
# A dynamic model to analyze the sustainability of extensive common-pasture-based livestock husbandry in Sahel

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*Abstract*

*Semi-arid regions in the Sahel have faced increasing environmental pressure due to population growth and decreasing rainfall. Building on earlier research we develop a stochastic dynamic programming model that describes extensive, common-pasture-based livestock under stochastic and spatially varying weather. We extend previous research by allowing animals' movements between two regions and allow decisions to be adjusted when new information about the weather arrives. Decision rules to sell and move animals under exogenous price, market and climate scenarios are investigated. Our numerical analysis demonstrates that in the absence of efficient feed markets and under unpredictable weather, transhumance can be a rational livestock management strategy. Increased frequency of extreme weather conditions, such as heavy drought or rainfall, can have cross-regional spillovers and larger impacts on livestock husbandry than gradual changes in the mean annual rainfall or temperature suggest. Hence, policies should aim at mitigating the negative consequences of extreme weather across regions.*

Keywords: livestock, common pasture, grazing, climate change, climate variability, drought, resilience

JEL codes: D80, O13, Q12

## 1. Introduction

Households in the arid or semi-arid regions often practice transhumance, which means that the household or part of it moves seasonally with animals from a common pasture to another. This is common also in Ferlo, Senegal, which is part of the Sahelian rangeland, and where movements of pastoralists are driven by spatial distribution of annual rainfall. Semi-arid regions in the Northern Senegal region have over the past fifty decades faced increasing environmental pressure as population has more than tripled and the amount of rainfall has decreased (Ickowicz *et al.* 2012). These changes pose substantial challenges to extensive pastoral livestock management, which is a prevalent economic activity in the area. Livestock serves as the most important source of food and cash for many households in the region. As a consequence of increased demand for food and reduced productivity of rangeland, the competition on feed and rangeland has increased and longer distances are travelled nowadays than in the past to feed the animals. Pastoralists can use several routes to move with their animals (Cesaro *et al.* 2010). One of the most important routes is from Ferlo towards the Peanut Basin area in the Southern Senegal.

We develop a dynamic programming model to describe rational livestock management under stochastic annual rainfall and spatial distribution of rainfall, and for various projections of future demand for meat. Management is organized so that it maximizes the total value of cattle as an asset of a representative household. Our model is built on an earlier model by Weikard and Hein (2011), which we extend in two important aspects. Firstly, we allow the movement of animals between two distinct regions (low vs. high rainfall region). While Ferlo is considered as the low rainfall area, Kaffrine is considered to receive more rainfall. Kaffrine is located in the Peanut basin area where there is more vegetation, higher market prices for livestock and more supplementary feeds are available for purchase than in the Northern Senegal.

Secondly, we optimize the movement of animals between regions and the number of animals to be removed from the stock in both regions each year under uncertainty. These extensions allow a representative household to account for all information that is available each time period and adjust the decisions as necessary when new information about the weather arrives. Movement away from Ferlo usually occurs at the end of the rainy season and return to Ferlo occurs when dry season is starting to turn to rainy season. Because transhumance is largely determined by the amount of rainfall, the decision to sell animals at the market and the rate of transhumance are made at the end of rainy season instead of deciding them before rainfall is observed as it was assumed by Weikard and Hein (2011). Also the long-term impacts on the production capacity of the soil are taken into account.

Optimal decision rules to sell animals and move them between regions are investigated under exogenously given scenarios, which can be regarded to address different price, market and climate change conditions. The goal of our analysis is to examine how different factors contribute to the animal stock and transhumance in a setting where the stakeholder maximizes the value of his/her asset. The results will illustrate how transhumance, or lack of it, can impact households in the two regions and how different state of nature where decisions regarding the herd are made, can affect the decisions.

Population growth can be expected to increase demand for meat. Price level of meat can also increase in the future due to globally increasing demand (OECD-FAO 2014). To address this, we consider a scenario in which the price level of meat increases over time. The increase is based on the projected and observed population growth rates in Ferlo. On the production side climate change can have major impact on the availability of vegetative biomass to animals. Climate change can decrease the average annual rainfall and also increase the variability of weather. For instance, McSweeney at al. (2010) projected that the rainfall in Senegal can decrease by approximately 3% per decade by 2060. Moreover, the variability of rainfall has been estimated to increase by 30%. Variability can be measured for by standard deviation (SD) of the mean. Section 2 describes a simulation model for pastoral rangeland management and objective function used in the dynamic programming model, section 3 reports results and section 4 draws conclusions.

## 2. Material and methods

### *2.1. Objective function*

Dynamic programming was used to analyze the pastoral livestock manager's problem. Similar method was used by Weikard and Hein (2010). The objective function of the pastoral livestock manager is to maximize the value of livestock herd by adjusting stocking rate and the rate of transhumance (see Figure 1 for the description when each event takes place):

$$V_t(\mathbf{S_t}, \mathbf{m_t}, \mathbf{r_t}) = \max_{\mathbf{h_t}}(\pi_t(\mathbf{S_t}, \mathbf{m_t}, \mathbf{r_t}, \mathbf{h_t}\ ) + \delta V_{t+1} E((\mathbf{S_{t+1}}, \mathbf{m_{t+1}}, \mathbf{r_{t+1}})))\ \ for\ t = 1, .., T, \qquad [1]$$

subject to: transition and biophysical Equations 2-6

$\mathbf{S_t}, \mathbf{m_t}, \mathbf{r_t}$ and $V_T(\mathbf{S_t}, \mathbf{m_T}, \mathbf{r_T})$ are given.

where $V_t(\mathbf{S_t}, \mathbf{m_t}, \mathbf{r_t})$ is the maximized value of livestock herd at time period *t* when the current stocking rate $\left(\mathbf{S_t} = \left\{S_t^{\text{Ferlo}}, S_t^{\text{Kaffrine}}\right\}\right)$, carbon content of the soil $\left(\mathbf{m_t} = \left\{m_t^{\text{Ferlo}}, m_t^{\text{Kaffrine}}\right\}\right)$ and the current year's rainfall $\left(\mathbf{r_t} = \left\{r_t^{\text{Ferlo}}, r_t^{\text{Kaffrine}}\right\}\right)$ in the two regions indicated by the superscripts are given; $\mathbf{h_t} = \{h_t^{\text{Ferlo}}, h_t^{\text{Kaffrine}}, h_t^{\text{move}}\}$ is the control vector which contains decisions to sell animals from the stock in Ferlo ($h_t^{\text{Ferlo}}$) and in Kaffrine ($h_t^{\text{Kaffrine}}$) and the decision to move seasonally with animals ($h_t^{\text{move}}$, transhumance is indicated as the percentage of Ferlo's livestock that is participating in transhumance) as indicated by the superscripts; $\pi_t(\mathbf{S_t}, \mathbf{m_t}, \mathbf{r_t}, \mathbf{h_t}\ )$ is the pastoral livestock manager's annual net cash flow; $\delta$ is the annual discount rate; *E* is the expectations operator; and *T* is the number of years examined. Transhumance directly affects soil carbon content in both regions and the amount of meat that can enter in the markets in the two regions, and it may affect the number of animals in stock in Kaffrine and Ferlo. During the dry season, transhumance increases competition on vegetative biomass in Kaffrine whereas in Ferlo the competition is reduced. Based on consultation with local herd owners, we assumed that maximum 90 % of livestock population in Ferlo can transhume because people not moving with the animals also need some livestock.

