale dams and reservoir (Dummy Variable)			-3.7687***	
lower slope (Dummy Variable)				-.2612**
Hydromorphic soils (Dummy Variable)				-0.2169

Moist, moderate soils (Dummy Variable)				-0.6101
Sub-humid, poor soils (Dummy Variable)				-.4660*
Response-Conservation Practice to Reduce Soil Loss (Dummy Variable)				.2848**
Higher Proportion of Land Degradation (80%)				-.2448*
Groundwater Extraction				
Response-Implement Soil Moisture Conservation techniques (Dummy Variable)				
Response-Integrated plant nutrition management to enhance soil productivity (Dummy Variable)				
Arid agri ecological Zone (Dummy Variable)				
Sub-humid, moderate soils (Dummy Variable)				
Constant	.45317731*	1.6836795***	3.5858437***	1.8548074***

legend: * p<.05; ** p<.01; *** p<.001

12.13 Appendix 23: Predictive margins (average predicted probability) of Crop Production Impacts

The table below shows the average predicted probability of interventions on crop production impacts. The data below shows that in relation to crop production impacts that an intervention increases the probability from highly negative at 0.010, to positive, with a probability of 0.378, with the probability declining after this point.

		Delta-method				
	Margin	Std. Err.	z	P>z	[95% Conf.	Interval]
Highly Negative	0.010	0.004	2.250	0.024	0.001	0.019
Negative	0.012	0.005	2.470	0.014	0.003	0.022
Slightly Negative	0.045	0.009	4.840	0.000	0.027	0.063
No Impact	0.073	0.012	6.290	0.000	0.050	0.096
Slightly positive	0.148	0.016	9.350	0.000	0.117	0.178
Positive	0.378	0.022	17.430	0.000	0.336	0.421
Highly Positive	0.334	0.021	16.250	0.000	0.294	0.375

12.14 Appendix 24: Predictive margins (average predicted probability) of Benefit Cost Impacts

The table below shows the average predicted probability of interventions of benefit cost impacts. The data below shows that in relation to benefit cost impacts that an intervention increases the probability from highly negative at 0.002, to highly positive, with a probability of 0.488.

		Delta-method				
	Margin	Std. Err.	z	P>z	[95% Conf.	Interval]
Highly Negative	0.002	0.002	1.420	0.157	-0.001	0.006
Negative	0.002	0.002	1.420	0.157	-0.001	0.006
Slightly Negative	0.005	0.002	2.010	0.045	0.000	0.010
No Impact	0.014	0.004	3.350	0.001	0.006	0.022
Slightly positive	0.097	0.010	9.430	0.000	0.077	0.118
Positive	0.391	0.017	22.980	0.000	0.357	0.424
Highly Positive	0.488	0.017	28.740	0.000	0.455	0.522

12.15 Appendix 25: Predictive margins (average predicted probability) of Water harvesting Impact

The table below shows the average predicted probability of interventions of water harvesting impacts. The data below shows that in relation to water harvesting impacts that an intervention increases the probability from negative at 0.009, to highly positive, with a probability of 0.448.

		Delta-method				
	Margin	Std. Err.	z	P>z	[95% Conf.	Interval]
Negative	0.009	0.009	1.010	0.313	-0.009	0.027
No Impact	0.037	0.018	2.070	0.038	0.002	0.073
Slightly positive	0.152	0.033	4.560	0.000	0.087	0.218
Positive	0.352	0.045	7.850	0.000	0.264	0.440
Highly Positive	0.448	0.043	10.470	0.000	0.364	0.532

