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It depends on the rain: Smallholder farmers' perceptions on the seasonality of feed gaps and how it affects livestock in semi-arid and arid regions in Southern Africa

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A B S T R A C T

The risk of climate-induced feed gaps, i.e. seasonal deficiencies in forage quantity and quality, is a major constraint for livestock in the dry regions of southern Africa. In South Africa particularly, the frequent occurrence of drought is a challenge for livestock farming and, coping strategies to mitigate feed gaps on smallholder farms are urgently needed. We chose the Limpopo province, of northern South Africa to study livestock farmers' perceptions of the temporal patterns of feed gaps and their perceived impacts on livestock production across different agro-ecological zones (AEZ) and farm types (i.e., livestock only, mixed crop-livestock farms). We combined a semi-structured questionnaire on ninety farms with data from herbage analysis (mineral nutrient concentrations of grasses grazed in winter). Additionally, we explored the effect of seasonal feed availability on feed gaps, expressed as gross primary productivity (GPP), based on long-term simulated vegetation data. We found a close correlation between farmers' perceived feed gaps and GPP (Pearson's $r = -0.77$, $p < 0.01$). Farmers' perceptions of feed gaps are related to precipitation deficits that restrict rangeland productivity especially in winter and spring across the AEZ. Consequently, farmers considered that feed gaps occur mainly in winter (80%) followed by spring (30%) and autumn (20%). In addition, our analysis demonstrated that in winter the mineral concentration in rangeland biomass is inadequate to meet the livestock feed requirements. The percentages of farmers who perceived feed gaps and animal weight loss in the winter season did not differ significantly between farm types ($p = 0.40$) and AEZ ($p = 0.41$). Among livestock-only farmers, feed gaps were perceived to occur more in autumn ($p < 0.01$) whereas for mixed crop-livestock farmers the feed gap perception was greater in spring ($p < 0.01$). Farmers located in the drier zone perceived feed gaps more in spring ($p < 0.05$), leading to the significant perception of livestock weight loss for that period ($p < 0.01$). As strategies to deal with feed gaps, farmers rely on crop residues and/or reduction of livestock numbers. To improve the sustainability of the livestock system, our results show that feed gaps follow a strong seasonal pattern and they suggest that intervention strategies do not necessarily need to account for local climatic differences but rather for farm operation types.

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1. Introduction

Southern African smallholder livestock farming is complex and heterogeneous since the individual components (e.g., water resources, rangelands, feed resources) of the farming systems interact differently across agro-ecological zones, farm types, and typology (Herrero et al., 2013). Rangelands and, in the case of mixed crop-livestock farms, also arable land, play an important role as key feeding resources for livestock, as also discussed by Herrero et al. (2013). Both mixed-crop livestock and livestock-only farming systems are crucial for food production, and particularly in supporting the livelihoods of inherently resource-constrained farmers that mainly rely on grazed rangeland biomass and crop residues for livestock feeding (Descheemaeker et al., 2016; Thornton and Herrero, 2015). However, these developed management options are coming under pressure due to climate change, as many regions in southern Africa are affected by changes in rainfall amounts and distribution, increased heatwaves and droughts (Zhao and Dai, 2015). Moreover, such impacts bring changes in the availability and utilization of resources, with decreased rangeland productivity (Masson--Delmotte et al., 2018). Consequently, the effects of climate-related drought will affect the quantity and quality of feed and water resources for livestock. This presents a major risk to livestock production, unless adequate coping strategies are found (Rojas-Downing et al., 2017). It is likely that smallholder farmers that rely mainly on natural resources are particularly affected by climate extremes because of their limited technological knowledge and vulnerability to fodder shortages, resulting in feed gaps for the livestock during the year (Kom et al., 2020). Feed gaps, as explained by Moore et al. (2009), are the result of biological and socio-economic factors, and they occur during a period of the year when feed supply, in quality and its quantity, are insufficient or unavailable to sustain livestock productivity. According to Moore et al. (2009), feed gaps may occur frequently ('regular') due to intra-annual variability in the feed supply, or occur less frequently ('irregular') due to inter-annual variability in the distribution and supply of feed to livestock.

In southern Africa, smallholder cattle farmers rely predominantly on the communal use of natural resources, particularly rangelands. As rangeland productivity is affected by seasonal and inter-annual climate variability, farming households are especially vulnerable to changes in rainfall (Nyamushamba et al., 2017). Various studies in southern Africa, have suggested that smallholder farmers already perceive climate change and the variability associated with it as weather shocks, such as a decrease in rainfall days as shown in Tanzania (Mkonda et al., 2018), or increased drought and heat in Zimbabwe (Makuvaro et al., 2018). Similar findings have been reported for South Africa (Hitayezu et al., 2017), Botswana and Malawi (Simelton et al., 2013). One of the consequences of such climate-related shocks for communal livestock production is feed shortages, as shown in studies in arid and semi-arid regions of southern Africa (Tavirimirwa et al., 2019; Vetter et al., 2020). Therefore, recognizing farmers' perceptions on when and where feed gaps occur in relation to variations in seasonal productivity of communal rangelands could be very important for targeting strategic interventions. In South Africa in particular, the vulnerability of smallholder livestock farmers to feed gaps might have been further aggravated by previous land policies established in the Apartheid era, under which unproductive communal rangelands were settled by indigenous peoples (Bennett et al., 2013), as well as adaptive incapacities due to low economic resources (Tibesigwa et al., 2016). In line with this, in Limpopo, the poorest region of South Africa, efforts for improving the productivity of smallholder cattle farming systems have been implemented through a more efficient use of communal resources (Marandure et al., 2020a). Despite such initiatives to support smallholder cattle farmers in Limpopo, there is growing evidence of limitations to achieve high productivity due to psychological, socio-economical, cultural, ecological, institutional and, governmental constraints (Kom et al., 2020; Marandure et al., 2020a). For smallholder cattle farmers in Limpopo, the frequent and prolonged drought could be considered as an extended feed gap resulting in low productivity of the farming sector. In general, the perception of feed gaps at the farm level might vary greatly even within agro-ecological zone (AEZ) in relation to farm types, as some are better adapted than others for various reasons (Mkonda et al., 2018; Thornton and Herrero 2015). Consequently, Mkonda et al. (2018) argued that farmers located in arid zones (the most vulnerable AEZ) were more sensitive and responsive to climate variability and risks. Furthermore, farm types are likely to respond differently to climate variability impacts, and earlier studies have shown that mixed crop-livestock systems may be the least vulnerable as they offer diverse feed resource-opportunities for efficient adaptation (Thornton and Herrero, 2015; Weindl et al., 2015). In order to further explore these issues, the present study provides insights on farmers' perceptions on the seasonality of feed gaps, the impact on cattle productivity as perceived by animal weight loss and death, and the coping mechanisms against feed gaps. These assessments are linked to modelled vegetation productivity, and forage mineral nutrient concentrations, could serve to find prime examples for improved climate risk management plans to support smallholder livestock farmers at different farm operational types (i.e. livestock-only, mixed crop-livestock) and for different AEZ.