The pastoral livestock managers' annual profit, $\pi_t$, is described by

$$\pi_t\left(\mathbf{S_t}, \mathbf{m_t}, \mathbf{r_t}, \mathbf{h_t}\ \right) = p_t^{\text{Ferlo}} h_t^{\text{Ferlo}}(1 - h_t^{\text{move}}) + p_t^{\text{Kaffrine}} h_t^{\text{Ferlo}} h_t^{\text{move}} + \ p_t^{\text{Kaffrine}} h_t^{\text{Kaffrine}} - \left(c + c_{\text{move}} h_t^{\text{Ferlo}}\right) s_t^{\text{Ferlo}} - c s_t^{\text{Kaffrine}} - c_0. \quad [6]$$

where superscript denotes region where the parameter is relevant, $p_t$'s denote regional meat prices in period *t*, *c*'s denote variable costs of having the livestock and $c_{\text{move}}$ denotes the costs of transhumance per TLU/ha (Tropical Livestock Units per hectare of land) and $c_0$ is fixed annual costs.

*2.2 Simulation of livestock and biomass in the rangeland*

This section describes the generic model for a *single* region when transhumance does not take place. We model annual grass production (annual production of dry matter), $F_t$, as a function annual rainfall, $r_t$, rain-use efficiency of a semi-arid rangeland, $R_t$, and carbon content of the soil, $m_t$:

$$F_t = \alpha \frac{m_t}{m_0} r_t R_t \quad [2]$$

Time is denoted by *t*, initial soil organic matter content by $m_0$, and $\alpha$ represents the relative impact of reduced carbon content on plant productivity. Weikard *and* Hein (2011) neglected the impact of soil carbon in increasing the retention of nutrient and water, and thus improving the plant productivity. However, historical records show that intensity of land use alters soil productivity (e.g. Bauer and Black 1994), affects plant diversity (e.g. Müller et al 2012) and it is important to include such relationship in dynamic optimization of livestock management. Based on our test simulations and literature, parameter $\alpha$ is set at $\alpha = 1$ for Ferlo rangelands.

The dynamics of soil organic matter are described as:

$$m_{t+1} = m_t + \mu F_t - v s_t \quad [3]$$

where $\mu$ and *v* are parameters and $s_t$ represents the stocking rate of the livestock (TLU)
Rainfall efficiency is described as a parabolic function

$$R_t = \beta\left(min(r_t, \check{r}) - \underline{r}\right)\left(1 - \frac{min(r_t, \check{r})}{\bar{r}}\right) \quad [4]$$

where $\beta$ is a scaling parameter, $\underline{r}$ describes minimum rainfall required for plant growth and $\bar{r}$ stands for (hypothetical) level of rainfall where productivity drops to zero. Empirical observations (Hein and De Ridder 2006) suggest that during the years with exceptionally high rainfall, *R* may be lower than during years with average rainfall, although it never goes close to zero. The model by Weikard and Hein (2011) was modified accordingly by adding a parameter $\check{r}$ that makes sure that *R* does not go below 90% of its maximum level even during the years with much rainfall. Finally, rangeland productivity was translated into its annual capacity to support livestock grazing, $\bar{s}_t$, by diving grassland productivity by a parameter $\varphi$:

$$\bar{s}_t = \frac{F_t}{\varphi} \quad [6]$$

The dynamics of livestock are described as

$$S_{t+1} = S_t + \gamma\left(1 - \frac{s_t}{\bar{s}_t}\right)s_t - e^{-s_t} - h_t \quad [6]$$

where $S_t$ denotes the state variable for livestock, $s_t$ is the chosen stock rate, $h_t = S_t - s_t$ denotes sold animals, $\gamma$ represents the reproduction capacity of the livestock.

In the event that transhumance occurs, a proportion of animals are moved within a year from Ferlo to Kaffrine and back. This alters the dynamics in two important ways. Firstly, a proportion of soil organic matter originating from Ferlo animals will be for the benefit of Kaffrine. Secondly, during transhumance the relevant animal population will consume vegetative biomass available at Kaffrine instead of that available in Ferlo. Third impact, which does not affect model dynamics, is that a proportion of animals sold by livestock managers originating from Ferlo will access the markets at Kaffrine.

### *2.3 Data*

Monthly statistics on rainfall (1950-2012) available for Dahra observation station located in the southern Ferlo and for a Kaffrine observation station were used to describe the weather. Mean, variance and covariance of weather data were estimated based on the statistics. Next, probability distributions for annual rainfall were simulated for each iteration. Future projections of rainfall were based on mutually independent draws from the random distributions but taking into account the correlation between the two regions. Apart from the parameters specified in the previous section, other parameters in equations 2 to 6 were similar to Weikard and Hein (2011). The parameter values are summarized in Table 1.

An important additional aspect is that the price of meat varies by season and region. The price of meat is typically higher in the rainy region than in the dry region (CSA 2014). Hence, we use two prices, one for animals sold in Ferlo and another for the animals sold in Kaffrine. The meat price scenario for Kaffrine was based analysis of statistics and news about seasonal fluctuation of meat price. This analysis, in addition to interviews with the herdsmen in Ferlo, suggested that the price of meat is higher in Kaffrine than in Ferlo. As opposed to Turner and Williams (2002), an analysis conducted with the FAO long-term price statistics and Senegalese weather data do not suggest the assumption that locally observed drought would significantly affect meat prices in the region. Other price parameters were based on information obtained from interviews of herdsmen in Ferlo during a field study. $T$ was set at 30 years.