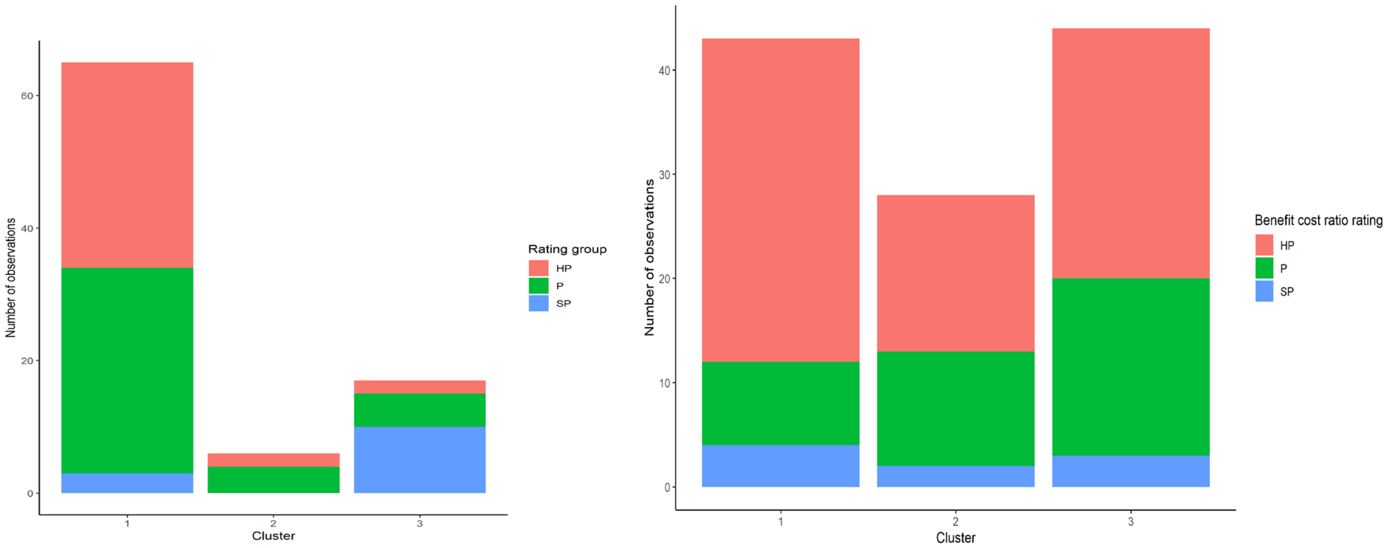
12.16 Appendix 26: Predictive margins (average predicted probability) of Soil loss Impacts

The table below shows the average predicted probability of interventions on soil loss impacts. The data below shows that in relation to soil loss impacts that an intervention increases the probability from highly negative at 0.002, to highly positive, with a probability of 0.429.

		Delta-method				
	Margin	Std. Err.	z	P>z	[95% Conf.	Interval]
Highly Negative	0.002	0.002	1.000	0.316	-0.002	0.007
Negative	0.002	0.002	1.000	0.316	-0.002	0.007
Slightly Negative	0.007	0.004	1.740	0.082	-0.001	0.014
No Impact	0.035	0.009	4.110	0.000	0.019	0.052
Slightly positive	0.134	0.016	8.490	0.000	0.103	0.164
Positive	0.390	0.023	17.050	0.000	0.345	0.435
Highly Positive	0.429	0.022	19.200	0.000	0.386	0.473

12.17 Appendix 27: Clustering Results

The cluster analysis results shows the benefit cost ratings of sites within each cluster group for two different responses, organic agriculture practices and sustainable planted forest management. The responses were chosen as there were sufficient observations for these two categories.



Organic Agriculture   Sustainable planted forest management

Figure A27.1: Stacked histogram of the composition of the three clusters according to benefit cost ratio rating. HP – highly positive, p – positive, and SP – slightly positive.

For the response category, organic agriculture, the number of application cases in each cluster varied significantly (n=65, 6 and 17 for Cluster 1, 2 and 3, respectively). There was no clear alignment of the three clusters with the three rating groups. The first two clusters (Cluster 1&2) were dominated by highly positive and positive, while the majority of cluster 3 was slightly positive. This means that the patterns in the variables that best distinguish three cluster groups do not distinguish from the rating of each application. It had been hoped that each cluster group would generally correspond with a single rating group.

