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Published in:
Agricultural Systems

DOI:
10.1016/j.agsy.2023.103636

Print publication: 01/04/2023

Agricultural Systems 207 (2023) 103636

Contents lists available at ScienceDirect

Agricultural Systems

journal homepage: www.elsevier.com/locate/agsy

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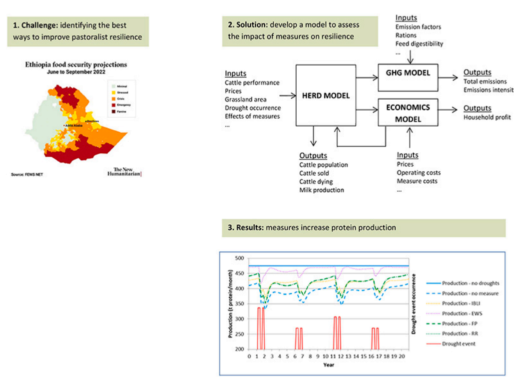
HIGHLIGHTS

- A model of a pastoral cattle system in Ethiopia was developed and used to investigate resilience.
- Four measures were analysed: livestock insurance; managed destocking; rangeland restoration; fodder planting.
- Destocking provides the biggest increase in production and profit, due to the way it changes the herd size and structure.
- Fodder planting and rangeland restoration increase production and profit. Insurance increases production but not profit.
- All of the measures increase the total GHG emissions but lead to little change in emissions intensity.

GRAPHICAL ABSTRACT



ARTICLE INFO

Editor: Dr. Mark van Wijk

Keywords:
Pastoralism
System dynamics
Resilience
Climate smart agriculture

ABSTRACT

CONTEXT: Pastoral and agro-pastoral (PAP) systems in East Africa face a range of challenges including increased climate variability. Various measures have been proposed to improve the resilience of pastoral/agro-pastoral (PAP) systems to drought. However, identifying the most effective measure for a given system and location is complicated, and tools are required to appraise measures on a consistent basis.
OBJECTIVE: This paper develops a model of a PAP system and uses it to assess the effects of four measures (Index-based livestock insurance, IBLI; Commercial destocking with an early warning system, EWS; Rangeland restoration, RR; Fodder planting, FP) on the resilience of the PAP system. It also quantifies the greenhouse gas (GHG) effects of the measures, thereby identifying potential trade-offs and synergies between the policy objectives of resilience and climate smart agriculture (CSA).

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https://doi.org/10.1016/j.agsy.2023.103636
Received 19 October 2022; Received in revised form 28 February 2023; Accepted 2 March 2023
Available online 24 March 2023

METHODS: A dynamic model of the Borena pastoral cattle system was developed to undertake the analysis. At its core is a herd model that calculates the changes in cattle population over time. Feed availability and drought occurrence affect fertility and mortality rates, which in turn determine the population and (meat and milk) production. A suite of indicators covering the three dimensions of CSA (increasing productivity, enhancing resilience and reducing GHG emissions) were developed, and used to compare the situation with and without measures.

RESULTS AND CONCLUSIONS: Destocking with an early warning system provides the biggest increases (relative to the no measure situation) in production and profit, due to the way it changes the herd size and structure. It maintains a larger herd than any of the other measures, and a greater proportion of the herd are adult females. Fodder planting and rangeland restoration provide moderate increases in production and profit. Index-based livestock insurance provides a moderate increase in protein production, but has no effect on profit, as it is designed to reduce risk rather than increase productivity or profit, at least in the short term.

All of the measures increase the total emissions relative to the no measure scenario. In terms of the three dimensions of climate-smart agriculture, IBLI leads to some improvements in productivity and resilience but leads to large increases in total emissions, and modest increases in emissions intensity (EI). EWS leads to large increases in productivity and resilience. However, it also leads to large increases in total emissions and a mixed effect on EI. FP and RR improve productivity and increase total emissions, while having little effect on EI or resilience.

SIGNIFICANCE: This paper illustrates the way in which systems dynamic model can be used to appraise measures designed to improve resilience. The result identify potential synergies and tensions between the goals of resilience and climate smart agriculture, and raises the question of whether fully climate-smart goals are viable in these systems.

1. Introduction

1.1. Background

Pastoralism has been defined as "a complex interaction of people, natural resources, and livestock, predominantly practiced in arid and semi-arid lowlands" (Gebremeskel et al., 2019, p1). Climate variability is one of the main challenges for pastoralists in East Africa. Studies have found statistically significant links between climate (particularly rainfall and drought incidence) and cattle populations (Megersa et al., 2014; Kimaro et al., 2018; Araro et al., 2019). It has been argued that "As climate change advances, the downward trend in cattle numbers is expected to persist, implying that the centuries-old cattle pastoralism is likely to become a precarious livelihood option" (Megersa et al., 2014).

Various measures have been proposed to enhance the resilience of pastoral/agro-pastoral (PAP) systems. For example, Gebremeskel et al. (2019, p34) proposed a range of interventions that sought to enhance resilience by: transforming livestock production; integrating rangeland and water development and securing access to key resources; enhancing access to basic social and economic services and disaster risk management; institutional capacity building. However, identifying the most effective measure for a given system and location is complicated and tools are required that enable measures to be appraised on a consistent basis.

