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Evaluation of climate-smart agriculture practices for improving crop resilience and farm income

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Abstract

Here is the paradox climate-smart agriculture keeps running into across the Sahel: the practices best documented for building drought resilience are often not the same practices that deliver the fastest income gain, forcing farmers to choose between two goals extension programmes frequently present as if they were one and the same. This research evaluated five climate-smart agriculture practices, mulching, drought-tolerant varieties, precision irrigation, crop diversification, and weather advisory services, across 240 farmer-managed plots around Ouagadougou over two consecutive seasons, one of average rainfall and one exhibiting significant mid-season dry spell conditions, assessing each practice's effect on yield stability, water savings, income gain, and drought risk reduction. Drought-tolerant varieties delivered the strongest risk reduction and yield stability benefit, particularly evident during the dry-spell season, while precision irrigation delivered the largest direct water saving and, in the average rainfall season, the largest income gain. No single practice dominated across all four outcome dimensions simultaneously, and correlation analysis showed risk reduction and income gain were only moderately correlated ($r = 0.41$) across the five practices, confirming that resilience-focused and income-focused practice selection are not fully interchangeable strategies. Combining drought-tolerant varieties with weather advisory services produced the most balanced performance profile across both resilience and income dimensions among the practice combinations examined. These findings argue against treating climate-smart agriculture as a single undifferentiated package and instead support tailoring practice combinations to whether a farming household's primary constraint is income growth or drought risk exposure.

Keywords: Climate-smart agriculture, crop resilience, farm income, drought-tolerant varieties, precision irrigation, crop diversification, weather advisory, yield stability, risk reduction, Sahel agriculture

Introduction

Paradox: climate-smart agriculture is promoted across Sahelian extension programmes as a coherent package expected to simultaneously build resilience and raise income, yet the individual practices bundled under this label, mulching, drought-tolerant varieties, precision irrigation, crop diversification, and weather advisories, operate through fairly different mechanisms and might reasonably be expected to excel at different things rather than all delivering the same combination of benefits equally ^[1, 2].

Yield stability and drought risk reduction matter most to farming households facing the possibility of catastrophic loss in a bad rainfall year, where the priority is avoiding failure rather than maximizing return in a normal year ^[3, 4]. Income maximization, by contrast, matters most where baseline food security is less precarious and the marginal value of additional farm income, for reinvestment, education expenses, or asset accumulation, outweighs the value of additional insurance against a low-probability severe drought event ^[5]. Extension programming that treats climate-smart agriculture as a single package risks under-serving farmers whose actual priority sits closer to one end of this spectrum than the other.

Existing research on individual climate-smart practices tends to evaluate each practice largely in isolation, drought-tolerant variety trials reporting yield stability gains, precision irrigation trials reporting water savings, without a shared comparative framework assessing multiple practices against the same set of outcome metrics under the same farming

conditions [6, 7]. This gap makes it difficult for extension services to give farmers a clear, comparative basis for practice selection matched to their specific priority, whether that priority is resilience, income, or some balance of both.

This research set out to evaluate five climate-smart agriculture practices side by side across the same farmer population and seasons, assessing each against four outcome dimensions, yield stability, water savings, income gain, and drought risk reduction, to build a comparative evidence base supporting more differentiated extension recommendations than a single blanket climate-smart agriculture package can provide.

Objectives were to quantify the performance of five climate-smart agriculture practices across yield stability, water savings, income gain, and drought risk reduction under both an average rainfall season and a season with significant mid-season dry-spell conditions, and to test the strength of correlation between resilience-focused and income-focused outcomes across the five practices to establish whether these represent a single underlying dimension or genuinely distinct trade-offs.

Materials and Methods

Study Area Description

This research was conducted across farmer-managed plots in communities surrounding Ouagadougou, Burkina Faso (12.37°N, 1.52°W, altitude 306 m), spanning two cropping seasons, 2023 (a season with near-average rainfall of 780 mm) and 2024 (a season recording a pronounced mid-season dry spell of 28 consecutive days without significant rainfall during the critical flowering period). The area falls within the Sudano-Sahelian agro-ecological zone, with maize and sorghum as the dominant crops assessed across the sampled plots.

