Impacts of grazing and rainfall variability on the dynamics of a Sahelian rangeland revisited (Hein, 2006) – new insights from old data

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Abstract

Understanding the dynamics of semi-arid rangelands is a prerequisite for their proper management and long-term enclosure experiments are an important tool to investigate grazing impact. Hein (2006) presents findings from a 10 year enclosure experiment in the semi-arid Ferlo, Senegal. His main conclusion is that current high grazing pressure (0.15–0.20 TLU/h) negatively affects rain use efficiency and productivity especially in dry years because differences between treatments are significant for the whole period as well as for dry years only.

A re-analysis under the framework of non-equilibrium theory of rangeland science leads to an alternative interpretation of the data: The vegetation on the more intensively grazed site possesses a remarkable resilience after the drought of 1983 & 1984. Standing crop recovers fast and for two years is even higher on the "high grazing" treatment than on the less intensively grazed treatment. Statistical analysis confirms this: a general linear model for standing crop against effective precipitation and grazing treatment finds a significant contribution of precipitation only ($p < 0.0001$). Thus, vegetation dynamics in the semi-arid Ferlo largely follows a non-equilibrium dynamic as it is rather driven by precipitation dynamics than by grazing. This also leads to different policy implications: droughts reduce livestock density and thus are important to allow the vegetation to rest for one or two years.

1) Introduction

In the paper "The impacts of grazing and rainfall variability on the dynamics of a Sahelian rangeland" Hein (2006) presents an analysis of the findings of an GTZ-supported enclosure experiment in the Senegal based on reports by Klug (1982), Andre (1998) and Miehe (1992; 1997). The experiment consists of two treatments: Within the enclosure a medium, fixed maximum stocking rate of 0.10 TLU/ha was maintained (labelled "medium grazing pressure treatment"), while outside the enclosure, grazing was uncontrolled and therefore variable, corresponding to an average stocking density of around 0.15–0.20 TLU/ha (labelled "high grazing pressure treatment"). Data on development of standing crop and annual precipitation from 1981 to 1990, rain use efficiency derived from these data, and on species composition for dry and wet years are presented. The following major findings from these data are:

- No significant difference in **species richness** can be found between both treatments.
- **Species composition** changes towards less palatable species under variable "high" grazing regime
- The differences between **standing crop** and between the **rain use efficiency** of the different treatments are significant for the whole period as well as for dry years only.

From these results Hein concludes that “the current, high grazing pressure of 0.15–0.20 TLU/ha appears to affect the RUE and the productivity of the Ferlo, in particular in dry years. In years with below average rainfall, aboveground phytomass production decreases because of low water availability as well as a reduced RUE. Consequently, the impacts of high grazing pressures on the productivity of the Ferlo are hardly noticed during years with normal or above normal rainfall, but they are particularly strong during a drought“ (p. 500). However, a thorough re-analysis does not hold these conclusions as will be shown below.

In discussions about degradation of grazing systems generally two components are regarded as essential to identify negative effects of e.g. grazing on the vegetation: 1) Changes in species composition, which by selection of preferential forage species leads to an increase of species less valuable as forage for livestock and therefore result in a deteriorating forage quality (e.g. Fuhlendorf *et al.*, 2001). 2) The productivity of the vegetation is significantly reduced; this is especially often discussed as reduced regeneration ability of the vegetation (resilience) after a drought (see e.g. Pickup, 1996; Prince *et al.*, 1998). However these two points are actually not addressed in the paper due to terminological and methodological flaws:

2) Changes in species composition and its effects on forage quality

The conclusion that the high intensity variable grazing treatment leads to a negative trend in species composition is based on data presented in Hein’s table 1 (2006, p. 495). This table lists species with more than 1 % cover found on the two different grazing regimes each for dry and for wet years. From that Hein concludes that the “occurrence of most palatable species has decreased in the plots with high grazing pressures” (p. 494), and “the amount of perennial grasses is reduced in the intensively grazed pastures - in both dry and wet years” (p. 494). However this presentation of vegetation data seems somehow arbitrary. Why are only species with a cover value of more than 1 % listed in table 1, but no further analysis of vegetation composition is presented? Which data are exactly presented in table 1? Are these average values for all dry and wet years for the respective treatments, or maybe only exemplary plots under any dry or wet year – and if so, of which years?

As data obviously exist for the whole time series (“Species composition was examined annually in 10 1-ha sample plots“ p. 492), an ordination diagram of the data (e.g. NMDS, CCA) would have given a much clearer picture on the development of vegetation composition inside and outside the fence during that time than the flat presentation of a unspecified species list (generally see e.g.: Kent & Coker, 1992; Jongman *et al.*, 1995, for an example from Senegal see Lawesson, 1997). As the data are presented in the table only, the reader gets no idea about the variability of the species composition – neither between the different treatments nor between the different years. An ordination further would have shown, whether the claimed degradation trend outside the fence really exists and what would have been the most important, how it possibly developed: whether slowly by gradual changes from year to year or by abrupt changes e.g. after a dry year. However, without any information of that kind the changes in species composition are not comprehensible.