We hypothesized that the perception of feed gaps and coping strategies is dependent on the extent to which additional feed resources are available. Since mixed crop-livestock farmers have a greater range of available feed resources, we hypothesized that farmers categorized within that system perceive that feed gaps are less frequent or less important. As rangeland productivity is related to rainfall patterns, a second hypothesis is that the perception of feed gaps, and the perception of animal weight loss, are greater in the drier AEZ irrespective of the farm type.

2. Materials and methods

2.1. Description of the study area

The study was conducted in the Limpopo province of the Republic of South Africa bordering Mozambique, Botswana and Zimbabwe and covers an area of 125,755 km^2 of which approximately 81% is used for livestock grazing (Oni et al., 2012). The climate varies from warm-arid in the lowland valleys to humid subtropical in the highlands (Cai et al., 2016) and average rainfall varies from

< 200 mm to > 1000 mm (drier in the north-eastern parts and wetter along the Tzaneen valleys). The rainfall in the province mostly occurs in spring till summer (September-February) and in the remaining period there is little or no rain. In summer, the average temperature is about 27 °C with maximum temperatures reaching between 45 °C and 50 °C in the lowlands. The climatic patterns brought the development of different vegetation types which include grasslands (mainly C4 species), savannas, bush Feld, and forests (Mpofu et al., 2017). In 2016, an estimated 369,460 households in Limpopo were engaged in farming activities, predominantly livestock-only farming (43%) but farming households also engage in cropping-only (38%) and mixed systems (18%) (Stats, 2018). About 90% of Limpopo's population lives in rural communities, thus, farming is dominated by subsistent smallholders for self-supply with a low level of production inputs and technology (Stroebel et al., 2011). Past El Niño events with anomalously low precipitation and extreme heatwaves, with impacts (i.e. severe droughts), have rapidly stressed the agricultural sector in Limpopo (Archer et al., 2017; Hitayezu et al., 2017). Furthermore, climate change projections indicate that the region will become drier with frequent summer dry-spells in addition to the regular winter dry-seasons that particularly affect cattle herd dynamics and productivity (DEA, 2017).

2.2. *Data collection: farm-level information and grass sampling*

A survey was conducted among 90 farms with the support of extension officers from June to September 2019. The data collection refers to a stratified farm household survey based on a semi-structured interview where farm owners or managers answered the questions. For this purpose, farm households were selected in three AEZ representative of the climatic conditions of the province (warm arid n = 29, warm semi-arid n = 29, cool semi-arid n = 32) (Mpandeli et al., 2015) (Table 1). In each AEZ, two or three villages were selected and farm households were classified into two farm types, i.e., livestock-only or mixed crop-livestock farming. We collected farm-specific information on the livestock system and production principles (here we defined production as mechanisms to ensure crop-livestock production and sustenance), feed gap patterns and impacts on the production system, coping strategies, and overall constraints to livestock production (the questionnaire is available in the Appendix S1). The impact of feed gaps on livestock production was measured as farmers' perception of animal weight loss and death during the period of feed deficit (Moore et al., 2009). For the mixed crop-livestock farm type, the crop production component was surveyed as well. The description of the variables is presented in Table 2. The questionnaire was divided into four parts. The first part took records of general information (e.g., site information, coordinates, altitude). The second part (questions 1–22) considered farming production principles and characteristics (e.g., cattle number, purpose, feeding regime, farm types). Parts three and four reported on the perception of feed gap periods and risks (e.g., perception of feed gap periods, perception of animal weight losses, death due to feed gaps, questions 23–34), coping strategies, and constraints (questions 35–37). The variables were used to capture the dynamics of feed gap perceptions, i.e. how and when farmers perceive feed gaps, and whether the farmer has developed responses or not. Before we carried out the questionnaire with the local farmers, we trained a facilitator who assisted in understanding and communicating to avoid misinterpretation of questions and answers from English-Local (Pedi and, or Tsonga) and Local-English language.

The surveyed farms were mainly characterized by small herd sizes (90% having 5–25 cattle) dominated by culturally and locally well-adapted 'Ngunis' and their crossbreeds. With respect to the cattle feeding regime, farmers depend on communal grazing lands for year-round continuous grazing. Hence, we collected plant biomass samples (grasses only) at the village level on the communal grazing lands to analyze the AEZ-specific rangeland biomass composition. Since sampling was done in the dry season where no growth takes place, the dry grasses (short and tall grasses) were either hand plucked or cut from inside a 50 cm × 50 cm quadrat near the soil surface. Before sampling, evidence of grazing was searched for (either by sampling near the animals on the rangelands or evidence of relatively abundant dung patches and grazed plants). Four dry grass samples were randomly taken on each grazing site following a longitudinal transect-based approach (5 m apart). Samples were dried at 60 °C, ground, and analyzed for phosphorus (P), potassium (K), magnesium (Mg), calcium (Ca), sulphur (S), sodium (Na), boron (B), copper (Cu), iron (Fe), manganese (Mn), zinc (Zn) and molybdenum (Mo) using the calcium-acetate-lactate (CAL) nutrient extraction method (Schüller, 1969). The concentrations of P and K were determined in continuous flow analysis coupled to a flame photometer (K) or UV/VIS spectro-photometer (P) (San System, Skalar, the Netherlands). The remaining nutrient concentrations were determined using atomic absorption spectrometry (AAnalyst 400, Perkin Elmer Inc, Waltham, USA).

