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FARMER MANAGEMENT RESPONSES TO CONTRASTING WATER STRESS IN UPLAND AND LOWLAND RICE SYSTEMS OF UGANDA

RÉPONSES DES AGRICULTEURS À DES STRESS HYDRIQUES CONTRASTÉS DANS LES SYSTÈMES RIZICOLES DE PLATEAU ET DE PLAINE EN OUGANDA

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ABSTRACT

Rice (*Oryza sativa* L.) production in Uganda occurs under contrasting hydrological conditions, ranging from soil moisture deficits in upland fields, to excess water and flooding in lowland environments. Farmers adjust management practices to cope with these different forms of water stress; however, the field practices under which such practices are applied and their effectiveness across production systems remain poorly documented. This study examined farmer management responses to contrasting water stress across upland, rain-fed lowland and irrigated rice production systems in Uganda. The study was conducted in Butaleja and Bugiri districts in eastern Uganda; and Lira and Nwoya districts in northern Uganda, during September and October 2025. Evidence was obtained through structured focus group discussions (FGDs) and consultations with district agricultural officers and analysed through comparative assessment across production systems. Results showed that although districts experienced similar rainfall disturbances, including delayed onset, intermittent dry spells and intense rainfall events, crop responses differed markedly among production systems. Upland fields experienced soil moisture deficits; whereas lowland fields experienced flooding, seed wash-off and prolonged waterlogging. Farmers implemented several management practices across systems, including early planting, varietal substitution, drainage construction and transplanting; however, their effectiveness depended on prevailing field water conditions. Moisture-conserving practices were more effective in upland systems, whereas drainage and water-control measures were critical in lowland environments. Stable production was reported where agronomic practices matched prevailing hydrological conditions and where seed delivery systems, advisory services and water-control infrastructure were functional.

Key Words: Climate variability, farmer adaptation, *Oryza sativa*

RÉSUMÉ

La production de riz (*Oryza sativa* L.) en Ouganda se déroule sous des conditions hydrologiques contrastées, allant des déficits d'humidité du sol dans les champs de plateau aux excès d'eau et aux inondations dans les environnements de plaine. Les agriculteurs adaptent leurs pratiques de gestion pour faire face à ces différentes formes de stress hydrique ; cependant, les pratiques culturales mises en œuvre et leur efficacité selon les systèmes de production restent peu documentées. Cette étude a examiné les réponses de gestion des agriculteurs face à des stress hydriques contrastés dans les systèmes rizicoles de plateau, de plaine pluviale et irriguée en Ouganda. L'étude a été menée dans les districts de Butaleja et Bugiri, à l'est de l'Ouganda, ainsi que dans les districts de Lira et Nwoya, au nord du pays, en septembre et octobre 2025. Les données ont été recueillies par des discussions de groupe structurées (FGDs) et des consultations avec les agents agricoles des districts, puis analysées par une évaluation comparative entre systèmes de production. Les résultats ont montré que, bien que les districts aient connu des perturbations pluviométriques similaires, notamment un retard du début des pluies, des sécheresses intermittentes et des épisodes de pluies intenses, les réponses des cultures différaient fortement selon les systèmes. Les champs de plateau ont subi des déficits d'humidité du sol, tandis que les champs de plaine ont été confrontés à des inondations, au lessivage des semences et à un engorgement prolongé. Les agriculteurs ont mis en œuvre diverses pratiques de gestion, telles que les semis précoces, la substitution variétale, la construction de drains et le repiquage; toutefois, leur efficacité dépendait des conditions hydriques du champ. Les pratiques de conservation de l'humidité se sont révélées plus efficaces dans les systèmes de plateau, tandis que les mesures de drainage et de contrôle de l'eau étaient essentielles dans les environnements de plaine. Une production stable a été observée lorsque les pratiques agronomiques correspondaient aux conditions hydrologiques dominantes et lorsque les systèmes de distribution de semences, les services de conseil et les infrastructures de contrôle de l'eau étaient fonctionnels.

Mots Clés: variabilité climatique, adaptation des agriculteurs, *Oryza sativa*

INTRODUCTION

Rice (*Oryza sativa* L.) has evolved from a minor crop into an important staple and income source for rural households in Uganda, as demand and cultivation area have expanded across diverse agro-environments. Across many African farming systems, rice also contributes significantly to food security and rural livelihoods under conditions of environmental stress (Brika, 2023). In Uganda, smallholder production occurs in upland fields, rain-fed wetlands and irrigation schemes, exposing farmers to contrasting water conditions (Wichern *et al.*, 2023). Maintaining stable productivity under increasingly variable rainfall conditions has therefore become a major agronomic challenge.