1.2. Aim and objectives

The overall aim of this paper is to develop a model of a PAP system and use it to explore the effects of measures designed to improve resilience. The specific objectives are to:

1. Quantify the dynamic effects of drought events on PAP systems in the Borena zone of Oromia, southern Ethiopia.
2. Assess the effects of four measures on the resilience of the PAP systems.
3. Quantify the GHG effects of the measures, thereby identifying potential trade-offs and synergies between the policy objectives of resilience and climate smart agriculture.

1.3. Scope

This paper focuses on cattle in PAP systems in southern Ethiopia, specifically Oromia region. This system/location was chosen due to its (social and economic) importance and vulnerability to the effects of drought, as well as because of the data availability in the region.

1.4. The concept of resilience

Resilience can be defined in different ways. Indeed, Tendall et al. (2015) have argued that "The very vagueness of the term resilience has promoted its popularity… This same vagueness, however, poses the risk of using the concept of resilience subjectively, for example as an argument for supporting the status quo (Kirchhoff *et al.*, 2010, 2012)." To avoid such vagueness, we provide a clear definition of resilience and link it to a series of indicators (see Table 1). Resilience is defined in this report as: *the capacity of livestock production systems to either maintain or quickly restore production and income in the face of disturbances and shocks associated with or worsened by climate change.* This definition is an adaptation of the definition presented in IPCC (2014).

1.5. Climate smart agriculture and resilience

Climate-smart agriculture (CSA) aims to simultaneously increase productivity, enhance resilience and reduce GHG emissions (World Bank, 2022). So while it encompasses resilience, it has a broader scope that enables it to consider "the synergies and tradeoffs that exist between productivity, adaptation and mitigation" (World Bank, 2022). The resilience indicators (Table 1) were augmented with indicators for GHG emissions (total emissions and emissions intensity measured over 1, 5 and 20 years), to create a suite of indicators covering the three dimensions of CSA.

2. Measures

PAP systems can respond to droughts in a variety of ways depending on their starting point and the severity of the drought. Fig. 1 in the Supplementary Information illustrates the chain of events that can be initiated by a drought, leading ultimately to PAPs moving, seeking additional feed and water, selling cattle and restocking post drought or exiting the sector.

There are many different ways in which the resilience of pastoralists can be improved. The most appropriate set of measures will vary depending on where the particular farmer is starting from, and the pathway they are on, which in turn depends largely on their market and resource access. In this study, four measures were chosen that seek to improve resilience in different ways (thereby making the analysis relevant to a wide range of pastoralists). The measures chosen for analysis were:

1. Index-based livestock insurance (IBLI)
2. Drought early warning system and destocking (EWS)
3. Rangeland restoration (RR)
4. Fodder planting (FP)

Insurance enables the purchase of feed (and other inputs) in drought years to prevent livestock losses. The early warning system plus destocking reduces feed demand in years when feed supply is predicted to be low, while rangeland restoration and fodder planting seek to increase feed supply by increasing the production of grass and crop feed materials. Measures targeting cattle nutrition were chosen because of its fundamental importance to resilience and because there is evidence of increasing feed scarcity in Oromia (World Bank, n.d. forthcoming). Adequate nutrition is also a prerequisite for other measures (Gebremeskel et al., 2019, p36). However, other approaches are also important, such as those identified by de Haan (2016):

- Enhancing mobility through water resource development and land use planning
- Integration of PAP systems with more intensive fattening/finishing operations
- Livelihood diversification
- Strengthening clinical veterinary services

2.1. Index-based livestock insurance (IBLI)

IBLI is a type of risk financing that provides farmers with money to maintain their livestock during droughts. A key feature of IBLI is that it triggers payments to farmers when a predetermined and objectively measured value of an indicator (such as NDVI) is met. These payments enable farmers to adopt measures to mitigate the drought impacts, such as purchasing feed and water, thereby reducing the negative impacts of drought on cattle mortality and fertility.

2.2. Drought early warning system and destocking (EWS)

Cattle physical condition declines during a drought, until they become too weak for transport and commercial sale. This leads to emergency slaughter and meat distribution. This measure improves resilience by using an EWS to predict when and where drought is likely to occur. It enables action to be taken to facilitate the orderly sale of livestock (offtake), thereby allowing animals to be sold in better condition. Mortalities are reduced and better prices are achieved for cattle sold, giving farmers the means to maintain more of their breeding herd and restock more rapidly after the drought.

2.3. Fodder planting (FP)

The measure entails farmers planting crops on land that is currently unused or under-used, thereby achieving increases in feed availability that increase growth rates, cow fertility, and the offtake rates of adult males.

2.4. Rangeland restoration (RR)

This measure refers to active restoration (rather than passive restoration via just resting rangeland), i.e. planting desired herbaceous plant species and removal of woody plants/invasive plant species to restore productivity for grazing. It also entails supplementary feeding with purchased hay to allow a reduction in grazing pressure. This measure has similar effects as fodder planting, i.e. it increases growth rates, cow fertility, and the offtake rates of adult males.

