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A pilot study into biomass yield and composition under increased stocking rates and increased stocking densities on a Namibian organic beef cattle and sheep farm

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Abstract Sustainable rangeland management is crucial for conservation and improvement of global grassland ecosystems, livestock performance and grassland-linked livelihoods. This applies in particular for Sub-Saharan African countries like Namibia with its rangeland-based low external input livestock husbandry. In the local savannas, productivity and resource distribution is spatially heterogeneous and temporally variable, which calls for adaptive and responsive grazing strategies to meet the needs of livestock and vegetation. The adjustment of stocking rate (SR; kilogramme livestock per hectare per year) and stocking density (SD; kilogramme livestock per hectare during a specific grazing event) is considered as a key success factor but very different rates and densities have been recommended in the past by practitioners, scientific evidence is lacking. On an Organic Namibian beef cattle and sheep farm were these recommendations assessed in order to investigate the responses of savanna rangelands to varying grazing intensities. Since 2014, forage biomass production and composition under three different grazing regimes have been assessed: (1) the routine management (here Holistic Management) as control and in comparison to this (2) an increased SR or (3) increased SD. Destructive biomass sampling was done each May in 2014, 2015, 2016 and 2017, respectively. The results showed that the increased SR or SD can be beneficial for average fodder production, but not significantly. However, the negative standing dead biomass accumulation was significantly reduced.

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Introduction

Grassland ecosystems are of local and global importance, since they cover about 40% of the global terrestrial surface (e.g. White et al. 2000; WRI 2000; MEA 2005). Their products (e.g. meat, wool, firewood) and services (e.g. ecological services, carbon sequestation, tourism) contribute directly to livelihoods of over 800 million rural households in grassland areas (e.g. White et al. 2000; WRI 2000) and respective national gross national income GNI (Rass 2006; Lee et al. 2008). This applies in particular in Namibia, because natural grassland area and pastoral and ranching livelihoods dominate the rural area of the country. Not only the agro-ecological circumstances but also land use history and current social and infrastructural conditions favour grassland-based low external input systems with ruminants and other herbivores (Rahmann et al. 2015). The ecological conditions of savanna grasslands are particularly challenging for farmers since rainfall cannot be predicted and has big spacial, as well as inter- and intra-annual variabilities (semi-arid zone). Therefore, the biomass cannot be predicted by farmers in advance, the herd size must react spontaneously. Unfortunately, degradation (e.g. bush encroachment, decreasing soil fertility) of half of the Namibian savanna is giving cause for concern, and great parts of this area are rangelands (Bischofberger et al. 2016; de Klerk 2004; Rothauge 2007). In future, global processes like climate change will affect and may intensify the situation (Rahmann et al. 2008). Lohmann et al. (2012) projected different climate scenarios for semi-arid savannas showing that rangeland carrying capacities could decline severely under worse future rainfall conditions while under more favourable conditions capacity improvement would be at most small. This might concern organic farmers in particular, since their ability to respond to resource variability is even more limited by organic policy restrictions, e.g. regarding selection and availability of feeding supplements (Rahmann et al. 2017).

The given situation puts emphasis on the questions, what impact grazing, trampling and manure distribution by livestock actually has on vegetation parameters (e.g. species composition, growth rates, production) and how their impact can be managed (e.g. by altering timing, frequency and intensity of grazing and resting periods, stocking rates and stocking densities). In the past, different rangeland management systems emerged, which essentially vary in recommended stocking rate and stocking density. This has caused a vivid controversy among practitioners and scientists (Homewood and Rodgers 1987; Briske et al. 2008; Teague et al. 2008; Rahmann et al. 2009) and gave reason to our study.

The stocking density (SD) basically describes animal concentration, meaning the amount of animals grazing on a specific area at a specific point in time (Rahmann and Seip 2007). The stocking rate (SR) is the amount of animals (the number, or live weight in kilogramme or livestock units) in an area over a period of time (a year or a season). In Namibia, all variations of SR and SD along the continuum of grazing management intensity are present: from continuous extensive grazing to multi-rotational or even ration or circuit grazing systems. Often an inflexible SR is set according to the regional rangeland carrying capacity (the amount of animals a hectare can supply with forage throughout a year). Some approaches with flexible SR and SD, like ‘Holistic Grazing Planning’ (Savory and Butterfield 1999), have shown convincing success in practical rangeland management although they lack scientific endorsement (Briske et al. 2014). As yet, there only seems to be contentious indication, that rotational grazing is superior to continuous grazing in savannas (Teague et al. 2008; Rothauge 2001).

Accordingly, neither a specific SR or SD nor a particular approach for their determination can be propagated as the per se sustainable concept for savanna rangeland management. Taking above mentioned spatial heterogeneity and temporal variability of resource distribution into account, it becomes reasonable to rather focus on targeted, variable decision making than on a fixed grazing strategy, which is referred to as ‘adaptive grazing’ or ‘responsive grazing’ (Laca 2009; Steffens et al. 2013). Thereby, the farmer should achieve sufficient recovery of defoliated plants while meeting the livestock’s needs. Ortega et al. (2013) observed increased ‘[…] grazing capacity and profitability of the ranch, even during drought’, when stocking rate was set in response to the variable forage production. Likewise, Lohmann et al. (2016) showed in simulations a ‘[…] [positive] effect of the “adaptive” rotational herd management strategies’ on grass biomass production and composition, thereby supporting higher livestock densities in the long run.

Flexible SR and SD modification seems advisable, but it remains uncertain, how a farmer identifies adaptive rates and densities. In order to contribute to the development of decision support tools, we investigated the responses of savanna rangelands to variations in SR and SD. Therefore, we started an in-farm research study on a Namibian organic livestock farm in 2014, were we monitored three different grazing regimes. First, grazing according to ‘Holistic Management’ (Savory and Butterfield 1999) as it was practiced on the farm before and which served as control. It is a rather flexible approach, which sets SR in response to the yearly ‘fodder bank’ that is assessed each May at the end of the growing period. We then implemented two variations in comparison to the routine management, some paddocks were treated with an increased SR and some with an increased SD.