Field water conditions strongly influence rice performance through their effects on soil moisture availability and water control, with changes in soil moisture regimes affecting crop growth, productivity and grain quality (Nuwamanya *et al.*, 2025). Across sub-Saharan Africa (SSA), erratic rainfall and rising temperatures have increased the occurrence of droughts, floods and associated pest outbreaks (Omotoso *et al.*, 2023; Omokpariola *et al.*, 2025). Simulation studies further indicate that temperature and rainfall variability can substantially alter rice yield outcomes under climate change scenarios (Oteng-Darko *et al.*, 2012). Such disturbances disrupt crop establishment, flowering and grain filling, particularly in systems dependent on seasonal rainfall timing (Alimagham *et al.*, 2024; Liu *et*

et al., 2025). In Uganda, dry spells and intense rainfall events have been widely documented (Mubiru *et al.*, 2018), but their crop effects differ markedly between moisture-limited upland fields and water-excess lowland environments.

Smallholder rice production in Uganda is organised into three principal production systems: upland, rain-fed lowland and irrigated lowland (Saito *et al.*, 2018). These systems differ substantially in soil moisture dynamics, water retention and infrastructure reliability. Upland systems depend directly on rainfall and are therefore vulnerable to moisture deficits, while rain-fed lowlands are prone to flooding and waterlogging, and irrigated schemes rely on canal infrastructure to regulate water supply (Solaja *et al.*, 2024). Because of these differences, similar rainfall disturbances may produce contrasting crop responses across production systems. This variation highlights the need for system-specific management approaches rather than uniform recommendations.

Research on crop water-stress effects in SSA agriculture generally follows two broad approaches: biophysical and socio-economic studies. Biophysical studies quantify crop responses to rainfall and temperature variability (Adhikari *et al.*, 2015; Mukhopadhyay and Das, 2023), whereas socio-economic studies document farmer adaptation practices and adoption constraints (Upendram *et al.*, 2023; Ismail *et al.*, 2025). Although both approaches provide valuable insights, they seldom explain why similar farmer management practices lead to different outcomes under contrasting field water conditions.

Farmer decisions are implemented within both physical and institutional constraints, including soil moisture conditions, drainage capacity, infrastructure reliability and access to advisory services (Babyenda *et al.*, 2023; Appiah-Otoo *et al.*, 2024). Understanding production outcomes, therefore, requires examining farmer responses within specific

production-system contexts. This issue is particularly relevant for rice, where crop performance is strongly determined by water availability and field water control.

Integrating farmer observations with institutional perspectives provides an opportunity to clarify how field water conditions and management practices interact across production systems. However, comparative evidence on farmer responses to contrasting water-stress conditions across rice production systems in sub-Saharan Africa remains limited (van Oort and Zwart, 2017; Solaja *et al.*, 2024). The objective of this study was therefore to examine how farmer management responses and crop outcomes differ under contrasting water-stress conditions across upland, rain-fed lowland and irrigated rice production systems in Uganda.

MATERIALS AND METHODS

Study area. The study was conducted in four major rice-producing districts of Uganda, namely Butaleja and Bugiri in eastern Uganda, and Lira and Nwoya in northern Uganda. These districts represent the country's principal rice production systems: irrigated lowland, rain-fed lowland and upland systems (Wichern *et al.*, 2023). The study sites fall within the eastern and northern rice-growing belts where rice cultivation is an important source of both household food and income.

The production systems differ substantially in water control and soil moisture dynamics. Upland fields depend directly on rainfall and are vulnerable to soil moisture deficits, whereas rain-fed lowlands are prone to flooding and prolonged waterlogging. Irrigated schemes rely on canal infrastructure that regulates water supply but may also expose fields to flooding during heavy rainfall events (van Oort and Zwart, 2017). Farmers in all districts experience delayed rainfall onset, dry spells and intense rainfall events that influence crop establishment and management decisions.

Agricultural support in these areas is provided through extension services and development programmes, including the Agriculture Cluster Development Project (ACDP), the Project for Restoration of Livelihoods in Northern Region (PRELNOR), and the Promotion of Rice Development (PRiDe) programme.

Table 1 summarises dominant water-related risks and typical management adjustments across districts.