3. Methods

3.1. Overview of the model

A dynamic model of the pastoral cattle system was developed to undertake the analysis (Supplementary Information Figs. 2 and 3). At its core is a herd model that calculates the population and production each month, based upon the input values for herd parameters (e.g. fertility, mortality and offtake/replacement rates), and taking into account drought occurrence and stocking rate. The household profit is calculated in the Economics model, based on output from the Herd model and other input values. The total GHG emissions and emissions intensity are calculated in the GHG model, which combines output from the herd model with a set of input values for parameters including emission factors, assumptions about ration composition and digestibility etc. The model was parameterised using a combination of published data and calibration. In the latter, relationships between key parameters (such as drought index, fertility and mortality) were varied until a good match was achieved between the modelled and reported population trends.

The theoretical behaviour of the population under three different scenarios is shown in Fig. 1. With no droughts (Scenario A), the population increases until it is constrained by feed availability. As the population increases, the stocking rate increases and the fertility rate decreases (and at high stocking rates, mortality increases) until the births are equal to the deaths, i.e. the herd reaches its equilibrium population. In Scenario B (droughts but no measures) the population is reduced when drought 1 occurs (due to increased mortality and sales, and decreased fertility). This also lowers the stocking rate, which leads to a higher fertility rate post-drought. The population grows until a second drought occurs in year 15. Implementing a measure (Scenario C) reduces the impact of drought, enabling smaller reductions in population and/or more rapid recovery post-drought. In order to determine the effect of the measures, the model is run until the no drought scenario is in equilibrium. The population and production for this period are then compared to the same period with droughts and measures. The effects of

Table 1
Indicators used to estimate the effect of each measure on resilience. *production measured in terms of mass of protein. **income in terms of operating profit per household (HH).

	Livestock production*	Income**	Tendall et al. (2015)
Time to impact	Time between start of drought and 20% reduction in protein production	Time between start of drought and 20% reduction in household income	Capacity to withstand
Duration of impact	Time taken (from start of drought) to return to 90% of pre-drought production levels	Time taken to return to 90% of pre-drought household income	Rapidity, flexibility
Change in output	Change in production with the measure over the 1 and 5 year periods after the start of the drought compared to production without the measure	Change in income with the measure over the 1 and 5 year periods after the start of the drought compared to income without the measure	Capacity to absorb, resourcefulness, adaptability
Extent of recovery	Production 1 year and 5 years after the start of the drought as a % of pre-drought production	Income 1 year and 5 years after the start of the drought as a % of pre-drought income	Capacity to absorb, resourcefulness, adaptability

drought index and stocking rate on cattle populations are explained further in the Supplementary Information.

Drought is represented in the model using a drought index based on Normalized Difference Vegetation Index - NDVI. The drought index for 2000–2020 (based on satellite imagery) was used to calibrate the model. Rainfall and temperature projections from three different climate models were used to estimate the NDVI trends in Oromia for the 2021–2100 period, and the results indicated that drought events will continue to pose serious challenges to the resilience of pastoralists in the future. The effects of the resilience measures were analysed using a theoretical drought scenario reflecting the frequency and intensity of droughts over the last twenty years. In this scenario, two severe droughts, two moderate droughts and four mild droughts occur over a twenty year period (see World Bank, n.d. (forthcoming).

In order to measure changes in resilience consistent with this definition, a series of indicators were developed (Table 1). This table also shows how these indicators map on to the components of resilience proposed by Tendall et al. (2015).

3.2. GHG calculations

The scope of the emissions calculation is cradle to farm-gate, i.e. it includes the emissions arising on-farm, and the emissions arising pre-farm from the production of feed, fertiliser and fuel. Post-farm emissions arising from the distribution, processing and consumption of commodities are not included. The GHG categories included are summarised in Table 2.

The emissions are quantified using formulae established by the Intergovernmental Panel on Climate Change (IPCC, 2006, 2019). The IPCC guidance provides a choice of methods for quantifying emissions, from the relatively simple Tier 1 approach to more complex Tier 2 or 3 approaches. This study adopts a Tier 2 approach for livestock, i.e. key processes such as feed consumption and excretion rates are calculated based on the PAP livestock characteristics (e.g. herd structure, animal weight, growth rates, milk yields and ration composition).

The results are expressed in terms of total emissions (in CO_2-equivalent) and emissions intensity, i.e. the amount of CO_2e produced per unit of output. The output is expressed in kg of protein, i.e. the amount of meat protein in cattle sold plus the net milk yield (milk secreted minus the milk consumed by calves).

3.3. Model assumptions, calibration and validation

The values and assumptions for key parameters, and their derivation are given in the Supplementary Information Table 1. There is evidence that droughts lead to decline in cattle populations by reducing fertility rates and increasing mortality rates (Angassa and Oba, 2007; Tuffa and Treydte, 2017). To determine realistic fertility and mortality rates, a process of calibration was undertaken where the values of parameters with a strong influence on population were varied (within defined ranges) until the best fit between the modelled cattle population and the real population over the period 1994–2018 was obtained (Supplementary Information, Fig. 5).

The values for selected parameters (fertility rate, mortality rates, age at first calving, growth rates and milk yields) were compared against other studies and found to be in the reported ranges (see World Bank, n.d. (forthcoming, Appendix D).