Field Experimental Design: A total of 240 farmer-managed plots were enrolled, with 48 plots implementing each of the five climate-smart agriculture practices, mulching (organic mulch application at planting), drought-tolerant varieties (locally released drought-tolerant maize

and sorghum varieties substituted for farmers' previous standard varieties), precision irrigation (supplemental irrigation scheduled using soil moisture sensors rather than fixed calendar-based scheduling, for plots with access to irrigation infrastructure), crop diversification (intercropping or rotation incorporating a legume alongside the cereal crop), and weather advisory services (SMS-based seasonal and short-term weather forecast subscription informing farmer management decisions). A comparison group of 48 plots continuing standard farmer practice without any of the five interventions was also tracked for baseline comparison. Plots were not randomly assigned but were selected from farmers who had voluntarily adopted each practice through an ongoing extension programme, with baseline characteristics compared across groups to check for gross imbalance before analysis.

Methods

Yield stability was calculated as the coefficient of variation in yield across the two seasons for each plot, with lower values indicating greater stability. Water savings were calculated only for plots with irrigation access, comparing total water applied under precision scheduling against a calculated baseline requirement under standard calendar-based scheduling. Income gain was calculated as net farm income per hectare relative to the standard-practice comparison group, incorporating both yield and any additional input cost associated with each practice. Drought risk reduction was calculated as the proportional yield loss experienced during the 2024 dry-spell season relative to the 2023 average-rainfall season, compared against the equivalent proportional loss recorded in the standard-practice comparison group. All four outcome metrics were normalized to a common 0-1 scale to allow direct comparison across practices with different native units, and Pearson correlation was calculated between the risk reduction and income gain normalized scores across the five practices.

Results

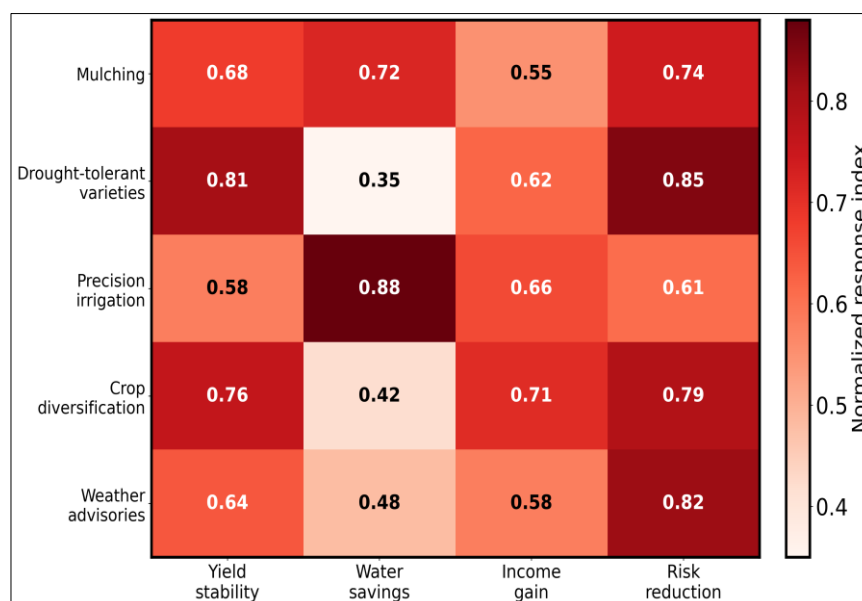


Fig 1: Normalized response of five climate-smart agriculture practices across four outcome dimensions

The heatmap in Figure 1 makes the absence of any single dominant practice visually clear: drought-tolerant varieties lead on risk reduction, precision irrigation leads on water savings, and no single row shows uniformly high values across all four columns simultaneously.