However, regarding the impact of changing species composition on the forage quality Hein (2006) himself states that although “the two grazing pressures lead to a markedly different herbaceous species cover, in terms of the occurrence of dominant species”, “this does not evoke substantial differences in the overall feed quality of the herb layer” (p. 501). Thus it has to be concluded (which seems contrary to the data presented in the table and discussed in the text) that forage quality has not been affected by the grazing treatments.

3) Effects on standing crop / productivity

One of the major reasons for the interpretations of Hein (2006) may be the misleading terminology applied in his paper. He introduces the parameter of “above-ground phytomass production” and states that it was measured as “peak standing crop” (p. 492). This is not a simple terminological mistake as those two terms are confounded throughout the text. Hein does not distinguish between the different processes which influence the two parameters: Annual productivity is controlled by abiotic limitations to plant growth only and not influenced by herbivory, while standing crop is the result of the combined effects of productivity and herbivory. Thus, two systems with identical productivity can exhibit large differences in standing crop under different grazing regimes – especially when grazing is variable, and one part of the area has already been grazed while another one has not. Of course standing crop can be used as an indicator for the status of grazing systems, but the combined nature of the parameter has to be acknowledged in the discussion, and this has not been done by Hein (2006).

On page 496 he states that “high grazing pressures have a significant impact on herbaceous biomass production in the Ferlo, and this impact is concentrated in dry years”. However, this cannot be concluded from the presented data. Of course standing crop can be significantly different under different grazing regimes, but this alone does not allow conclusions about the productivity of both treatments. This is an effect of the confusing usage of the terminology.

The incorrect and misleading terminology continues in the usage of the term “rain use efficiency” (RUE), which has been defined as “the quotient of annual primary production by annual rainfall” (Le Houerou, 1984). Calculation and interpretation of the rain use efficiency of different e.g. grazing systems is an accepted and frequently used method in arid land research (e.g. Guevara *et al.*, 1996; Prince *et al.*, 1998; Diouf & Lambin, 2001), although it is not as unifying as it was intended to be (Le Houerou, 1984). This maybe partially due to the fact, that the reference measure of production is often not stated explicitly. As Le Houerou writes: “It may be expressed in above ground net primary production, in maximum standing crop (for therophytic or ephemeroid vegetation types), in herbage yield or in any other production measurement system, as long as the reference system is clearly indicated”. This is exactly what is missing in the paper of Hein when productivity and standing crop are mixed up.

4) Interpretation of presented data in the light of the actual non-equilibrium debate

Although central papers of the ongoing non-equilibrium theory discussion of drivers for the vegetation dynamic in grazed semi-arid ecosystems are cited (e.g. Wiens, 1984; Ellis & Swift, 1988; Scoones, 1993; Illius & Connor, 1999; Sullivan & Rohde, 2002; Briske *et al.*, 2003), the discussion of the results is very weak regarding the actual debate. The most serious flaw in the paper of Hein (2006) in my eyes is the strange interpretation of the standing crop data presented in his Fig. 2 (redrawn in Fig. 1 of this paper). Non-equilibrium theory states that precipitation variability is more important for determining species composition and standing crop than grazing because livestock numbers lag behind the vegetation development (e.g. Wiens, 1984; Ellis & Swift, 1988). Based on the assumption of a non-equilibrium dynamic in the investigated ecosystem (< 300 mm annual precipitation) I would like to offer an alternative explanation of the data (see Fig. 1): Not surprisingly the data show a typical dependence of vegetation growth on precipitation throughout the investigation period (correlation between both treatments $r^2= 0.96$, between effective precipitation and “medium constant grazing” treatment $r^2= 0.83$, and between effective precipitation and “high variable