2.3. *Modelling patterns of regional feed availability using aDGVM*

A dynamic vegetation model was used to quantify the gross primary productivity (GPP) of vegetation within the selected AEZs in order to compare these outputs with the farmer's perception of feed gaps. The GPP is usually expressed as carbon (C) accumulation rate (g C m^{-2} day^{-1}). For this, we extracted GPP from simulations with aDGVM (adaptive Dynamic Global Vegetation Model) presented by Martens et al. (2020). The model has been used previously and evaluated for vegetation simulation studies and dynamics in the context

Table 1
Characteristics of the selected sites.

Agro-ecological zones	Mean altitude (m)	Range of annual precipitation (mm)	Mean cattle number (±SD)	Number of livestock-only/mixed crop-livestock farms
Warm arid	369	200–300	15.96 (8.16)	12/17
Warm semi-arid	681	400–500	10.25 (6.48)	11/18
Cool semi-arid	1097	500–600	45.08 (28.6)	28/4

Table 2
Description of the variables used for the farm survey.

Variable names	Variable description*
Part I: General information	
Altitude	Continuous
Agro-ecological zones	Dummy (warm arid, warm semi-arid, cool semi-arid)
Coordinates	
Farm ID	
Part II: Farm characteristics	
Farm type	Dummy (livestock only, mixed crop-livestock)
Livestock type	Dummy (sheep, goats, pigs, poultry etc.)
Rearing purpose	Dummy (security, sales, home consumption)
Cattle number	Continuous
Feeding systems	Dummy (year-round, zero grazing, stall feeding)
Crops grown (mixed systems)	Dummy (maize, cowpea, lablab, sorghum, etc.)
Crop yield utilization (mixed systems)	Dummy (sales, home consumption, livestock feed)
Crop growing months (mixed systems)	Dummy (months of the years)
Part III: Feed gaps perception and risks	
Months of feed gaps	Dummy (months of the year)
Seasons of feed gaps	Dummy (spring, summer, autumn, winter)
Seasons of feed availability	Dummy (spring, summer, autumn, winter)
Perception of feed gaps frequency	Dummy (regular, irregular)
Perception of animal weight losses	Dummy (yes, no)
Seasons of perceived weight losses	Dummy (spring, summer, autumn, winter)
Perception of animal death due to feed gaps	Dummy (often, sometimes, not likely)
Part IV: Strategies and constraints	
Coping strategies	Dummy (crop residues, feed purchase, feed aid, etc.)
Constraints to livestock production	Dummy (feed, theft, water, access to market, etc.)

*Dummy variables take up 1 when response corresponds or 0 when it does not.

of climate change for South Africa and the Limpopo province (Martens et al., 2020; Scheiter et al., 2018). The modelling exercises were not developed specifically for this study; Martens et al. (2020) provides all details on aDGVM and the simulation protocol. To understand the feed gap patterns in the study area and further compare the perception of the farmers (with data), the daily GPP ranging from 1990 to 2019 was simulated and retrieved for our study locations from the model and then grouped by season (Fig. 2). For each AEZ, the nearest neighbor sites of available climatic data (average distance between the climatic source and site 20 km $\pm$ 7 km) were used, and mean values ($\pm$SD) for vegetation only (grass and tree) are reported.

2.4. Statistical analysis

The data analysis focused on the perceptions regarding feed gaps and it makes comparisons of the farm types (livestock-only vs. mixed crop-livestock) across AEZs (warm arid, warm semi-arid, and cool semi-arid) and between AEZs across farm types using R 3.6.0 (R core Team, 2019). For these comparisons, the dependent and independent variables (Table 2) from the household survey data were subjected to basic descriptive statistical analyses (mean, frequency, percentage) on farmers' perceptions of feed availability, livestock weight loss and coping strategies, using the prettyR package (Lemon et al., 2019). A non-parametric test (Chi-square) was performed to test for similarities and differences in the perceptions or coping strategies between dependent variables expressed as percentages of farmers between farming systems across AEZs or between AEZs across farming systems (categorical, binary, and continuous variables) (Tesfahunegn and Gebru, 2019). For example, we tested for differences in the variability of perception of feed gaps in relation to seasons between farm types, or by testing for differences in the perception between livestock-only and mixed crop-livestock within one season. The Chi-square test is commonly used by adopting the classic Neyman and Pearson (1933) theorem. The test is normally valid when the percentages being analyzed are not too close to 0% and 100%, which is, unfortunately, the case when considering small sample size. For the analysis, we set the chisqtest () with the function correct = FALSE that returns the invalidity of the test automatically, which is corrected by implementing the Fisher's test based on Perezgonzalez (2015).

Additionally, we used Pearsons' correlation to identify the relationship between perceived feed gaps (farmers' perception) and actual feed gaps in terms of rangeland vegetation productivity (GPP). This relationship was established by plotting the average daily GPP (g C m^{-2} day^{-1}) per season against the mean proportion of farmers' perception on seasonal feed gaps across the three AEZ (warm arid, warm semi-arid, cool semi-arid). Since binary numbers (0,1) were used to report on farmers' perception on feed gaps i.e., 1 if a farmer perceives feed gaps and 0 when a farmer perceives no feed gaps, the mean proportion was calculated after grouping the perception per season across AEZ. A mean number closer to 0 consequently refers to no feed gap perception.