Table 2
Summary of the GHG categories included in the calculations.

Name	Description
Feed soil C	(Positive and negative) emissions from changes in soil C, arising from rangeland restoration and fodder planting
Feed: N_2O	Direct and indirect N_2O from (a) application of (synthetic and manure) N to crops, (b) crop residue management and (c) direct deposition of dung/urine by grazing animals
Feed CO_2	CO_2 from energy use in the production of feed materials, i.e. production of synthetic fertilisers applied to feed crops, field operations, feed transport and processing
Manure N_2O	Direct and indirect N_2O arising during the management and storage of excreted N
Manure CH_4	Methane arising during the management and storage of excreted volatile solids
Enteric CH_4	Methane arising from the microbial decomposition of feed in the rumen

4. Results

4.1. Trends in production and profit

Figs. 2 and 3 show the trends in production and profit with each of the measures, compared to the trends with no droughts and with droughts but no measures. Eight droughts occur over the 20 year period, two severe droughts in year 1, two moderate droughts in year 11 and two mild droughts in years 6 and 16. Each measure is assumed to be adopted by 20% of the PAP population, and the results are the average for the whole PAP population, i.e. adopters and non-adopters.

EWS provides the biggest increases (relative to the no measure situation) in production and profit, due to the way in which it leads to changes the herd size and structure. EWS maintains a larger herd than any of the other measures, and a greater proportion of the herd are adult females. Fodder planting and rangeland restoration provide moderate

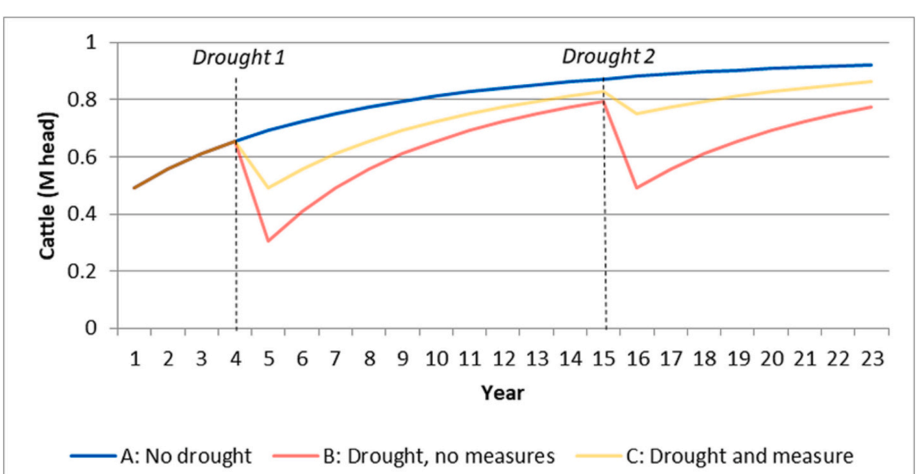

Fig. 1. The theoretical behaviour of the cattle population under three different scenarios.

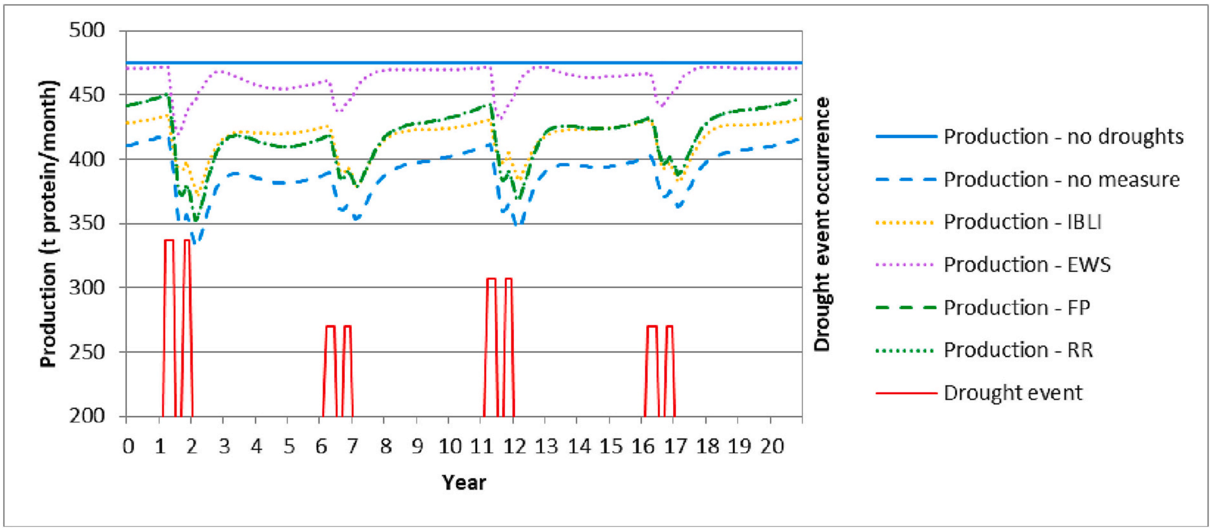

Fig. 2. Protein production for all PAP cattle in Oromia with: no droughts; droughts but no measure; droughts and each of the measures (IBLI, EWS, FP and RR) adopted by 20% of the pastoralists. "Drought event" indicates the timing of the eight droughts. Results are for a period when the no-drought scenario has reached equilibrium (see Fig. 1).