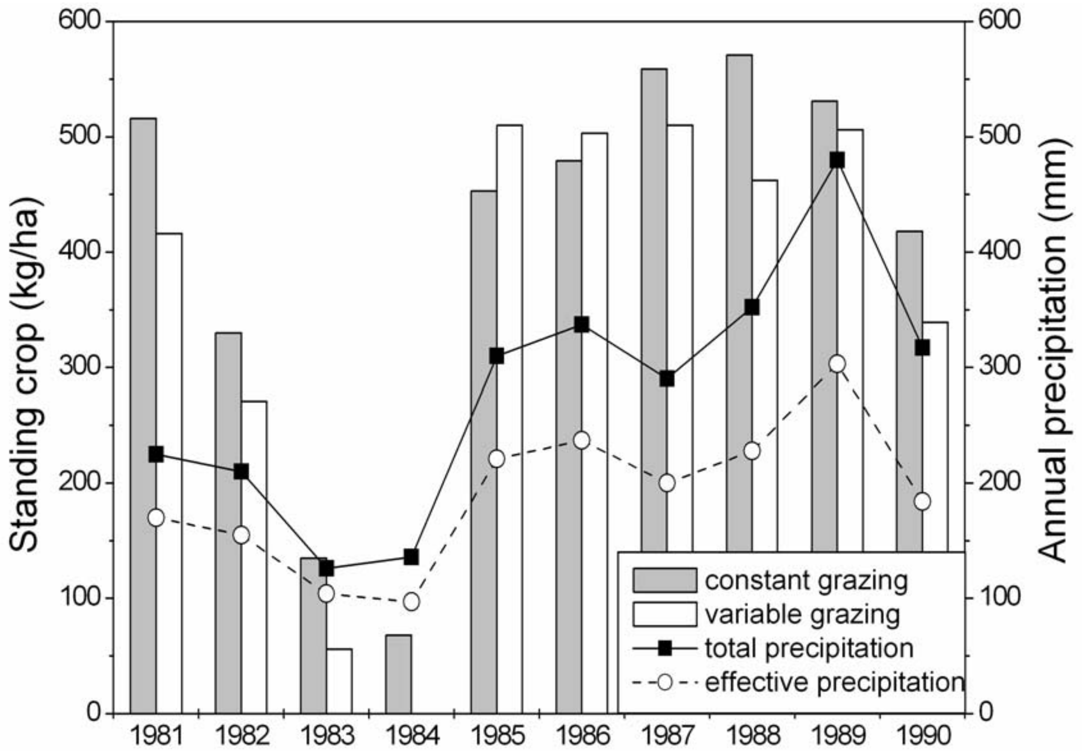

Figure 1: Data on the development of standing crop on the two grazing treatments of constant medium grazing intensity and variable grazing intensity and total and effective precipitation from 1981 to 1990. Data digitized from Hein (2006).

grazing" treatment r^2= 0.88 for all: p<0.0001). The development after the drought of 1983 and 1984 however, is most interesting: Here we can see a clear recovery effect on the variably grazed vegetation after a drought, which very likely killed some of the livestock grazing in the area: Thus, during the two years following the drought livestock numbers likely are lower on the variably grazed treatment and as a consequence also standing crop is higher on this treatment. Afterwards, livestock can recover and therefore consumes higher proportions of standing crop, so that standing crop is lower again on the variably grazed areas. This alone however, is not a sign of overgrazing at all, but a normal development when there are more herbivores feeding on the available phytomass, and nobody will deny that the grazing of herbivores does reduce standing crop.

The question must rather be whether the regeneration ability of the plants is affected. This has been proposed and largely accepted as an indicator for the degradation of such semi-arid arid systems, and often is assessed by remote sensing (Pickup, 1996; Diouf & Lambin, 2001; Dube & Pickup, 2001). However, for a system which in the description of the study site has been claimed to be degraded by the increasing sedentarization of herders due to the usual triad of the construction of wells, expansion of agricultural areas on the cost of former grazing lands, and settlement schemes proposed by the government, the system still possesses a remarkable resilience ability after a two year drought, indicated by the approximately same productivity on both grazing treatments. Obviously the vegetation can cope – at least regarding the parameter of phytomass.

A re-analysis of the data (digitalized from the published graph and presented again in Fig. 1) using a general linear model with the dependent variable standing crop, the independent continuous variable effective precipitation, and treatment as categorical variable underlines these arguments: only effective precipitation contributes significantly to the final model, the effect of the treatment is not significant (table 1). This is a strong indication that precipitation variability is a much more important driver for vegetation growth than grazing intensity, just as it is supposed to be in non-equilibrium systems (e.g. Wiens, 1984; Ellis & Swift, 1988; Sullivan & Rohde, 2002) and has been found in numerous studies of semi-arid grassland ecosystems around the world (see e.g. Ellis & Swift, 1988; Behnke *et al.*, 1993; Scoones, 1993; Ward *et al.*, 1998; Fernandez-Gimenez & Allen-Diaz, 1999; Oba *et al.*, 2003; Stumpp *et al.*, 2005; Wesche & Retzer, 2005; Hendricks *et al.*, 2005).

