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Interactions between intervention packages, climatic risk, climate change and food security in mixed crop–livestock systems in Burkina Faso

C. Rigolot [a,b,*], P. de Voil [c], S. Douxchamps [d], D. Prestwidge [a], M. Van Wijk [e], P. Thornton [f], D. Rodriguez [c], B. Henderson [a], D. Medina [a], M. Herrero [a]

[a] Commonwealth Scientific and Industrial Research Organization, St. Lucia, QLD 4067, Australia
[b] INRA, UMR 1273 Metafort, F-63122 Saint Genes Champanelle, France
[c] The University of Queensland, Queensland Alliance for Agriculture and Food Innovation (QAAFI), Toowoomba, Australia
[d] International Livestock Research Institute (ILRI), Ouagadougou, Burkina Faso
[e] International Livestock Research Institute (ILRI), PO Box 30709-00100, Nairobi, Kenya
[f] CGIAR Research Program on Climate Change, Agriculture and Food Security, (CCAFS), PO Box 30709-00100, Nairobi, Kenya

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ABSTRACT

Smallholder crop–livestock farming systems have an important role to play for food security in Sub-Saharan Africa, but they have to cope with the effects of climate variability and change. In this study, we test the impacts of different interventions in two contrasting mixed farms in Northern Burkina Faso against the background of plausible current and future climate scenarios. For this purpose, we developed a dynamic farm-household modeling framework around existing tools: crop and animal production models APSIM and LivSim, the household model IAT and the climate generator Marksim. The two farms (a small and a larger) were selected and parameterized based on information collected in a household survey. Tested interventions included different crop fertilization and animal supplementation levels, mulching with crop residues and an alternative livestock feeding strategy. Baseline (2013) and a 2050 projection based on IPCC RCP 8.5 describe two climate scenarios (90 years) for comparison. The maximum level of inputs increases farm energy production by +90% and +76% compared to the baseline for the small and the larger farm, respectively. Input levels maximizing net incomes are moderate, though higher than those currently used in both farms. The inter-annual distributions of net income show that the use of external inputs increases both upside and downside risks, i.e. the probability of getting both very high and very low results. This is because the interventions are more effective at increasing the highest yields in good years than at preventing the low production levels of some years. The 2050 climate scenario has a negative impact on energy production and potential income, especially for the scenarios with high input levels. Downside risks could partly explain why farmers do not currently use optimal input levels, and the results suggest that these constraints could intensify with climate change.

1. Introduction

Smallholder crop–livestock farming systems have an important role to play for food security in Sub-Saharan Africa (Herrero et al., 2010). First, they are the main contributor in terms of the number of farmers supported and food production (Herrero et al., 2010). Second, they are currently characterized by having large crop and livestock yield gaps i.e. there is a significant potential for improvement. Third, in the coming years they will be exposed to a substantial increase in consumer demand for crop and animal products, creating unprecedented market opportunities (Delgado et al., 1999). This diagnosis is particularly valid in Burkina Faso, where many households currently live below the poverty line and cannot produce or buy enough food to meet a satisfactory intake of kilocalories and proteins (Sanfo and Gerard, 2012).

However, to achieve their potential, mixed crop–livestock systems will have to evolve while adapting to climate change and variability (Thornton et al., 2009, 2014). There is evidence that climate change is likely to have significant impacts on crop production in sub-Saharan Africa (Challinor et al., 2007; Cooper et al., 2008; Wood et al., 2014). Less is known about the specific effects on livestock or mixed cropping — livestock farming systems (Thornton et al., 2009). Most impacts on livestock are expected to be indirect i.e. through variations in feed availability, indicating the need for integrated assessments involving both crop and livestock activities (Thornton et al., 2009). Furthermore, the great majority of climate change impact studies tend to focus on progressive changes in mean climate, while effects of climate variability and climate extremes on production have been studied in less detail (Herrero and Thornton, 2013; Thornton et al., 2014; Wood

* Corresponding author.
E-mail address: cyrille.rigolot@clermont.inra.fr (C. Rigolot).

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et al., 2014). If the effects of climate risks are not well quantified, we might seriously underestimate the full impacts of climate change on mixed crop-livestock systems (Thornton et al., 2014).

The farm household is the central unit of analysis to characterize and quantify the vulnerability of smallholders to climate variability and change in Sub-Saharian Africa, and their potential to adapt (Rodriguez and Sadras, 2011). The farm household corresponds to a basic decision making unit where key adaptive properties emerge (Schiere et al., 2002; Darnhofer et al., 2010). Particularly, studies at farm level are relevant to exploit the interactions between crop and livestock production and the synergies between interventions, rather than focusing on the effects of single "silver bullets" (McIntire et al., 1992; Herrero et al., 2010; Rodriguez et al., 2014). Agricultural interventions are complementary to the development of off-farm income options, which are also critical for food security and farm resilience (Vermeulen et al., 2013).