Material and methods

Experimental site

The study was carried out on the 9500-ha cattle and sheep farm Springbockvley, which is located about 180 km Southeast of Windhoek (farmstead at − 23.303° N; 18.305° E; approximately 1350 m above sea level). Soils are sandy and partly limestone dominated. The climate is semi-arid with on average 260-mm annual rainfall in a mono-modal distribution mainly between December and April (Fig. 1). Often, the spatial distribution is patchy and intra and inter-annual variability in precipitation is high. Vegetation growth starts with the onset of rain and usually terminates in May. The open *Acacia* savanna landscape is dominated by tuft grasses, which are complemented by legumes, non-legume dicotyledonous plants, bushes and trees (e.g. Black Thorn *A. mellifera*, Camelthorn *Vachellia erioloba*, Sweet Thorn *V. karoo*). Main forage grasses are *Stipagrostis uniplumis*, *Schmidtia kalahariensis* and *Aristida stipitata*.

On Springbockvley, Nguni cattle and Damara sheep are raised. Both breeds are indigenous, small-framed and robust. The cows deliver a calf every year with calving peaks from December to February and May to July. Calves suckle 6 to 8 months. Afterwards, they are kept in a separate 'oxen herd' until they gain a slaughter-ready live weight of about 450 kg (1 LU), approximately at the age of 3 years. The ewes deliver about one lamb each year with lambing peaking between May and August.

The average live weight (LW) we considered to be 290 kg per cattle livestock unit and 35 kg per sheep unit (Rahmann 1995). Farm infrastructure and operational procedures did not allow more frequent weighing. The weight of the cattle unit (one cow and calf, or one ox respectively) and the sheep unit (one ewe and one lamb) are based on an initial LW measurement, done at the beginning of the experiment in May 2014 and yearly follow-ups of some cattle (sold stock) at different season, age, sex and performance. Consequently, our weight-related calculations do not consider the LW changes between and within seasons but the deviation will be the same over all treatments so that relative comparisons will be acceptable. Other options are usually not possible under comparable conditions and the approach of using average weight of livestock units (LU) is recommend by Glatzle (1990) and Scoones (1989).On the farm lived on average 890 cattle and 3700 sheep between June 2013 and May 2016 (approx. 387,600 kg livestock biomass resp. 861 livestock units LU at 450 kg LW). All livestock is split into three herds:

(1) *Cows*: on average 458 cows plus calves (133,000 kg livestock biomass, 296 LU)

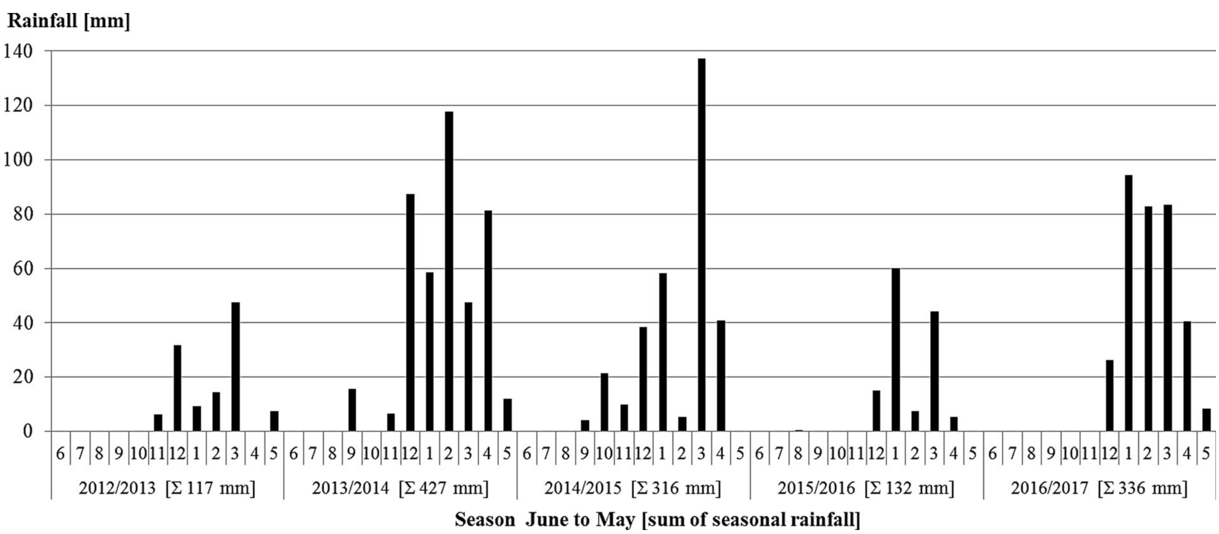


Fig. 1 Rainfall [mm] on farm Springbockvley per month and summed per season between June 2012 and May 2017

(2) *Oxen*: on average 336 oxen and cows plus on average 229 slaughter-ready sheep (106,000 kg livestock biomass, 236 LU)
(3) *Sheep*: on average 3441 sheep plus on average 93 young fattening bulls (148,000 kg livestock biomass, 329 LU)

Grazing management on Springbockvley and implemented variations

(1) *Normal management (Control, C)*: Springbockvley is under Holistic Management since 1990 and was certified organic in 2013 by Namibian Organic Association (NOA). Since 2013, the farm has been grazed in a full farm rotation with the three herds grazing all 60 paddocks in the same pre-assigned sequence. Grazing events are scheduled according to Holistic Management Grazing Planning (Savory and Butterfield 1999) for each herd and paddock after visual biomass assessment at the end of the growth period in May. The planning relates paddock size to herd size and then takes estimated biomass into account. Grazing duration per paddock is shorter during the growing period and longer during the dry period. Average resting periods between 80 and 100 days between grazing events are granted. Every herd grazes every paddock on the farm about once a year. The resulting stocking rates and densities vary vastly between paddocks and herds, given the different paddock sizes (ranging between 45 and 330 ha) and the inter- and intra-annual changes in livestock numbers. The average overall stocking rate was approximately 41 kg LW/ha between June 2013 and May 2016.