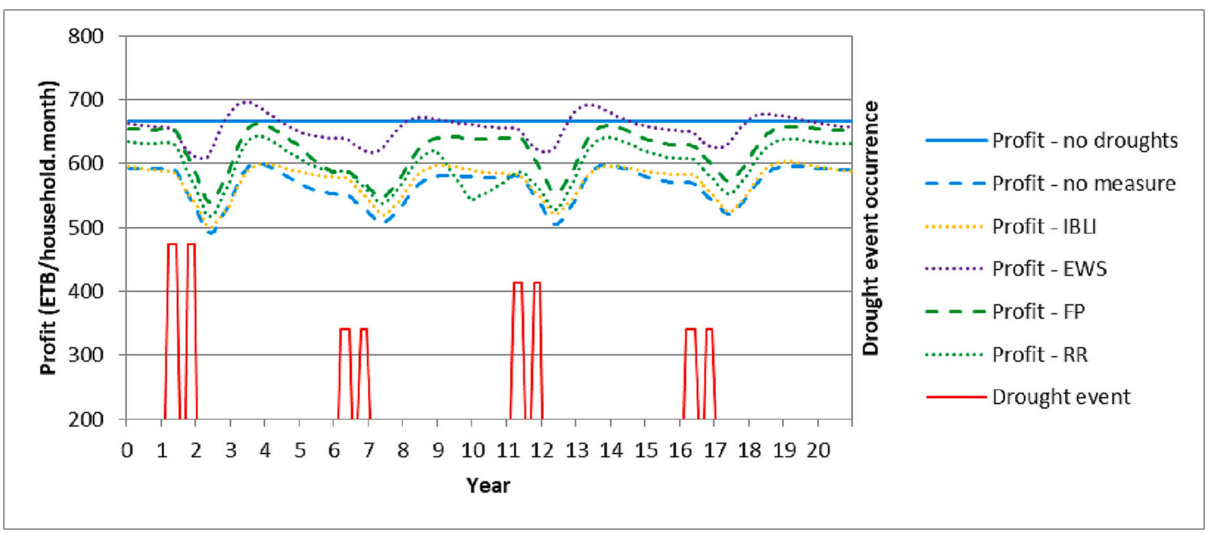

Fig. 3. Household profit for all PAP cattle in Oromia with: no droughts; droughts but no measure; droughts and each of the measures (IBLI, EWS, FP and RR) adopted by 20% of the pastoralists. "Drought event" indicates the timing of the eight droughts. Results are for a period when the no-drought scenario has reached equilibrium (see Fig. 1).

increases in production and profit (relative to the no measure situation); in practice the different characteristics of these measures could lead to different levels of uptake and impact. IBLI provides a moderate increase in protein production, but has no effect on profit, as it is designed to reduce risk rather than increase productivity or profit, at least in the short term.

4.2. Emissions intensity with no measures

The emissions intensity with no measures is shown in Fig. 4. Enteric methane dominates, accounting for 84% of the emissions. This reflects the rations, which consists of unmanaged grassland with low (55%) digestible energy content and the absence of feed CO_2 (as no synthetic fertiliser is applied, or fossil fuels used in feed production). The enteric methane emission factors calculated in this study are consistent with those reported in Wilkes et al. (2020), and the IPCC (2019) Tier 1a default values (Supplementary Information Table 2).

4.3. Change in EI in response to droughts

The EI in Fig. 4 is the average over a twenty year period. During this time the EI varies in response to droughts. The trends in EI over a twenty year period with eight droughts are shown in Fig. 5. Prior to the first drought the population and stocking rate increase and, in response, the fertility rate decreases. The decrease in fertility rate reduces the amount of milk produced per head, thereby increasing the emissions intensity. When the two severe droughts occur in year 1, there is an immediate increase in the EI caused by the decrease in fertility and increase in mortality during the droughts. These also lead to a drop in population and stocking rate, so that post-drought the fertility rate increases and the EI decreases then starts increasing again as the population recovers.

4.4. Effect of the measures on productivity, resilience and emissions

The effect of the measures in terms of a suite of CSA indicators is summarised in Tables 3 and 4. Positive changes (i.e. those enhancing

