Agronomic constraints and implementation of good agricultural practices among smallholder rice farmers in Kimira-Oluch irrigation scheme, Kenya

Hallorine Aketch Otieno[1]
Benard Odhiambo[2]
Johnson Kwach[3]

[1]hallorine.aketch011@gmail.com

[1,2,3] Tom Mboya University, Kenya

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ABSTRACT

Rice productivity in Kenya remains below its potential despite investments in irrigation development. This study assessed agronomic challenges and implementation of Good Agricultural Practices (GAPs) among smallholder rice farmers in Kimira-Oluch Irrigation Scheme (KOIS), Homa Bay County, Kenya. The study was anchored in Agricultural Innovation Systems Theory, Diffusion of Innovations Theory, and Farming Systems Theory. A mixed-methods cross-sectional design was employed, involving 273 randomly selected farmers, 13 purposively selected key informants, and seven focus group discussions. Data were collected using structured questionnaires, key informant interviews, and focus group discussions. Quantitative data were analysed using descriptive statistics, pairwise ranking, Pearson correlation and multiple linear regression, while qualitative data were analysed thematically. Poor soil fertility emerged as the most severe constraint (mean scores: 4.09 farmers, 4.15 stakeholders), followed by limited access to certified seed (3.90, 4.15) and high input costs (3.84, 3.77). Farmers reported high implementation of routine practices such as weeding (3.93), land preparation (3.69), and timely planting (3.55), whereas technical practices including soil testing (1.04), certified seed use (1.35), and fertilizer recommendations (1.90) remained low. Agronomic challenges were significantly negatively associated with rice yield ($r = -0.257$, $p < 0.001$), while the regression model explained 15.0% of yield variation ($R^2 = 0.150$). The study concludes that poor soil fertility, limited access to certified seed and high input costs are key constraints to rice productivity in KOIS, while low implementation of technical GAPs, particularly soil testing, certified seed use, and adherence to fertilizer recommendations, limits farmers' capacity to address these challenges. Strengthening Integrated Soil Fertility Management, improving access to affordable quality inputs and enhancing extension services are essential for improving rice productivity and sustainability in KOIS.

Keywords: Certified Seed, Extension Services, Input Costs, Rice Yield, Soil Fertility, Soil Testing;

I. INTRODUCTION

Rice (*Oryza sativa* L.) is one of the world's most important food crops, providing approximately 20% of the daily caloric intake for more than half of the global population and playing a critical role in food security, nutrition, and rural livelihoods (Futakuchi et al., 2021; Saito et al., 2023). In Sub-Saharan Africa, rice consumption has increased rapidly due to population growth, urbanisation and changing dietary preferences, yet production has not kept pace with demand, resulting in continued dependence on imports (Saito et al., 2023; Balasubramanian et al., 2007). Similar trends are evident in Kenya, where rice is the third most important cereal after maize and wheat. Despite significant irrigation potential, domestic production satisfies only about 11–16% of national demand, making the country heavily reliant on imports and vulnerable to fluctuations in international markets (Ministry of Agriculture and Livestock Development, 2024; United States Department of Agriculture [USDA], 2024; Dianga et al., 2021)

To address this production deficit, the Government of Kenya, in collaboration with development partners, established irrigation schemes such as the Kimira-Oluch Irrigation Scheme (KOIS) to improve agricultural productivity, food security and household incomes (Odoyo, 2013; Onyango, 2014). However, despite investments in irrigation infrastructure and farmer support, rice productivity in KOIS remains low, averaging about 2.59 t ha^{-1} compared with the national average of 4.0 t ha^{-1} and an irrigated yield potential of approximately 8 t ha^{-1} (Dianga et al., 2021; Homa Bay County Rice Value Chain Action Plan (HBCRVCAP), 2024; Makone et al., 2020). This persistent yield gap is associated with multiple agronomic, socio-economic, institutional and environmental constraints (Atera et al., 2018; Makone et al., 2020; Wudil et al., 2023).

Good Agricultural Practices (GAPs), including improved crop establishment, balanced nutrient management, efficient water use and integrated pest and weed management, have been shown to enhance rice productivity and sustainability when appropriately implemented (Mkanthama, 2013; Senthilkumar, 2022; Tafere, 2021). Nevertheless, implementation of these practices among smallholder farmers remains constrained by limited technical knowledge, financial barriers and inadequate extension support (Oo & Usami, 2020; Awio et al., 2022; Urfels et al., 2023). Although previous studies have examined rice production challenges in Kenya, empirical information specific to Kimira-Oluch

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Irrigation Scheme remains limited. In particular, there is insufficient evidence on the agronomic constraints affecting smallholder rice farmers and the extent to which farmers implement recommended GAPs under the scheme's unique production environment. This knowledge gap limits the design of targeted extension programmes, resource allocation and evidence-based interventions for enhancing rice production.

1.1 Research Objectives

i. identify and prioritise the major agronomic challenges affecting rice productivity in KOIS;
ii. assess the extent of implementation of Good Agricultural Practices among smallholder rice farmers;
iii. determine the relationship between agronomic constraints and rice yield; and
iv. recommend evidence-based strategies for improving rice productivity in KOIS based on the study findings.

II. LITERATURE REVIEW

2.1 Theoretical Review

This study draws on three complementary theories: Agricultural Innovation Systems Theory, Diffusion of Innovations Theory, and Farming Systems Theory. Together, these theories explain how agronomic constraints, access to agricultural inputs, institutional support, and farmers' implementation of Good Agricultural Practices (GAPs) influence rice productivity among smallholder farmers in Kimira-Oluch Irrigation Scheme (KOIS).

2.1.1 Agricultural Innovation Systems Theory

Agricultural Innovation Systems (AIS) Theory views agricultural productivity as a result of interactions among farmers, researchers, extension officers, government institutions, input suppliers and markets. Effective collaboration among these stakeholders facilitates access to improved technologies, quality inputs and technical knowledge (World Bank, 2012; Klerkx & Begemann, 2020). In rice production, weak institutional linkages, inadequate extension services and unreliable input supplies can limit farmers' implementation of recommended agronomic practices. This theory is relevant to this study because it helps explain how institutional support, farmer training and access to agricultural inputs influence GAP implementation and rice productivity in KOIS.

2.1.2 Diffusion of Innovations Theory

Diffusion of Innovations Theory, developed by Rogers (2003), explains how new technologies and practices spread among individuals and communities. Adoption depends on perceived benefits, compatibility with existing farming systems, complexity, opportunities for trial, and visibility of results. In rice farming, innovations include certified seed, soil testing, appropriate fertilizer application, correct crop spacing, and integrated pest management. Adoption may be limited by high input costs, inadequate technical knowledge, and limited access to extension services. Studies indicate that improved agronomic practices can increase rice yields, although their adoption depends on farmers' resources and production conditions (Arouna et al., 2017; Awio et al., 2022; Senthilkumar, 2022). This theory therefore helps explain variations in GAP implementation among farmers in KOIS.