Study design and sampling. A comparative field inquiry was used to examine how farmer responses to variable rainfall and water conditions differ across rice production systems. Districts were purposively selected to capture contrasting water-management environments representing upland, rain-fed lowland and irrigated rice systems.

Within each district, active rice-growing communities were identified in consultation with District Agricultural Officers (DAOs). Information was obtained from experienced rice farmers responsible for seasonal production decisions and from extension officers involved in advisory support.

A total of five focus group discussions (FGDs) and four consultations with District Agricultural Officers (DAOs) were conducted across the study districts. One FGD was conducted in Bugiri, Lira and Nwoya districts because each district represents a dominant rice production system (rain-fed lowland in Bugiri and upland systems in Lira and Nwoya). In Butaleja district, two FGDs were conducted to capture both irrigated and rain-fed lowland production systems present in the district. Each FGD therefore represented a distinct production system. Each discussion involved 10–12 male and female farmers with long-term rice farming experience. This group size was considered appropriate for facilitating active participation while allowing diverse perspectives to emerge during group discussion, which is consistent with recommended focus group sizes in qualitative agricultural research (Braun and Clarke, 2019).

TABLE 1. Rice production systems, dominant water constraints and farmer management practices in the study districts

District	Rice System	Dominant water constraints	Typical Farmer Adaptations	Key Institutional Programmes
Butaleja	Irrigated and Rain-fed Lowland	Flooding, canal overflows	Canal maintenance, drainage channels, staggered planting	Doho Irrigation Scheme, ACDP
Bugiri	Rain-fed Lowland	Erratic rainfall, flash floods	Early planting, short-maturing varieties	ACDP
Lira	Upland	Delayed onset, drought, occasional floods	Soil bunds, drought-tolerant varieties, early planting	PRELNOR
Nwoya	Upland	Prolonged drought, irregular rainfall	Early planting, mechanization, seed switching	PRELNOR, PRiDe

Study sites and participant characteristics are presented in Table 2.

Data collection. Data were collected between September and October 2025 through guided focus group discussions with farmers and semi-structured consultations with District Agricultural Officers. Prior to participation, all respondents were informed about the purpose of the study and voluntarily agreed to participate. Key themes explored during the discussions included seasonal weather changes, observed crop responses, farmer management adjustments and production constraints. Consultations with District Agricultural Officers focused on the provision of advisory services, seed distribution systems, water management practices, and policy or operational challenges affecting rice production.

Discussions were conducted in local languages with translation into English for analysis by the lead researcher, assisted by resident agricultural officers. Participants were informed that the discussions were not linked to input distribution programmes. With participants' consent, discussions were audio-recorded and supplemented with field notes prepared immediately after each meeting. Respondents were assured that the information provided would be used solely for research purposes and reported in anonymised form.

Combining farmer focus group discussions with consultations from District Agricultural Officers allowed triangulation of field-level observations with institutional perspectives, thereby improving reliability and contextual

interpretation of reported production challenges and management responses.

Data processing and analysis. Audio recordings were transcribed and organised by district and production system. Data were analysed using reflexive thematic analysis following the six-step procedure of Braun and Clarke (2019). The analysis compared reported water-related disturbances, crop responses and farmer management practices across production systems.

Interpretation focused on four analytical dimensions: (i) water-related stresses experienced, (ii) crop responses to these stresses, (iii) farmer management responses, and (iv) institutional support conditions. Information from farmers was cross-checked with accounts provided by District Agricultural Officers to confirm the consistency of reported production patterns across districts. Field notes were used to support interpretation and ensure internal consistency across districts.

RESULTS

Water-stress conditions across study districts. Farmers across study districts reported increasing variability in seasonal rainfall, characterised by delayed onset, intermittent dry spells and intense rainfall events (Table 3). However, the dominant water-related stress differed across production systems and districts.