### *2.4 Solution method*

Numerical methods were used to solve the model because of their flexibility in future uses of the model. The state and control variables were discretised and interpolation was applied between the evaluation nodes. As the Taylor's series expansion was applied, the state and control variables were piecewise continuous. The numerical model was developed and programmed in Matlab R2013a (8.1.0.604), Mathworks inc.). The model was solved by using the value function iteration method (i.e. backwards, see e.g. Ljunqvist and Sargent 2000).

### *2.5 Exogeneously given scenarios for prices and climate change*

We examine optimal stocking rates, level of transhumance and prospects for sustainable pastoral livestock management under stochastic annual weather and exogenously given scenarios for prices and climate change. The results are reported in the event of low, medium or high rainfall in the two study areas. In the baseline scenario, there is a two-region model where transhumance can be practiced. Before the baseline scenario, we however first examine how taking into account the possibility of transhumance affects model results.

Further analysis examines scenarios where one the following characteristics are adjusted from the baseline model while keeping other factors at the same level as in the baseline. The scenarios differ from the baseline scenario by adjusting the mean of rainfall, the standard deviation of rainfall, meat price, and discount rate (Table 2). Increases in the mean and the standard deviation of rainfall reflect climate change scenarios and they are based on climate change UNDP climate change country profile for Senegal (McSweeney *et al.* 2010).

## 3. Results

### *3.1. Baseline scenario: Two-region model with transhumance*

In the baseline scenario transhumance can be practiced across two regions. Figure 2 illustrates the change (%) in the animal stock (i.e. newly born animals minus off-take) during one year period. The change is represented for different combinations of stocking rate in Kaffrine (measured in the beginning of rainy season), stocking rate in Ferlo and for three rainfall scenarios (both regions having either low, mean or high rainfall)). Hence, the intersection of red and blue represents a contour where the offtake of animals is equal to the rate of reproduction of animal in that year.

The sustainability of current animal population in both Ferlo and Kaffrine depends on the rainfall and stocking density in both regions because there is a movement of animals between the regions. In the event of the a year with an average rainfall, Figure 2 shows that Ferlo (Figure 2c) can accommodate less animals (i.e. a lower stocking rate) than Kaffrine (Figure 2d). Stocking rate also influences the offtake of animals. The larger stocking rate in the beginning of a year the more animals are removed from the stock during the year. The result is linked to the number of animals that one hectare of common pasture can feed. The rainfall impact so that in a rainy year (e.g. Figure 2a) the stocking rate can increase during the year to a higher level than in a dry year (e.g. Figure 2e).

Figure 3 describes the rate of transhumance (% livestock population in Ferlo affected) by the stocking rate in Ferlo and in Kaffrine. A higher proportion of population is participating in transhumance in a dry year than in a rainy year. Stocking density in Kaffrine is also sensitive towards pastoral livestock's situation in Ferlo when transhumance is possible. As transhuming herds are competing about the same resources as pastoral livestock in Kaffrine. Hence, the option to practice transhumance increases stocking density in Ferlo by approximately 10 to 20%, but decreases it in Kaffrine by almost 5%. Transhumance can act as a balancing factor and increase the aggregate stocking rate. However, the decrease in stocking rate in Kaffrine depends on the situation in Ferlo. If there are a lot of animals in the stock in Ferlo in the beginning of the year, the reduction in the Kaffrine stock can be more dramatic (even more than 30%) than if there is a small stock in Ferlo.

Figure 4 represents three scatterplots where the range of change in stocking density is plotted against stocking density in the beginning of the year, and transhumance rate (% of stock in Ferlo to move) is plotted against the number of animals in stock in Ferlo relative to the total animal stock in both areas. Since other stocking density or soil carbon content variables can vary even if one of the state variables is fixed, these figures represent the range where actions are taken in the model. For instance, even if stocking density in Ferlo is fixed at 0.1 TLU per ha, the change in stocking density can range from -5% to +45%.

The rate of transhumance increases rapidly when animal stock in Ferlo increases. However, when stocking rate in Kaffrine is large enough, there is more competition about the biomass and the rate of transhumance increases less rapidly when stocking rate in Ferlo increases. Similar pattern can be observed also in cases where there is a lot of rainfall in Ferlo. In our simulations we have limited transhumance so that not all animals in Ferlo can move seasonally. The situation becomes more complex if there is a drought in Ferlo. In that case, the rate of transhumance can have a U-shaped curve with respect to stocking rate in Kaffrine, if there is a drought also in Kaffrine. i.e. transhumance is practiced less frequently in cases where stocking rate in Kaffrine is close to sustainable level. The level of sustainability however depends on the amount of rainfall in Kaffrine.

*3.1. Two-region model when transhumance is not possible*

When transhumance cannot be practiced, the optimal sustainable stocking rate is higher in Kaffrine than in Ferlo and the change in the stocking rate is dependent only on the initial stocking rate in the same region, but not in the other region. This can be seen by examining changes in stocking density in Figure 2 and comparing it to Figure 5. The result is as expected because there is on average more rainfall in Kaffrine than Ferlo. Moreover, stocking density has a smaller impact of stocking rate in Kaffrine than in Ferlo. When stocking rate in Ferlo increases, it rapidly results in the selling of significant proportion of animals from the stock whereas Kaffrine is less sensitive to overstocking. Particularly when there is a drought, the stock in Ferlo can decrease significantly in the event of initially high stocking density. Ferlo is also more sensitive to drought, and years with plenty of rain in Kaffrine seem not to increase stocking density much.

The option to practice transhumance was simulated to increase the value of livestock activity by approximately 5%. Introducing the possibility of transhumance increases the optimal stocking rate

*3.3. Impact of scenarios*

Next we examine alternative scenarios when compared to the baseline scenario. Climate scenario B shows interesting results. If rainfall is to decrease on average by 3% per decade in both regions as projected by UNDP, then stocking rates are at least in the short term quite unaffected. Also transhumance is simulated to remain quite stable in the short run. However, the impact is more prominent when more distant future is examined: Drought can reduce stocking rates in both regions and to some extent also strengthen the pattern of transhumance. Over the long run, stocking rates were simulated to decrease in Kaffrine in cases where the initial stocking rate was low.

If the variability of weather increases by 30% (scenario C: SD increases by 30%) in both regions, then stocking rate is simulated to decrease in Ferlo a little especially in the event of a low-rainfall year. In Ferlo it is already quite dry and in some years livestock managers in Ferlo can benefit from heavy rainfall elsewhere and adjust their stocking rate accordingly (Figure 6).