2.1.3 Farming Systems Theory

Farming Systems Theory conceptualizes agricultural production as an interconnected system in which agronomic factors input costs, markets and institutional support interact to influence farm performance. It emphasizes the need to address interrelated production constraints rather than treating them as isolated problems**.** In rice production, agronomic challenges, institutional factors, input access and limited financial resources may jointly reduce yields. Integrated Soil Fertility Management (ISFM), which combines mineral fertilizers, organic nutrient sources, improved germplasm, and locally appropriate management practices, provides an example of an integrated approach to improving productivity (Vanlauwe et al., 2019). This theory is relevant to KOIS because it supports interventions that combine good agronomic practices, input access, and effective extension services. Collectively, these theories provide a foundation for examining agronomic constraints, GAP implementation, and the influence of input access and institutional support on rice productivity in KOIS.

2.2 Empirical Review

2.2.1 Rice Production and Productivity in Sub-Saharan Africa and Kenya

Rice (Oryza sativa L.) is an important food crop that contributes to food security, nutrition, employment and rural livelihoods. Increasing population, urbanization, and changing dietary preferences have contributed to rising rice consumption in sub-Saharan Africa, placing pressure on domestic production systems (Balasubramanian et al., 2007; Saito et al., 2023). Although rice production in the region has expanded substantially, productivity remains relatively low compared with the crop's attainable yield potential. Saito et al. (2023) reported that much of the growth in African rice production has resulted from expansion of harvested area rather than substantial increases in yield. The authors

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identified suboptimal crop management, soil-related constraints, water stress, and limited use of productivity-enhancing technologies as important contributors to the yield gap.

Kenya faces similar challenges. Rice is the country's third most important cereal after maize and wheat, and production is dominated by smallholder farmers operating under irrigated and rain-fed systems. Irrigation schemes provide opportunities for improved water control and more reliable production, but yields remain constrained by agronomic management, access to quality inputs and institutional limitations (Onyango, 2014; Atera et al., 2018; Dianga et al., 2021). In western Kenya, rice production is supported by irrigation schemes, including Ahero, West Kano, Bunyala, and Kimira-Oluch. Nevertheless, studies have reported persistent production challenges associated with input access, and institutional support (Atera et al., 2018; Makone et al., 2020; Dianga et al., 2021). Kimira-Oluch Irrigation Scheme in Homa Bay County creates opportunities for increasing production through its irrigation infrastructure, however, the yield levels reported in the scheme remain below attainable levels (Ouma et al., 2020; Makone et al., 2020; HBCRVCAP, 2024).

Senthilkumar (2022) found that integrating appropriate GAPs offers considerable potential for increasing rice yields and improving nutrient-use efficiency in African production systems. Appropriate seed selection, nutrient management, timely planting, crop establishment, weed control, and efficient water use are necessary to realize the potential of improved varieties. Research across African rice-growing environments has demonstrated that yield improvements depend on the combined implementation of appropriate agronomic practices rather than the introduction of a single technology (Saito et al., 2023; Senthilkumar, 2022).

2.2.2 Agronomic Constraints Affecting Rice Productivity

Rice productivity is influenced by interacting biophysical, economic, and institutional factors. Major constraints include declining soil fertility, inadequate nutrient management, limited access to certified seed, pests and diseases, weeds, poor water management, high input costs and inadequate extension services (Atera et al., 2018; Saito et al., 2023). Soil fertility and nutrient management. Soil fertility is essential for crop growth and grain formation. Continuous cultivation without adequate nutrient replenishment can deplete soil nutrients and reduce productivity (Saito et al., 2023. Vanlauwe et al. (2019) emphasize Integrated Soil Fertility Management, which combines mineral fertilizers, organic resources, and improved crop varieties. Soil testing can further support appropriate fertilizer recommendations, although limited access to testing services and technical advice may hinder its application.

Seed quality and input access. Certified seed and improved varieties can enhance crop establishment and yield potential. However, high input costs and unreliable availability may prevent farmers from obtaining quality seed, fertilizers, and crop protection products. These limitations can reduce the implementation of recommended agronomic practices and contribute to persistent yield gaps (Arouna et al., 2017; Saito et al., 2019). Pests, diseases, weeds and water management. Pests, diseases, and weeds reduce crop performance through direct damage and competition for resources. Effective management requires timely identification, field monitoring, and appropriate control measures (Savary et al., 2019). Similarly, inadequate water distribution and poor irrigation management can limit rice growth despite the presence of irrigation infrastructure (Saito et al., 2023). These constraints may vary in severity across production environments. Identifying and prioritizing the most important constraints in KOIS is therefore necessary for developing interventions that respond to farmers' actual production challenges.

2.2.3 Implementation of Good Agricultural Practices among Smallholder Rice Farmers

Good Agricultural Practices (GAPs) comprise recommended crop management practices intended to improve productivity, product quality, resource-use efficiency and environmental sustainability. In rice production, these practices include appropriate variety selection, land preparation, timely planting, correct crop spacing, balanced nutrient management, efficient water management, weed control, integrated pest and disease management, and proper harvesting and post-harvest handling (Mkanthama, 2013; Senthilkumar, 2022).

Evidence indicates that implementation of individual practices can improve crop performance, but the integration of complementary practices is particularly important for closing yield gaps. Senthilkumar (2022) reviewed rice yield-gap studies in Africa and found that integrated GAPs can generate substantial yield improvements, with the benefits depending on production environment and existing farm management. A more recent multi-country assessment also reported yield improvements and reduced yield variability where GAPs were implemented across African rice-growing environments.

Nevertheless, adoption of GAPs among smallholder farmers is often uneven. Routine practices, such as weeding and land preparation, may be easier to implement using farmers' existing knowledge and resources. In contrast, practices requiring specialized knowledge, financial investment, or access to external services may be adopted less consistently. Oo and Usami (2020) examined farmers' perceptions of GAPs in rice production in Myanmar, while Awio et al. (2022) investigated rice management practices and yields following farmer participation in joint experimentation in Doho rice irrigation scheme, Eastern Uganda. These studies highlight the importance of farmer knowledge, practical learning, and locally appropriate agricultural advice. Soil testing, certified seed use and adherence to fertilizer recommendations are

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particularly important because they influence nutrient management and crop establishment. However, implementation may be limited where farmers face high input costs, inadequate extension support, or difficulty accessing technical services. Vanlauwe et al. (2019) emphasized the need to adapt soil fertility interventions to local resource conditions, while Arouna et al. (2017) highlighted the importance of enabling conditions for improved rice variety adoption.

