Household modelling and trade-off analysis to design resilient crop-livestock farming systems in dry regions of Senegal

Report

CGIAR | AICCRA
Accelerating Impacts of CGIAR Climate Research for Africa

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About AICCRA Reports

The paper examines how agricultural households can be modeled to better understand their land management, crop, and livestock management decisions, considering the constraints of arid climatic conditions. Using trade-off analysis methodologies, the study aims to identify best practices for designing resilient agricultural systems that maximize yields while minimizing risks from harsh climate conditions. The results of this research could have important implications for sustainable agricultural development in dry regions of Senegal and beyond.

Photos

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About AICCRA

AICCRA Accelerating the Impact of CGIAR Climate Research for Africa

Accelerating Impacts of CGIAR Climate Research for Africa (AICCRA) is a project that helps deliver a climate-smart African future driven by science and innovation in agriculture. It is led by the Alliance of Bioversity International and CIAT and supported by a grant from the International Development Association (IDA) of the World Bank. Explore our work at **aiccra.cgiar.org**

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ABBREVIATIONS

AICCRA	Accelerating Impacts of CGIAR Climate Research for Africa
CGIAR	The Consultative Group for International Agricultural Research
CIS	Climate Information Systems
CSA	Climate Smart Agriculture

SUMMARY

This paper analyzes integrated crop-livestock farming systems in dryland regions of Senegal using household survey data and whole farm household modeling. It focuses on the Kaffrine and Thies regions, which exhibit differences in cultivated land area, staple crops grown, and livestock holdings. The analysis identifies region-specific opportunities to sustainably enhance productivity, resilience, and food security. The mechanistic model incorporates factors like crop mixes, livestock herd dynamics, climate impacts, economics, and labor to simulate entire farms. It finds crops generating most of the household income in the more crop-focused Thies region versus only about one-third in livestock-centric Kaffrine, where nearly half of incomes are from small ruminants. Three resilience enhancing interventions were evaluated in the model – i. introducing improved cattle, ii. farmer participation in climate smart agriculture (CSA) and climate information services (CIS) program, and iii. Combining intervention scenario-i and intervention scenario-ii. Introducing improved cattle have over twice the marginal impact on farm cashflows in cattle-dominant Kaffrine compared to crop-focused Thies. Farmers participation in CSA and CIS program raises their incomes in comparable percentages in both regions given the broad importance of crops. Pursuing integrated crop and livestock interventions yields additive income gains in mixed farming Kaffrine versus specialized Thies. The analysis demonstrates greater opportunities for synergies between crops and livestock in Kaffrine's mixed system context compared to Thies. It provides empirical evidence to inform agricultural policies and investments tailored to regional production patterns. Overall, the paper shows the value of integrated, context-specific approaches to enhancing productivity, resilience, and food security across Senegal's diverse smallholder systems.

1. Background and Introduction

Crop-livestock integrated farming systems hold tremendous potential to simultaneously boost incomes, food security, and resilience for Africa's smallholder farmers. However, these synergistic mixed crop-livestock systems lack sufficient investment and stakeholder support. Sustainably incorporating livestock into diverse smallholder cropping systems presents a major opportunity to concurrently improve rural livelihoods, nutrition, and capacities to overcome intensifying climatic, economic, and environmental stresses. Targeted investments and research promoting sustainable crop-livestock integration are critically needed to develop resilient, biodiverse farms blending complementary crops and livestock. This

can sustainably increase productivity, stability of yields, and farmer earnings despite mounting uncertainties from climate change, land degradation, population growth, and other factors.

Strategic integration of diverse crops and ruminants also promises to promote development of ecologically sustainable, economically viable, and socially equitable agricultural systems benefitting smallholder rural families. But action must come soon, as needs are extremely high even while available natural grazing land becomes exhausted. The Consultative Group for International Agricultural Research's (CGIAR) Accelerating Impacts of CGIAR Climate Research in Africa (AICCRA) program presents a timely opportunity to address these interconnected challenges holistically. AICCRA capacity building efforts span six African countries, including pilot activities in Senegal focused on disseminating climate smart agriculture technologies and climate information, analytical decision-making tools, and technological innovations that empower more targeted climate change adaptation efforts.

This study leverages AICCRA support to collect rich household-level data from three ago-ecological zones spanning dryland region of Senegal with diverse crop-livestock systems. Context-specific integrated crop-livestock approaches are suggested as a key strategy for enhancing smallholder farmer livelihood resilience (Komarek et al., 2015; Kumar et al., 2021; Varadan et al., 2022). However, to support stakeholders in designing appropriate crop-livestock integration, there is need to generate systematic information on synergies and trade-offs arising out of different crop-livestock integration strategies considering ago-climatic conditions, markets, and the household's family labour. Hardly any literature is available on the effect of crop-livestock integration and technology choices on farming system's income and resilience in Senegal in whole farm way.

