The relationship between dry grassland vegetation and microclimate along a west-east gradient in Central Germany*

Helge Bruelheide and Ute Jandt

14 figures and 5 tables

Abstract

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In the southern Harz and Kyffhäuser Mountains dry grasslands are found on calcareous soils on gypsum bedrock along a steep climatic gradient. With only little differences in soils and land use, climate can be assumed to be the main factor controlling the occurrence of different vegetation types of dry grasslands. For gradient studies at broader scales, climate data are normally available only from official weather stations and, thus, refer to macroclimate. As the microclimate encountered by plants on a specific site usually differs considerably from standard weather station recordings, this paper addresses the questions (1) whether a gradient in the study area is also apparent in microclimate, (2) whether macroclimate is reflected in microclimate, and (3) to which degree microclimate explains the floristic gradient in the study area.

Climate data were compiled at three different temporal scales for twelve sites along a gradient running from north-west to south-east at equal altitudes: (1) long-term averages from official meteorological stations, (2) hourly temperature records over one year from automatic microclimate datalogger and monthly precipitation recordings from 12 dry grassland sites, and (3) half-hourly temperature, air humidity and evaporation data over one day from a measurement campaign carried out simultaneously at all sites.

The results showed that a microclimate gradient was clearly apparent in precipitation but not in temperature. Dry grasslands in the southern Harz and Kyffhäuser Mountains encounter more or less the same microclimatic conditions with respect to temperature but differ considerably in amount of precipitation. In consequence, there was no correlation between microclimate and macroclimate for temperature but a significant relationship for precipitation. The floristic inventory of the study sites showed a clear gradient from west to east, which is well reflected in microclimate conditions. Among all climate variables measured, stronger correlations with floristic composition were encountered for precipitation than for temperature. We conclude from this that the most relevant climate factor for the differentiation of dry grassland vegetation along the studied gradient is precipitation rather than temperature.

Keywords: climate gradient, dry grassland, floristic gradient, Kyffhäuser, microclimate, precipitation, Southern Harz Mountains, vegetation gradient

1 Introduction

The hilly landscape south of the Harz Mountains and the slopes of the Kyffhäuser Mountains have attracted botanists since centuries. Floristic records are already mentioned in the flora of Thal (1588). The area is well known for its floristic richness and the occurrence of range boundaries of a large number of species, as described already by Grisebach (1847), Andrée (1874), Vocke & Angelrodt (1886), Petry (1889), Peter (1901) or Weiss (1924). Meusel (1939, 1937–1962) mapped the plant species' distribution in this region and assigned the range limits to the occurrence of different vegetation types. Range boundaries in

* This paper is dedicated to our highly valuated PhD advisor, Prof. Dr. Hartmut Dierschke, to his 70th birthday.

the Harz and Kyffhäuser area are usually attributed to a steep climatic gradient with rather cool and rainy climate in the west that changes to warmer and drier conditions towards the east (GLÄSSER 1994).

What makes this gradient appear so strong compared to other regions in Germany or whole Europe is a high invariability of other environmental conditions (JANDT & BRUELHEIDE 2002). In particular, soils and land use do not exhibit much change from west to east. The dry grasslands investigated in this study occur at the so-called Zechstein rim, which is characterized by the occurrence of gypsum and dolomite of the Lower and Upper Zechstein formation (Perm) as bedrock. The dry grasslands were used over centuries as unproductive grazing grounds for sheep and goats. The prevailing soil types on slopes and hill crests are rendzinas with a shallow top soil horizon (Ah) and solid gypsum, anhydrite or dolomite rocks just beneath (JANDT 1998, 1999). In consequence, the soils have no great water retaining potential and the vegetation suffers from summer drought. The plant species composition of these dry grasslands of the class *Festuco-Brometea* reflects these growing conditions. The class is subdivided into the two orders *Brometalia erecti* Braun-Blanquet 1936 (subatlantic dry grasslands) and *Festucetalia valesiacae* Braun-Blanquet et Tüxen 1943 (subcontinental dry grasslands). Their occurrence is related to climatic conditions and it is generally assumed that this differentiation of continental versus oceanic dry grassland types is caused by both temperature and precipitation regime. Continental areas in Europe are characterized by large temperature amplitudes between winter and summer temperatures and by small amounts of precipitation prevailingly falling during summer months (JÄGER 1968). The climatic gradient of our study area includes subatlantic conditions in the west and subcontinental conditions to the east and vegetation types of both orders are represented.