In Kenya, these issues are particularly relevant to smallholder irrigation schemes, where access to water alone may not ensure appropriate crop management. Makone et al. (2020) examined socioeconomic influences on crop productivity among Kimira-Oluch smallholder farmers, while Ouma et al. (2020) examined challenges and coping strategies associated with System of Rice Intensification practices in Oluch Irrigation Scheme. These studies provide a useful local context for investigating farmers' production practices and the conditions affecting technology adoption. Despite this evidence, information on the implementation of individual GAP components among rice farmers in KOIS remains limited. In particular, there is a need to distinguish between routine crop husbandry practices and technical practices that require soil diagnosis, certified inputs, and specialized recommendations. The study addresses this gap by assessing the reported implementation levels of fifteen GAP components among smallholder rice farmers in the scheme.

2.2.4 Relationship between Agronomic Constraints, Input Access, Institutional Support, and Rice Yield

Rice yield is influenced by the interaction of agronomic practices, input availability, technical knowledge, and institutional support (Saito et al., 2023). Access to certified seed, fertilizers, and crop protection products enables farmers to implement recommended practices, provided that the inputs are affordable, suitable, and available when needed. However, access to inputs alone may not guarantee higher yields because their effectiveness depends on appropriate application and complementary management practices (Arouna et al., 2017; Saito et al., 2019).

Institutional support, including extension services, farmer training, demonstrations, and technical advice, can improve farmers' ability to identify production problems and apply appropriate solutions. Agricultural innovation depends partly on effective interactions among farmers and other agricultural stakeholders (Klerkx & Begemann, 2020). Nevertheless, differences in input access and farming practices may result in different yields among farmers with similar access to inputs. Although previous studies have examined rice yield gaps and agricultural practices in Africa, empirical evidence combining agronomic constraints, input access, institutional support, and rice yield in KOIS remains limited. This study therefore examines the relationship between the Agronomic Constraint Index and rice yield while accounting for input access and institutional support.

2.3 Summary of the Empirical Review and Research Gap

The reviewed literature shows that rice productivity in sub-Saharan Africa and Kenya is constrained by poor soil fertility, inadequate nutrient management, limited access to certified seed, high production costs, pest and disease pressure, and insufficient extension services (Atera et al., 2018; Saito et al., 2019; Saito et al., 2023). The literature also demonstrates that GAPs can improve productivity when complementary practices are implemented together. However, their implementation depends on farmers' financial resources, access to quality inputs, technical knowledge, and institutional support (Arouna et al., 2017; Awio et al., 2022; Senthilkumar, 2022). Although studies by Makone et al. (2020) and Ouma et al. (2020) provide insights into agricultural productivity and production challenges in the Kimira-Oluch area, further evidence is needed on the relative severity of agronomic constraints, implementation of individual GAP components and the relationships between constraints, input access, institutional support, and rice yield.

This study addresses these gaps by identifying and prioritizing agronomic constraints, assessing GAP implementation, examining the relationship between agronomic constraints and rice yield while accounting for input access and institutional support, and identifying evidence-based interventions to improve rice productivity. The findings are intended to support the development of locally appropriate strategies for enhancing the productivity and sustainability of smallholder rice farming in KOIS.

III. METHODOLOGY

3.1 Research Design

This study adopted a mixed-methods cross-sectional research design to assess agronomic constraints, implementation of Good Agricultural Practices (GAPs), and factors influencing rice productivity among smallholder farmers in Kimira-Oluch Irrigation Scheme (KOIS), Homa Bay County, Kenya. The design combined quantitative and qualitative approaches to provide a comprehensive understanding of rice production challenges and farmers' agricultural practices. The quantitative approach facilitated the collection and statistical analysis of data on agronomic constraints, GAP implementation, input access, institutional support, and rice yields. The qualitative approach provided additional insights into farmers' experiences and stakeholders' perspectives on production challenges and potential interventions. The cross-sectional design enabled data to be collected from respondents during a defined study period, providing a snapshot of rice production practices and constraints in KOIS

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3.2 Study Area

The study was conducted during the long rainy season (March–April 2026) at the Kimira-Oluch Irrigation Scheme (KOIS) in Homa Bay County, Kenya. The study area is located between 34°30′–34°39′ E and 0°20′–0°30′ S, within the Lower Midland (LM2–LM4) agro-ecological zones, at an altitude of 1,140–1,220 m above sea level (Ouma et al., 2020; Manzi & Gweyi-Onyango, 2021; Jaetzold et al., 2012). The area experiences a tropical climate, with annual temperatures ranging from 22–30 °C and annual rainfall ranging from 740–1,200 mm. Rainfall occurs in a bimodal pattern, with the long rains received from March to June and the short rains from September to November, providing favourable conditions for rice and other food and cash crop production. The scheme comprises 849 households, with an average farm size of 1.87 ha (Ouma et al., 2020; Manzi and Gweyi-Onyango, 2021; Jaetzold et al., 2012).

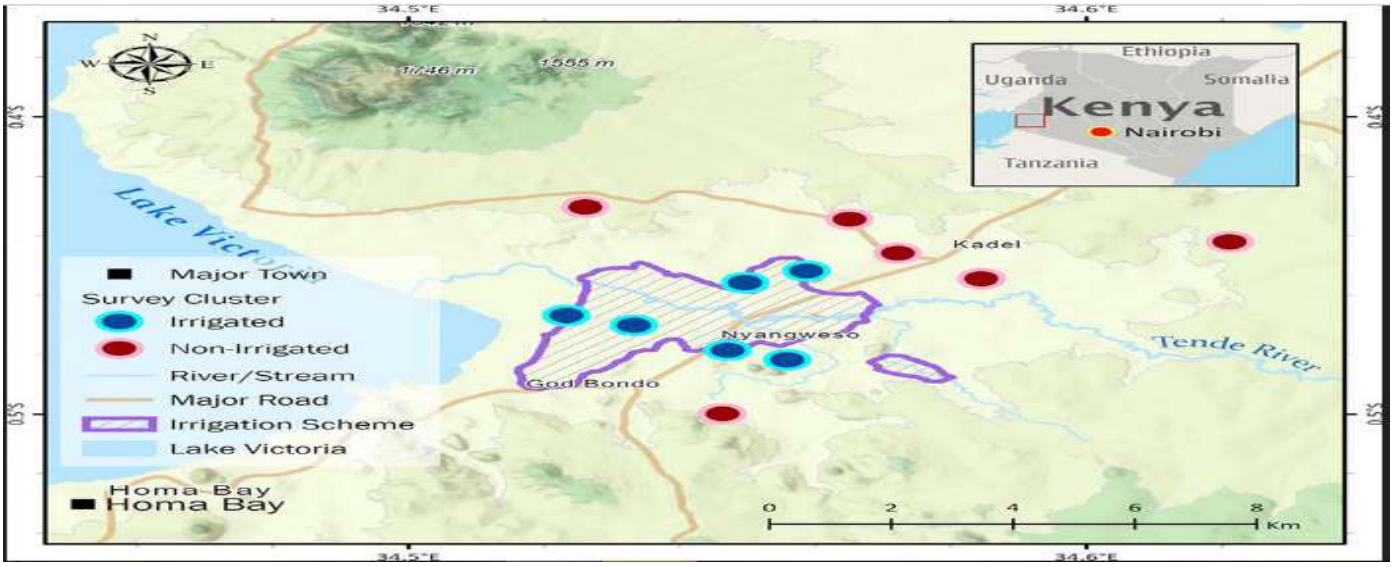


Figure 1

Location of the Kimira-Oluch Irrigation Scheme (KOIS), Homa Bay County, Kenya. Reproduced from Omondi et al. (2022) under the Creative Commons Attribution 4.0 International (CC BY 4.0) licence.