If the price of meat increases (decreases) by 20%, the rate of transhumance increases (decreases) a little. The optimal stocking rate can increase (decrease, Figure 7) at least temporarily and in Ferlo because less animals will be sold in the event that the stocking rate is low in either of the regions. When meat price is simulated to increase by 2% a year, the optimal stocking rate is simulated to decrease a little. If prices were expected to increase by 2% a year, then transhumance is simulated to increase, but the increase is only marginal in the short run. The patterns of instantaneous sales of animals are simulated to change. At low stocking densities Ferlo's herdsmen are to sell fewer animals than in the baseline scenario whereas in high stocking densities close to the baseline scenario. Thus a higher stocking density and higher sales (number of animals) are expected at higher prices.

Doubling the discount rate from 5.5% to 11% is simulated to increase the rate of transhumance. However, even larger effect is simulated on stocking rate, which is simulated to decrease in most cases (Figure 8).

Table 3 represent the change (%) in value function when the baseline scenario and alternative scenarios are compared.  The results suggest that the largest impact among the scenarios is due to the increase in the discount rate. In addition, an increase in meat price either instantly by 20% or gradually by 2% a year both resulted in 21% increase in the value function. By contrast, gradual decrease in rainfall or instantaneous 30% increase in the standard deviation of rainfall were simulated to decrease the value function by 1% and 3%, respectively.

## 4. Discussion

In this paper we have developed a model to study stocking rates and transhumance in an extensive livestock husbandry in Ferlo, Senegal. Results suggest that the adjustments of animal stock size and transhumance are determined either by natural constraints (the availability of feed) or by economic decisions to ration stocking rate. Rainfall has a major impact on the optimal stocking rate and on the amount of livestock sold. In the event of drought more animals will be sold than in a normal year. In particular it affects stocking rate in Ferlo where water is really limiting the production of vegetative biomass. By contrast, when there is a plenty of rainfall, the availability of vegetative biomass may not be a limiting factor, and animal stock is managed so as to maximize the value of herd over a time horizon.

Transhumance and stocking rate in the rainy region are buffers which are adjusted according to the rainfall in our model. In the absence of efficient feed markets, transhumance can be a rational way to adjust the livestock activity point to varying weather conditions. It increases the possibilities of Ferlo's inhabitants to keep their livestock. However, it can increase stocking rate to a level which is not sustainable in some years. Results suggest that market conditions and time value of money (i.e. discount rate) can have a small impact on the stocking rates and transhumance. For instance, a larger discount rate can reduce animal stock and the present value of it.

Our results don't show substantial immediate impacts of more variable weather of lower mean rainfall on the value function. However, the effect can be more prominent over a longer time horizon. Climate change has been suggested to increase the frequency and the magnitude of heavy droughts and heavy rainfalls. These may have more visible impacts on extensive, common pasture based livestock husbandry than changes in the mean weather parameters. Hence, policies should try to mitigate the effects of these extreme events.

Livestock managers in Ferlo could benefit from the option to purchase feeds from the markets instead of practicing transhumance. However, the uptake of purchased feeds is dependent on the price. If the costs of feed logistics are excessive, it can be more rational to practice transhumance than purchase feeds. Purchased feeds and transhumance are substitutes but they do not exclude each others. Hence, transhumance is likely to continue although it could be carried out in a smaller scale.

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Table 1. Parameter values used in the model.

| Parameter | Default value | Remarks |
|---|---|---|
| $m_0$ | 2557.5 | |
| $\alpha$ | $1.251*10^{-5}$ | |
| $r_t^{Ferlo}$, distribution's mean value | 282 | SD 83, Dahra observation station |
| $r_t^{Kaffrine}$, distribution's mean value | 611 | SD 38, Kaffrine observation station |
| $\check{r}$ | 29 | |
| $\bar{r}$ | 252 | |
| $\varphi$ | 2511 | |
| $\mu$ | 0.001 | |
| $v$ | 27.6 | |
| $\beta$ | 0.6 | |
| $H$ | 44 | Mean household size, Weikard and Hein (2011) |
| $\bar{m}$ | - | Currently not used |
| $p_t^{Ferlo}$ | 129366 | CFA/TLU, calculated from the market price statistics |
| $p_t^{Kaffrine}$ | 170537 | CFA/TLU, calculated from the market price statistics |
| $c$ | 2700 | CFA/TLU, cost of labor |
| $c_{move}$ | 3259 | CFA/TLU, estimated extra labor, water and vaccination costs |
| $c_0$ | 0 | Not relevant in this study |
| $\delta$ | 5.5 % | real discount rate |
| $T$ | 30 | Number of years |

Table 2. Elaboration of how each scenario differs from the baseline scenario

| Scenarios | | Reference |
|---|---|---|
| A | Baseline | |
| B | rainfall -3% per decade | McSweeney *et al.* 2010 |
| C | SD of rainfall +30% | McSweeney *et al.* 2010 |
| E | Meat price +20% | Scenario |
| G | Meat price -20% | Scenario |
| H | Meat price +2% per year | Scenario |
| L | Discount rate doubled | Scenario |

Table 3. Change (%) in value function when the baseline scenario and alternative scenarios are compared

| Scenarios | | Percentage change in the value function[1)] |
|---|---|---|
| B | Mean rainfall -3% per decade | -1 % |
| C | Standard deviation of rainfall +30% | -3 % |
| E | Meat price +20% | 21 % |
| G | Meat price -20% | -21 % |
| H | Meat price +2% per year | 21 % |
| L | Discount rate doubled | -37 % |

1) Compared to the baseline scenario.