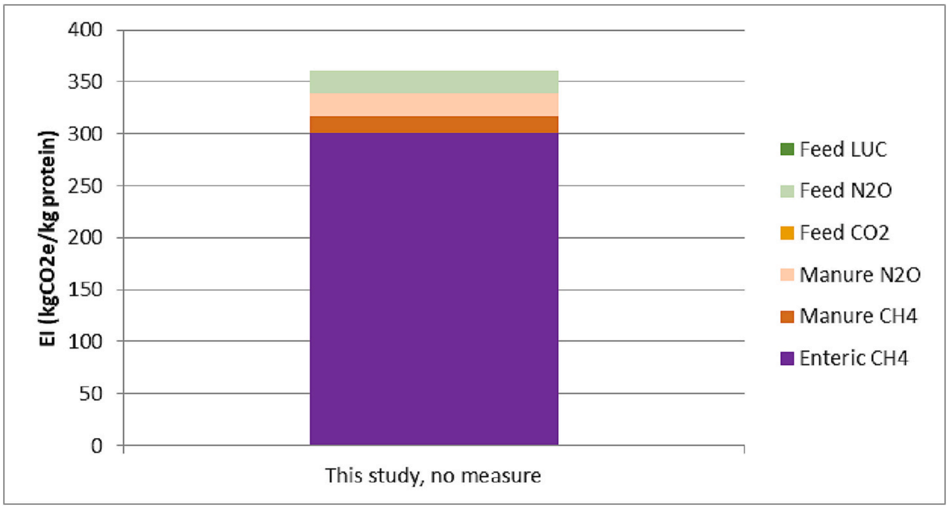

Fig. 4. Twenty year average emissions intensity with droughts and no measure. The EI is measured per kg of milk and meat protein ouput.

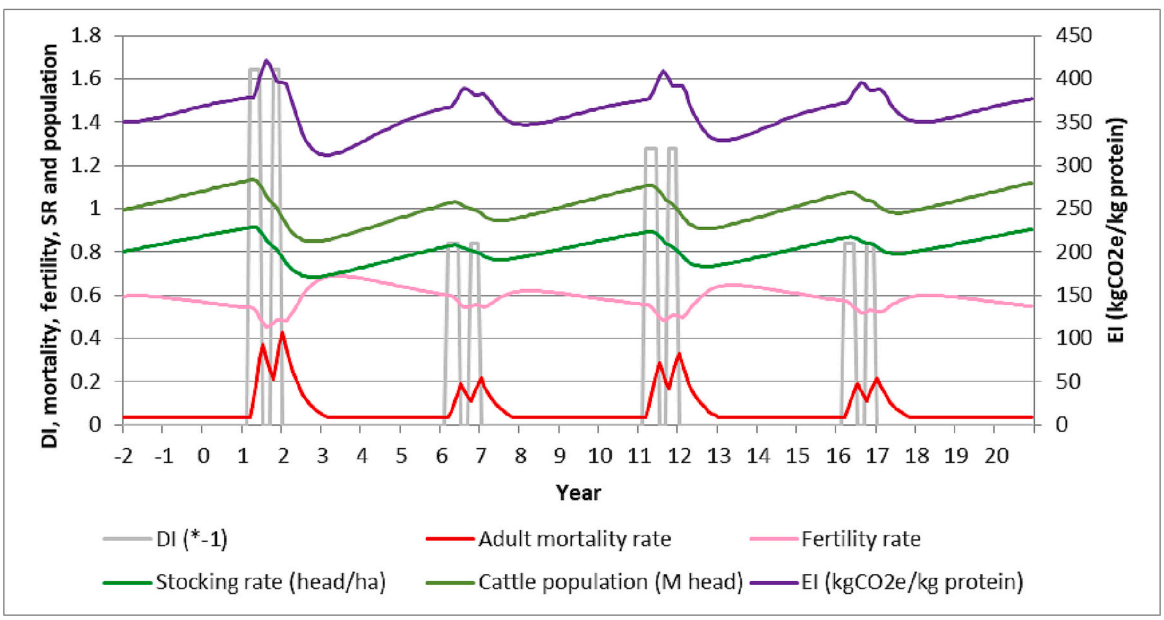

Fig. 5. Trends in EI over a twenty year period in response to drought events. The adult mortality rate is the proportion of adult cattle dying each year and the fertility rate is the proportion of adult females giving birth each year.

productivity or resilience, or reducing emissions) are coloured green, while negative changes are coloured red. Changes with a small effect (<5% change) are left white.

IBLI leads to some improvements in productivity and resilience but leads to large increases in total emissions, and modest increases in EI. While IBLI reduces drought mortalities (reducing the EI) this is offset by the reduction in fertility that arises from the increase in population and stocking rate. EWS leads to large increases in productivity and resilience. However, it also leads to large increases in total emissions and a mixed effect on EI. The destocking sales increase the 1-year meat production, reducing the EI, and while EWS also leads to higher stocking rates and lower fertility, this is compensated for by the way in which the destocking of male cattle means that EWS increases the proportion of cows in the herd. FP and RR improve productivity and increase total emissions, while having little effect on EI or resilience.

5. Discussion

Whether or not the measures are climate smart depends on what they are compared to, and how trade-offs between the three objectives of CSA are addressed. All four measures lead to increases in protein production and total emissions. Is the increase in emissions an acceptable cost? In order to determine this we would need to either quantify the net social cost/benefit of each measure (using cost-benefit analysis) and/or compare the additional emissions to those that would arise from the same increase in production without the measures (using a combination of economic modelling and life-cycle analysis).

The results suggest that productivity and resilience can be improved without increasing EI. It may be possible to improve productivity and resilience while also reducing EI. Sensitivity testing (Supplementary Information Table 3) indicates that EI could theoretically be reduced by increasing feed digestibility and/or milk yield. However, it is not clear how a significant improvement in feed quantity and/or quality could be achieved given the apparent feed deficit in Oromia. Feed could be

Table 3
CSA indicator values for each scenario. *">80%" and **">90%"indicates that protein/profit does not go below 80% or 90%.