3.3 Target Population

The target population comprised 849 registered smallholder rice farmers in KOIS. These farmers formed the population from which the household survey respondents were selected. Relevant agricultural, irrigation, and institutional stakeholders were also included to provide additional information on rice production, extension services, irrigation management and value chain development. The official register of registered rice farmers retrieved from the Department of Agriculture, Homa Bay served as the sampling frame for selecting survey respondents.

3.4 Sampling and Sample Size

The sample size for the farmer survey was determined using Yamane's formula (Yamane, 1967; Kumar, 2022):

$$n = \frac{N}{1+N(e^2)}$$

where n is the required sample size, N is the population size (849 farmers), and e is the level of precision (0.05).

Thus,

$$= \frac{849}{1+849(0.05^2)} = \frac{849}{1+2.1225} = \frac{849}{3.1225} = 271.9$$

The calculated sample size was therefore 272 farmers. One additional farmer was included to compensate for potential non-response, resulting in a total sample of 273 respondents. Farmers were selected using simple random sampling based on computer-generated random numbers from the farmer register. Thirteen key informants representing six stakeholder categories were purposively selected to provide expert insights into rice production, irrigation management and value chain development. In addition, seven focus group discussions (FGDs), each comprising an average of 15 participants, were conducted with purposively selected farmer groups from the 39 registered groups in KOIS. The key informant interviews and FGDs complemented the quantitative survey and facilitated triangulation of the findings.

3.5 Data Collection Instruments and Procedures

Data were collected using a structured questionnaire, key informant interviews (KIIs), and focus group discussions (FGDs). The questionnaire was administered to the 273 randomly selected farmers and included both closed-

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and open-ended questions. It captured information on farmers' socioeconomic characteristics, rice production practices, implementation of GAPs, agronomic constraints, access to production inputs, institutional support, and rice productivity. The questionnaire demonstrated acceptable internal consistency, with a Cronbach's alpha coefficient of 0.76. Key informant interviews were conducted using semi-structured interview guides to obtain expert perspectives on institutional support, extension services, irrigation management, and rice production within the scheme. Focus group discussions were guided by semi-structured discussion guides and explored farmers' perceptions of production constraints, the prioritization of agronomic challenges, and potential interventions for improving rice productivity. The combination of questionnaires, interviews, and group discussions enabled the collection of complementary information from farmers and stakeholders.

3.6 Data Analysis

Quantitative data were analysed using IBM SPSS Statistics Version 27.0, while qualitative data were analysed thematically. The analysis involved descriptive statistics, construction of composite indices, pairwise ranking, Pearson correlation, and multiple linear regression.

3.6.1 Descriptive and Inferential Statistics

Descriptive statistics were used to summarize farmers' socioeconomic characteristics, production practices, GAP implementation, agronomic constraints, input access, and institutional support. Appropriate measures, including frequencies, percentages, and means, were used to describe the findings. Rice yield was determined from farmers' reported paddy harvest during the most recent production season (Long rains 2025/2026) and expressed in 90 kg bags per acre. Pearson correlation analysis was used to assess the relationship between the Agronomic Constraint Index and rice yield. Multiple linear regression was employed to examine the relationship between rice yield and selected explanatory variables, including the Agronomic Constraint Index, Input Index, and Institutional Support Index. Multicollinearity among predictor variables was assessed using tolerance and variance inflation factor (VIF) values. Statistical significance was determined at $p<0.05$.

3.6.2 Construction of Composite Indices

Composite indices were developed to assess agronomic constraints, access to production inputs, and institutional support. The indices were derived from variables measured on a five-point Likert scale. For the Agronomic Constraint Index, scores ranged from 1 (low constraint severity) to 5 (very severe constraint), with higher values indicating greater production limitations. The Input Index was constructed from indicators measuring access to certified seed, fertilisers, pesticides, and other production inputs, while the Institutional Support Index comprised indicators related to extension services, farmer training, technical advice, demonstrations, and institutional linkages.
For each respondent, index scores were calculated as the mean of the indicator scores:
$\text{Index} = \Sigma X/n$

where Index = composite index score for each respondent, ΣX = sum of the scores for all indicators included in the index, and n = number of indicators included in the index. Equal weighting was applied because all indicators were considered equally important components of their respective constructs.

3.6.3 Pairwise Ranking of Agronomic Constraints

Pairwise ranking was conducted during the FGDs to prioritize the 15 identified agronomic constraints. Within each farmer group, constraints were compared in pairs. A score of 1 was assigned when a constraint was considered more important than the alternative, while a score of 0 was assigned when it was considered less important. Scores from the seven farmer groups were aggregated to determine the overall ranking. Constraints with higher cumulative scores were considered more important by the participating farmers.

3.6.4 Qualitative Data Analysis

Qualitative data from key informant interviews and FGDs were analysed thematically. The analysis involved organizing the information, identifying recurring patterns, grouping related responses into themes, and interpreting the findings in relation to the study objectives. The qualitative findings were compared with quantitative results to provide a more comprehensive understanding of agronomic constraints, GAP implementation, and potential interventions in KOIS

3.7 Ethical Considerations

Permission to conduct the study was obtained through a research permit issued by the National Commission for Science, Technology and Innovation (NACOSTI), Permit No. 389926. Field-level administrative support was obtained from the Homa Bay County Department of Agriculture, Irrigation and Livestock Development and the relevant National Government Administration Officers in the study area. All participants were informed about the purpose of the study,

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participation was voluntary, and informed consent was obtained before data collection. Confidentiality and anonymity of respondents were maintained throughout the data collection, analysis, and reporting processes.

IV. FINDINGS & DISCUSSION

4.1 Socio-economic Characteristics and Rice Production Context

Table 1 presents the socio-economic characteristics of the 273 smallholder rice farmers who participated in the study.

Table 1

Socio-demographic characteristics of smallholder rice farmers in KOIS (N = 273).