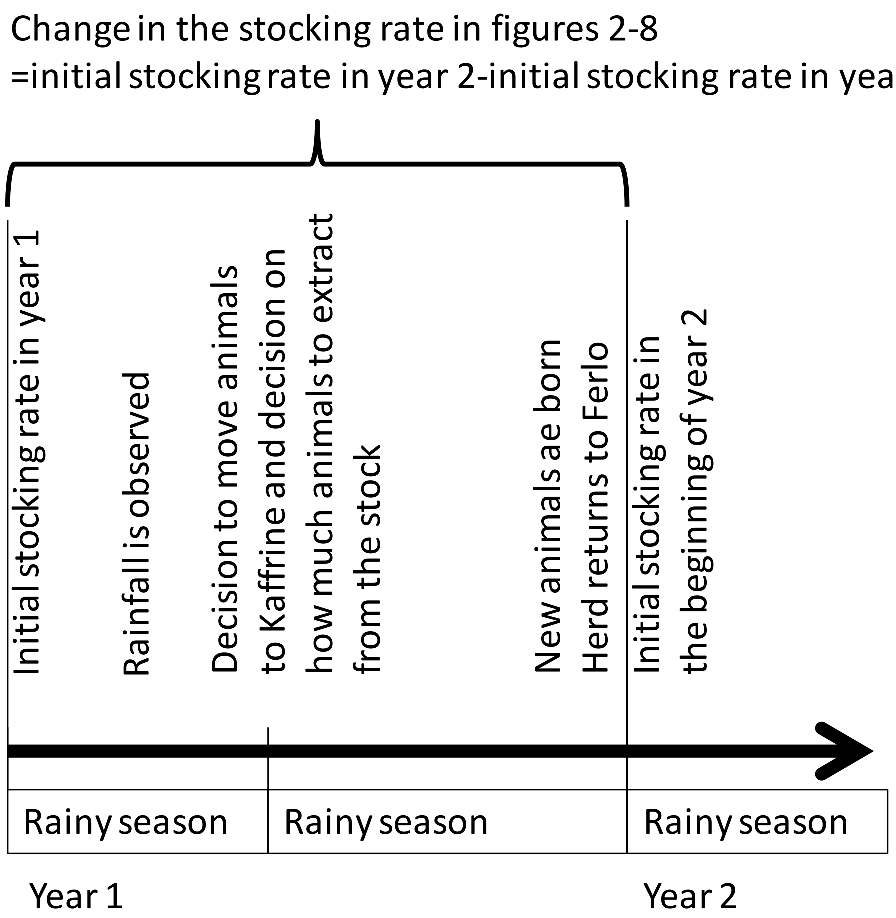


Figure 1 Description of the timing of stock-relates actions and the change of stocking rate as used in Figures 2-8.

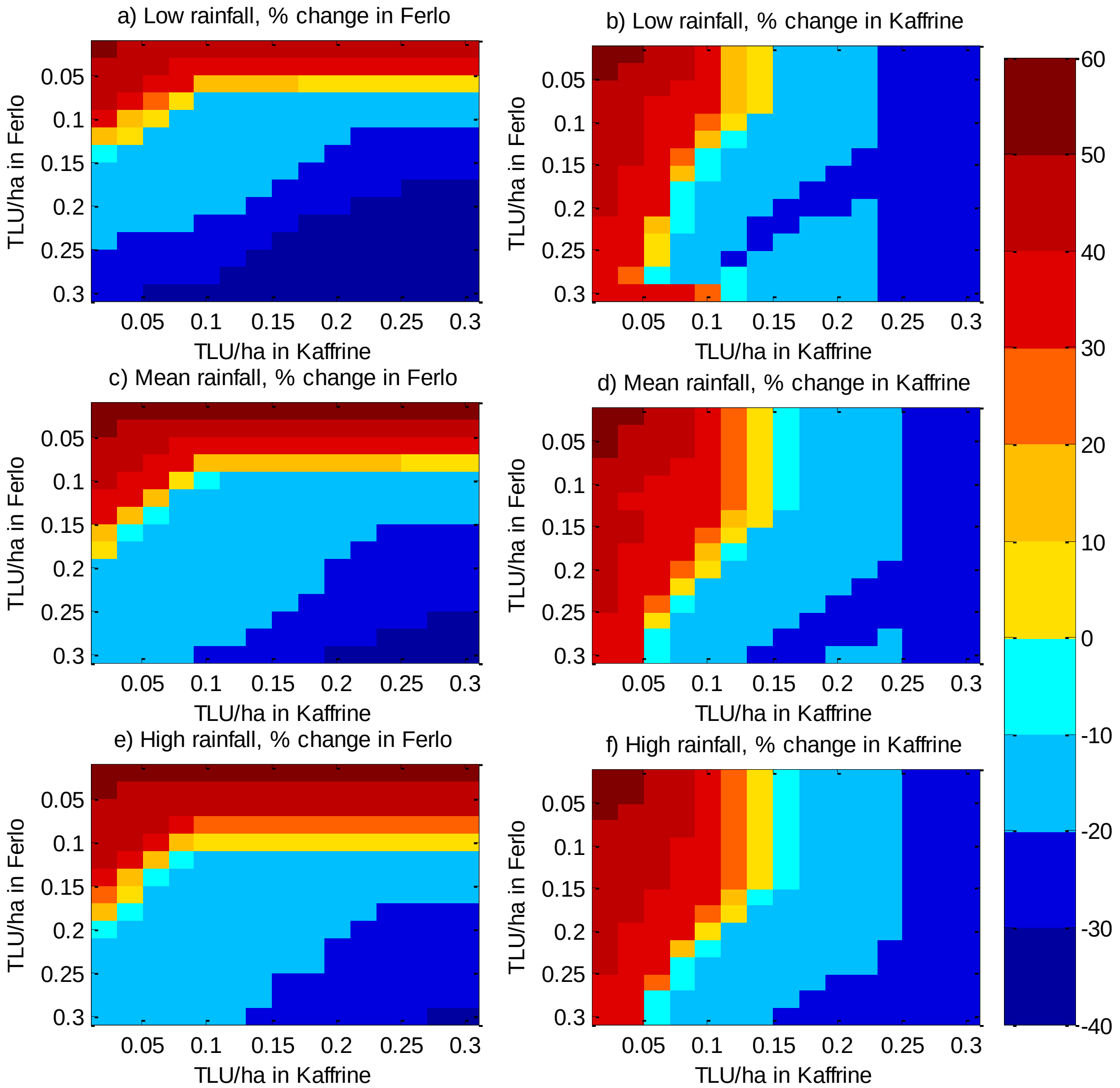


Figure 2. Change (%) in the stocking rate (TLU/ha) in Ferlo (Figures a, c, e) and in Kaffrine (b, d, f) for the low (a, b), mean (c, d) and high (e, f) rainfall scenarios, at different initial stocking stocking rates in the respective regions in the beginning of the year, and when transhumance is allowed and soil carbon content is 2500 kg per ha.