3. Results and discussion

3.1. Seasonality of feed perception and the vegetation growth

More than 50% of the surveyed farmers across all AEZ and farm types perceived the 4-month period of June to September to be affected by feed gaps, with the peak months being July and August, when 80% of the farmers perceived feed gaps (Fig. 1A). In spring (September-November), about 30% of the farmers perceived feed gaps, and in autumn (March-May) it was only about 20%. The summer (December-February) was clearly the season of feed availability, linked to precipitation in that period. No farmer perceived year-round feed gaps while <10% of the total thought that there are no feed gaps. These perceptions indicate that farmers are indeed aware of the erratic occurrence of precipitation and low productivity of vegetation associated with perceived animal body weight losses (80% in winter, 40% in spring, Fig. 1B). In Limpopo, vegetation patterns are strongly linked to precipitation and this explains the clear and obvious perception of feed gaps in winter across farm types and AEZ. The perception of feed gaps is in accordance with the modelled vegetation growth rates (Fig. 2) which, unsurprisingly were associated with the seasonal rainfall. Using the modelled results, we found that the calculated annual GPP sum for each AEZ shows an increase over the years considered (1990–2000, 2001–2010, 2011–2019) (Fig. 2). The overall increase in the annual GPP sum across AEZ is partly related to an increase in the average annual rainfall in the region. In their description of rainfall frequencies in the Limpopo region, Thomas et al. (2007) showed a notable intra to inter-annual variability in the rainfall records. This variability is presented by a rainfall trend towards February – April, which could explain the increase over time in the daily GPP for the autumn months (March – May). Aside from that, the increase in GPP over time, as suggested by Martens et al. (2020), can be explained by a combination of other factors, which may include increased concentration of atmospheric carbon dioxide. In line with our modelled GPP results, Hyvärinen et al. (2019) who investigated vegetation patterns in the semi-arid areas of South Africa using Landstat multispectral data and soil adjusted vegetation indices, attributed the increase in vegetation productivity to increased precipitation. Therefore, although vegetation dynamics and productivity in semi-arid and arid regions are influenced by both biotic and abiotic factors, rainfall patterns or water availability are particularly reported as the main driver of its productivity. This may explain why the accumulated seasonal values of the summer GPP (Fig. 2) were largest in the cool semi-arid AEZ which receives more summer rainfall (Table 1, 3, the years of mean GPP values ranged from 12.67 to 14.97 g C m^{-2} $season^{-1}$), and the lowest GPP values were in the warm arid AEZ (6.13 – 8.69 g C m^{-2} $season^{-1}$). The accumulated GPP values in the warm semi-arid AEZ for the summer were intermediate (7.26 – 9.3 g C m^{-2} $season^{-1}$) between the two zones. For 1990–2000 the accumulated sum of GPP in g C m^{-2} for the cool semi-arid, warm arid and warm semi-arid zones was 22.7, 14.3 and 15.0. For 2001–2010, corresponding GPP values were higher at 24.9, 18.1 and 18.1, and for 2011–2019 values were higher still at 27.4, 19.8 and 21.2. The results suggest that the common grazing resources among smallholder farmers in the study area are constrained by low precipitation in the winter and spring seasons especially. The modelled GPP near to zero during winter (June-July-August) (Fig. 2) is related to the model assumption of leaf fall during the dormant stage of development without any carbon assimilation (Martens et al., 2020) but is also related to a lack of precipitation during the winter dry season. In this regard, we found a strong negative and significant relationship ($P < 0.01$) while comparing the average daily GPP (g C m^{-2} day^{-1}) accumulated per season against the mean proportion of farmers' perception of seasonal feed gaps (Fig. 3). This indicates that the farmers' perceptions on the seasonality of feed gaps are associated with temporal changes in rangeland productivity. Therefore, when GPP is low the mean perception value based on proportion of farmers' answers is closer to 1 (1 = feed gaps).

Furthermore, to increase the feed dry matter intake by cattle, there is the need to increase the feed quality. This is because an adequate supply of macro-nutrients and trace elements is crucial to promote cattle live weight gain. For instance Costa E Silva et al. (2015) estimated the dietary requirements for maintenance for beef cattle and assuming a live weight of 300 kg (1.2 Tropical Livestock

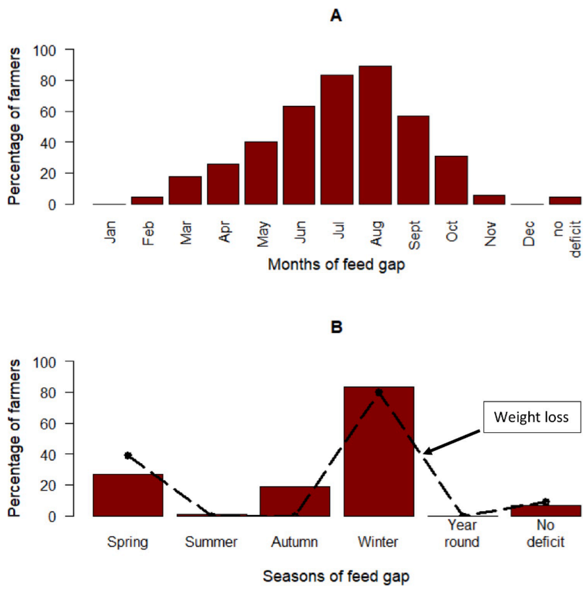

Fig. 1. Perception of feed gaps by months (A) and by seasons (spring: Sept-Nov, summer: Dec-Feb, autumn: Mar-May, winter: June-Aug) (expressed as % of total farmers) with the corresponding perceived feed gaps impact given as animal weight losses (black line) (B) across farm types and agro-ecological zones (also expressed as % of total farmers).

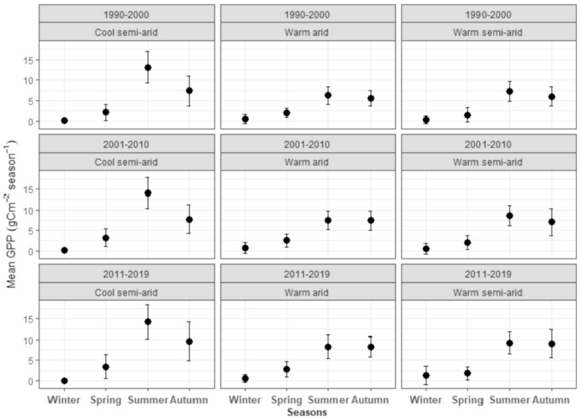

Fig. 2. Summary of the modelled accumulated mean GPP per season (spring: Sept-Nov, summer: Dec-Feb, autumn: Mar-May, winter: Jun-Aug) (±SD) in g C m^{-2} $season^{-1}$ across agro-ecological zones (results reported for 1990–2000; 2001–2010; 2011–2019).