Characteristic	Category	N	%
Gender	Male	148	54.2
	Female	125	45.8
Age (years)	Below 25	11	4
	25-34	41	15
	35-44	99	36.3
	45-54	86	31.5
	55 and above	36	13.2
Marital status	Single	23	8.4
	Married	201	73.6
	Widowed	49	17.9
Education level	No formal education	37	13.6
	Primary	57	20.9
	Secondary	107	39.2
	College/University	72	26.4
Land owned (acres)	0-1.0	50	18.3
	1.1-3.9	195	71.4
	4.0-6.9	25	9.2
	7.0-10.0	3	1.1
Main crop	Rice	205	75.1
	Maize	52	19
	Vegetable	15	5.5
	Sorghum	1	0.4

The results show that 54.2% of respondents were male and 45.8% were female. Most farmers (67.8%) were aged between 35 and 54 years, while 65.6% had attained secondary education or higher. Most respondents (71.4%) owned between 1.1 and 3.9 acres, indicating that rice production in KOIS is largely undertaken by smallholder farmers.

These characteristics provide important context for understanding the adoption of improved agricultural practices. Although most respondents had attained at least secondary education, the implementation of technical practices such as soil testing and adherence to fertilizer recommendations remained low. This suggests that education alone may not be sufficient to support the adoption of improved practices where access to inputs, technical services, and financial resources is limited. Similar socioeconomic and resource-related challenges affecting smallholder rice production have been examined in Kenyan irrigation systems, including the Mwea Irrigation Scheme (Randall, 2012), while Makone et al. (2020) and Ouma et al. (2020) provide evidence from the Kimira-Oluch area.

4.1.2 Rice Varieties and Productivity

Farmers reported cultivating both traditional and improved or hybrid rice planting materials, accounting for 54.6% and 29.7% of respondents, respectively. Among the farmer-reported names, Akinyi was the most frequently mentioned (31.9%), followed by Atieno (25.6%) and Komboka (21.6%). The origins and official varietal identities of Akinyi and Atieno could not be verified during the study; therefore, these names are presented as reported by farmers. Seed availability was the main factor influencing variety selection (67.4%), followed by perceived yield potential (18.7%).

The average reported rice yield was 11.63 bags of 90 kg per acre per season, equivalent to approximately 2.59 t ha^{-1}. Individual yields ranged from 2 to 32 bags per acre, indicating substantial variation in productivity among farmers. The importance of seed availability suggests that access to planting materials may influence farmers' choices alongside

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their perceptions of varietal characteristics. This finding is consistent with Arouna et al. (2017), who identified access to quality seed as an important consideration in the adoption of improved rice varieties in sub-Saharan Africa.

The mean production cost score was 3.36 on a five-point scale, while the mean revenue and profit scores were 4.39 and 4.34, respectively. These scores represent farmers' perceptions as measured by the questionnaire and should not be interpreted as actual monetary amounts. The findings also relate to Diffusion of Innovations Theory (Rogers, 2003), which explains that adoption of agricultural innovations is influenced by perceived benefits and the practical conditions affecting access and use. In KOIS, the prominence of seed availability suggests that access to planting materials may be an important consideration in farmers' variety selection.

4.1.3 Characteristics of Key Informants

A total of 13 key informants representing institutions involved in rice production and management within the Scheme participated in the study. The key informants comprised extension service providers (30.8%), Irrigation Water Users' Associations (23.1%), irrigation specialists (15.4%), national government administration officers (15.4%), and representatives from the Lake Basin Development Authority (7.7%) and Kenya Agricultural research institutions (7.7%). The largest proportion (46.2%) had worked in KOIS for 6 - 10 years.

The participation of stakeholders from different institutions provided perspectives on agronomic constraints, irrigation management, extension services, and agricultural support. Comparing their views with farmer survey findings and focus group discussions helped provide a broader understanding of rice production challenges in the scheme. This approach is consistent with Agricultural Innovation Systems Theory, which emphasizes interactions among farmers, researchers, extension providers, and other agricultural stakeholders in supporting productivity-enhancing innovations (Klerkx & Begemann, 2020).

4.2 To Identify and Prioritize the Major Agronomic Constraints Affecting Rice Productivity in KOIS

4.2.1 Farmers' and Stakeholders' Perceptions of Agronomic Constraints

Table 2 presents the mean scores and rankings of agronomic constraints reported by farmers and stakeholders. Scores ranged from 1 (not severe) to 5 (extremely severe).

Table 2

Comparison of farmers' and stakeholders' perceptions of agronomic challenges affecting rice productivity in KOIS.

Agronomic Challenge	Farmers Mean	Farmers Rank	Stakeholders Mean	Stakeholders Rank
Poor soil fertility	4.09	1	4.15	1
Low access to certified/improved seed	3.9	2	4.15	1
Pest infestation	3.86	3	3.38	7
High input costs	3.84	4	3.77	4
Inadequate extension services	3.64	5	3.38	7
Inadequate post-harvest handling	3.57	6	3.69	5
Lack of machinery	3.32	7	3.62	6
Inadequate soil sampling and testing	3.25	8	4	2
Inadequate water/poor irrigation	3.03	9	3.31	8
Disease outbreaks	2.97	10	3.08	11
Unpredictable weather patterns	2.8	11	2.9	12
Poor weed management	2.79	12	2.8	13
Poor crop spacing	2.48	13	3.3	9
Labour shortage	2.31	14	2.31	15
Poor land preparation	2.16	15	2.7	14

Values represent mean scores where 1 = Not severe, 5 = Extremely severe.

Poor soil fertility was the highest-ranked constraint among farmers (mean = 4.09) and stakeholders (mean = 4.15). Limited access to certified or improved seed was also rated highly by both groups, with mean scores of 3.90 and 4.15, respectively. Farmers further emphasized pest infestation (3.86), high input costs (3.84), and inadequate extension services (3.64). Stakeholders identified inadequate soil sampling and testing as another major concern (mean = 4.00). The prominence of poor soil fertility indicates that nutrient management is a major concern for rice farmers in KOIS. Continuous cultivation without adequate nutrient replenishment can deplete soil nutrients and reduce crop productivity. These findings agree with Dianga et al. (2021), who reported soil fertility challenges in western Kenyan rice production systems, and Vanlauwe et al. (2019), who emphasized the importance of Integrated Soil Fertility Management (ISFM) in smallholder farming systems.

Limited access to certified seed was another major constraint. The finding is consistent with Arouna et al. (2017), who identified access to quality seed as an important factor influencing the adoption of improved rice varieties in Africa. It also corresponds with the results in Section 4.1.2, where seed availability was the leading factor influencing

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farmers' variety selection. High input costs were also important, particularly when considered alongside the focus group findings. The cost of fertilizers, quality seed, and crop protection products may limit farmers' ability to implement recommended practices, even when they recognize their potential benefits. Musaba and Mukwalikuli (2019) similarly highlighted socioeconomic limitations affecting smallholder rice production.