	Indicator	Units	No measure	IBLI	EWS	FP	RR
	Protein production: 1 year average	t/month	370	401	498	395	395
	Protein production: 5 year average	t/month	378	413	468	405	405
	Protein production: 20 year average	t/month	388	416	471	417	417
	Profit per HH: 1 year average	ETB/month	514	523	607	567	544
	Profit per HH: 5 year average	ETB/month	557	567	652	609	593
Productivity	Profit per HH: 20 year average	ETB/month	564	572	655	620	595
	Time to impact: protein	months	11	>80%*	>80%*	11	11
	Time to impact: profit	months	>80%*	>80%*	>80%*	>80%*	>80%*
	Duration of impact: protein	months	19	15	>90%**	19	19
	Duration of impact: profit	months	21	21	>90%**	21	21
	Extent of recovery: protein, 1 year	%	80%	86%	100%	79%	79%
	Extent of recovery: protein, 5 years	%	93%	98%	98%	93%	93%
	Extent of recovery: profit, 1 year	%	85%	87%	93%	85%	84%
Resilience	Extent of recovery: profit, 5 years	%	93%	98%	98%	90%	93%
	Total emissions - 1 year average	ktCO2e/month	147	165	176	158	156
	Total emissions - 5 year average	ktCO2e/month	132	156	168	142	140
	Total emissions - 20 year average	ktCO2e/month	140	156	174	150	148
	Emissions intensity: 1 year average	kgCO2e/kg protein	399	412	354	400	395
	Emissions intensity: 5 year average	kgCO2e/kg protein	351	378	361	351	346
Emissions	Emissions intensity: 20 year average	kgCO2e/kg protein	360	376	371	360	355

Table 4
Change in CSA indicator values relative to the no measure scenario. ND: not determined as the value remains >80% in the "No measure" scenario.

	Indicator	IBLI	EWS	FP	RR
Productivity	Protein production: 1 year average	9%	35%	7%	7%
	Protein production: 5 year average	9%	24%	7%	7%
	Protein production: 20 year average	7%	21%	7%	7%
	Profit per HH: 1 year average	2%	18%	10%	6%
	Profit per HH: 5 year average	2%	17%	9%	7%
	Profit per HH: 20 year average	2%	16%	10%	5%
Resilience	Time to impact: protein	-100%	-100%	0%	0%
	Time to impact: profit	ND	ND	ND	ND
	Duration of impact: protein	-21%	-100%	0%	0%
	Duration of impact: profit	0%	-100%	0%	0%
	Extent of recovery: protein, 1 year	7%	26%	-1%	-1%
	Extent of recovery: protein, 5 years	6%	5%	0%	0%
	Extent of recovery: profit, 1 year	2%	9%	0%	-1%
	Extent of recovery: profit, 5 years	6%	5%	-4%	0%
Emissions	Total emissions: 1 year average	12%	19%	7%	6%
	Total emissions: 5 year average	18%	27%	7%	6%
	Total emissions: 20 year average	12%	25%	7%	6%
	Emissions intensity: 1 year average	3%	-11%	0%	-1%
	Emissions intensity: 5 year average	8%	3%	0%	-1%
	Emissions intensity: 20 year average	4%	3%	0%	-1%

imported, but whether many pastoralists would be able to afford the amount of feed supplementation required to change feed digestibility or milk yield is open to question. EI is also sensitive to increases in the offtake rate of adult male cattle, because doing so increases the proportion of adult females in the herd, the number of cattle sold and the number of calves born each year, leading to increases in protein production and profits. The extra profits could be used to improve cattle performance (thereby further reducing EI) via investment in cattle nutrition, genetics and access to veterinary services. However, in practice farmers may be reluctant to increase offtake rates for fear of losing animals to drought and disease; low offtake rates are in part a way of managing risk.

From a policy perspective, focussing on measures that improve resilience in PAP systems, rather than provide fully climate-smart solutions, may be justifiable given the vulnerability of PAPs to drought, conflict and other risks. Once resilience is improved, PAPs will be in a better position to exploit the opportunities afforded by the ongoing process of economic transformation in Ethiopia. People may decide to remain in pastoralism, and make use of the various mitigation and adaptation actions in Ethiopia's Nationally Determined Contribution, such as improved rangeland management, increased animal health services and greater provision of drought early warning information (FDRE, 2021). Or they may decide to seek opportunities outside pastoralism. Ultimately the future of PAPs should be decided by the pastoralists themselves from a position of security, rather than dictated by drought-induced desperation.

6. Conclusions

PAP systems in East Africa face a range of challenges including increased climate variability. While various measures have been proposed to improve their resilience, tools are required that enable measures to be appraised on a consistent basis. This paper developed a dynamic model of the PAP system in the Borena zone of Oromia, southern Ethiopia and used it to assess the effects of four measures in terms of their effects on resilience, productivity and GHG emissions.