In the upland systems of Lira and Nwoya, farmers consistently reported prolonged dry spells during the growing season. These dry

TABLE 2. Study locations and sources of field information

District	Rice production system	Field information source
Butaleja	Rain-fed lowland and irrigated (Doho scheme)	Rice farmers and DAO
Bugiri	Rain-fed lowland	Rice farmers and DAO
Lira	Upland	Rice farmers and DAO
Nwoya	Upland	Rice farmers and DAO

TABLE 3. Crop damage and farmer management responses under different rice production systems across study districts in Uganda

Production system	Major water-stress effects	Observed consequences	Farmer responses
Upland			
Rain-fed Lowland	Prolonged drought, heat stress	Flower abortion, poor grain filling	Early planting, drought-tolerant seed
	Flooding, waterlogging	Seed wash-off, siltation, stand loss	Drainage channels, raised bunds
Irrigated Lowland	Canal overflow, heavy rainfall	Water surges, pest outbreaks	Canal repairs, staggered planting

periods were associated with rapid soil moisture loss, particularly in sandy or well-drained soils (Table 3). Farmers explained that droughts occurred frequently during the reproductive stages of the crop, leading to poor grain filling and yield reduction. One farmer explained:

“At the beginning of last year we experienced a lot of sunshine and it destroyed everything we had planted”.

In contrast, farmers in the rain-fed lowland systems of Bugiri district reported frequent flooding following heavy rainfall events (Table 3). Fields located in depressions or poorly drained wetlands experienced prolonged waterlogging, which often resulted in seed wash-off, sediment deposition and poor crop establishment. As one farmer explained:

“The land where I cultivate rice is very flat, so when heavy rain comes it washes away the rice”.

In Butaleja district, where both rain-fed and irrigated lowland systems occur, farmers described water stress in terms of excess water following heavy rainfall combined with failures in water-control infrastructure (Table 3). Farmers operating within the Doho irrigation scheme reported that heavy rainfall events occasionally damaged canal structures, allowing uncontrolled water flow into rice plots.

These observations indicate that similar seasonal rainfall disturbances produced contrasting field water conditions depending on production system and location. Table 3 summarises the dominant water-stress effects, crop responses and farmer management practices across the rice production systems. Crop responses to water stress across production systems

Upland systems (Lira and Nwoya districts). Farmers in upland districts reported that dry spells during the growing season affected crop

development at critical growth stages (Table 3). The most frequently mentioned damage occurred during flowering and grain filling, when insufficient soil moisture reduced grain development. One farmer from Lira noted:

“When the crop reaches flowering the soil dries quickly and the panicles form without grain”.

Another farmer described how seasons characterised by prolonged dry and hot conditions were associated with reduced yields:

“In a good season I harvest about 15 to 20 bags from my three acres, but last season when the sunshine affected us I harvested only six bags”.

District agricultural officers confirmed that moisture stress during reproductive stages was a common cause of yield reduction in upland rice fields.

Rain-fed lowland systems. In the rain-fed lowland systems, farmers in Bugiri district described excess water as the main constraint to crop establishment and growth (Table 3). Heavy rainfall frequently caused temporary flooding in low-lying fields, with flooding events often washing away newly planted seed, leaving fields submerged for several days. This resulted in seed loss, poor germination and plant yellowing due to prolonged waterlogging, as one farmer explained:

“Heavy rains wash away the seed or leave the field flooded for many days and the plants turn yellow”.

Farmers further reported that crop diseases often spread rapidly under such wet conditions:

“If disease affects one stem of rice it becomes yellow and later spreads to the entire garden”.

Farmers consistently identified flooding and prolonged waterlogging as the main production constraints in rain-fed lowland systems.

Irrigated lowland systems. In irrigated areas of Butaleja, particularly within the Doho irrigation scheme, farmers reported that heavy rainfall events occasionally caused damage to irrigation canals and water-control structures (Table 3). When canal embankments were damaged, large volumes of water could enter rice fields uncontrollably. Farmers described cases in which sudden water inflow flattened rice plants or disrupted transplanted seedlings. One participant explained:

“When the canal breaks after heavy rain, water rushes into the field and even transplanted rice can be flattened”.

Farmers also noted that flooding events often resulted in reduced harvests:

“If I normally harvest about fifteen bags per acre, when flooding disturbs the garden I may get only eight or nine bags”.

These observations highlight the importance of irrigation infrastructure maintenance in determining crop outcomes within irrigated rice systems.

Farmer management responses and adaptation practices. Farmers across the study districts reported implementing a range of management practices to cope with variable water conditions (Table 3). Although similar strategies were mentioned across production systems, their purpose and effectiveness differed depending on prevailing field water conditions.

Early planting was widely reported as a common response to unpredictable rainfall (Table 4). In upland systems, farmers used early planting to allow crops to establish before the onset of dry spells later in the season. Some farmers indicated that this strategy improved yields under uncertain rainfall conditions:

“I use early planting and it has been somewhat successful. Instead of getting five bags, I can get about eight bags when I plant early”.