Differences between farmers' and stakeholders' rankings were also evident. Farmers placed greater emphasis on pest infestation, whereas stakeholders rated soil sampling and testing more highly. These differences may reflect their distinct experiences: farmers may prioritize visible crop damage, while technical stakeholders may emphasize underlying soil and nutrient management problems. The findings support Farming Systems Theory, which views agricultural productivity as the result of interactions among soil conditions, crop management, input availability, and socioeconomic circumstances. The prominence of soil fertility, input costs, and seed availability demonstrates that rice productivity cannot be improved by addressing individual constraints in isolation.

4.2.2. Pairwise Ranking of Agronomic Challenges from Focus Group Discussions

Focus group discussions were used to compare 15 agronomic constraints in pairs and prioritize them according to their perceived importance.

Table 3

Aggregated pairwise ranking scores of agronomic challenges across seven farmer groups in KOIS.

Agronomic Challenge	Total Score	Rank
Poor soil fertility	83	1
High input costs	78	2
Low access to certified seeds	68	3
Pest infestation	60	4
Disease outbreaks	53	5
Inadequate soil sampling and testing	50	6
Poor weed management	45	7
Inadequate extension services	43	8
Poor crop spacing	42	9
Inadequate water/irrigation	40	10
Labor shortage	38	11
Unpredictable weather	37	12
Lack of machinery/equipment	35	13
Inadequate post-harvest handling	26	14
Poor land preparation	20	15

The pairwise ranking confirmed poor soil fertility as the most important constraint, with a cumulative score of 83. High input costs ranked second (78), followed by limited access to certified seed (68), pest infestation (60), and disease outbreaks (53). The consistency between the pairwise ranking and questionnaire results strengthens the evidence that soil fertility, input affordability and seed availability are priority challenges in KOIS. Although farmers and stakeholders differed in their assessment of some constraints, the combined findings indicate that interventions should address both soil-related limitations and the resources required to implement recommended practices.

These findings support Integrated Soil Fertility Management, which combines appropriate mineral fertilizer application, organic nutrient sources, and locally adapted soil management practices (Vanlauwe et al., 2019). Improving access to affordable inputs and strengthening extension support are also important for addressing the constraints identified. Agricultural Innovation Systems Theory further explains why these interventions require collaboration among farmers, extension officers, research institutions, government agencies, and input suppliers. Effective coordination can improve farmers' access to appropriate technologies and production resources, thereby supporting efforts to overcome the identified constraints (Klerkx & Begemann, 2020).

4.3 To Assess the Implementation of Good Agricultural Practices among Smallholder Rice Farmers in KOIS

Table 4, presents the reported implementation of ten Good Agricultural Practices (GAPs). Scores ranged from 1 (never practised) to 5 (always practised).

Table 4

Implementation of Good Agricultural Practices (GAPs) among rice farmers in KOIS.

Good Agricultural Practice	Mean	SD	Implementation Level
Correct weeding	3.93	0.876	High

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Proper land preparation	3.69	0.733	High
Timely planting	3.55	0.962	High
Water management	3.49	0.940	High
Pest and disease scouting	3.38	0.681	Moderate-high
Harvest and post-harvest handling	2.90	0.694	Moderate
Correct spacing	2.59	0.682	Moderate
Adherence to fertilizer recommendations	1.90	0.860	Low
Use of certified seed	1.35	0.544	Low
Soil testing	1.04	0.197	Very low

Values represent mean scores where 1 = Never practiced, 5 = Always practiced.

The findings indicate that GAP implementation was uneven. Farmers reported relatively high implementation of routine practices, particularly correct weeding (mean = 3.93), proper land preparation (3.69), and timely planting (3.55). Water management (3.49) and pest and disease scouting (3.38) were also practised relatively frequently. In contrast, technical practices were less consistently implemented. Soil testing recorded the lowest mean score (1.04), followed by certified seed use (1.35) and adherence to fertilizer recommendations (1.90). Correct spacing (2.59) and harvest and post-harvest handling (2.90) were implemented at moderate levels. The relatively high implementation of routine practices suggests that farmers regularly undertake basic crop husbandry activities. However, the low implementation of soil testing, certified seed use, and recommended fertilizer application indicates limitations in more technical aspects of rice management. These practices may require financial resources, specialized services, and technical advice that are not consistently available to all farmers.

The findings are consistent with Vanlauwe et al. (2019), who emphasized the importance of adapting integrated soil fertility management practices to local farming conditions. Similarly, Chen et al. (2024) demonstrated the importance of optimizing nitrogen and potassium application to improve rice yield, grain quality, and nutrient-use efficiency. These findings reinforce the need to strengthen soil fertility management in KOIS, where poor soil fertility was identified as the leading agronomic constraint and adherence to fertilizer recommendations was low. Arouna et al. (2017) highlighted the importance of enabling conditions for the adoption of improved rice varieties. Awio et al. (2022) examined the contribution of farmer experimentation and practical learning to rice management and productivity. Likewise, Futakuchi et al. (2021) emphasized that adoption of certified seed enables farmers to exploit the higher yield potential, improved grain quality, and greater resilience of improved rice varieties.

The GAP findings correspond closely with the constraints identified under Objective One. Poor soil fertility was the leading production constraint, yet soil testing and adherence to fertilizer recommendations were among the least implemented practices. Similarly, limited access to certified seed was a major constraint, while certified seed use recorded a mean of only 1.35. This indicates that the identified constraints are reflected in farmers' reported production practices.

Respondents also rated the overall contribution of the GAPs they implemented to improving rice yields relatively low (mean = 2.15). This perception should be interpreted cautiously because the score does not independently establish the yield effect of individual practices. Nevertheless, the findings indicate a need to strengthen farmers' access to soil testing, quality seed, appropriate fertilizer recommendations, and practical extension support. Diffusion of Innovations Theory (Rogers, 2003) helps explain the differences in GAP implementation. Routine practices may be easier to implement using farmers' existing knowledge and resources, whereas soil testing and recommended fertilizer application may require additional technical guidance, financial investment, or access to specialized services. The theory therefore highlights the importance of making recommended practices accessible, practical, and beneficial to farmers.

Agricultural Innovation Systems Theory also emphasizes that adoption depends on more than individual farmers' decisions. Extension services, farmer training, input suppliers, and research institutions have important roles in facilitating access to technologies and the knowledge needed to apply them effectively (Klerkx & Begemann, 2020). In conclusion, the findings suggest that promoting GAPs in KOIS requires more than encouraging farmers to adopt recommended practices. It also requires addressing the resource, service, and technical constraints that limit implementation. Senthilkumar (2022) similarly emphasized the potential of integrating complementary agronomic practices to reduce rice yield gaps in African production systems.