Table 1: Results of a general linear model for standing crop against effective precipitation and treatment (after data from Hein, 2006).

	dF	SS	MS	F	p
Intercept	1	16303.1	16303.1	1.67648	0.212704
Effective precipitation	1	444794.0	444794.0	45.73908	0.000003
Treatment	1	11858.5	11858.5	1.21943	0.284858
Error	17	165318.1	9724.6		

5) General shortcomings in the data analysis and presentation of data

Apart from the terminological misinterpretations as discussed above, there are some other shortcomings in the statistical analysis. For example as only a single enclosure exists according to the description in Hein (2006), it might be asked whether the sampling design is spatially autocorrelated and pseudoreplicated as all replicates are located within this enclosure (see e.g. Hurlbert, 1984; Quinn & Keough, 2003). I gladly acknowledge the difficulty of maintaining even a single enclosure under field conditions in the Senegal, but this point should a least have been mentioned in the description of the methodology and in the discussion.

Generally, the description of the statistical analyses is poor. Nevertheless it seems to me that the matched pair t-test used to test differences of above-ground phytomass and rain use efficiency is not the best method for the given data structure. If replicated data exist for a series of years from 1981-1990 a repeated measures ANOVA might have been used (Quinn & Keough, 2003), otherwise simple t-tests for comparison of means seem appropriate (Sokal & Rohlf, 1995). As obviously replicates exist for the different sampling points the standard deviation or variance of the data should have been indicated in the figures. But Hein (2006) does not make use of this information nor present it to the reader; on the contrary he eliminates it, as “Biomass was summed over the different plots in order to obtain the per hectare above-ground phytomass production” (p. 491). This is especially strange in the analysis of the effects of RUE, which are ”analysed for the whole period (1981–1990), as well as for dry and wet years separately, with a matched pairs test” (p. 493 f). From this description it is not clear, how the analysis was conducted. Either Hein (2006) actually used the replicated data to calculate a t-test for each single year, or he used a global t-test for all 10 years of data. In the first case the analysis conducted with RUE is superfluous as RUE is derived from standing crop data by dividing it by effective rainfall (p. 492) which must be the same for both variants and therefore this is the same analysis as has been conducted already for standing crop. In this case it is not surprising that the “RUE data” show the same trend as the above-ground phytomass data and any conclusions from RUE on standing crop data would be circular reasoning. If, on the other hand he used the 10 years of sampling as replicates, it is astonishing that the results should be significant. I used the data presented in Hein's Fig. 3 for the period from 1981-1990 to re-analyse the different standing crop and RUE of the two treatments using a t-test for independent variables and could not find a significant difference neither for standing crop nor for rain use efficiency (p=0.34 and 0.56, respectively), although both exhibit lower values on the high intensity variable grazing treatment. Thus, Hein's (2006) conclusions that "during a drought, biomass production in the Ferlo is affected both by the low availability of water to plants, and by a reduced efficiency of herbaceous plants to use the available water" (p. 501) is not comprehensible.

6) **Conclusions**

Summarizing the results it can be stated that the grazing treatments do not significantly differ in species richness, forage quality, nor in the development of standing crop. Furthermore standing crop is rather determined by precipitation variability than by grazing treatments. This indicates that the dynamics experienced at the experimental site in Widou-Thiengoly, Ferlo, Northern Senegal can largely be explained by non-equilibrium dynamics. Thus the conclusion drawn by Hein that the "current, high grazing pressure of 0.15–0.20 TLU/ha appears to affect the RUE and the productivity of the Ferlo, in particular in dry years. In years with below average rainfall, aboveground phytomass production decreases because of low water availability as well as a reduced RUE. Consequently, the impacts of high grazing pressures on the productivity of the Ferlo are hardly noticed during years with normal or above normal rainfall, but they are particularly strong during a drought" (p. 500) cannot be sustained. On the opposite, the differentiation between constant and variable grazing likely is more important than that of average high or medium grazing. This difference is crucial not only for the interpretation of data but also for the effects of the grazing.

However the classification of ecosystems into a binary system of pure non-equilibrium and equilibrium dynamics is a reduction of a colourful world towards a black-and- white view. Rather ecosystems can be sorted along a gradient between non-equilibrium and equilibrium systems (Wiens, 1984). Therefore questions remain regarding the vegetation dynamic in the Ferlo which cannot be answered with the data presented by Hein (2006). For example the vegetation data presented in his table 1 may actually indicate changes in species composition towards a vegetation dominated by annuals rather than perennials. This could lead to changes in ecosystem services such as nutrient and water retention etc. (see e.g. Schulte, 2001). However, more data from the project are needed to allow a sound interpretation of the vegetation dynamics.

Furthermore, the years 1985-1990 have shown remarkably stable and high precipitation for a semi-arid region with usually highly variable precipitation. Such stable conditions could allow for a coupling of livestock numbers and vegetation because livestock numbers are not regularly reduced well below vegetation carrying capacity by drought which would allow for a regeneration of the vegetation (see e.g. Retzer & Reudenbach, 2005). Thus, longer series of data and a more thorough analysis of the existing data are needed to derive valid management conclusions for the Northern Senegal.

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