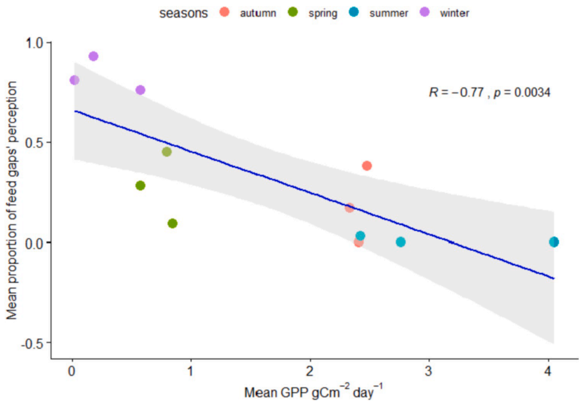

Fig. 3. Correlation (Pearson method) between the daily mean GPP accumulated per season (g C m^{-2} day^{-1}) and the mean proportion of perceived seasonal feed gaps across AEZ and farm type.

Unit (TLU), 1TLU = 250 kg), the macro-nutrient requirement (g kg^{-1} day^{-1}) for maintenance is 9.7 Ca, 15.4P, 5.6 Mg, 16.7 K, 6.5 Na and 11.1 S, and the requirement for trace elements (mg kg^{-1} day^{-1}) is 67.4 Cu, 1545 Fe, 70.5 Mn, and 451 Zn. The mineral nutrient concentration in the rangeland forage sampled in the present study (Table 3) was in the range reported previously for semi-arid and arid zones (Hussain and Durrani, 2008) but is not adequate to meet the requirements of the grazing cattle. Given these values are appropriate for the local breeds, rangeland forage concentrations of nearly all nutrients are insufficient to meet cattle requirements in this period. In addition, the crude protein content of rangeland biomass has been reported to be extremely low (2.7% in dry-matter) during the winter period (Moyo et al., 2012).

Table 3
Mean values (±SD) of macro and micro-nutrient content of grazed grasses in the winter period across three agro-ecological zones (two sites per AEZs and four samples per site).

Nutrients	Warm arid	Warm semi-arid	Cool semi-arid
P (g/kg)	1.26 (0.75)	0.49 (0.09)	0.63 (0.62)
K (g/kg)	13.41 (3.17)	11.12 (6.68)	7.23 (2.59)
Mg (g/kg)	2.02 (0.66)	2.78 (0.29)	0.91 (0.36)
Ca (g/kg)	3.54 (0.28)	3.24 (0.38)	2.81 (1.38)
S (g/kg)	1.38 (0.11)	1.37 (0.78)	1.59 (0.76)
Na (g/kg)	3.14 (2.01)	0.41 (0.06)	0.28 (0.05)
B (mg/kg)	7.46 (3.18)	5.16 (1.18)	4.32 (1.73)
Cu (mg/kg)	11.71 (4.58)	4.88 (0.99)	2.92 (0.48)
Fe (mg/kg)	422.13 (88.77)	314.75 (106.43)	186.83 (44.27)
Mn (mg/kg)	74.29 (25.26)	80.01 (30.42)	157.55 (116.59)
Zn (mg/kg)	34.75 (13.56)	38.84 (10.52)	32.73 (11.06)
Mo (mg/kg)	0.86 (0.11)	0.43 (0.19)	0.72 (0.21)

Consequently, in addition to the problem of feed gaps, the available forage does not meet the nutritional demands of cattle in terms of its nutrient mineral content. Moreover, increasing growth of drought-tolerant shrubs during the dry seasons, many of which are avoided by livestock, further reducing the feed value of rangelands (Hitayezu et al., 2017; Mapiye et al., 2009). Even though the dry matter intake is affected by a number of different factors (e.g. body weight, environmental factors, feed level and type), the perceived body weight loss of livestock, specifically during winter and spring (Fig. 1B) can be linked to the combination of a scarcity of feed resources and the mineral composition of the available forage.

3.2. *Perceptions of feed gaps by farm types*

There was no significant difference between farm types in the proportion of perceived feed gaps in winter (86% and 79% for livestock-only and mixed crop-livestock farmers, respectively) (Table 4). Nevertheless, the perception of feed gaps in spring and autumn differed significantly between farm types. Approximately 46% of the mixed crop-livestock farmers perceived feed shortages in spring while among livestock-only farmers, 12% perceived feed gaps in spring. In contrast, a larger proportion of livestock-only farmers perceived feed gaps in the autumn (33%), which was not the case for mixed crop-livestock farmers (0%). In many parts of southern Africa, subsistence crop production is part of a culture-based mechanism for sustaining livelihoods (Nyamushamba et al., 2017). Smallholder cropping is generally restricted to crops such as maize and beans, and the residues from these crops provide an additional feed resource for livestock keeping once crops on arable land are harvested, especially in arid and semi-arid regions (Thornton and Herrero, 2015). Therefore, the low perception of feed gaps in spring on mixed crop-livestock farms may be related to a limited amount of crop residues during late winter through spring. Typically, farmers start sowing as soon as first rainfall occurs in the region which can vary between October and December. Harvesting of crops is between March and May, and crop residues are left directly on the fields for livestock during autumn and winter. For mixed crop-livestock farmers, the perceptions on forage scarcity in spring is further reinforced by low rangeland growth rates during that time (Fig. 2). Meanwhile, livestock-only farmers rely heavily on the rangelands as the primary feed source. Consequently, feed shortages are experienced shortly after the onset of the autumn season

Table 4
Comparisons of perception responses (% of farmers) to feed gaps, feed availability, frequency of feed gaps, animal weight loss due to feed gaps, weight loss in seasons of feed gaps, animal death due to feed gaps, coping strategies and constraints of production. P-Values refer to the comparison of each proportion of the farmers' responses between farm types based on chi-squared tests.