Studying vegetation along climate gradients has a long tradition in vegetation science. For example, PERRING (1960) studied limestone grasslands across England to France and from Eiffel to Sauerland in North-Rhine-Westphalia (Germany). He found clear gradients in soil conditions and in species composition, with a sequence of species occurring on all aspects in the driest area but being absent from the wettest, and conversely, a sequence of species which occurred on all aspects in the wettest end +of the gradient but were absent from the dry end.

The patterns of occurrence of the different types at a particular site suggest that not only the macroclimate but also the microclimate is decisive for the distribution of the vegetation types (GRACE 1987). A macroclimatic gradient can be strongly modified by relief (e.g. GEIGER 1965) and by vegetation structure (STOUTESDIJK & BARKMAN 1992). PERRING (1959) showed that the species composition of limestone grassland was strongly influenced by slope and aspect. Species typical of warmer and dryer conditions within British dry grasslands were only encountered on steep slopes exposed to south and west, e.g. *Veronica teucrium, Teucrium montanum, Helianthemum canum, H. apenninum, Euphorbia esula, Bupleurum falcatum* and *Ononis spinosa.* In a re-survey of Perring's plots after 50 years, BENNIE et al. (2006) could not only confirm the importance of slope and aspect in an ANCOVA analysis but also demonstrate that vegetation change was least on south-facing slopes, intermediate on north-facing slopes and highest on flat plots. Probably, steep slopes receive higher radiation loads and, thus, vegetation suffers more severely from drought events.

In consequence, the microclimate encountered by plants on a specific site usually differs considerably from the climatic conditions recorded at an official weather station. For example, SCHULZ & BRUELHEIDE (1999) found minimum temperatures at growth locations of *Euphorbia amygdaloides* to be 3.3 K lower than temperatures measured in standard weather stations in the neighbourhood. Similarly, leaf temperature measured at *Digitalis purpurea* in the Harz Mountains over one year were 0.34 K higher than the air temperature recorded at the nearest weather station in Braunlage (BRUELHEIDE & HEINEMEYER 2002). In the case of dry grasslands such differences might not only result in a drier and warmer microclimate compared to data from standard weather stations but also in less pronounced differences in microclimate compared to macroclimate along the same geographical gradient.

The objectives of this paper are to address the following questions:

(1) Is there a microclimatic gradient along dry grassland sites from west to east in the southern Harz Mountains? If yes, which are the microclimatic variables that perform best?

(2) Does microclimate along the gradient correspond to macroclimate? If yes, which variables show the highest correlation?

(3) Is the floristic gradient in dry grassland vegetation in the southern Harz Mountains reflected in microclimatic variables? If yes, which microclimatic variables show the highest correlation with floristic composition?

2 Materials and methods

2.1 Study area

The study area includes the southern rims of the Harz and Kyffhäuser Mountains (Fig. 1). All sites are characterised by a gypsum or dolomite bedrock (Zechstein, Perm). The western part lies in Lower Saxony with the town of Osterode at the westernmost limit. The study area continues in Thuringia with Nordhausen in the centre and Saxony-Anhalt with Sangerhausen at the eastern and Bad Frankenhausen at the southern limit. This eastern section is part of Germany's driest region, the "Mitteldeutsches Trockengebiet" (Hendl & Endlicher 2003).

2.2 Macroclimate

Monthly mean values of temperature and rainfall were obtained from the WORLDCLIM dataset (Hijmans et al. 2005), and interpolated for the study sites using ArcGis 9.0. The strong gradient along the study area is evident in a significant rank correlation of site sequence with mean annual temperature (Fig. 2) and precipitation (Fig. 3) (for data analysis see chapter 2.4). The climate gradient is also reflected in the long-term averages of the three weather stations at the ends of the gradient (Osterode in the west and Artern and Bad Frankenhausen in the east), for which both temperature and precipitation data are available (Deutscher Wetterdienst 1992a, 1992b, 1996, 1998, Walter 1955, Walter & Lieth 1967). The westernmost weather station at Osterode shows mean annual temperatures of 7.6 °C and mean annual rainfall of 860 mm, while Bad Frankenhausen has 8.7 °C and 492 mm and Artern has 8.4 °C and 455 mm. The precipitation gradient is mainly caused by the prevailing western winds, which force the moist air to ascend on the western slopes of the Harz Mountains and thus result in mean annual precipitation of more than 1000 mm (at Bad Sachsa). The importance of ascending air masses decreases steadily from Osterode to Nordhausen and further east sites are located in the Harz' rain shadow (Glässer 1994). The Kyffhäuser Mountains represent a similar obstacle to clouds, although they themselves are already shielded from westerly winds by the Harz and Hainleite Mountains. In consequence, the climate is driest and sunniest in the southeast of the study area.