In addition to the current grazing regime, two variations were implemented in May 2014, where either the stocking rate (SR) or the stocking density (SD) was increased compared to the one that would have been applied with usual 'Holistic Grazing Planning' (according to Savory and Butterfield 1999).

(2) *Variation double stocking rate (DSR)*: These paddocks were grazed at double SR (kg LW/ha per season June–May). Therefore, the herds stayed twice the number of days that would have been scheduled for the paddock under the normal grazing regime. SD was same as usually foreseen each May in the current grazing plans (according to Glatzle 1990).
(3) *Variation higher stocking density (HSD)*: These paddocks were grazed at higher SD (kg LW/ha). Therefore, the area was subdivided with a mobile electric fence and a new parcel was opened for the herd every 1 or 2 days. SR was same as usually foreseen each May in the current grazing plans (according to Glatzle 1990).

For each treatment, four paddocks were selected: respectively, one paddock at the four farm sections 'House', 'Sand', 'Achab' and 'Pan', which differ in ecological conditions (soil, vegetation, water). Thus, 12 paddocks are part of the experiment. The variations had been integrated into the normal grazing routine, so that the herds entered the test paddocks according to the grazing plan as assigned each May. Following the paddock sequence, a herd entered the DSR paddock first at every replication. Then two paddocks were grazed according to the normal grazing plan, allowing the livestock to adapt to the different grazing conditions. The second was assessed as Control. Afterwards, the herd moved to the HSD paddock.

Data collection and data analysis

A description of the whole research project, further test methods and previous data evaluations are given by Rahmann et al. (2015) and Ludwig et al. (2017). In this paper, we will give preliminary results on the responses, of *production* (i.e. *yield and output*) and *productivity* (i.e. *yield*$_{rel}$ *and output*$_{rel}$) of different plant biomass fractions to variations in SR and SD. We considered the main fractions standing dead, litter and fodder. Fodder biomass is living or recently dead biomass that has grown within the season. It is composed of perennial and annual grasses, legumes and forbs; we excluded browse. Litter (i.e. seeds, broken fresh and dead plant parts) and standing dead contain accumulated material of previous seasons and material that was converted since the last measurement.

Plant biomass was monitored quantitatively by harvesting each May (end of growing period) between 2014 and 2017. Therefore, a one square meter metal frame was placed every 20 m along a 200-m transect in ten replications for each of the 12 paddocks. Biomass within the frame was collected or clipped directly above ground (i.e. in 0.5 to 2-cm height) and separated by species, standing dead material and litter. The samples were weighed fresh, stored in paper bags, dried at ambient temperature under shade and weighed air dried (here referred to as dry matter (DM), but it is not actual dry matter identified under laboratory conditions). Based on the measurements, we calculated amounts per hectare for different parameters:

(1) The harvested amount of fodder, litter or standing dead, we refer to as the respective biomass *yield*. It is the result of the vegetation's development within the season, i.e. since the last cutting. Between two measurements, the seasonal conditions (e.g. precipitation, grazing) influence transformation processes (e.g. conversion of fodder to standing dead and litter, erosion, germination, growth and regrowth of living biomass) and removal of biomass by livestock and thereby the yield at the end of a season. The yield then serves as fodder during the following dry period and is the basis for plant germination and growth in the next rain period. Hence, we will interpret high fodder yields, constant amounts of litter and reduced standing dead as a positive outcome of the seasonal conditions.

(2) From our production-oriented perspective, we assumed that not only high fodder yield but also the amount of removed fodder, i.e. consumption, is very important for a farmer. We refer to the summed amounts of fodder consumed within a season and fodder yield at the end of a season as fodder *output*. It indicates how good vegetation responded to the season's conditions in terms of fodder production. There are a few methods to monitor utilisation by livestock (BLM 1996; Smith et al. 2012) but those were not applicable to our question or not practicable due to the restricted extent of this in-farm pilot study. Therefore, we estimated consumption for each grazing event at the respective stocking rate, assuming a daily feed intake per animal of 3 % of its live weight. Thereby, the fodder output considers the varying stocking rates among the paddocks and is rather comparable than yield.

(3) Both, yield and output, characterise a paddock's production but do not show long-term changes in productivity because they do not consider differences in production of the reference season before the implementation of treatments (Baumann 2009). Hence, we also calculated a season's *relative yield* (*$yield_{rel}$ of fodder/litter/standing dead*) and *relative output* (*$output_{rel}$ of fodder*) as a percentage of the initial yield and output of the 2013/2014 season.

For our preliminary data analysis, we only used Microsoft Office Excel. We conducted following procedures, in which we set a significance level of 0.05:

(1) linear regression analysis to analyse the effects of

- the independent metric variables seasonal rainfall, cumulated stocking rate (CSR) and average stocking density (ASD)
- on the dependent metric variables yield/$yield_{rel}$ and output/$output_{rel}$

(2) analysis of variance (ANOVA) to analyse the effects of

- the independent categorical variables season and treatment
- on the dependent metric variables average yield/$yield_{rel}$ and average output/$output_{rel}$

Results

Fodder biomass

In Table 1, fodder biomass yields per paddock are given as measured in May at the end of the respective growing season. Table 1 also contains fodder biomass outputs per paddock and season. Overall, yield and output showed a wide range of values (yield: 0.21 to 3.39 t DM/ha; output: 0.53 to 3.79 t DM/ha) and variance between factor levels.

