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Effects of climate change and adaptation on the livestock component of mixed farming systems: A modelling study from semi-arid Zimbabwe

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ABSTRACT

Large uncertainties about the impacts of climate change and adaptation options on the livestock component of heterogeneous African farming systems hamper tailored decision making towards climate-smart agriculture. This study addressed this knowledge gap through the development and use of a dynamic modelling framework integrating climate, crop, pasture and livestock models. The framework was applied to a population of 91 farms located in semi-arid Zimbabwe to assess effects on livestock production resulting from climate change and management interventions. Climate scenarios representing relative "cool-wet", "hot-dry" and "middle" conditions by mid-century (2040–2070) for two representative concentration pathways were compared with the baseline climate. On-farm fodder resources and rangeland grass production were simulated with the crop model APSIM and the pasture model GRASP respectively. The simulated fodder availability was used in the livestock model LIVSIM to generate various production indicators including milk, offtake, mortality, manure, and net revenue. We investigated the effects of two adaptation packages targeting soil fertility management and crop diversification and quantified the sensitivity to climate change of both current and improved systems. Livestock productivity was constrained by dry-season feed gaps, which were particularly severe for crude protein and caused by the reliance on rangeland grazing and crop residues, both of low quality in the dry season. Effects on grass and stover production depended on the climate scenario and the crop, but year-to-year variation generally increased. Relative changes in livestock net revenue compared to the baseline climate varied from a 6% increase to a 43% decrease, and the proportion of farmers negatively affected varied from 20% to 100%, depending on the climate scenario. Adverse effects of climate change on average livestock production usually coincided with increased year-to-year variability and risk. Farms with larger stocking density faced more severe feed gaps and were more sensitive to climate change than less densely stocked farms. The first adaptation package resulted in increased stover production and a small increase in livestock productivity. The inclusion of grain and forage legumes with the second package increased milk productivity and net revenues more profoundly by 30%. This was attributed to the alleviation of dry-season feed gaps, which also reduced the sensitivity to climate change compared to the current system. Clearly, individual farms were affected differently by climate change and by improved farm management, illustrating that disaggregated impact assessments are needed to effectively inform decision making towards climate change adaptation.

1. Introduction

Smallholder farming systems are vulnerable to climate change and likely to be adversely affected to varying extents across sub-Saharan Africa (Naab et al., 2012; Descheemaeker et al., 2016a). Mixed crop-livestock systems are the predominant farming system throughout the semi-arid and sub-humid zones of the continent with important contributions to meat and milk production, to crop production through the provision of traction and manure, and to livelihoods for millions of rural people (Herrero et al., 2010; Tarawali et al., 2011). To improve the resilience of these farming systems, context-specific information is needed for effective decision making and for the selection and implementation of strategies towards climate-smart agriculture (Lipper et al., 2014; Thornton and Herrero, 2014). However, large

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uncertainties and knowledge gaps persist about the likely effects of climate change and adaptation options, in particular for effects on the livestock component (Weindl et al., 2015) and for heterogeneous farm populations (see Descheemaeker et al. (2016a) for a review of the gaps).

Farming systems in sub-Saharan Africa are diverse, with enormous heterogeneity between households in terms of objectives, attitudes and access to natural, financial, physical, human and social capitals (Giller et al., 2011; Descheemaeker et al., 2016b). Hence, the impact of climate change and adaptation options is likely to differ between farm types (Masikati et al., 2015; Traore et al., 2017), and should not be generalized in impact assessments (Thornton et al., 2007). Integrated assessments can inform strategies towards climate-smart agriculture (Claessens et al., 2012; Antle et al., 2016), but need data produced with detailed, process-based models that allow simulating the effects of climate and adaptation options on the biophysical components of the farm (e.g. crops, livestock, soils). Yet, especially for the livestock component, methods to quantify these effects for heterogeneous African farming systems are only now being described and tested (Rodriguez et al., 2017).

Livestock are affected by climate change through changes in feed resources, including their quantity, quality and temporal and spatial distribution, changes in temperature (heat stress), changes in the availability and quality of water resources and changes in disease occurrence and pressure (Thornton et al., 2009; Godber and Wall, 2014). In mixed smallholder farming systems, feed resources include grazed biomass from rangelands, crop residues and, to a lesser extent, forages and concentrates (Valbuena et al., 2015). Each of these feed resources may be affected by climate change in different ways. Smallholders usually keep livestock for multiple purposes, including functions for which herd size matters more than individual animal productivity, such as insurance, banking, socio-cultural and crop-supporting (manure, traction) functions (Moll, 2005; Mekonnen et al., 2011). As such, excessively large herd sizes often compromise the efficiency of milk and meat production. The different functions of livestock might be affected differentially by climate change and adaptation options, but also here, little is known about these impacts.

