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The economic potential of residue management and fertilizer use to address climate change impacts on mixed smallholder farmers in Burkina Faso

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ABSTRACT

There are large yield gaps in the mixed smallholder farming systems of Africa, with limited opportunities to sustainably increase productivity and adapt to climate change. In this study, the *ex-ante* potential of residue retention and fertilization measures to meet this challenge is assessed using a positive mathematical programming (PMP) model. This micro-economic model captures decision making at the farm level for a sample population in Northern Burkina Faso for the 2010 to 2045 simulation period. In contrast to previous studies of mixed farms in this area, we model each individual farm in the sample population, instead of one or a small number of representative farms. We are therefore able identify groups of farms for which each measure is profitable, applied either individually or as a combined package. This approach also enables simulation of the economic impacts from indiscriminate applications of the measures or "smart" applications which are restricted to the farms that profit from the measures. Our findings are aligned with other studies showing that residue retention causes trade-offs between crop and livestock production, while fertilization can synergistically raise returns to both production activities. The annual profit losses from the "middle of the road" RCP6 trajectory of climate change assumed in this study were estimated to reach 15% by 2045. The smart package of measures increased aggregate profit the most, although not by nearly enough to claw back the losses from climate change. The fertilizer measures were the next most profitable, with indiscriminately applied residue retention being the only measure to reduce aggregate profit relative to this climate change baseline. Importantly, the measures that are the most profitable at the aggregate level are not necessarily those that would be the most widely adopted. For example, residue retention is profitable for a larger share of the sample population than fertilization. The advantage of the population scale analysis used in this study is that it prevents measures such as residue retention, which can benefit a significant share of farms, from being disregarded by practitioners because they appear to be unprofitable at the aggregate level or when viewed through the lens of an average representative farm. Finally, amidst the growing emphasis of studies on the benefits of packages compared to individual measures, the findings from this study are more equivocal about this choice, suggesting that extension programs should have the flexibility to apply measures individually or as a package.

1. Introduction

Mixed crop-livestock smallholdings are the mainstay of the agricultural sector in developing countries in the tropics, producing most of the cereals and livestock products consumed in these countries (Herrero et al., 2010). Reliance on mixed smallholder production is set to continue over the long term, especially in Africa where the human population is projected to grow well into the twenty-second century, in both urban and rural areas (Herrero et al., 2010). The integration of crop and livestock activities is particularly advantageous in situations where access to external inputs such as fertilizer and feed is limited, because the by-products from these activities are an important source of mutually beneficial production resources (Thornton et al., 2017). Stalks and other crop residues remaining after the harvest of cereals are often an important source of dry season feed for ruminant livestock, and manure can be a useful source of nutrients for crop production. Ruminant animals are also often the only viable source of traction for ploughing and preparing fields for cereal production.

There are large yield gaps in the mixed crop-livestock smallholder farming systems of Sub-Saharan Africa (Henderson et al. 0.2016), but there are very limited opportunities to sustainably increase the productivity of smallholder production in much of this region. Moreover, the impacts of climate change are expected to make this goal more challenging, but also more necessary in the future (Thornton and Herrero, 2015). Given the high level of resource integration in mixed farming systems, practice changes can generate both trade-offs or

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synergistic benefits between different parts of the system. For example, the retention of mulched crop residues combined with no-till is widely regarded as one of the main pillars of conservation agriculture, given its role in controlling weeds, raising soil health and fertility, and conserving water (Thornton et al., 2017; Rusinamhodzi et al., 2015). However, *ex ante* analyses by Rigolot et al. (2017), Rusinamhodzi et al. (2015) and Baudron et al. (2014), reveal that the reductions in ruminant feed availability caused by this practice often outweigh the benefits to crop production with regard to both economic returns and household nutrition. These studies also reveal that nitrogen (N) fertilization is more likely to be mutually beneficial to both crop and livestock activities.

We complement these studies by assessing the *ex-ante* production and economic impacts of these measures, within a micro-economic framework that simulates farmers' endogenous responses to changing yields and prices from these measures and from climate change. More specifically, we use the Positive Mathematical Programming (PMP) to model decision making at the level of the farm unit and farm population, drawing information from a sample of farms within our study site, based in Northern Burkina Faso. In contrast to the previous studies of mixed farms in this area, we apply our model to all individual farm households in the sample population instead of focusing on one or a small number of representative farms. By including the farm sample within our model framework, we are able to capture the natural heterogeneity within the population including variations in yield, farm size and enterprise mix. With this model, we assess the impacts of climate change on farm performance with and without climate change impacts, with the introduction of residue retention and fertilization interventions, individually and combined as a package. Since Howitt (1995) introduced the PMP approach, it has been used to simulate the impacts of agricultural practices and policies by several studies but, as far as we are aware, only for developed country farming systems. These include applications in Europe (Arata et al., 2017; Afrini et al., 2012; Buysse et al., 2007; Kanellopoulos et al., 2010), the United States (Howitt et al., 2012; Mérel et al., 2013) and Australia (Querishi et al., 2013; Querishi et al., 2014).