Therefore, we have applied an integrated farming system assessment framework using whole farm modelling techniques, a household modelling tool to suggest the best combination of crop-livestock activities and technologies for enhanced farm income and resilience. The mechanistic model integrates diverse factors like crops grown, livestock herd dynamics, projected climate impacts, production costs, commodity prices, available labor, and more. This system's approach identifies high-potential leverage points for ratcheting up climate-resilient profitability across different prevailing crop-livestock farm configurations. Findings will inform evidence-based policies, investments and interventions that unlock the full socio-economic and environmental benefits sustainably integrated crop-livestock systems can provide to rural Senegalese households.

2. Data and methodology

A multidisciplinary research team collaboratively developed and implemented a structured survey questionnaire to collect detailed farming system data from 45 randomly selected households across three dryland regions in Senegal – Kaffrine, Louga, and Thies (figure 1). Fifteen (15) households from each region were randomly sampled to provide sufficient data to successfully run the crop-livestock integrated analysis tool (IAT) [1] model, which holistically assesses entire farm systems. With the aim to identify farm household type specific crop-livestock integration and technology options that improve farm family income and farming system's climate resilience, we analysed different intervention scenarios using farm household level systems model- Integrated assessment tool- IAT (Komarek et al., 2015; McDonald et al., 2019a, 2019b). The scenario analysis helped in assessing the competitiveness of range of competing crop-livestock enterprises/ combinations and best management/ marketing strategies and their impacts on whole household incomes/cash flows and on risk management plans considering climatic variability, family labour and consumption preferences, farmers' capacity, land holdings and other socio-economic constraints and conditions. The survey instrument gathered key information through in-person interviews on covariates like crop yields, fodder production, farm inputs usage, technology adoption status, livestock production and marketing, and agricultural product sales channels. This approach enabled understanding current integrated crop-livestock farming system constraints, performance gaps, and opportunities to sustainably improve productivity, food security, nutrition, and rural livelihoods through better connecting producers to livestock and crop value chains.

Local research teams conducted surveys in the predominant language at each site using tablets and KoboToolbox[2] software for convenient and precise data collection and aggregation. The structured interviews captured details beyond agricultural production quantities and economics to also cover qualitative perceptions from rural households. For example, questions explored decision-making roles, views on existing marketing outlets, opinions on household food security status and causes of any shortfalls or deficiencies. The comprehensive dataset compiled by the survey facilitates exploration of multiple options for targeted agricultural development interventions tailored to the diverse contexts and needs of smallholder farmers in the region.

[1] For further details about IAT please go through **https://research.csiro.au/livegaps/tools/integrated-analysis-tool-iat/**

[2] KoboToolbox is an intuitive, powerful, and reliable software used to collect, analyze, and manage data for surveys, monitoring, evaluation, and research.

After checking data quality and alignment with modeling input requirements, the project team analyzed integrated crop-livestock systems dynamics for each distinct farm household classification identified across the three study regions. Summary data tables were prepared covering over 20 factors such as typical crop mix and yields, fodder production, crop expenses and revenues, livestock production costs and sales prices, labor utilization and other farm budget components. These aggregated tables for the main farm types of feed into the IAT model. The IAT model was successfully run using the survey data to simulate each representative farm and generate complete profit/loss statements alongside other sustainability and food security indicators while accounting for interactions between crops and livestock enterprises. The simulation outputs help identify integrated crop-livestock interventions that can simultaneously increase smallholder farmer incomes, build resilience to climate change, and enhance nutrition for rural communities throughout the area given local environmental and socioeconomic constraints.