Due to inter- and intra-annual as well as spacial variation of rainfall, less biomass was harvested after the first year, except for the replication 'Achab' and the control at 'House', where biomass slightly increased. In May 2016, the available biomass had declined in all paddocks but then increased yields were measured at the end of season 2016/17. Output of the 2014/15 season was reduced compared to the initial season, except for the replication 'Achab' and the C and DSR paddocks at 'House', where it slightly increased. In the third season, fodder output decreased in all paddocks but then

Table 1 Fodder yield and output per paddock at applied cumulated stocking rates (CSR) and average stocking densities (ASD) in the initial season 2013/2014 and the three following seasons with implemented treatments

Factor												
Replication		House			Sand			Achab			Pan	
Treatment	DSR	C	HSD	DSR	C	HSD	DSR	C	HSD	DSR	C	HSD
Paddock	H09	H01	H02	S07	S10	S11	A03	A05	A06	P09	P03	P04
Size [ha]	95	80	90	130	145	150	145	160	160	150	150	160
Season rainfall	2013/2014 427 mm											
CSR	9	3	4	30	46	52	51	65	63	50	53	50
ASD	1113	1097	1470	933	879	894	927	847	884	766	711	756
Yield	1.85	1.78	2.15	3.39	3.08	3.22	1.99	1.45	1.56	2.18	1.84	1.36
Output	1.95	1.82	2.19	3.72	3.59	3.79	2.55	2.16	2.25	2.73	2.41	1.91
Season rainfall	2014/2015 316 mm											
CSR	58	30	47	74	49	50	81	38	36	88	49	54
ASD	1070	1227	2353	1145	993	2978	835	780	2110	781	759	1884
Yield	1.36	1.80	1.48	1.93	1.93	2.80	2.02	2.34	1.89	1.39	1.80	1.09
Output	2.00	2.12	1.99	2.74	2.47	3.35	2.90	2.76	2.28	2.36	2.34	1.67
Season rainfall	2015/2016 132 mm											
CSR	29	20	35	105	67	64	105	56	59	26	28	22
ASD	1559	1841	3102	1071	968	2605	974	896	2747	839	772	3243
Yield	0.21	0.59	0.47	0.55	0.37	0.74	0.32	0.66	1.11	0.52	0.41	0.59
Output	0.53	0.81	0.85	1.70	1.10	1.43	1.47	1.28	1.75	0.80	0.71	0.83
Season rainfall	2016/2017 336 mm											
CSR	46	32	42	43	49	32	57	54	50	54	36	38
ASD	1203	1309	3053	1029	855	2534	801	853	1756	910	876	3543
Yield	1.84	1.95	1.36	1.56	1.04	1.29	0.75	1.39	2.24	1.91	1.05	1.70
Output	2.35	2.31	1.81	2.03	1.58	1.64	1.37	1.98	2.78	2.50	1.45	2.12

DSR double stocking rate. *C* control, *HSD* higher stocking density

Season (e.g. 13/14) time between two measurements, i.e. end of May (e.g. 2013) to end of May (e.g. 2014)

CSR [kg LW/ha/a] cumulated stocking rate over the season

ASD [kg LW/ha] average stocking density

Yield [t DM/ha] average fodder ($n = 4$ replications) measured at the end of one season in May

Output [t DM/ha] yield plus fodder consumed within the season (estimated given the respective stocking and assuming an daily feed intake per animal of 3% DM/kg LW with an average animal LW of 290 kg)

increased in the 2016/17 season, except for the DSR paddock at Achab, where it decreased again.

Corresponding to our research objective, we looked into connections between variations in SR and SD and those in absolute and relative fodder yield and output. Taking CSR and/or ASD as explanatory variable, scatterplots did not suggest any pattern and linear regression models did not show any significant linear relationship (all $R^2 < 0.05$, all p values of regression coefficients > 0.05). However, if *precipitation* was included as single or second explanatory variable, regression analysis showed that rainfall had a significant impact on the respective dependent variable (all $p < 0.01$). Precipitation explained 50 to 60% of the variance within yield, yield_{rel}, output and output_{rel}, respectively (adjusted R^2).

Averages of fodder production and productivity by *treatment and season* are shown in Fig. 2. Yield and output were quite similar between treatments within a season. In the third and fourth season, i.e. after 2and 3 years of treatment, means were highest under HSD. Similarly, HSD paddocks maintained the highest average productivity (yield$_{rel}$ and output$_{rel}$) over the years, which was 10 to 25% improved against DSR and C paddocks. DSR paddock's yield$_{rel}$ was lower while output$_{rel}$ was similar to C treatment. However, analysis of variance showed no significance between treatments but a significant impact of the season on yield, yield$_{rel}$, output and output$_{rel}$, respectively.

In Fig. 3, composition of fodder biomass yield is shown as an average per treatment and season. In all years, *perennial grasses* had the highest share in fodder biomass. Despite similar initial yields in May 2014, mean yield and yield$_{rel}$ developed differently over the years. HSD paddocks production and productivity were the most balanced, and achieved the highest absolute and relative averages after 2 and 3 years of treatments. Mean yield and yield$_{rel}$ of perennials were always lowest under DSR; productivity was 20 to 48% lower than the highest average yield$_{rel}$. *Annual grasses* were accounting for the second largest shares. Highest average yields were always found in the DSR paddocks yet averages of yield$_{rel}$ indicated pretty similar productivity between the treatments. Observed differences in mean yield and yield$_{rel}$ of perennial and annual grasses between treatments were not significant; however, they were significant between seasons ($p < 0.001$). Absolute and relative yields of *legumes and forbs*, averaged by season and treatment, performed pretty alike, although a wide range of values was observed within and between paddocks. The number of species also includes shrubs and was on average highest in the control paddocks, except in 2017, when it was highest under HSD conditions. Generally, the number of species showed little variance.

Litter and standing dead biomass

Besides fodder biomass, standing dead plant material and litter were measured (cf. Fig. 4). The amount of litter appeared pretty constant over years and treatments and no significant difference was found. However, average standing dead yield showed significant differences between treatments ($p < 0.03$) and seasons ($p < 0.008$). Its accumulation was much higher under C conditions, where average yield$_{rel}$ increased eightfold during the second season. Both variations, HSD and DSR showed much less accumulation than C paddocks. During the fourth season, average yield$_{rel}$ was reduced compared to the initial season.