4.4 To Determine the Relationship between Agronomic Constraints and Rice Yield, Accounting for Input Access and Institutional Support

This objective sought to determine the relationship between agronomic constraints and rice yield among rice farmers in KOIS, while accounting for access to production inputs and institutional support. Pearson correlation analysis was conducted to establish the bivariate relationship between agronomic constraints and rice yield, followed by multiple regression analysis to assess whether this relationship remained significant after accounting for input access and

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institutional support. These complementary factors were included because farmers' capacity to address agronomic challenges depends partly on their access to essential production resources, technical knowledge, and advisory services (Vanlauwe et al., 2019; Senthilkumar, 2022; Saito et al., 2023).

4.4.1 Correlation between Agronomic Constraints and Rice Yield

Pearson correlation analysis was conducted to establish the relationship between agronomic constraints and rice yield among the 273 respondents.

Table 5

Pearson correlation between agronomic challenges and rice yield.

Variable	Correlation	Average Yield (90-kg bags per	Agronomic Index
Average Yield	Pearson Correlation	1	-0.257**
	Sig. (2-tailed)		<0.001
	N	273	273
Agronomic Index	Pearson Correlation	-0.257**	1
	Sig. (2-tailed)	<0.001	
	N	273	273

** Correlation is significant at the 0.01 level (2-tailed).

The results revealed a statistically significant negative relationship between the Agronomic Index and average rice yield ($r = -0.257$, $p < 0.001$). This indicates that farmers experiencing higher levels of agronomic constraints generally obtained lower rice yields. The finding suggests that agronomic challenges were associated with differences in rice productivity among farmers in KOIS. However, the correlation analysis examined the relationship between agronomic constraints and rice yield without controlling for other factors. Therefore, multiple regression analysis was conducted to determine whether agronomic constraints remained significantly associated with rice yield after accounting for access to production inputs and institutional support.

4.4.2 Multiple Regression Analysis of Agronomic Constraints, Input Access, Institutional Support, and Rice Yield

Multiple regression analysis was conducted to examine the relationship between agronomic constraints and rice yield while accounting for input access and institutional support. The analysis assessed the overall explanatory power of the model and the independent association of each predictor with rice yield.

Table 6. Model summary for multiple regression analysis of factors influencing rice yield.

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	0.387a	0.150	0.141	4.807

Predictors: (Constant), Institutional Index, Input Index, Agronomic Index

The regression model produced an R^2 value of 0.150 and an adjusted R^2 value of 0.141. This indicates that agronomic constraints, access to production inputs, and institutional support jointly explained 15.0% of the variation in rice yield among the respondents. After adjusting for the number of predictors, the model explained approximately 14.1% of the variation. The remaining 85.0% of the variation was not explained by the variables included in the model and may be associated with other factors, such as climate variability, soil characteristics, farm management practices, and farmers' socio-economic circumstances. These factors were not directly assessed by the reported regression model.

Table 7

Analysis of variance (ANOVA) for the regression model.

Model	Sum of Squares	Df	Mean Square	F	Sig.
Regression	1097.860	3	365.953	15.838	<0.001b
Residual	6215.652	269	23.107		
Total	7313.513	272			

Predictors: (Constant), Institutional Index, Input Index, Agronomic Index

The regression model was statistically significant, $F(3, 269) = 15.838$, $p < 0.001$. This indicates that agronomic constraints, input access, and institutional support, considered jointly, were significantly associated with rice yield. The finding demonstrates that these factors collectively contributed to explaining differences in rice productivity among farmers in KOIS.

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4.4.3. Regression coefficients for factors influencing rice yield.

Table 8

Regression coefficients for factors influencing rice yield.

Predictor	B	Standardized β	t	p	Tolerance	VIF
Constant	21.790	-	8.845	<0.001	-	-
Agronomic Index	-0.600	-0.665	-6.851	<0.001	0.336	2.979
Input Index	3.433	0.330	3.972	<0.001	0.457	2.190
Institutional Index	1.984	0.253	3.416	0.001	0.577	1.733

Agronomic constraints had a significant negative association with rice yield ($B = -0.600$, $\beta = -0.665$, $p < 0.001$). This relationship remained significant after accounting for input access and institutional support. The finding agrees with Vanlauwe et al. (2019) and Tafere (2021), who highlighted agronomic challenges and limitations in adopting improved practices as important constraints to agricultural productivity.

Access to production inputs was positively associated with rice yield ($B = 3.433$, $\beta = 0.330$, $p < 0.001$). This suggests that better access to essential inputs supports higher productivity, consistent with Arouna et al. (2017) and Balasubramanian et al. (2007). Similarly, institutional support showed a significant positive association with yield ($B = 1.984$, $\beta = 0.253$, $p = 0.001$), highlighting the importance of extension services and technical assistance. This finding is consistent with Arouna et al. (2019), who associated effective extension services with improved agricultural practices and productivity. Agronomic constraints had the largest absolute standardized coefficient among the three predictors, suggesting the strongest standardized association with rice yield. Collinearity diagnostics indicated no serious multicollinearity concerns, with VIF values ranging from 1.733 to 2.979.

The estimated regression equation was:

$$\hat{Y} = 21.790 - 0.600(\text{Agronomic Index}) + 3.433(\text{Input Index}) + 1.984(\text{Institutional Index})$$

Where Y^ represents predicted rice yield in 90-kg bags per acre.

The findings demonstrate that agronomic constraints remained negatively associated with rice yield after accounting for input access and institutional support. The positive associations of input access and institutional support suggest that improving farmers' access to production resources, extension services, and technical guidance may complement efforts to address agronomic challenges and enhance rice productivity in KOIS. However, since the model explained 15.0% of yield variation, other factors not included in the analysis may also contribute to differences in productivity.

V. CONCLUSION & RECOMMENDATIONS

5.1 Conclusion

This study identified poor soil fertility, limited access to certified seed, and high production costs as the principal agronomic challenges constraining rice productivity in the Kimira-Oluch Irrigation Scheme (KOIS). These findings were consistently supported by farmer surveys, stakeholder interviews, focus group discussions, and inferential analyses, demonstrating that rice productivity is constrained by interacting biophysical, institutional, and resource-related factors rather than a single production problem. Farmers generally adopted routine agronomic practices but showed limited implementation of technical Good Agricultural Practices, particularly soil testing, fertilizer recommendations, and certified seed use. The significant negative association of agronomic challenges on rice yield confirms that addressing these constraints is essential for improving productivity. The findings therefore highlight the need for integrated approaches that simultaneously strengthen soil fertility management, improve access to quality agricultural inputs, and enhance institutional support to achieve sustainable rice production in KOIS.

5.2 Recommendations

Based on the study findings, agricultural agencies should strengthen soil fertility management in KOIS by promoting regular soil testing, balanced fertilizer application, and the integration of organic nutrient sources with inorganic fertilizers. Site-specific fertilizer recommendations should be communicated to farmers in practical and accessible formats to improve the application of nutrients according to soil conditions and crop requirements. To facilitate implementation, scheme management and agricultural extension providers should collaborate with existing soil testing facilities and research institutions to improve farmers' access to affordable soil analysis services. These measures directly address the poor soil fertility and limited adoption of recommended soil management practices identified by the study.