In contrast, farmers in lowland systems used early planting primarily to reduce the risk of seed loss from heavy rainfall occurring later in the planting period.

Varietal choice differed across production systems and districts, with farmers cultivating both local and improved rice varieties (Table 4). In upland districts such as Lira and Nwoya, farmers commonly reported drought-tolerant and short-duration varieties including *WITA 9* and other improved short-duration varieties, which help reduce the risk of yield losses under variable rainfall conditions. In contrast, farmers in lowland systems such as Butaleja and Bugiri reported varieties including *Komboka* and *NARO Rice 2*, together with adaptable varieties such as *NARO Rice 1*, which perform relatively well under wetter field conditions.

Consultations with district agricultural officers further indicated that early-maturing improved varieties such as *WITA 9* and *NARO Rice 1* are widely promoted because they allow farmers to harvest before the onset of prolonged dry spells, while maintaining stable yields under rainfall variability. In Butaleja, varieties including *WITA 9*, *NARO Rice 1* and *WDR* (Water-Deficit-Resistant rice line) are promoted for their drought tolerance, disease resistance and improved yield performance. Farmers in upland districts, particularly Nwoya, also cultivate traditional aromatic varieties such as *Sindani*, while varieties such as *Super* are promoted because of their grain quality and higher market value. These

TABLE 4. Rice varieties grown across districts and production systems and reasons for adoption

District	Production system	Varities reported by farmers	Varities promoted by DAOs	Main reasons for adoption
Butaleja	Irrigated and rain-fed lowland	K5, K85, K98, Basmati, Nerica, Komboka, WITA 9	WITA 9, NARO Rice 1, WDR	Early maturity, tolerance to drought and erratic rainfall, disease resistance, improved yields
Bugiri	Rain-fed lowland	K5, K85, K98, NARO Rice 1, NARO Rice 2,	WITA 9	WITA 9 Early maturity, ability to perform under variable rainfall, yield stability
Lira	Upland	K5, K85, K98, Namuche varieties,	Short-duration improved	Higher Nerica, WITA 9 varieties yield potential, early maturity, adaptation to rainfall variability
Nwoya	Upland	K5, Namuche varieties, Nerica, Sindani	Super, Sindani, improved short-duration varieties	Aromatic grain quality, higher market value, tolerance to drought conditions

observations indicate that varietal choice reflects both adaptation to climatic risks and farmer preferences related to yield stability and market value.

In rain-fed lowland systems, farmers reported constructing drainage channels and reinforcing bunds to reduce waterlogging after heavy rainfall events (Table 3). These structures were intended to improve field water control and protect rice plants from prolonged flooding. One farmer explained:

“Our land is very flat, so when floods occur the water has nowhere to flow. We need drainage channels to guide the water away from the rice fields”.

In irrigated systems, farmers emphasised the importance of maintaining irrigation canals and regulating water flow within the scheme.

Institutional support and constraints.

District agricultural officers reported their primary roles to be providing extension advisory services and facilitating access to improved seed varieties (Table 5). However, they also acknowledged several operational challenges that limited the effectiveness of these services. The officers noted that rainfall variability had disrupted traditional planting calendars and crop development. As one district officer explained:

“Sometimes the rain comes late, and other years it comes early and then disappears during flowering, which causes poor grain filling and significant losses”.

The district agricultural officers also reported operational constraints related to staffing and input delivery. One officer stated:

“We have few extension officers and inputs arrive late, so we cannot reach all farmers in time for field operations”.

Both farmers and officers noted that irrigation infrastructure maintenance and drainage

TABLE 5. Limitations in advisory and input support affecting rice production in the study districts in Uganda

Farmer needs	Existing support	Observed gaps	Implications
Timely improved seed	Demonstration plots, limited distribution	Late delivery, high cost	Low adoption rates
Localised weather info	National forecasts via radio	Not downscaled; late; unclear	Poor timing of planting decisions
Reliable water management	Irrigation schemes	Poor maintenance; slow repairs	Flood damage persists
Regular extension visits	District officers	Too few staff; high farmer–officer ratio	Knowledge–practice gap

management often occurred later than required, particularly following heavy rainfall events. These limitations sometimes prevented farmers from implementing recommended management practices at the appropriate time.

Table 5 summarises the key limitations in advisory services, input access and infrastructure support reported across the study districts.