	Livestock only farmers (n = 51)	Mixed farmers (n = 39)	P-values
Feed gaps perception			
Feed gaps in winter	86%	79%	0.40
Feed gaps in spring	12%	46%	**<0.01**
Feed gaps in summer	2%	0%	1.00
Feed gaps in autumn	33%	0%	**<0.01**
Feed availability perception	good-satisfactory-low	good-satisfactory-low	
Feed availability perception (whole year)	18%–65%–12%	31%–59%–10%	0.45
Feed quality in period of feed gaps	0%–14%–78%	5%–15%–79%	0.38
Feed quality in period of feed abundance	51%–39%–2%	69%–20%–3%	0.26
Frequency of feed gaps	regular-irregular	regular-irregular	
Feed gaps occurrence	75%–25%	67%–33%	0.42
Animal weight loss due to feed gaps	yes–no	yes–no	
Animal weight loss	94%-5%	85%-15%	0.13
Weight loss in seasons of feed gaps			
weight loss in winter	84%	74%	0.12
weight loss in spring	41%	36%	0.56
No weight loss	4%	15%	0.07
Animal death due to feed gaps	often-sometimes-not likely	often-sometimes-not likely	
Animal death	1%-37%-53%	18%-31%-51%	0.50
Coping strategies			
Government aid	22%	23%	0.86
Feed purchase	72%	56%	0.11
On-farm resources	57%	85%	**<0.01**
Feed budgeting	4%	5%	1
Reduce herd size	63%	45%	0.72
Feed storage during summer	18%	4%	0.15
Pasture management	0%	4%	0.18
Other strategies	37%	5%	**<0.01**
Constraints to production			
Feed availability	78%	54%	**< 0.05**
Unavailability of aid (feed aid)	12%	10%	1.00
Access to water (household, farms)	43%	46%	0.78
Theft	45%	64%	0.07
Animal walking distance to get water	8%	31%	**< 0.01**
Animal walking distance to get pasture	10%	38%	**<0.01**
Diseases	43%	49%	0.60

where the growth on rangelands has already ceased (Fig. 2). The availability of cropping residues in mixed crop-livestock farms may, therefore, be a distinct advantage over livestock-only farms in helping to minimize the vulnerability to feed gaps before the winter dry season. Furthermore, the occurrence of feed gaps is accepted to be a regular intra-seasonal phenomenon that does not depend on farm types, as reflected in the perception of animal weight loss (Table 4). Only a small but significant proportion (15%) of mixed crop-livestock farmers asserted that they did not perceive feed gaps throughout the year. Previous contextual studies have shown the vulnerability of the livestock farming systems to current climate variability (Rojas-Downing et al., 2017; Thornton et al., 2009). Through similar assessments, Weindl et al. (2015) expected a shift from single-purpose livestock farming to mixed crop-livestock farming especially under a climate vulnerable to drought. In line with this expectation, Tibesigwa et al. (2017) investigated the climate impact among single crop, livestock-only, and mixed crop-livestock farmers in areas prone to drought, and found that the mixed system was the least vulnerable. Our findings support these claims, although no systematic differences in the perception of the impacts of feed gaps' were found between the farming systems. Although mixed farms may have the possibility to feed from crop residues, the perception of seasonal weight loss appears to be the same across the different farm types. This is because the decrease in forage resources affects the availability of nutrients (Table 3) which presents problems for farmers from both farm types. Moreover, few mixed crop-livestock farmers claimed that they always preferred their cattle to graze on the dry pasture in the period of feed gaps rather than feeding maize residues as the latter is perceived to be of poorer quality. Despite this affirmation, the main coping strategy among farmers interviewed in this study reflects the use of on-farm feed resources (crop residues) which complements the limited amount of forage for grazing during the dry seasons. This strategy was significantly noted for mixed-crop livestock farmers. The integration of arable cropping coupled with livestock production increases the flexibility of the farming system to cope not only with socio-economic issues, but also climate variability as demonstrated by studies in Zimbabwe (Homann-Kee Tui et al., 2015). This is particularly true among the rural farmers in the stuy area who generally suffer from the effects of economic inequality, causing further resource-constrained problems (Kom et al., 2020). Additionally, farmers who are more secure financially may purchase fodder, thereby reducing the competition between farms for the use of crop residues. In periods of severe drought, where the coping measures

Table 5

Comparisons of perception responses (% of farmers) to feed gaps, feed availability, frequency of feed gaps, animal weight loss due to feed gaps, weight loss in seasons of feed gaps, animal death due to feed gaps, coping strategies and constraints of production. P-Values refer to the comparison of each proportion of farmer's responses between agro-ecological zones based on chi-squared tests.

	warm arid (n = 29)	warm semi-arid (n = 29)	cool semi-arid (n = 32)	P-values
Feed gaps perception				
Feed gaps in winter	93%	76%	81%	0.41
Feed gaps in spring	45%	26%	9.00%	**<0.05**
Feed gaps in Summer	0%	3%	0%	0.64
Feed gaps in autumn	17%	0%	37%	**<0.01**
Feed availability	good-satisfactory-low	good-satisfactory-low	good-satisfactory-low	
Feed availability perception (whole year)	3%-14%-76%	52%-0%-48%	16%-19%-63%	**<0.01**
Feed quality in period of feed gaps	0%-7%-86%	3%-31%-66%	3%-6%-84%	**<0.05**
Feed quality in period of feed abundance	28%-62%-3%	100%-0%-0%	50%-38%-3%	**<0.01**
Frequency of feed gaps	regular-irregular	regular-irregular	regular-irregular	
Feed gaps occurrence	90%–10%	45%–55%	78%–22%	**<0.01**
Animal weight loss due to feed gaps	yes–no	yes–no	yes–no	
Animal weight loss	97%-3%	83%-17%	91%-6%	0.21
Weight loss in seasons of feed gaps				
Weight loss in winter	86%	72%	81%	0.36
Weight loss in spring	66%	10%	41%	**< 0.01**
No weight loss	3%	17%	6%	0.21
Animal death due to feed gaps	often-sometimes-not likely	often-sometimes-not likely	often-sometimes-not likely	
Animal death	34%-41%-24%	0%-31%-69%	6%-31%-63%	**< 0.01**
Coping strategies				
Government aid	3%	17%	19%	0.38
Feed purchase	66%	48%	81%	**<0.05**
On-farm resources	93%	72%	44%	**<0.01**
Feed budgeting	0%	3%	9%	0.32
Reduce herd size	79%	38%	66%	**< 0.01**
Feed storage during summer	38%	17%	16%	0.08
Pasture management	0%	7%	0%	0.21
Other strategies	0%	10%	47%	**<0.01**
Constraints to production				
Feed availability	97%	24%	81%	**<0.01**
Unavailability of aid (feed aid)	7%	21%	6%	0.18
Access to water (household, farms)	28%	66%	41%	**<0.05**
Theft	62%	76%	25%	**<0.01**
Animal walking distance to get water	14%	41%	0%	**<0.01**
Animal walking distance to pasture	17%	48%	3%	**<0.01**
Diseases	59%	62%	19%	**<0.01**
Other constraints	41%	10%	38%	**<0.05**