The national and county governments, in collaboration with seed companies and other relevant agricultural stakeholders, should improve the availability and affordability of certified rice seed and other essential production

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inputs. Strengthening seed distribution channels within the scheme would enable farmers to access quality seed and suitable improved rice varieties when required. In addition, interventions addressing the high cost of production should be informed by farmers' input affordability constraints and the availability of resources to support appropriate measures. Improving access to these inputs would help farmers overcome the resource-related barriers that limit the adoption of recommended agronomic practices and constrain rice productivity.

Agricultural extension providers should intensify practical farmer training to improve the implementation of Good Agricultural Practices. Training should focus on soil fertility management, fertilizer application, certified seed use, crop establishment, and integrated pest management, reflecting the agronomic practices that farmers were found to implement inadequately. Farmer Field Schools, demonstration plots, field days, and regular advisory visits should be used to provide practical guidance under local production conditions. These activities should also encourage farmer-to-farmer learning and enable extension personnel to identify and address gaps in farmers' understanding and application of recommended practices.

The national and county governments, irrigation scheme management, agricultural research institutions, extension service providers and farmer organizations should establish a coordinated framework for implementing and monitoring these recommendations. Implementation should be phased over an indicative period of three to five years, beginning with improved access to certified seed and strengthened extension services, alongside measures to address input affordability. Access to soil testing and the dissemination of site-specific fertilizer recommendations should be expanded concurrently as institutional and financial capacity permits. A multi-stakeholder implementation committee should coordinate activities and periodically assess progress using indicators such as farmers' adoption of recommended agronomic practices, access to certified seed, uptake of soil testing services, and changes in rice productivity. This coordinated approach would ensure that interventions remain aligned with the study findings and address the interacting agronomic, institutional, and resource-related constraints affecting rice production in KOIS.

Declaration of Interest

The authors declare that they do not have any known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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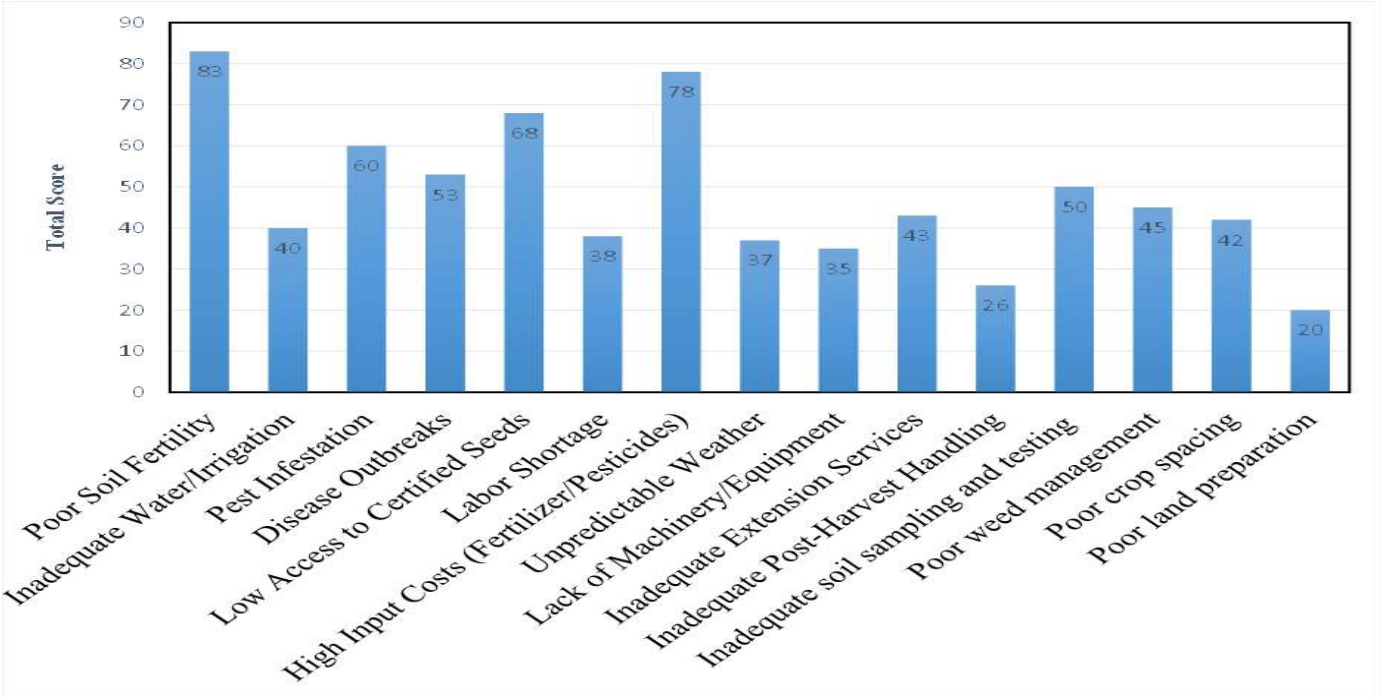
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Appendices

Figure S1

Total Pairwise Ranking Scores of Agronomic Challenges.



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Table S1

Aggregated Pairwise Ranking of Agronomic Challenges from Focus Group Discussions (FGDs)

S/No	Agronomic Factors/Challenges	Kotieno	Block 9	Block 3	Kajwang	Block 2	Kawere	Block 1	Total Score	Rank
1	Poor Soil Fertility	14	13	11	9	12	12	12	**83**	**1**
2	High Input Costs (Fertilizer/Pesticides)	13	10	13	14	10	11	7	**78**	**2**
3	Low Access to Certified Seeds	12	11	11	5	8	8	13	**68**	**3**
4	Pest Infestation	9	11	6	10	8	8	8	**60**	**4**
5	Disease Outbreaks	8	8	5	7	8	8	9	**53**	**5**
6	Inadequate Soil Sampling and Testing	5	6	8	6	9	7	9	**50**	**6**
7	Poor Weed Management	6	10	5	5	6	7	6	**45**	**7**
8	Inadequate Extension Services	4	3	7	9	6	8	6	**43**	**8**
9	Poor Crop Spacing	1	3	8	4	10	8	8	**42**	**9**
10	Inadequate Water/Irrigation	9	8	7	4	8	2	2	**40**	**10**
11	Labor Shortage	4	7	4	12	5	3	3	**38**	**11**
12	Unpredictable Weather	4	5	6	4	7	5	6	**37**	**12**
13	Lack of Machinery/Equipment	7	5	4	4	2	7	6	**35**	**13**
14	Inadequate Post-Harvest Handling	4	1	5	3	4	4	5	**26**	**14**
15	Poor Land Preparation	5	3	3	3	2	3	1	**20**	**15**

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