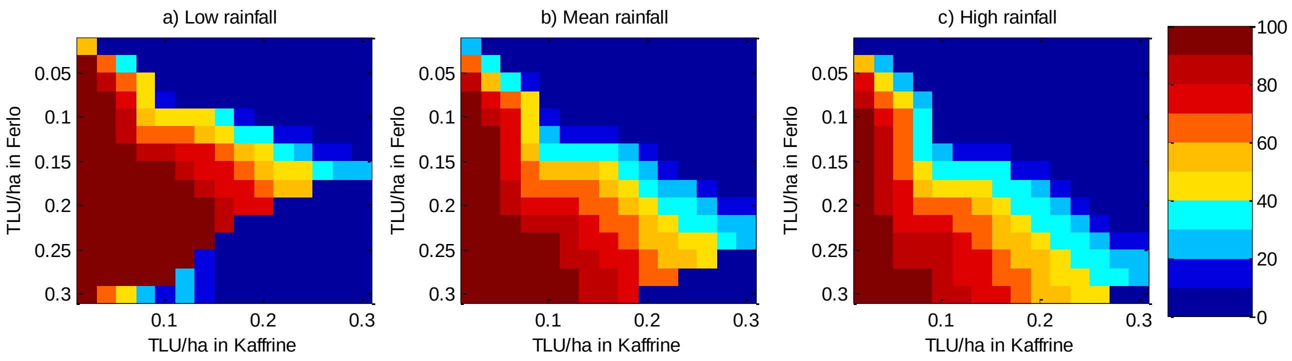


Figure 3. The rate of transhumance (% livestock population in Ferlo affected) by the stocking rate (TLU/ha) in Ferlo and in Kaffrine in the beginning of the year (dark colors imply stronger reduction in the animal stock over a year) and for three year types rainfall (average, low, high rainfall).

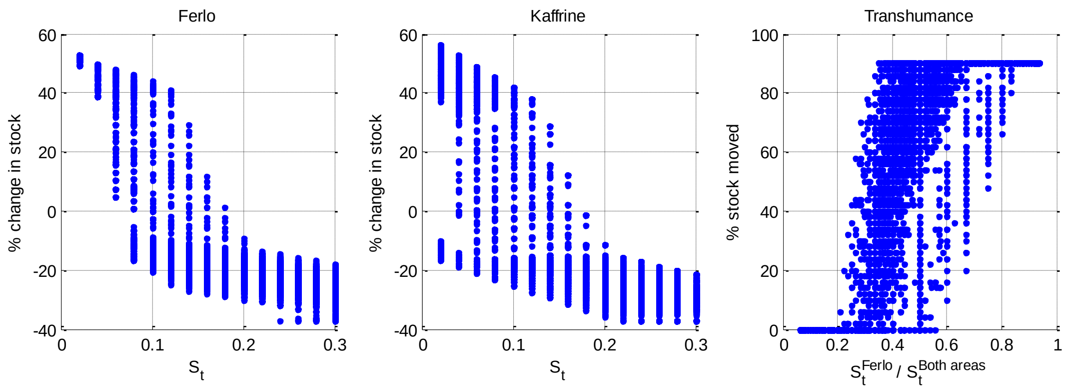


Figure 4. The range of change in animal stock in Kaffrine and Ferlo and rate of transhumance in the event of fixed prices and mean rainfall in the baseline scenario.

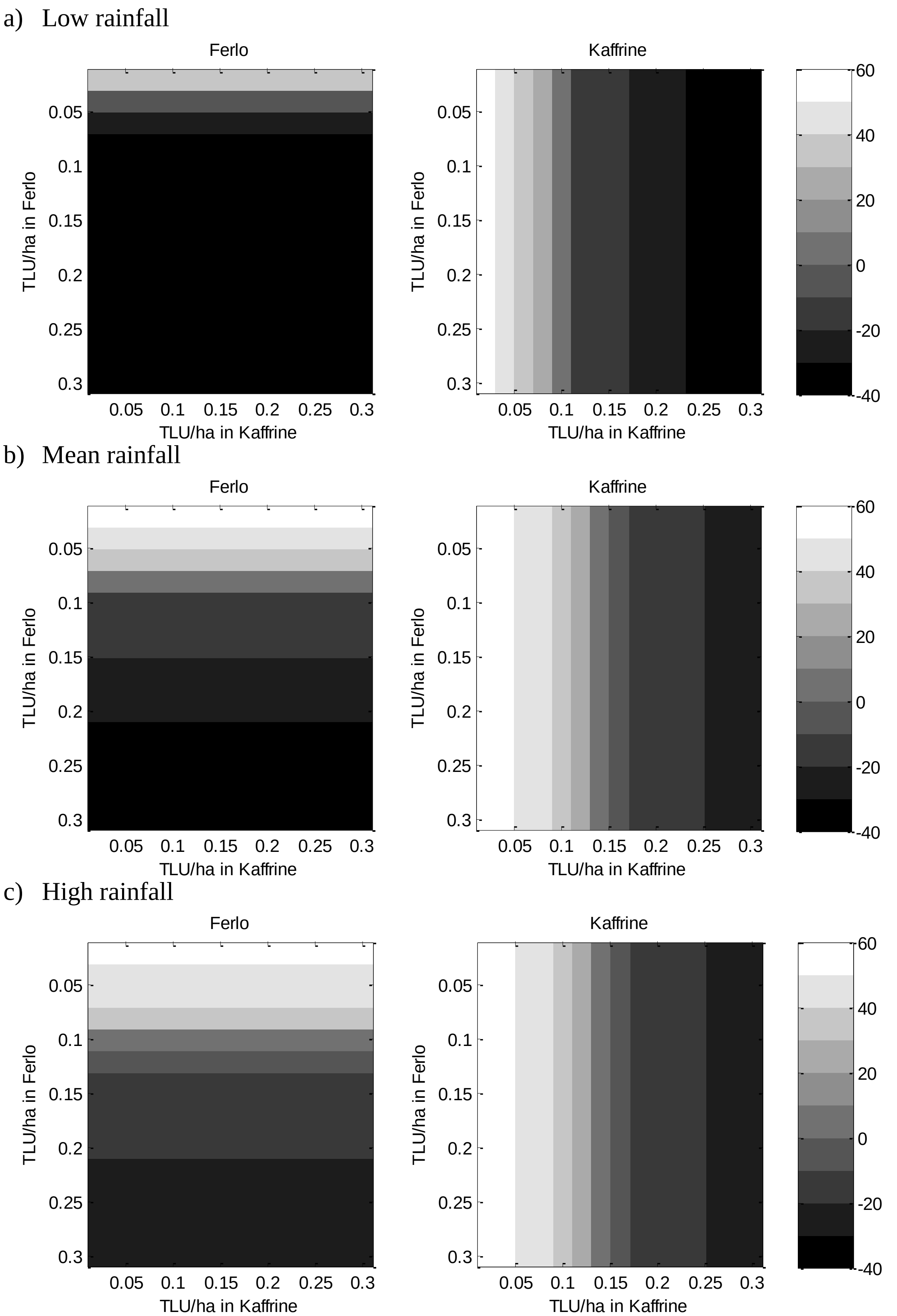


Figure 5. Change in the animal stock by the amount of rainfall (medium rainfall or drought (10% of the driest years)) in the region (Ferlo in the left and Kaffrine in the right) when transhumance cannot be practiced and there is 2500 kg carbon in the soil per ha.