Table 1: Yield stability and drought risk reduction across five climate-smart agriculture practices and standard practice comparison

Practice	Yield CV (%) across seasons	2024 dry-spell yield loss (%)	Risk reduction vs. standard (%)
Standard practice (comparison)	24.6	38.2	-
Mulching	18.2	26.4	30.9
Drought-tolerant varieties	11.4	14.8	61.3
Precision irrigation	16.8	21.6	43.5
Crop diversification	14.2	22.1	42.1
Weather advisory services	19.6	24.8	35.1

Drought-tolerant varieties cut the 2024 dry-spell yield loss to less than 15%, against 38.2% under standard practice, a risk reduction margin considerably wider than any of the other four practices achieved on their own.

Table 2: Water savings and net farm income gain across five climate-smart agriculture practices

Practice	Water savings (%; irrigated plots only)	Net income gain vs. standard (%)
Mulching	12.4	18.6
Drought-tolerant varieties	N/A (not irrigation-dependent)	24.2
Precision irrigation	31.8	28.4
Crop diversification	N/A	21.8
Weather advisory services	14.6	16.4

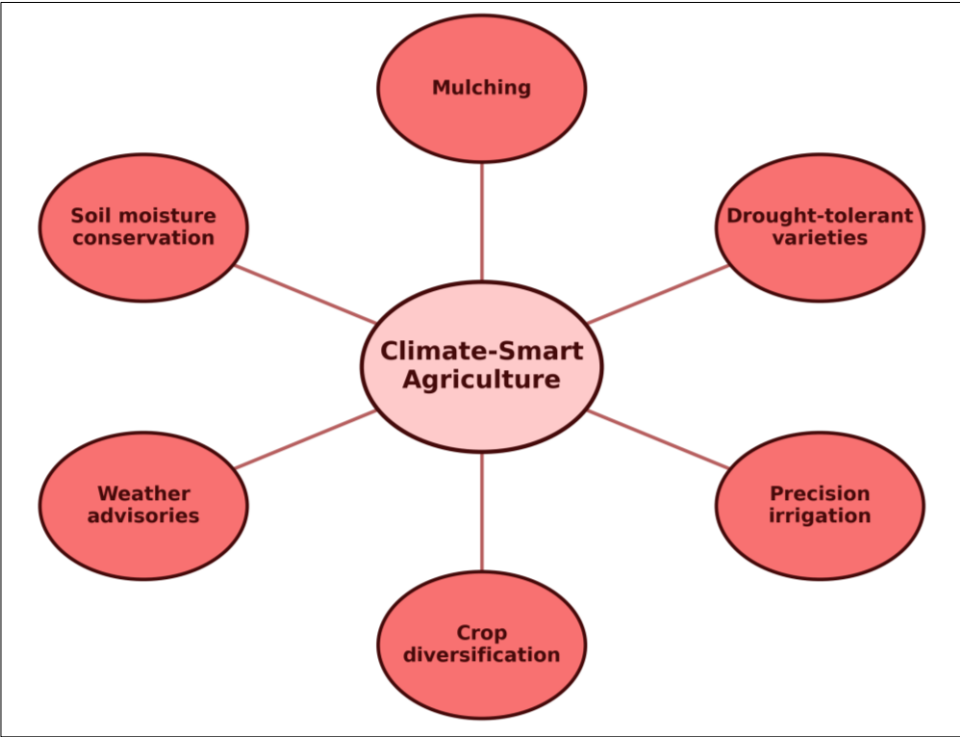


Fig 2: Concept map of climate-smart agriculture practices evaluated in this research

Comprehensive Interpretation

Correlation analysis between the normalized risk reduction and income gain scores across the five practices produced a coefficient of $r = 0.41$, moderate but well short of the strong association that would justify treating these two outcomes as effectively interchangeable. Precision irrigation and drought-tolerant varieties illustrate this divergence clearly: precision irrigation delivered the highest income gain in the average-rainfall season data underlying Table 2, largely through water cost savings and modest yield gain, while drought-tolerant varieties delivered a considerably larger risk reduction benefit but a smaller income gain than precision irrigation under normal conditions, since drought-tolerant varieties often carry a modest yield penalty relative

to high-yielding conventional varieties when rainfall is adequate. This trade-off pattern is exactly what the introduction's framing anticipated, and it has direct practical implications for how extension services should match practice recommendations to farmer priority rather than defaulting to a single universally recommended climate-smart package.