The results indicate that FP and RR improve productivity, while IBLI and EWS improve productivity and resilience. The effects on emissions are mixed; all measures increase total emissions, while the EI is largely unchanged. This is partly a reflection of the measures chosen, which are primarily designed to improve resilience rather than reduce emissions.

The model is, by necessity, a simplification of a more complex reality. It assumes that, given the same starting conditions and drought magnitude, PAP systems will respond in the same way at different points in time. However, it is possible that fundamental change will occur in response to repeated droughts. Such threshold effects are hard to predict. It is also possible that the measures could have effects not captured in the model. For example, the way in which IBLI reduces risk could enable farmers to change their behaviour. Furthermore all of the measures increase food availability and economic accessibility (via increased household profit), which should improve PAP households' food security and productivity. How these effects play out over time is hard to predict, but worthy of further investigation. It is possible that while the measures analysed in this paper do not lead to immediate reductions in emissions, their positive effects on productivity and resilience could contribute to a longer-term transition to more climate smart PAP systems.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

Acknowledgements

This work was undertaken as part of the Programme for Climate-Smart Livestock Systems (PCSL), implemented by Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) together with the International Livestock Research Institute (ILRI) and the World Bank on behalf of the German Federal Ministry for Economic Cooperation and Development (BMZ) through the German Agency for International Cooperation (GIZ GmbH) under Externally Financed Outputs nos. 1388 and 1621. The authors would also like to acknowledge the support of Scottish Government Strategic Research Programme 2022-27: Theme C: Human Impacts on the Environment. The funders had no role in the study design, analysis or paper drafting. It has benefited from input received from: Polly Ericksen, Francesco Fava and Nathaniel Jensen (ILRI); Stanley Karanja (CIAT), Getachew Animut (Ethiopian ATA).

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.agsy.2023.103636.

References

Angassa, A., Oba, G., 2007. Relating long-term rainfall variability to cattle population dynamics in communal rangelands and a government ranch in southern Ethiopia. Agric. Syst. 94, 715–725. https://doi.org/10.1016/j.agsy.2007.02.012.

Araro, K., Addisu, S., Meshesha, D., 2019. Climate change and variability impacts on rural livelihoods and adaptation strategies in southern ethiopia. Earth Syst. Environ. 4 https://doi.org/10.1007/s41748-019-00134-9.

de Haan, C. (Ed.), 2016. Prospects for Livestock-Based Livelihoods in Africa's Drylands. World Bank Washington, DC, World Bank Studies available at. https://openknowledge.worldbank.org/handle/10986/24815.

FDRE, 2021. Updated Nationally Determined Contribution Addis Ababa: Federeal Democratic Republic of Ethiopia.

Gebremeskel, E., Nigatu, S.D., Kassa, G.K., 2019. Pastoral Development in Ethiopia: Trends and the Way Forward. Development Knowledge and Learning. World Bank, Washington, DC. License: Creative Commons Attribution CC BY 3.0 IGO.

IPCC, 2006. In: Eggleston, H.S., Buendia, L., Miwa, K., Ngara, T., Tanabe, K. (Eds.), 2006 IPCC Guidelines for National Greenhouse gas Inventories, Prepared by the National Greenhouse gas Inventories Programme. IGES, Japan.

IPCC, 2014. Summary for policymakers. In: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part a: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York.

IPCC, 2019. In: Calvo Buendia, E., Tanabe, K., Kranjc, A., Baasansuren, J., Fukuda, M., Ngarize, S., Osako, A., Pyrozhenko, Y., Shermanau, P., Federici, S. (Eds.), 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories. Published: IPCC, Switzerland.

Kimaro, E.G., Mor, S.M., Toribio, J., 2018. Climate change perception and impacts on cattle production in pastoral communities of northern Tanzania. Pastoralism 8, 19. https://doi.org/10.1186/s13570-018-0125-5.

Megersa, B., Markemann, A., Angassa, A., Ogutu, J.O., Piepho, H.-P., Zaráte, A. Valle, 2014. Impacts of climate change and variability on cattle production in southern Ethiopia: Perceptions and empirical evidence. Agric. Syst. 130, 23–34. https://doi.org/10.1016/j.agsy.2014.06.002.

Tendall, D.M., Joerin, J., Kopainsky, B., Edwards, P., Shreck, A., Le, Q.B., Kruetli, P., Grant, M., Six, J., 2015. Food system resilience: defining the concept. Global Food Security 6, 17–23. https://doi.org/10.1016/j.gfs.2015.08.001.

Tuffa, S., Treydte, A.C., 2017. Modeling Boran cattle populations under climate change and varying carrying capacity. Ecol. Model. https://doi.org/10.1016/j.ecolmodel.2017.03.009.

Wilkes, A., Shimels, E., Wassie, S.E., Tadesse, M., 2020. Inventory of GHG emissions from cattle in Oromia Region (1994–2018) calculated using the IPCC Tier 2 approach. Draft v.1 for sharing with OFLP team. 20th October 2020.

World Bank, 2022. Climate-Smart Agriculture. https://www.worldbank.org/en/topic/climate-smart-agriculture. Accessed 6/7/22.

World Bank, n.d. Improving the resilience of pastoral cattle production in southern Ethiopia Washington DC: The World Bank, (forthcoming).