(e.g. crop residues, feed purchase) are insufficient to deal with feed gaps, farmers reported reducing their herd size. This coping strategy is common among livestock keepers in arid and semi-arid zones. According to Karimi et al. (2018), it may be linked to a number of factors including the social and economic status (e.g. livestock number, access to capital) of the farmer. Hence, a farmer who has access to sufficient feed residues, or capital to purchase required amounts, may not be forced to reduce the herd size during feed gaps. As we envisaged, due to poor economic resources (and to some extent the failure of reducing herd size) some farmers, at times may not engage in any coping strategies. The proportion of farmers admitting this situation is greater among the livestock-only farmers (37%) than among the mixed crop-livestock farmers (5%) (Table 4), thus confirming the vulnerability of the sole livestock keeping system. The argument here, which is supported by Taruvinga et al. (2016), is that a 'no strategy' as observed among resource-constrained livestock farmers in South Africa, is generally conditioned by several factors such as social and financial status.

In the drier areas of southern Africa, the challenge of feed supply in quantity (Mapiye et al., 2018; Vetter et al., 2020) and quality (Maleko et al., 2018) is the biggest constraint and key to maintaining smallholder livestock production irrespective of farm type, as shown by the results of the present study. The proportion of farmers recognizing this challenge was significantly greater among livestock-only farmers (78%) than mixed crop-livestock farmers (54%) (Table 4). Our first hypothesis is thus confirmed, as the results between farm types showed that livestock-only farmers are likely to perceive the existence of more feed gaps. Though this perception of feed gaps and the attitude towards it may be motivated by social pressures, as mentioned above, the analysis here supported the risks of feed gaps due to limited complementary feeding resources among livestock-only farmers.

3.3. Feed gaps for different Agro-ecological zones

The results of the differences in perception between AEZ indicated that farmers, despite their agro-ecological location, are not affected differently by the winter dry period (June – August, Table 5). Across all AEZ, the winter season is a period of precipitation deficit that leads to decreasing availability of pasture forage sources (Fig. 2; Mpandeli et al., 2015). However, farmers perceived feed gaps in spring and autumn differently. Among farmers located in the warm arid zone, 45% of perceived feed gaps occurred in spring, which was the highest proportion, ahead of farmers in the warm semi-arid (26%) and cool semi-arid zone (9%). In the autumn, 37% of farmers in the cool semi-arid climate zone perceived feed gaps, followed by 17% of farmers in the warm arid zone and 0% in the warm semi-arid zone. As expected, and supported by Pfeiffer et al. (2019), values for rangeland productivity in the study area were constrained in zones where the annual rainfall is below 500 mm (Fig. 2). Farms located in the warmer region of the present study, where the average annual precipitation is about 300 mm, do not therefore have favourable conditions for forage production. Hence, the largest proportion of farmers that perceived feed gaps in winter (93%) and spring (45%) were found in the warm arid zone. In addition, in the warm arid zone, there was a significantly higher proportion of farmers who reported suffering from a regular intra-annual feed gaps often leading to livestock losses (Table 5).

Our results are consistent with recent literature for the southern African region, which shows that smallholder livestock keepers perform poorly under warmer climates (Descheemaeker et al., 2016; Mpofu et al., 2017). According to Descheemaeker et al. (2016), lower rainfall and higher temperatures under such a climate may have direct effects on the physiological functions of the livestock leading to losses. Moreover, approximately 17% of farms in the cool semi-arid zone perceived the existence of feed gaps in autumn (March–May) (Table 5). This larger proportion of farmers in the cool semi-arid zone experiencing feed gaps in autumn, compared to those in the warm-arid and warm semi-arid zones, is also likely to be influenced by an imbalance of farm types in the dataset for that zone (28 livestock-only and 4 mixed crop-livestock farmers, recognizing that farm types are nested in AEZ, Table 1). As mentioned above (Section 3.2), livestock-only farmers significantly perceived feed gaps in autumn because of their dependency on rangeland pasture where the productivity decreases in March – May. In the warm semi-arid zone, 52% of farmers believed that feed availability is adequate to maintain the annual production and farmers in this AEZ appear to be the least affected by the frequent occurrences of feed gaps. This could be explained by the environmental conditions for forage production being influenced not only by rainfall patterns but also by soil type, as reported by Mpofu et al. (2017) in the context of the performance of Nguni calves across different AEZ in the study area. In that study, there was a significantly lower performance in the arid zone where precipitation is about 300 mm and the land has been affected by soil erosion, with low water holding capacity and limited plant available nutrient content. The combination of these limitations has caused reduced nutritional value of rangeland biomass. Linstädter et al. (2014) linked rangeland production to some significant drivers such as biotic (e.g. grazing) and abiotic (e.g. soil texture); these differ locally causing shifts in the vegetation and thus in the variability of livestock response. In the present study, the dominant soil texture in the warm arid and cool semiarid zones was sandy loam with low water holding capacity, whereas the dominant soil texture in the warm semi-arid zone is clay loam that can store more water and maintain rangeland production for a longer period without rainfall. Differences in perception in the warm semi-arid zone could be attributed to soil variables but also the availability of a larger grazing area with less bush encroachment. However, this also depends on the community-level stocking density, which was not covered in the present study. The interaction of these pedo-climatic conditions and socio-economic factors may also explain part of the significant differences in the perceptions by farmers with regard to feed gaps, feed availability and the frequency of feed gaps between different AEZ (Table 5).

Moreover, differences in the strategic approach by farmers to cope with feed gaps further explained the vulnerability of farmers located in the warm arid zone to the frequent occurrence of feed gaps. Strategies included purchasing feed, relying on the resources of crop residues from arable lands, and reducing herd size, among others. Farms in the warm arid zone recorded the greatest proportion (93%) of reliance on residues from their on-farm resources. Despite this, a high proportion (79%) additionally need to sell some animals to cope with the seasonal changes in the feed resources during the dry period (Table 5). Thus, forage shortages were always included among the major concerns for constrained farmers (Mapiye et al., 2018; Marandure et al., 2020a,b), but farmers that are the most exposed to climate hazards remain the most vulnerable to feed gaps (Karimi et al., 2018). As hypothesized, the impact of feed gaps is larger in the drier AEZ.