2. Data

This study uses farm production data for a site in the Yatenga province in northern Burkina Faso, from the IMPACTlite database, which was prepared by the International Livestock Research Institute (ILRI) for the CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS). The data were collected in farm surveys for the 2012 calendar year (Rufino et al., 2013; Douxchamps et al., 2015). The study site is in the Sahelian agro-ecological zone and has annual rainfall of 400–700 mm concentrated in one rainy season between May and October, with large inter-year variability and is located at an altitude of 300-350 m (Sijmons et al., 2013; Rigolot et al., 2017). The sample farms are predominately smallholdings with a mixture of crop and livestock production activities, with households supplementing their income with off-farm employment activities including gold mining (Rufino et al., 2013). The mixed smallholders devote all of their farmland to crop enterprises and feed their livestock with a mixture of crop by-products (e.g. residues such as crop straws) and forages sourced from communal areas outside the boundaries of their farms. To keep the selected PMP model used in this study tractable and to restrict the number of zero entries for farm activities, it was necessary to restrict the total number of crops. The six crops selected accounted for 97% of the total area devoted to crops within the analysed sample. Given the focus on mixed crop-livestock farms and the synergies and trade-offs in the use of farm resources by crop and ruminant enterprises, a key criteria for selecting sample farms was the presence of one of the six main crops and as well as one ruminant enterprise. Of the original 152 observations in for the study site sample, twelve were removed for not meeting this criteria. The sample size was further reduced to 43 observations after removing incomplete records which reported crop and livestock outputs, but did not include data on key production inputs such as cropland area and animal numbers. Some summary statistics for the final sample of farms are provided in Table 1. The average land area is < 4 ha with cowpea, millet and sorghum dominating the production area, and cattle accounting for the main share of ruminant animals in Tropical Livestock Unit (TLU) equivalent terms. Profit represents the annual gross margin of farm production, defined here as the value of production minus the cost of variable inputs, and therefore reflects the returns from production to farm capital, land and labour. For crops, the variable inputs available in the survey data included fertilizers, herbicides, seeds and other purchased inputs. For livestock, only the value of production was available. Given this lack of data on livestock variable costs, the mean ratio of gross margin profits relative to revenue for crops of 49% was assumed for livestock production. The sensitivity of the results to large variations in this assumed value is assessed in the sensitivity analysis section of this study. The average share of farm profit derived from livestock and crop production activities was nearly equal given their production levels and this assumption. Non-ruminant animals including chickens, guinea fowl, other poultry and rabbits, were excluded from this analysis; however, expressed in terms of TLUs, they only comprised 4% of all livestock in the sample.

Table 1
Farm sample characteristics for crop and livestock production and income.

	Mean	Standard deviation
Cropland area	3.97	3.33
Cowpea	1.47	1.99
Maize	0.23	0.40
Millet	1.10	0.98
Peanut	0.36	0.36
Rice	0.06	0.20
Sorghum	0.75	1.13
Livestock (TLU[a])	8.14	10.81
Cattle	5.37	8.72
Goats	1.19	1.73
Sheep	1.05	1.40
Donkeys	0.11	0.13
Farm profit (CFA[b])	532,800	577,310
Crop profit (CFA)	267,500	215,510
Ruminant profit (CFA)	265,300	496,090

[a] For purposes of comparison, ruminant animal numbers were standardized across species using the tropical livestock unit (TLU) index, which aims to account for the variations in different feed resource requirements between different species (ILRI, International Livestock Research Institute, 2011; FAO, 2003).

[b] In 2012, one US dollar was worth an average of 512 West African Francs (CFA).

The data on yield and price changes over time for the baseline and climate change scenarios, described later in the scenarios section, come from the global land use model MAgPIE (Lotze-Campen et al., 2008; Popp et al., 2014; Stevanović et al., 2016) which uses averaged climate data from four different global circulation models (GCMs), including Geophysical Fluid Dynamics Laboratory – Earth System Model (GFDL-ESM2M), Hadley Global Environment Model 2 – Earth System (HadGEM2-ES), Institut Pierre Simon Laplace Earth System Model for the 5th IPCC report (IPSL-CM5A), and Norwegian Earth System Model (NorESM1-M). The price and yield trajectories from the MAgPIE scenario were expressed as percentage changes from the 2010 base year, calculated at 5-year intervals, at the the $0.5^{o} \times 0.5^{o}$ level of resolution. The scenarios did not include CO_2 fertilization, given uncertainty about the impacts of CO_2 fertilization. Of the six crops covered, the MAgPIE baseline yield and price trajectories were only explicitly available for maize, peanuts and rice. For millet and sorghum the aggregate MAgPIE crop category of tropical cereals was used, and for cowpea the aggregate MAgPIE category of pulses was used. The percentage changes in prices and yields as a consequence of climate change (RCP6) relative to