For the sustainable planted forest management response category, the number of sites in each cluster also varied substantially (n=7, 45 and 63 for Cluster 1, 2 and 3, respectively), with no clear alignment of the three clusters with the three benefit cost ratings. Cluster 2 and 3 had a similar proportion of sites with highly positive and positive ratings, and all three clusters had a small number of sites with slightly positive ratings. This indicates that the explanatory variables used to derive the three cluster groups did not distinguish from the benefit cost rating of each application.

Instead of benefit cost impact, the study has also used crop production impact to evaluate its concordance with the cluster groups. The study has not specified any particular response and combined them. This increases the degree of freedom.

Figure A27.2 shows the ‘crop Production impact ratings of sites within each cluster group. The first six clusters were dominated by sites with HP and P ratings, while cluster 7 was dominated by sites SP and SN. Therefore, it led to no clear alignment.

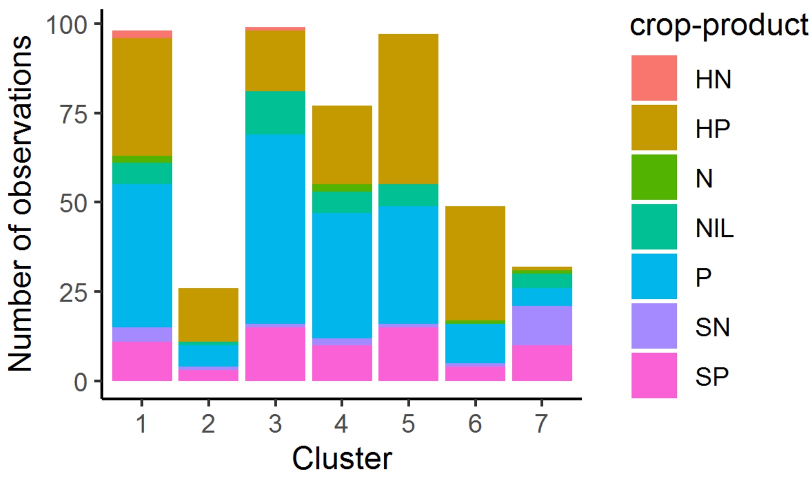


Figure A27.2: Stacked histogram of the composition of the six clusters according to crop production impact rating.

Results shows that the overall Random Forest (RF) model accuracy was 0.58 for the sustainable planted forest management and 0.56 for organic agriculture, suggesting that 58% and 56% of sites were correctly predicted by the model. The value of Cohen's Kappa is 0.16 and 0.25 for the sustainable planted forest management and organic agriculture respectively, indicating a poor agreement between the measured and predicted ratings. The confusion matrix shows that the classification error for each rating group is more than 0.25, with the error for the slightly positive group up to 1.00, meaning all 9 slightly positive sites were wrongly predicted by the RF model in the case of organic agriculture. The confusion matrix for organic agriculture shows that the classification error for each rating group is more than 0.3, with the error for the slightly positive group up to 0.77.

The prediction accuracy of the developed RF model is slightly better than random guessing but is not good enough to proceed with extrapolation to the rest of the world based on the whole spectrum of Impacts ranging from HN to HP. It will only work if the data is restricted to highly positive and positive outcomes.

Table A27.1: Confusion matrix of the developed Random Forest model prediction results for each benefit cost rating. The columns represent the predicted ratings, whilst the rows are the measured ratings.

Observed	Predicted Benefit Cost Impact in Sustainable Planted Forest Management			
	Highly positive	Positive	Slightly positive	Classification error
Highly positive	52	14	4	0.26
Positive	21	15	0	0.58
Slightly positive	9	0	0	1.00

	Predicted Benefit Cost Impact in Organic Agriculture			
Highly positive	20	13	2	0.43
Positive	10	27	3	0.33
Slightly positive	3	7	3	0.77