2.3 Microclimate

Microclimate data were gathered at twelve sites distributed along the macroclimate gradient (Fig. 1 and Table 1). The observation period lasted 14 months from January 1998 to February 1999. Air temperature was recorded at a height of 30 cm above ground level, which was mainly above the herb layer. The temperature was recorded every 72 minutes using single channel dataloggers (Orion Tinytalk Temp, Orion Components Ltd.). The sensors were insulated from direct radiation by a double aluminium shield. Temperature averages, minimum and maximum values were calculated for calendar months. Precipitation was recorded monthly with standard funnels and in winter additionally with buckets for snow.

Further microclimatic variables were recorded in a one-day field campaign with twelve fully equipped manual stations and twelve helpers. Measurements were performed simultaneously on a clear, sunny summer day on July 20, 1995 from 5 a.m. (before sunrise) until 5 p.m. We measured soil temperature at depths of -1, -5 and -15 cm and air temperature at heights 5, 50 and 150 cm. Air humidity was measured using an Assmann psychrometer. Evaporation was assessed with Piche evaporimeters at 5, 50 and 150 cm. Wind speed was measured with anemometers at 50 cm above ground level.

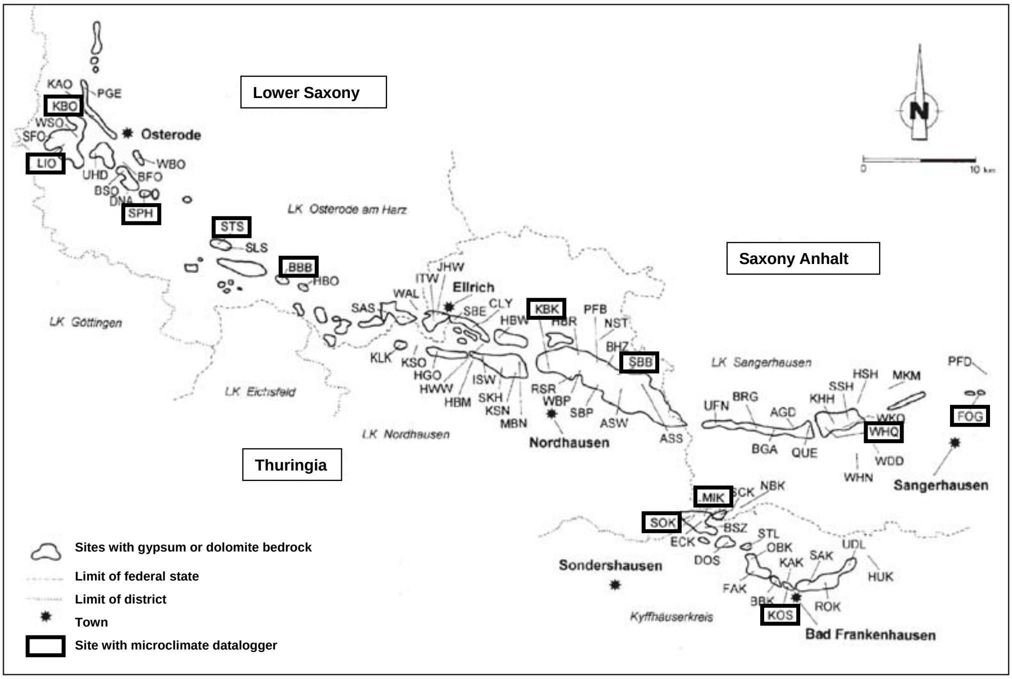

Fig. 1 Study area. The abbreviations refer to dry grassland sites as described in JANDT (1999). The twelve sites included in the floristic survey and long-term microclimate measurements in this study are marked with rectangles: KBO: Kalkberge near Osterode; LIO: Lichtensteingebiet west of Osterode; SPH: Spahnberg near Hörden; STS: Steinkirche near Scharzfeld; BBB: Butterberg near Bartolfelde; KBK: Kalkberg near Krimderode; SBB: Singerberg between Buchholz and Steigerthal; WHQ: „Trockentäler" between Wickerode, Hainrode and Questenberg; FOG: Finkenburg and Ölmühle near Gonna; SOK: Solberg between Auleben and Kelbra; MIK: Mittelberg between Auleben and Kelbra; KOS: Kosackenberg near Bad Frankenhausen. In addition, the following sites were included only in the one-day measurement campaign: HBM: Hainberg near Mauderode, HBR: Hopfenberg near Rüdigsdorf, RSR: Rüdigsdorfer Schweiz near Rüdigsdorf and BBK: Breiter Berg near Bad Frankenhausen.