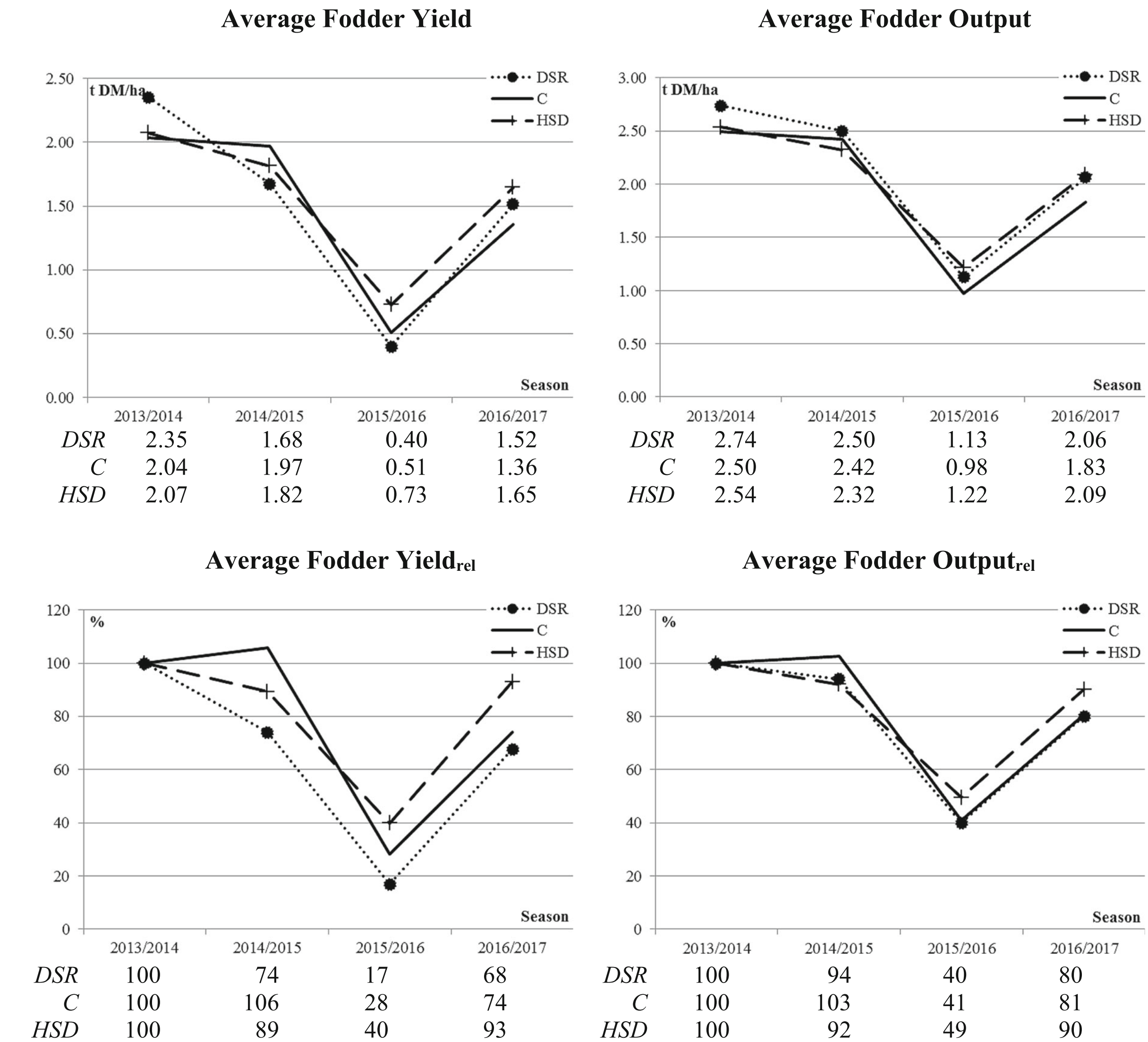
Discussion

The results showed how variations in stocking rate and stocking density (treatments DSR, C, HSD) influenced production (yield and output) and productivity (yield$_{rel}$ and output$_{rel}$) of different biomass fractions (fodder, litter and standing dead biomass).

Fodder biomass

The measured data and preliminary analysis suggest that both treatments might improve fodder production and productivity in some ways. HSD paddocks achieved the highest average production and productivity of in the third and fourth season. Average yield and yield$_{rel}$ of perennial grasses was also highest. DSR paddock's average fodder yield and yield$_{rel}$ were comparatively low but average fodder output was higher and average output$_{rel}$ was similar to C. Yield of annual grasses was always highest and average productivity was similar to the other variations, which might be beneficial for pasture quality. However, DSR paddocks showed a considerably lower average yield and yield$_{rel}$ of perennial grasses, which is concerning under savannah conditions in seasons with low precipitation, when germination and growth of annual grasses is reduced. A cause might be a higher removal of fodder and in particular of perennial grasses due to the higher stocking rate. As a result, we either only measured less of the production (output cannot be calculated) or it was actually produced less, maybe because plants could not cope with the defoliation under DSR.

However, none of the observed differences in average fodder production and productivity between treatments was significant, so either there are indeed no differences between treatments or we did just not detect them with our study approach. Our project framework only allowed for a small number of samples (4 replication, 3 treatments) within a very limited time frame (4 seasons). Also, there has been an ongoing and extensive discussion on how to monitor and assess rangelands (Wilson and Tupper 1982; NRC 1994; Baumann