Whole farm modeling studies are commonly used in ex-ante assessments in the identification of potential farming interventions to adapt to climate change and variability (Thornton and Herrero, 2001; Rodriguez et al., 2014), as they allow the exploration of synergies between different components in the farming system to quantify benefits and trade-offs from likely interventions. To date, few studies have tried to simulate interventions for food security in mixed crop–livestock systems against the background of climate variability and change. Yet, in a recent synthesis, Van Wijk et al. (2014) concluded that a range of modeling tools have reached a sufficient level of detail to analyze the combined effects of climate variability and change on food production and economic performance.

Here we present the results from an integrative whole farm modeling analysis to quantify the benefits and trade-offs from alternative incremental adaptation options to climate variability and change for two contrasting smallholder mixed case study farms from northern Burkina Faso. We quantify the average annual energy production and income obtained with different combinations (or packages) of interventions targeting both crop and livestock, and show the distribution of these indicators against the background of climate variability and change.

2. Materials and methods

2.1. Farming systems

The Yatenga province in Northern Burkina-Faso has been identified as relevant for climate change studies and one of the benchmark sites (square blocks of 30 × 30 km) of the Climate Change, Agriculture and Food Security research (CCAFS) program of the CGIAR is located in the province (Försch et al., 2011). The farming systems in this site were characterized in detail through surveys and workshops with stakeholders in 2012 and 2013 (Baseline survey, Försch et al., 2011; Douxchamps et al., 2015). The majority of the households rely on subsistence agriculture and extensive livestock production, often combined with off-farm activities such as gold mining. More than half of the households have access to less than 5 ha of land, and the most important crops grown are millet, sorghum, cowpeas and maize. Large and small ruminants are found in 70% and 90% of the households, respectively. The region corresponds to the Sahelian agro-ecological zone with about 650 mm of annual rainfall concentrated during a single rainy season from May to October. The inter-annual rainfall variability is high (300–900 mm), and the area is particularly prone to drought, with annual rainfall falling below 500 mm every 5 years on average (Institut National de la Météorologie, Ouahigouya). Presently farmers manage climate risks using soil and water conservation practices, agroforestry systems, production of small ruminants, and crop diversification into vegetable production, as well as improved crop varieties and mineral fertilization (Douxchamps et al., 2015).

2.2. Farm level case studies

A baseline farm survey (n = 200) collected in 2012 (Douxchamps et al., 2015) was used to identify two contrasting mixed crop–livestock farms. The data set included household composition, expenditure and consumption patterns, together with the data on crop and livestock production and management (Försch et al., 2011; Douxchamps et al., 2015). The farm households were separated into two groups based on their levels of food security (Douxchamps et al., 2015). For the testing of interventions against the background of climate variability and change, we used this classification to identify two farm case studies, i.e. a food insecure and a food secure households in two locations of the Yatenga province. These two farms corresponded to a small and a "larger" farm, respectively (Table 1).

The two farms had contrasting areas (6.5 and 1.25 ha) and land area per capita, which has been shown to be the main driver of food security together with land productivity (Douxchamps et al., 2015). The two farms also had contrasting herd sizes (7.1 and 4.0 Tropical livestock units). Both farms grow millet, but the larger farm grows sorghum and the small farm maize as a second crop (Table 1). The two households had a similar family composition, with an estimated annual energy requirement of 34,453 MJ/year for the larger farm and 32,299 MJ/year for the small farm. In both households, crop production is used in priority for home consumption and animal products are sold to generate income. Off-farm income in the small farm originated from gold mining. Contrary to other farms in the Yatenga, the two farms have no or negligible small vegetable, tree and chicken components. Both farmers are collecting crop residues to feed their animals, and only small amounts of external feed sources were used to cope with feed shortages. Neither of the farms used mineral fertilizer.

2.3. Analytical framework

The analytical framework we used combines three simulation components (Fig. 1): a) the farming system model APSFarm (Rodriguez et al., 2011), which is an extended configuration of APSIM (Keating et al., 2003); b) the livestock production model LivSim (Rufino et al., 2009); c) a household model derived from the IAT (Integrated Assessment Tool) model (Lisson et al., 2010), thereby allowing us to assess in detail climate effects on crop, livestock and farm household level. Inputs required are climate, soil characteristics and crop management practices for APSIM and herd structure and management practices for LivSim. The IAT model uses both APSIM and LivSim outputs, together with inputs and commodity prices to calculate farm income and food security indicators. For this study, only crop and livestock inputs (fertilizer and feed) and outputs (grain, meat and milk) have been taken into account for the economic calculations: we do not integrate labor, assets and living expenses, and off-farm income is considered to be constant. For APSIM, 90 years of climate data are provided by the Marksim climate generator (Jones and Thornton, 2000), and soil characteristics for each location are taken from the HC27 database (Harvest Choice, 2010).

Table 1
Initial structure of the 2 farms targeted for the analysis (from Douxchamps et al., 2015).

Farm type		Larger	Small
Household	Adults	5	4
	Children	6	7
Livestock	Total (TLU)	7.1	4
	Cattle	7	5
	Small ruminant	17	5
Area and main crops (ha)	Total area (ha)	6.5	1.25
	Millet	4.5	1
	Sorghum	2	–
	Maize	–	0.25
Off-farm income (USD/capita/day)		0	0.3