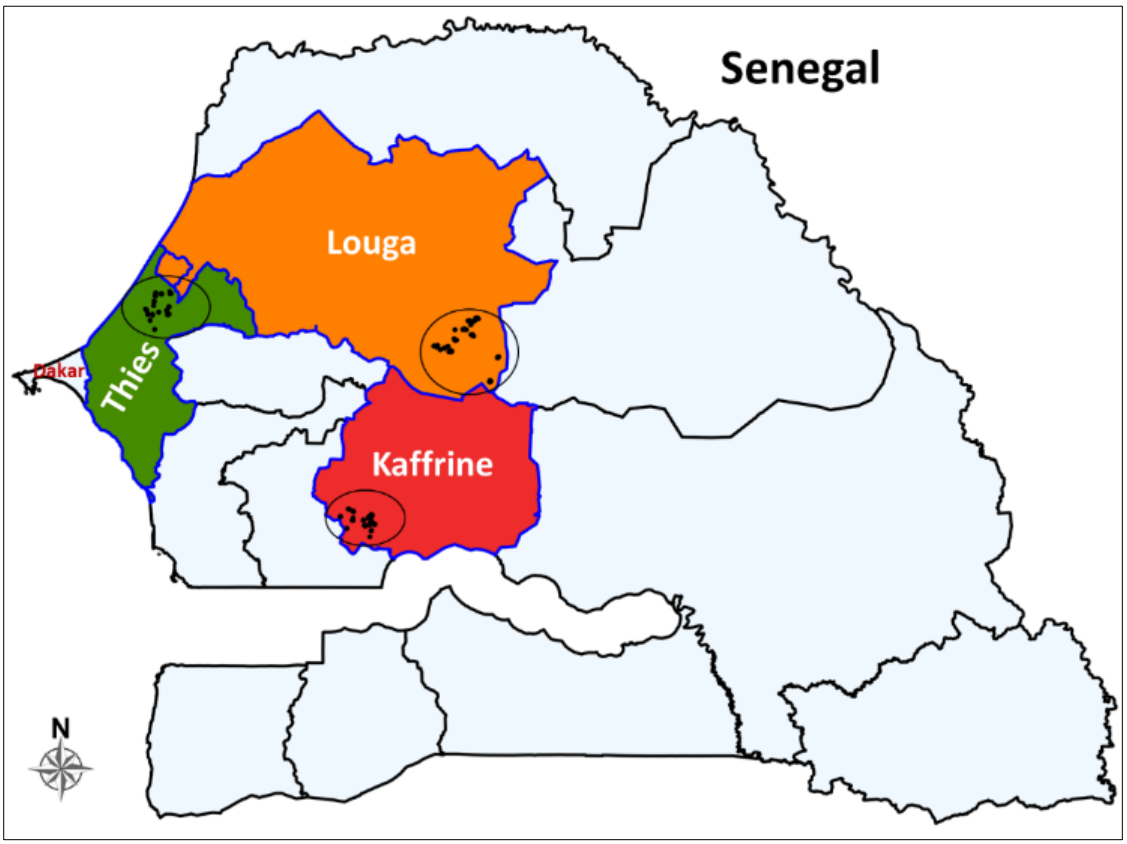

Figure 1: Location of the Study regions and study households in Senegal

This work is still in progress. We have completed and validated initial scenario analysis evaluating only a few options. We have also run additional scenarios evaluating the effect of interventions such as introducing small scale home gardening, watermelon, mango, climate information services, improved

sowing machine and other climate smart agricultural practices, however these scenarios still need to be validated by the stakeholders, hence not included in this publication.

3. Results and discussion

3.1. The Base model

The data collected covers three dryland regions in Senegal, but this scenario analysis focuses on two - Kaffrine and Thies. Table 1 compares key agricultural and livestock characteristics of these regions, using 5-year baseline averages for the key variables. The table compares key agricultural and livestock characteristics between the Kaffrine and Thies regions. In terms of area under cultivation, the two regions have similar average farm sizes for the study farm households. For major crops grown, there is overlap as well, with both regions cultivating millet, peanuts, and cereal grains as staples. However, the farmers in the Thies region also cultivate cowpea, which is not common in Kaffrine. The biggest differences are in livestock holdings - Kaffrine focuses more on cattle farming, whereas Thies has more draft animals, goats and especially sheep. The varying asset mix suggests differing environments and production systems tailored to regional agro climatic conditions and biotic stresses, though overall scale of operations is comparable. Without precise figures, the analysis shows both similarities and region-specific differences in dryland agriculture. The baseline average cash flow obtained from different farming system components has been presented in table 2 also comparing the average annual cash flows from farming systems in the Kaffrine and Thies regions. While the total cash flow is moderately higher in Thies at USD 2,327 versus USD 2,058 in Kaffrine, the relative contribution of different farm enterprises differs markedly between regions. Crop production generates 57% of farm cash income in Thies but only 35% in Kaffrine, whereas small ruminants (sheep and goats) contribute 49% in Kaffrine against 31% in Thies. Livestock rearing, especially of small stock, thus plays a relatively greater role in terms of income and resilience in Kaffrine households. The varying enterprise mix and cash flow structures reflect differing agricultural environments and production orientations between the two regions. Overall, the analysis shows significant regional variation within Senegalese smallholder farming systems.