Average Fodder Yield

	2013/2014	2014/2015	2015/2016	2016/2017
DSR	2.35	1.68	0.40	1.52
C	2.04	1.97	0.51	1.36
HSD	2.07	1.82	0.73	1.65

Average Fodder Output

	2013/2014	2014/2015	2015/2016	2016/2017
DSR	2.74	2.50	1.13	2.06
C	2.50	2.42	0.98	1.83
HSD	2.54	2.32	1.22	2.09

Average Fodder Yield$_{rel}$

	2013/2014	2014/2015	2015/2016	2016/2017
DSR	100	74	17	68
C	100	106	28	74
HSD	100	89	40	93

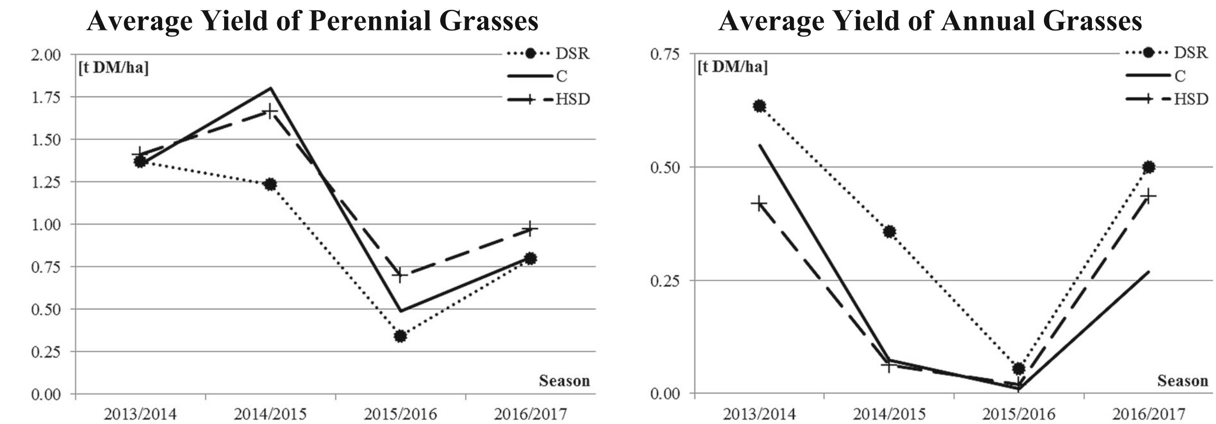
Average Fodder Output$_{rel}$

	2013/2014	2014/2015	2015/2016	2016/2017
DSR	100	94	40	80
C	100	103	41	81
HSD	100	92	49	90

DSR = Double Stocking Rate; *C* = Control; *HSD* = Higher Stocking Density;
Season (e.g. 13/14) = time between two measurements, i.e. end of May (e.g. 2013) to end of May (e.g. 2014);
Yield [t DM/ha] = average fodder (n=4 replications) measured at the end of one season in May;
Output [t DM/ha] = yield plus fodder consumed within the season (estimated given the respective stocking and assuming an daily feed intake per animal of 3 % DM / kg LW with an average animal LW of 290 kg);
Yield$_{rel}$ [%] = as percentage of the initial season 13/14; *Output$_{rel}$ [%]* = as percentage of the initial season 13/14

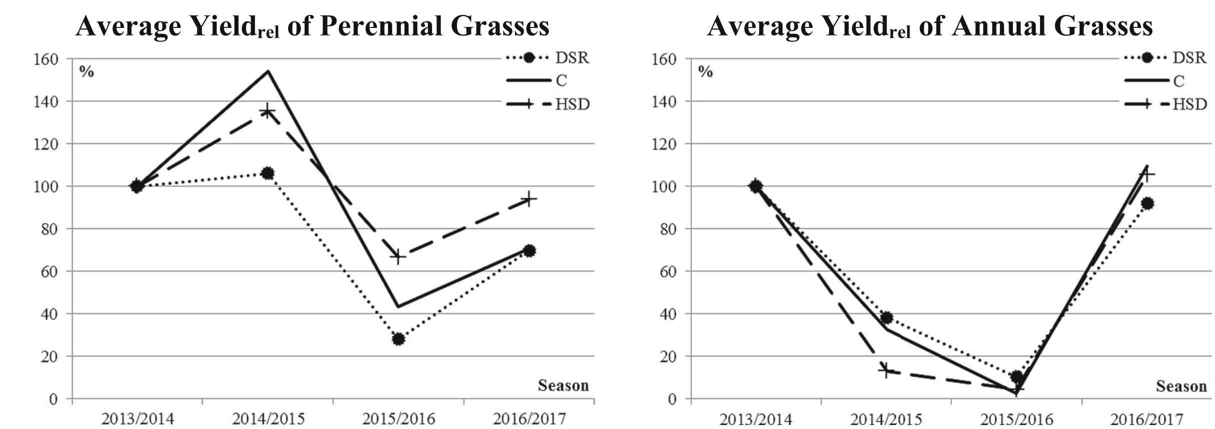
Fig. 2 Absolute und relative fodder yield and output grouped by treatment and season. *DSR* double stocking rate; *C* control; *HSD* higher stocking density; *Season* (e.g. 13/14) time between two measurements, i.e. end of May (e.g. 2013) to end of May (e.g. 2014); *Yield [t DM/ha]* average fodder ($n = 4$ replications) measured at the end of one season in May; *Output [t DM/ha]* yield plus fodder consumed within the season (estimated given the respective stocking and assuming an daily feed intake per animal of 3% DM/kg LW with an average animal LW of 290 kg); *Yield$_{rel}$ [%]* as percentage of the initial season 13/14; *Output$_{rel}$ [%]* as percentage of the initial season 13/14

2009) that has also questioned the informative value of point-in-time measurements such as the harvest method is one, although it is a quantitative and standardised procedure. We tried to compensate the weaknesses of the parameter yield by introducing the parameters yield$_{rel}$, output and output$_{rel}$. Since we had to estimate