DISCUSSION

Water-stress conditions across production systems. The results indicate that farmers across districts experienced broadly similar seasonal rainfall disturbances, including delayed rainfall onset, intermittent dry spells and intense rainfall events (Table 3). However, the resulting field water conditions differed markedly across production systems. Upland systems were primarily affected by soil moisture deficits, whereas rain-fed lowland fields experienced excess water, flooding and sediment deposition. In irrigated schemes, water stress was mainly associated with the unreliability of water-control infrastructure during periods of heavy rainfall.

These findings further indicate that flooding and waterlogging are the dominant water-stress conditions affecting rice production in rain-fed lowland systems, where excess water disrupts crop establishment and early vegetative growth. Similar effects of excess water on rice establishment have been documented in other lowland rice systems (van Oort and Zwart, 2017; Ariom *et al.*, 2022).

These results highlight the importance of local hydrological conditions in shaping how climate variability affects rice production. Similar observations have been reported in smallholder rice systems where production risks are mediated by landscape position, soil characteristics and water management infrastructure (Omotoso *et al.*, 2023; Wichern *et al.*, 2023). Distinguishing between moisture-deficit stress and excess-water stress is therefore essential for understanding crop

responses across different rice production environments.

Across the three production systems, the highest yield losses were most frequently reported in upland rice systems, particularly in Lira and Nwoya districts, where prolonged dry spells coincided with reproductive growth stages. Yield reductions were mainly attributed to soil moisture deficits during flowering and grain filling stages, which are highly sensitive to drought stress. In contrast, yield losses in rain-fed lowlands were mainly associated with flooding during crop establishment, while in irrigated systems losses were more episodic and linked to canal failures rather than seasonal moisture shortages.

Farmers reported several interventions to reduce these losses, including early planting, the use of drought-tolerant and short-duration varieties such as *WITA 9* and *NARO Rice 1*, drainage construction in lowlands and improved canal maintenance in irrigated systems. These varieties were already part of farmer adaptation strategies and were promoted by extension services due to their tolerance to moisture stress and their ability to mature before severe drought conditions. These findings suggest that scaling up dissemination of stress-tolerant varieties together with improved water management infrastructure could substantially reduce production risks across systems.

Crop responses to contrasting water conditions. Crop responses to water stress varied systematically across production systems (Table 3). In upland fields, farmers reported that yield losses occurred mainly during flowering and grain filling when soil moisture declined. Soil moisture deficit is well known to affect rice grain production by triggering physiological and biochemical changes that constrain reproductive development and starch synthesis, often leading to yield losses of up to 50–90%, depending on the growth stage (Lobell *et al.*, 2011; Zhao *et al.*, 2017). The most sensitive

periods are reproductive stages (panicle initiation to flowering), where water scarcity causes high spikelet sterility and reduced grain filling (Zhao *et al.*, 2017; Challinor *et al.*, 2014). Similar observations have been reported in upland rice systems where drought sensitivity strongly influences crop performance under moisture stress (Randriantsoa *et al.*, 2025).

In contrast, flooding and prolonged waterlogging emerged as the dominant water-stress conditions affecting rice production in rain-fed lowland systems (Table 3), where excess water disrupted crop establishment and early vegetative growth. This conforms with the findings of van Oort and Zwart (2017), who reported that excess water and flooding significantly reduce rice establishment and early growth in African lowland rice systems.

In irrigated schemes, the primary cause of crop damage was canal failure following heavy rainfall events, which resulted in uncontrolled water inflow into rice plots (Table 3). These contrasting responses reinforce the importance of considering production-system water dynamics when analysing climate impacts on rice production. The findings therefore confirm that similar rainfall disturbances may generate different production risks depending on field hydrology and infrastructure conditions.

Farmer management responses. Farmers across the study districts reported implementing broadly similar management responses to variable water conditions, including early planting, varietal substitution and the construction of drainage channels (Table 3). Comparable adaptive strategies have been documented in other smallholder rice systems exposed to rainfall variability (Solaja *et al.*, 2024; Ismail *et al.*, 2025). However, the effectiveness of these practices differed depending on the dominant hydrological constraints of each production system.

In upland environments, early planting and the use of drought-tolerant, short-duration

varieties improved crop performance under moisture-limited conditions. In contrast, these measures alone were insufficient to prevent flood-related crop losses in rain-fed lowland environments. Similarly, drainage structures were effective in reducing shallow flooding but proved inadequate where infrastructure failure resulted in uncontrolled water inflow. These findings suggest that adaptation practices must be aligned with the dominant water constraints of each production environment.