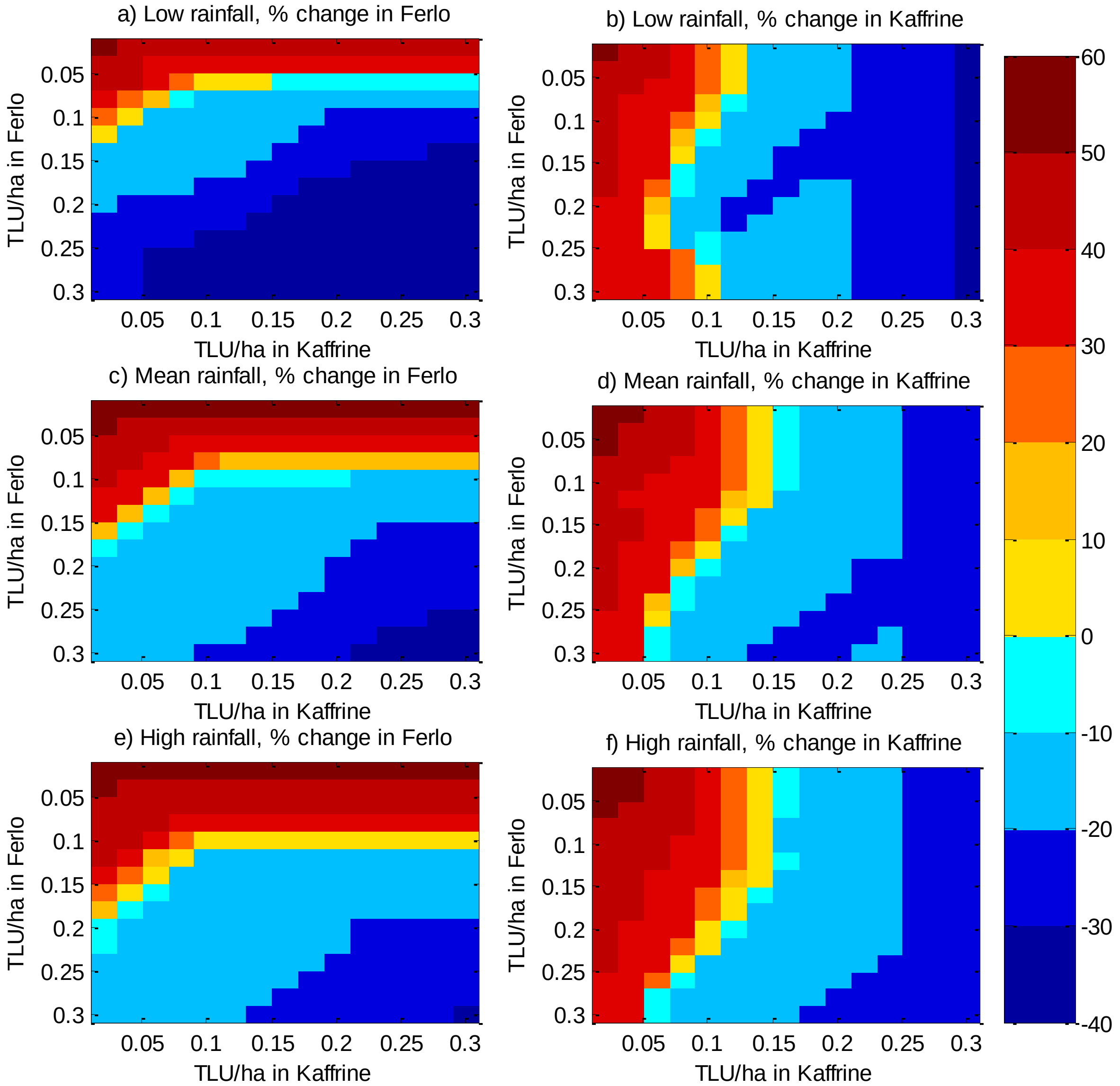


Figure 6. Change (%) in the stocking rate (TLU/ha) in Ferlo (Figures a, c, e) and in Kaffrine (b, d, f) for the low (a, b), mean (c, d) and high (e, f) rainfall scenarios, at different initial stocking stocking rates in the respective regions in the beginning of the year, and when transhumance is allowed and soil carbon content is 2500 kg per ha for scenario C (standard deviation of rainfall +30% when compared to the baseline).