	2013/2014	2014/2015	2015/2016	2016/2017
DSR	1.37	1.24	0.34	0.80
C	1.36	1.80	0.49	0.81
HSD	1.41	1.67	0.70	0.97

	2013/2014	2014/2015	2015/2016	2016/2017
DSR	0.63	0.36	0.05	0.50
C	0.55	0.07	0.01	0.27
HSD	0.42	0.06	0.02	0.44



	2013/2014	2014/2015	2015/2016	2016/2017
DSR	100	106	28	70
C	100	154	43	71
HSD	100	135	67	94

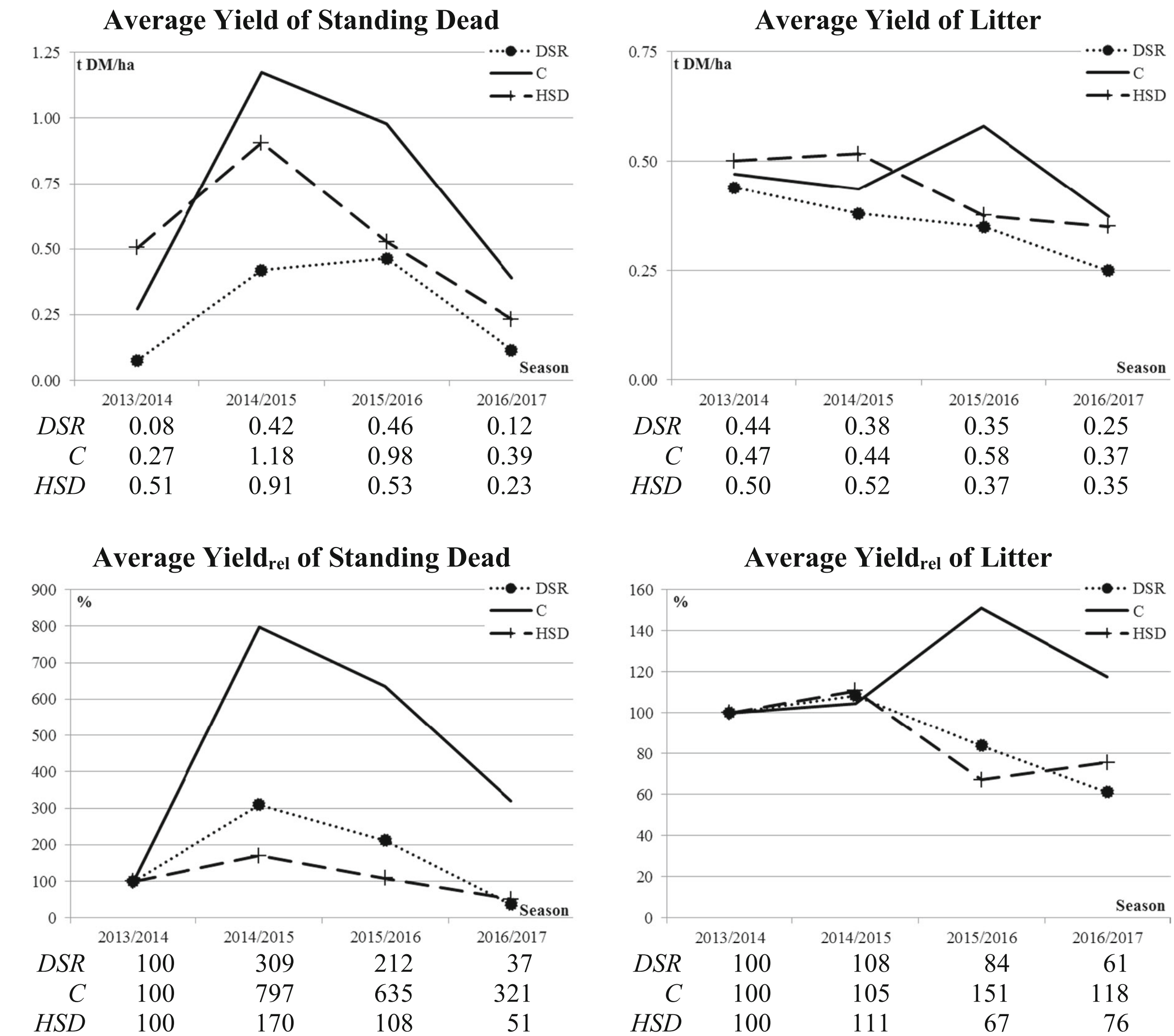
	2013/2014	2014/2015	2015/2016	2016/2017
DSR	100	38	10	92
C	100	32	3	109
HSD	100	13	4	105

DSR = Double Stocking Rate; *C* = Control; *HSD* = Higher Stocking Density;
Season (e.g. 13/14) = time between two measurements, i.e. end of May (e.g. 2013) to end of May (e.g. 2014);
Yield [t DM/ha] = average (n=4 replications) measured at the end of a season in May;
Yield$_{rel}$ [%] = percentage of the initial season 13/14

Fig. 3 Absolute und relative yields of perennial and annual grasses grouped by treatment and season. *DSR* double stocking rate; *C* control; *HSD* higher stocking density; *Season* (e.g. 13/14) time between two measurements, i.e. end of May (e.g. 2013) to end of May (e.g. 2014); *Yield [t DM/ha]* average ($n = 4$ replications) measured at the end of a season in May; *Yield$_{rel}$ [%]* percentage of the initial season 13/14

output and did not measure it, it worked as correction factor for different stocking rates, which made results more comparable but was particularly beneficial for DSR, although removal of fodder also might increase under increased stocking densities. Relative yield and output appear suitable to observe long-term changes, but it should be considered that in our study the initial season was an above-average year in terms of precipitation.

Even though average fodder production and productivity was not significantly different between treatments that do not necessarily mean that increased SR or SD has



Average Yield of Standing Dead (t DM/ha)

	2013/2014	2014/2015	2015/2016	2016/2017
DSR	0.08	0.42	0.46	0.12
C	0.27	1.18	0.98	0.39
HSD	0.51	0.91	0.53	0.23

Average Yield of Litter (t DM/ha)

	2013/2014	2014/2015	2015/2016	2016/2017
DSR	0.44	0.38	0.35	0.25
C	0.47	0.44	0.58	0.37
HSD	0.50	0.52	0.37	0.35

Average Yield$_{rel}$ of Standing Dead (%)

	2013/2014	2014/2015	2015/2016	2016/2017
DSR	100	309	212	37
C	100	797	635	321
HSD	100	170	108	51

Average Yield$_{rel}$ of Litter (%)