Farmers across all the considered farm types and AEZ have listed numerous challenges which demonstrate the adverse vulnerability of the local livestock farming systems to environmental and social shocks (Tables 4 and 5). Among the obvious challenges, the lack of water availability was thoroughly discussed.

Access to water for smallholder farms is a common challenge in the semi-arid and arid zones in Southern Africa (Descheemaeker et al., 2010). Water resources are an important part of livestock production systems and water scarcity is a fundamental issue that affects small farms particularly in the arid and semi-arid regions which have no access to watering infrastructures (Ricciardi et al., 2020). According to Ricciardi et al. (2020), 76.7% of small farms are located in water-scarce regions with disparities between irrigation schemes and coverages. South Africa is generally a water-challenged country with limited irrigation options for smallholder farmers. Current low rainfall patterns and high temperatures extend the vulnerability of the livestock systems (DEA, 2017). However, a specific challenge reported by farmers in this study is the walking distance to access water on rangelands. Other common challenges noted are (i) the unavailability of governmental feed aid (or feed aid not sufficient to improve feed supply in periods of feed gaps), (ii) diseases (livestock heartwater diseases, which is the main death cause of cattle and calves (iii) small grazing land with bush encroachments (iv) predators, and (v) access to capital . These challenges have been identified in the smallholder context as socio-economic, ecological and political issues that govern rural farmers and their production systems (Chepkoech et al., 2020). Furthermore, lack of coping strategies for rural farmers as noted in South Africa and in the study area specifically may be linked directly to farm typology, as poor farmers or farmers with no access to capital may fail to adapt (Mapiye et al., 2018).

3.4. *Limitations of the study and recommendations*

It is known from previous studies on the perspective of farmers that the livestock production suffers from climate change impacts. Based on the findings of the present study, where the perception of seasonality of feed gaps is linked to rangeland productivity and mineral nutrient content in the forage, evidence for seasonal adaptation or intervention strategies is provided that has relevance for southern African regions with simlilar agro-climatic gradients. However, the results from the present study may suffer from small sample size. Additionally, other factors besides rangeland productivity may account for the seasonality. For example, the animal weight loss could also be related to increased metabolic energy requirements for maintenance caused by the greater effort for walking in the search for grazing sites of sufficient quality during the dry period. The current smallholder community-rangeland-based livestock systems in southern Africa are generally in jeopardy due to rangeland degradation (Nyamushamba et al., 2017). Therefore, high stocking density could also lead to a quick decline in the quantity of forage, as demonstrated in the dry areas of South Africa (Vetter et al., 2020) and Zimbabwe (Tavirimirwa et al., 2019). Thus, from an ecological point of view, in communal livestock areas, where high stocking density could be problematic, appropriate herd size should be regulated to accommodate proper grazing management. However, Tavirimirwa et al. (2019), in their review of management options for communal grazing lands in Zimbabwe, reported a failure in the implementation of the destocking policy. This is because it threatens the economic, and sociocultural importance of keeping livestock since farmers normally attempt to maximize their herd size. Nevertheless, this policy could still be attainable in South Africa if destocking is subsidized for communal livestock keepers to be more in balance with the poor quantity and quality of forage during that part of the season. Moreover, crop residues are important for the smallholder livestock sector (Thornton and Herrero, 2015). However, in view of the perceived low quality, the establishment of a reliable testing system to determine the quantity and quality of cropping residues would contribute to a basis for coping that would also provide additional employment, should a *trans*-regional trade of residues develop. According to Tavirimirwa et al. (2019), future attempts in improving communal rangelands in arid and semi-arid areas should focus on improving fallow lands for controlled grazing. Therefore, it will be necessary to strategically focus on the farm types (i.e. livestock-only, or mixed crop-livestock) rather than on AEZ to improve the feed base. In addition, it is important to develop irrigation schemes that will provide watering points for the livestock, thus reducing the walking distances required during periods with feed gaps. It is also essential that future cattle development programs to facilitate the exchange of knowledge through proper training (e.g., water harvesting techniques) are targeted (Mapiye et al., 2018). Furthermore, the capacity of smallholder farmers in South Africa to implement these options can be influenced by many factors, including the type of feed gap, farmers' objectives, availability of infrastructure and provision of financing (Marandure et al., 2020b). Thus, in future studies, in order to evaluate rural policy, attempts to cope with feed gaps should be evaluated by farm types and the seasonality of feed gaps. Therefore, there is the need to evaluate the bio-economic effects of integrating different forage or feed conservation strategies, in a way to diversify the feed-base across smallholder farms as demonstrated in Mozambique (Cumbe et al., 2021) or in Zimbabwe (Descheemaeker et al., 2018) to support a final decision making.

4. Conclusion

Based on the approach we used in this study, it emerged that smallholder livestock farmers generally suffer from feed gaps during the dry winter seasons irrespective of farm types. We firstly hypothesized that mixed crop-livestock farms are less affected by feed gaps than the livestock-only farms. This hypothesis is partly confirmed since mixed crop-livestock farmers were able to compensate for a decline in community rangeland biomass production in autumn. Though the differences reported between agro-ecological zones may be related to farm types within the zones to some extent, livestock-only farmers in arid zones may be the most affected by feed gaps. Our second hypothesis, that the severity of feed gaps increases with aridity irrespective of farm types is also supported. Measures to reduce or cope with feed gaps do not necessarily need to account for local-climatic differences but rather for different farm operation systems. However, overcoming the frequent occurrences of feed gaps may prove to be difficult and complex as it is not only governed by biological factors, but also by farmer's socio-economic capacities. While we are aware that farmers on their own cannot afford to incorporate these suggestions, these specific policies/strategies can be implemented with the support of government institutions, credit institutions and scientists. Further livestock or mixed crop-livestock research in this context should consider assessing risks and feed-based balance strategies perhaps through a whole-farm modelling approach for the region.

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.

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