Semi-arid Zimbabwe was chosen as a case study, as it is representative for large areas of semi-arid land in southern Africa where rainfed agricultural production is the mainstay of the rural population but increasingly under threat from climate change (Masikati et al., 2015). Southern Africa is expected to be strongly exposed to the adverse effects of climate change, with a predicted temperature increase by the end of the century of up to 3–6 °C, combined with likely less and more variable rainfall (Niang et al., 2014). The reliable crop growing days in the study area are expected to drop below 90 by the year 2050 (Jones and Thornton, 2009). In such conditions, it is expected that rainfed crop production will become increasingly risky and farmers will shift to livestock keeping. This trend is likely to be reinforced by the increasing demand for livestock products in the region (OECD/FAO, 2016). However, notwithstanding the importance of the sector, livestock has received very little attention in regional policy documents aimed at climate adaptation (van Garderen, 2011).

In this paper we present and use a modelling framework for assessing impacts on the livestock component of mixed systems in heterogeneous farm populations. We start with describing the farming system in the study area, and in particular the intake of different feed types over time. We then assess the impact of climate change and of two adaptation packages on the feedbase and on livestock production, while taking into account the uncertainty associated with different climate scenarios. In doing so, we test the hypothesis that different types of farms are affected differently by climate change and also by improved management. We further investigate whether the improved system is less sensitive to climate change than the current system.

2. Materials and methods

2.1. Study area

The rural district of Nkayi in Natural Region IV of Zimbabwe was chosen as a representative study area for semi-arid areas that cover about a third of Zimbabwe (Homann-Kee Tui et al., 2013b). The average annual rainfall in Nkayi is 650 mm with high interannual variability, and minimum and maximum mean temperatures are 15 °C and 30 °C respectively. With > 76% of the rural population below the poverty line (ZimVAC, 2013) and food self-sufficiency varying from 3 to 10 months depending on rainfall, rural households are extremely vulnerable to the adverse effects of climate change. Low and variable rainfall, combined with poor soil fertility and limited input use result in low agricultural productivity (Homann-Kee Tui et al., 2013b). Farming systems in Nkayi are mixed crop-livestock systems (Homann-Kee Tui et al., 2015a), in which crop residues are used as dry season feed, and livestock provides draft power and manure to crop production. All farmers cultivate maize (*Zea mays* L.), whereas about a third grows sorghum (*Sorghum bicolor* (L.) Moench) and pearl millet (*Pennisetum glaucum* (L.) R.Br.) and a third includes groundnut (*Arachis hypogaea* L.). Current crop yields are low, with maize yielding on average 0.7 t ha^{-1} and millet and groundnut not surpassing 0.5 t ha^{-1}. About 60% of the households keep cattle and/or goats and donkeys, but productivity is also poor (Homann-Kee Tui et al., 2015a). Communal rangelands provide the major part of the livestock feedbase (Homann-Kee Tui et al., 2013b).

2.2. Modelling framework and data

We followed the Agricultural Model Intercomparison and Improvement Project (AgMIP) Regional Integrated Assessment (RIA) approach that links climate, crop, livestock and economic data and models for assessing the effect of climate change and adaptation options on heterogeneous farm populations (AgMIP, 2015). In this paper, we focused on the livestock component, and its links with the crop and rangeland components of the farming system. In our modelling framework (Fig. 1), field-level information on crop yields, community-level information on rangeland biomass, and herd-level information on animals is integrated with farm-level information on cropland allocation and soil, crop and livestock management practices. We assessed effects of climate change and two adaptation packages on feed availability and, through the feed, on various livestock outputs for all cattle-keeping households in a farm population. The AgMIP RIA models were calibrated for current production systems and run for the current and mid-century period (2040–2070). A detailed description of the methodology for the separate models can be found in the AgMIP RIA handbook (AgMIP, 2015), Antle et al. (2015) and Masikati et al. (2015). In what follows, we provide more details on the livestock model LIVSIM and the data and models feeding into LIVSIM.

2.2.1. Household information

Village and household data were collected in 2011 from 8 villages and a total of 160 households using individual interviews and group discussions. The sampling and interview methods are described in Homann-Kee Tui et al. (2013a). Farm households were stratified into three types (the extremely poor, poor and non-poor) based on resource endowments (Masikati et al., 2015). The modelling framework was run with specific settings for each household. Household-specific information on soil types, fertilizer rates and sowing windows were used in the crop growth model APSIM to simulate grain and stover yields of the major crops (see section 2.2.3). In combination with cropland areas, stover and forage yields were used to calculate farm-level feed availability for use in LIVSIM. Community-level information on rangeland areas and number of animals allowed estimating the rangeland stocking rate, which was used in combination with the grass simula-