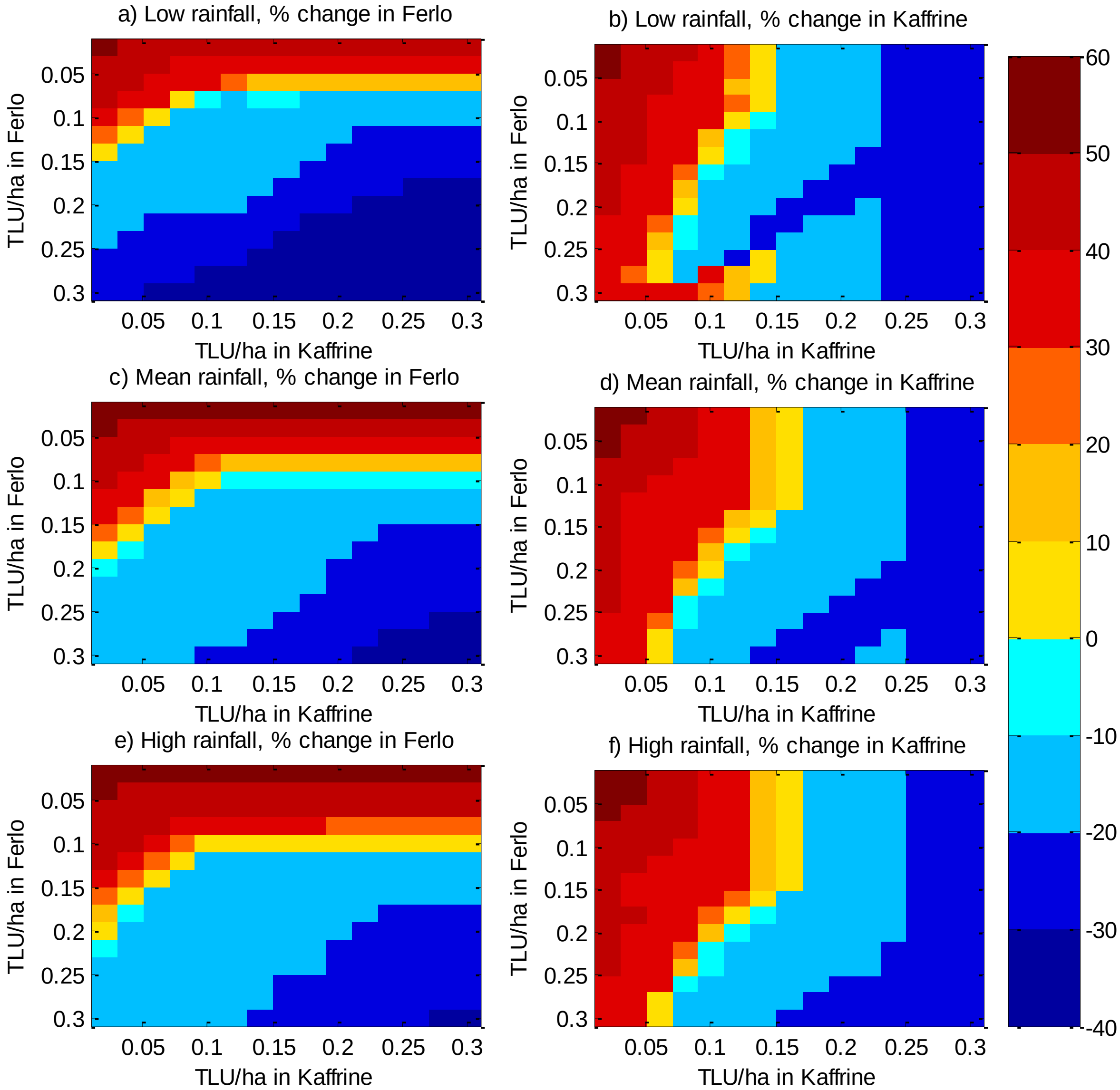


Figure 7. Change (%) in the stocking rate (TLU/ha) in Ferlo (Figures a, c, e) and in Kaffrine (b, d, f) for the low (a, b), mean (c, d) and high (e, f) rainfall scenarios, at different initial stocking stocking rates in the respective regions in the beginning of the year, and when transhumance is allowed and soil carbon content is 2500 kg per ha for scenario H (meat price increases as a trend by 2% a year when compared to the baseline).

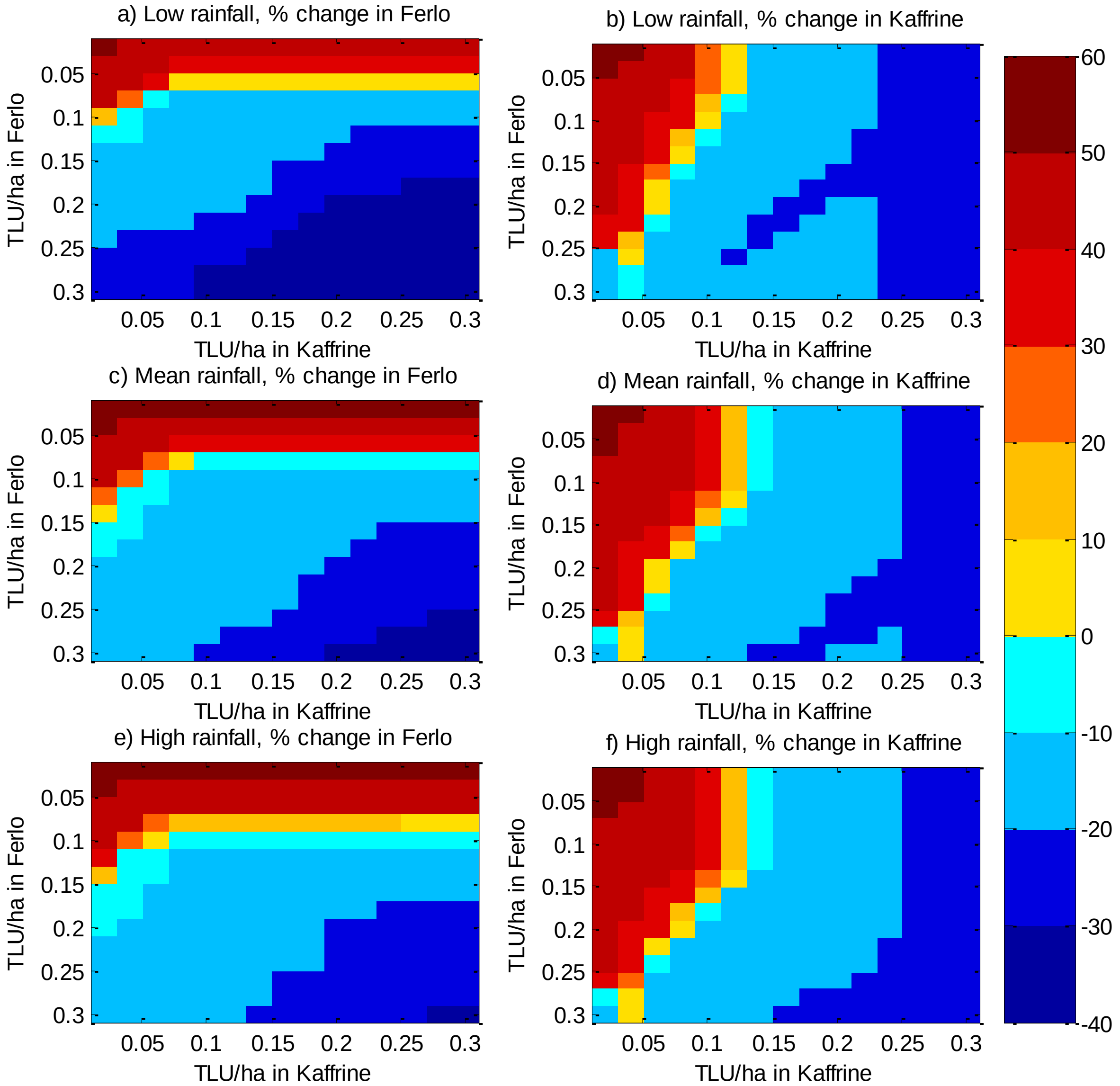


Figure 8. Change (%) in the stocking rate (TLU/ha) in Ferlo (Figures a, c, e) and in Kaffrine (b, d, f) for the low (a, b), mean (c, d) and high (e, f) rainfall scenarios, at different initial stocking stocking rates in the respective regions in the beginning of the year, and when transhumance is allowed and soil carbon content is 2500 kg per ha for scenario L (discount rate increases from 5.5% (baseline) to 11.0% (L)).