Tableau 1: Key baseline characteristics of Kaffrine and Thies regions in Senegal

PARTICULARS		REGION	
		KAFFRINE	THIES
AREA CULTIVATED (Ha)		5.28	5.5
MAJOR CROP CULTIVATED		MILLET, PEANUT, MAIZE	MILLET, PEANUT, COWPEA
LIVESTOCK (NO)	COW	4	0
	OXEN	0	16
	GOAT	8	7
	SHEEP	14	17

Tableau 2: Baseline farming system cash flows in Kaffrine and Thies region of Senegal (USD/annum)

PARTICULARS	REGION	
	KAFFRINE	THIES
CROPS	730 (35.48)	1328 (57.08)
COW AND OXEN	314 (15.28)	288 (12.36)
SMALL RUMINANTS (SR)	1013 (49.25)	711 (30.56)
TOTAL CASH FLOW	2058 (100)	2327 (100)

Note: Values in the parenthesis indicate percentage to household's total farm cash flows

3.2. The scenarios

To find out the most important and feasible strategies for enhancing profitability and resilience as compared to baseline farming system situation, the present study considered three different alternative intervention scenarios for both the regions. We have run the scenarios separately and the change in profit (%) as compared to the baseline has been depicted in Table 3. The table depicts simulated impacts on farm household cash flows in Kaffrine and Thies regions under three alternative intervention scenarios relative to a baseline. Introducing one additional improved dairy cow increases total cash flow by 14.8% in Kaffrine versus just 6.4% in Thies, indicating better potential for cattle development in Kaffrine aligned with its existing production focus. Adopting climate information services that increase crop yields by 15% lifts cash flows by comparable percentages of 11.7% and 6.4% for Kaffrine and Thies respectively. This underscores the importance of crops as farm enterprise in both regions. Pursuing the two interventions together yields additive gains, with a 26.5% cash flow increase for Kaffrine and 12.8% for Thies over baseline. The higher marginal impact in the Kaffrine region highlights greater scope for complementary benefits between crop and livestock interventions owing to its mixed farming system orientation. Overall, the analysis demonstrates region-specific pathways for agricultural development based on leveraging

existing production patterns – either crop or livestock centric. It provides useful insights for geographically targeted and farming system-specific rural development planning in Senegal.

Tableau 3: Potential impact of different interventions on farm household cash flows in the study regions

ALTERNATIVE INTERVENTION SCENARIOS	**Change in household's farm income from the baseline scenario (%)**	
	KAFFRINE	THIES
1. Introducing one additional improved cattle	14.78	6.43
2. Households participating in AICCRA CSA and climate information services program (15% higher crop yields)	11.70	6.41
3. Combining intervention scenario-1 and **intervention** scenario-2	26.46	12.84

4. Conclusions and implications

This study leverages survey data collected from 45 smallholder farming households across three agroecological regions in Senegal to analyze integrated crop-livestock systems using a whole farm modeling approach. The mechanistic model holistically assesses farm configurations incorporating interactions between multiple enterprises like crops, livestock herds, projected climate impacts, production economics, available labor and more. This system's perspective identifies high-potential interventions tailored to regional contexts that can sustainably enhance climate-resilient profitability and food security.

The analysis focuses on the Kaffrine and Thies regions, which exhibit both similarities and differences in terms of cultivated land area, staple crops grown, and livestock holdings asset mix. Households in the more livestock-centric Kaffrine derive 49% of cash flows from small ruminants versus 31% in the more crop-focused Thies, where 57% of incomes are from crops rather than 35% in Kaffrine. These varying enterprise combinations and income structures reflect differing agricultural environments and production orientations between the two regions.

Simulating three alternative development intervention scenarios – introducing high yielding cattle, participation in CSA and climate information services program to boost crop yields and combining both – demonstrates region-specific opportunities to leverage existing production patterns. Additionally improved cattle have over twice the marginal impact on farm budgets in cattle dominant Kaffrine (+14.8%) than Thies (+6.4%). Meanwhile participation in CSA and climate services program raise incomes through higher yields and reduced losses by comparable percentages (11.7% and 12.8%) in both regions given the importance of crops. Pursuing both interventions together yields additive gains, with a substantially higher 26.5% increase for Kaffrine versus 12.8% in Thies.

These modeled outcomes highlight greater scope for complementary synergies between crop and livestock interventions in Kaffrine's mixed system context compared to the more specialized crop focus in Thies. The analysis provides useful empirical evidence to inform regional targeting of agricultural development policies and investments aligned with prevailing smallholder production orientations in Senegal. The results of household modelling illustrate the utility of the tool to undertake whole farm analysis and identify the best strategies for different farm types to enhance income and resilience. Overall, it demonstrates the value of integrated, context-specific approaches to sustainably enhancing

productivity, resilience, and food security across the country's diverse and risk-prone crop-livestock farming systems.

The major contribution of this study that the household model has been parameterized for the dryland region of Senegal. We have completed and validated only few initial scenarios. We have also run additional scenarios evaluating the effect of interventions such as introducing small scale home gardening, watermelon, mango, climate information services, improved sowing machine and other climate smart agricultural practices, however these scenarios still need to be validated by the stakeholders, hence not included in this publication.

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