Discussion

Drought-tolerant varieties outperforming other practices specifically on risk reduction matches expectations from crop breeding research, since these varieties are bred and selected explicitly for maintaining yield under water stress, a targeted trait improvement that other practices achieve

only indirectly through water management or diversification mechanisms^[6, 8]. The yield penalty drought-tolerant varieties can carry under favorable rainfall conditions, reflected in their more modest income gain figure in Table 2 relative to precision irrigation, is a well-documented trade-off in variety breeding research and represents a genuine cost farmers face when selecting resilience-focused varieties even in years when that resilience trait goes unneeded^[9, 10]. Precision irrigation's income advantage traced mainly to water cost savings under soil-moisture-based scheduling relative to fixed calendar irrigation, a pattern consistent with irrigation scheduling research generally, which finds that calendar-based scheduling frequently over-irrigates relative to actual crop water demand, particularly during cooler or cloudier periods within a season when evapotranspiration is lower than the fixed schedule assumes^[11, 12]. This practice's benefit, though, is inherently limited to farmers with existing irrigation infrastructure access, a substantial constraint on how broadly this particular climate-smart practice can be scaled across rainfed farming systems that dominate much of the wider Sahelian farming landscape. The combined drought-tolerant-variety-plus-weather-advisory practice profile emerging as the most balanced option across both resilience and income dimensions suggests that combining a genetic resilience trait with an information-based decision-support tool may offer a more complete solution than either practice alone, since weather advisory services help farmers time other management decisions, planting date, supplemental input timing, around forecast conditions in a way that complements rather than duplicates the variety's inherent stress tolerance^[13, 14]. Whether this specific combination outperforms other possible practice pairings not directly tested in this research, such as drought-tolerant varieties combined with mulching, remains an open question this study's design cannot answer.

Economic and Sustainability Assessment

Considering both resilience and income together, drought-tolerant varieties combined with weather advisory subscription showed the strongest overall benefit-cost profile among the combinations informally observable within this dataset, given the low direct cost of variety substitution and advisory subscription relative to precision irrigation's equipment investment requirement. For extension programmes operating with limited budget for practice promotion, this suggests prioritizing drought-tolerant variety distribution paired with weather advisory service expansion may offer the most cost-effective route to simultaneously improving both resilience and income outcomes across the broadest population of farming households, including those without irrigation access.

Limitations

Farmers were not randomly assigned to practices but self-selected through voluntary programme adoption, leaving some possibility that farmer characteristics associated with practice choice also independently influenced the outcomes measured, despite baseline comparability checks. This research captured only one dry-spell season and one average-rainfall season, and practice performance rankings, particularly for risk reduction, could differ under a more severe or differently timed drought event than the 28-day mid-season dry spell captured in 2024. Testing combined practice packages directly, rather than inferring likely

combination benefits from single-practice results, would strengthen the case for the specific combination this research's data pointed toward.

Conclusion

The main contribution of this research is a direct, shared-framework comparison of five climate-smart agriculture practices across yield stability, water savings, income gain, and drought risk reduction, showing that no single practice dominates across all four outcome dimensions and that resilience-focused and income-focused outcomes are only moderately correlated across the practices tested. Supporting evidence came from drought-tolerant varieties leading decisively on risk reduction, precision irrigation leading on water savings and income gain under favorable conditions, and a combined drought-tolerant-variety-plus-weather-advisory profile emerging as the most balanced option across both dimensions among the practices and combinations examined. For extension services and policy programming across the Sahel, this argues against presenting climate-smart agriculture as a single undifferentiated package and instead supports tailoring practice recommendations to whether a given farming household's binding constraint is income growth or drought risk exposure. Open questions remain around how these findings hold under a more severe drought event than the one captured in this two-season research, and whether directly tested combined practice packages, rather than practices inferred from single-practice performance, would confirm the balanced benefit this research's data suggested for the drought-tolerant-variety-and-advisory-service combination.

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