Differences in varietal selection across districts further illustrate how farmers adjust crop choices to local hydrological conditions and climatic risks. In upland rice systems such as Lira and Nwoya, farmers preferred drought-tolerant and short-duration varieties including *WITA 9* and *Sindani* (Table 4), which allow crops to complete their growth cycle before the onset of prolonged dry periods. Similar patterns have been reported in several African rice systems where early-maturing varieties are adopted to reduce yield risks under increasing rainfall variability (van Oort and Zwart, 2017; Saito *et al.*, 2018).

In contrast, farmers in lowland systems such as Butaleja and Bugiri reported varieties including *Komboka* and *NARO Rice 2* that perform relatively well under wetter field conditions, reflecting adaptation to environments where flooding and waterlogging are more common (Oteng-Darko *et al.*, 2012). At the same time, the continued cultivation of traditional varieties such as *Sindani* and *Super* in upland areas indicates that varietal adoption decisions are influenced not only by climatic adaptation but also by grain quality and market preferences. Similar trade-offs between resilience and market value have been reported in smallholder rice systems (Nkuba *et al.*, 2016; Nuwamanya *et al.*, 2025).

Institutional support. Institutional perspectives further highlight the role of extension systems in shaping farmer adaptation. District agricultural officers

indicated that early-maturing improved varieties are promoted because they allow farmers to harvest before the onset of prolonged dry spells. However, delayed seed delivery, limited extension coverage and slow repair of irrigation infrastructure were reported as key operational constraints affecting timely field management. Similar institutional challenges have been documented in smallholder farming systems where advisory services and input supply strongly influence farm productivity (Babyenda *et al.*, 2023; Upendram *et al.*, 2023).

These findings further demonstrate that rice production outcomes are influenced not only by field water conditions but also by the availability and timing of institutional support services. The results therefore highlight the gap between farmer needs and the institutional support available for climate adaptation in rice production systems.

Improving the timeliness of input delivery, strengthening extension services and maintaining irrigation infrastructure may therefore be critical for reducing water-related production risks in rice systems. Strengthening institutional support systems may be as important as farm-level management practices for improving climate resilience.

Water-stress management strategies should therefore be tailored to the dominant hydrological risks of each production system. In upland systems, greater emphasis on moisture conservation and drought-tolerant varieties may improve resilience, whereas in lowland environments improved drainage management and reliable water-control infrastructure are likely to be more critical for stabilising rice productivity.

Collectively, the findings demonstrate that farmer responses to water stress are closely linked to production-system hydrology, varietal choice and institutional support conditions. Strengthening both field-level management practices and institutional support systems will therefore be essential for improving the resilience of smallholder rice production

systems under increasing climate variability in Uganda. Priority interventions should include dissemination of stress-tolerant varieties, strengthening drainage management in lowlands, improving irrigation infrastructure maintenance and enhancing extension delivery to support timely farmer decision-making.

CONCLUSION

This study has identified two key priorities for strengthening climate resilience in Uganda's smallholder rice systems namely: production-system-specific water risks and institutional support gaps. Although farmers across districts experience similar rainfall variability, the most critical constraints differ by production environment. Drought is the dominant production risk in upland systems, while flooding and waterlogging are the primary constraints in rain-fed lowlands, and irrigation performance depends largely on the reliability of water-control infrastructure. These findings demonstrate that rice adaptation strategies should be tailored to production-system hydrology rather than based on uniform recommendations. Priority interventions should, therefore, focus on drought-tolerant and early-maturing varieties in upland systems, improved drainage management in rain-fed lowlands, and strengthening irrigation infrastructure in irrigated schemes.

The results further show that institutional constraints represent a major limitation to effective farmer adaptation. Delayed seed delivery, inadequate extension coverage and weak maintenance of irrigation infrastructure emerged as the most critical barriers affecting timely farm management. Addressing these institutional gaps should therefore be a first priority for policymakers and development planners. Investments aimed at strengthening extension systems, improving the timeliness of input supply and maintaining water management infrastructure are likely to generate the greatest benefits for stabilising rice production under increasing climate

variability. Strengthening these institutional support systems alongside targeted agronomic interventions should therefore be prioritised in national rice development strategies to improve the resilience and productivity of smallholder rice systems in Uganda.

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