	2013/2014	2014/2015	2015/2016	2016/2017
DSR	100	108	84	61
C	100	105	151	118
HSD	100	111	67	76

DSR = Double Stocking Rate; *C* = Control; *HSD* = Higher Stocking Density;
Season (e.g. 13/14) = time between two measurements, i.e. end of May (e.g. 2013) to end of May (e.g. 2014);
Yield [t DM/ha] = measured at the end of a season in May; *Yield$_{rel}$ [%]* = percentage of the initial season 13/14

Fig. 4 Absolute und relative yields of standing dead and litter biomass grouped by treatment and season. *DSR* double stocking rate; *C* control; *HSD* higher stocking density; *Season* (e.g. 13/14) time between two measurements, i.e. end of May (e.g. 2013) to end of May (e.g. 2014); *Yield [t DM/ha]* measured at the end of a season in May; *Yield$_{rel}$ [%]* percentage of the initial season 13/14

no impact at all, e.g. it might have strong effects under specific conditions or in a particular paddock. The applied cumulated SR and average SD were very different, and we observed a pronounced diversity of yield, yield$_{rel}$, output and output$_{rel}$ among the paddocks and replications and between seasons. Averages by treatment with that many outliers in such a small sample are not very reliable. This is also the reason why average yield and output differ from the results published by Ludwig et al. (2017), since in that publication replication 'House' was omitted due to missing data. So far, our preliminary data analysis only considers the factors season and seasonal precipitation besides the treatment. Both had a significant effect on fodder production and productivity, respectively. Though rainfall explained over 50% of the variance in production and appears to be a season's main characteristic and, season and seasonal precipitation are not synonymous. A season has much more attributes we did not yet observe or consider, e.g. timing of grazing, temporal distribution of rain or effects of the previous season.

Standing dead biomass

In HSD paddocks, average accumulation of standing dead ($yield_{rel}$) was much lower than in C and DSR paddocks and in the fourth season, mean yield and $yield_{rel}$ was halved compared to the first measurement. Accumulation under DSR treatment was lower compared to C paddocks and average $yield_{rel}$ in 2017 was only 37%.

Differences in average yield and $yield_{rel}$ of standing dead were indeed significant. It remains unclear how the amount of standing dead was reduced, e.g. by grazing or trampling. Grazing would reduce fodder quality and be less favourable. Trampling might cause an increase in litter that might improve nutrient and carbon recycling and reduce erosion, but we did not observe such an increase. In consideration of the benefits of trampling and disadvantages of grazing, DSR and HSD treatment could be suitable as a tool for rejuvenation of plant stock.

Constraints of this study

Further data analysis and potential data collection ought to continue at higher temporal and spatial resolution. Overall, longer experiment periods are necessary to identify factors determining biomass production/ productivity and to establish possible quantitative relations. Such factors could then be incorporated in grazing management decision support tools. We suggest considering following constraints of this study in future:

(1) The parameters yield and output were introduced to assess biomass production but it should be considered that neither yield nor output can express the total performance of a paddock. A single measurement in May is not suitable to measure vegetation growth and losses and consumption should be rather measured than estimated. Furthermore, the harvest method is labour-intensive and probably not practice-oriented, which is why alternative methods should be considered (e.g. plate meter, see Ohm et al. 2014). It would be interesting to investigate growth rates under different grazing regimes in follow up studies. Further analysis of existing data will allow gaining knowledge on changes in feed quality within and between seasons.

(2) The 3 years of treatment vary extremely in rainfall, which probably is influencing overall biomass growth over the years and it would not be reliable to make generalisations based on a single good or bad season. Generally, longer study periods and larger sample sizes are necessary.

(3) The farmer's main asset is converting rangeland vegetation into animal produce. Assuming that there is indeed no difference between treatments, DSR or HSD might allow producing more livestock without negative effect on fodder production, which should be checked against data. However, the study does not consider livestock's responses to changes in vegetation (e.g. feed availability and quality) and the different phases of their live cycle (e.g. lactation). One response would be a varying feed intake, which is systematically overestimated in this pilot study. Secondly, the changes in livestock live weight were not yet considered. Following studies should include livestock parameters, e.g. by regular weight measurements, observing feed intake or measuring it with titanium dioxide markers.

Conclusions

Certainly, the data emphasises the spatial heterogeneity and temporal variability of resource distribution, production and productivity under semi-arid savanna conditions. Fodder yield is strongly correlated with precipitation, which restricts the farmer's scope of action. The vegetation of different paddocks and seasons showed divers responses to increased stocking rates and stocking densities. The results of this pilot study are not valid enough to suggest a particular treatment or specific SR or SD. Neither was any treatment significantly beneficial nor did we find any linear connection between fodder production or productivity and CSR or ASD, respectively. We assume that high or increased SR or SD is not inevitably bad or good for fodder production and productivity, but it reduces standing dead accumulation significantly. The results accentuate the need for targeted, adaptive grazing planning and show that flexibility and responsiveness are crucial to successful and sustainable rangeland management.

Within this in-farm study, SR and SD were set flexible and in response to the standing crop/residual biomass in May after visual assessment. SR and SD were determined by the farmer as usually done according to Holistic Management Grazing Planning and then variated for the treatment paddocks. Even though there was no significant difference between treatments, often vegetation within a replication and season responded well to increased SR or SD. Hence, these appeared to be more adaptive than the usually applied SR and SD under C conditions. Overall grazing planning could be more responsive. Temporal and spatial livestock distribution is given due to the prescribed sequence of herd movement over paddocks and the grazing schedule. Thereby, the allocation of herds and also density, speed and direction of grazing in response to observed indicators (e.g. condition of soil, vegetation, animals and weather) is limited. As yet, planning is done in response to available forage in May before the dry period, when following amount and timing of precipitation is completely uncertain. Consequently, SR and SD are not fully responsive to actual changes in biomass availability within the rainy season, which seems like a considerable weakness of this SR and SD determination approach.

This pilot project gives interesting insights into possible responses of vegetation to variations in stocking rate or stocking density, but our results and methods are not suitable for practical management. This study ought to be followed by financed projects, which provide better statistical analysis and pay more attention to the deficits of this study.

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