Abb. 1 Untersuchungsgebiet. Die Abkürzungen beziehen sich auf Trockenrasen-Gebiete nach JANDT (1999). Die zwölf Gebiete, für die die floristische Auswertung vorgenommen wurden und in denen langfristige Mikroklimamessungen in dieser Studie durchgeführt wurden, sind mit Rechtecken markiert.

2.4 Data analysis

All statistics were performed using SAS 6.12. For all regressions, Spearman's rank correlation coefficient was calculated (proc corr, SAS INSTITUTE 1988). For calculating rank correlations, the sequence of sites from west to east as used in Table 1 and Figures 2 and 3 was tested against climatic variables. We considered this approach more appropriate than to use absolute distance between sites as predictor because the site sequence did not conform to a straight line and differences in relief along the gradient resulted in a non-linear response of most variables to exact geographical distance. Differences in mean, maximum and minimum temperatures between sites were calculated with ANOVA, using daily mean, maximum and minimum temperatures as observations, time (day) as block factor and the Scheffé post-hoc test (proc anova, SAS INSTITUTE 1987). Significance level was $p = 0.05$ in all statistical analyses.

A floristic inventory was made for all the twelve study sites where long-term microclimate measurements were carried out by using the data compiled by JANDT (1999). Species nomenclature follows EHRENDOR-

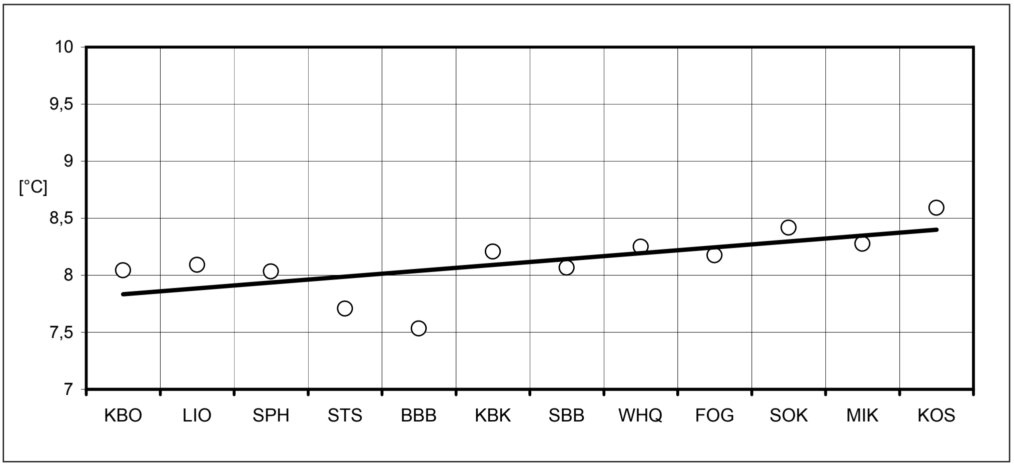

Fig. 2 Mean annual temperatures of the study sites (long-term averages 1930 to 1990), interpolated from the WORLDCLIM dataset (Hijmans et al. 2005). For site abbreviation see Fig. 1. Sites are arranged from west (KBO) to southeast (KOS). Spearman rank correlation coefficient of temperature and site sequence: $r_s = 0.790$, $p = 0.002$.

Abb. 2 Jahres-Mitteltemperatur der Untersuchungsgebiete (langfristige Mittelwerte 1930 bis 1990), interpoliert aus dem WORLDCLIM Datensatz (Hijmans et al. 2005). Für die Gebietsabkürzungen s. Abb. 1. Die Gebiete sind von West (KBO) nach Südost (KOS) angeordnet. Spearman Rang-Korrelationskoeffizient für Temperatur und Gebietsreihenfolge: $r_s = 0.790$, $p = 0.002$.

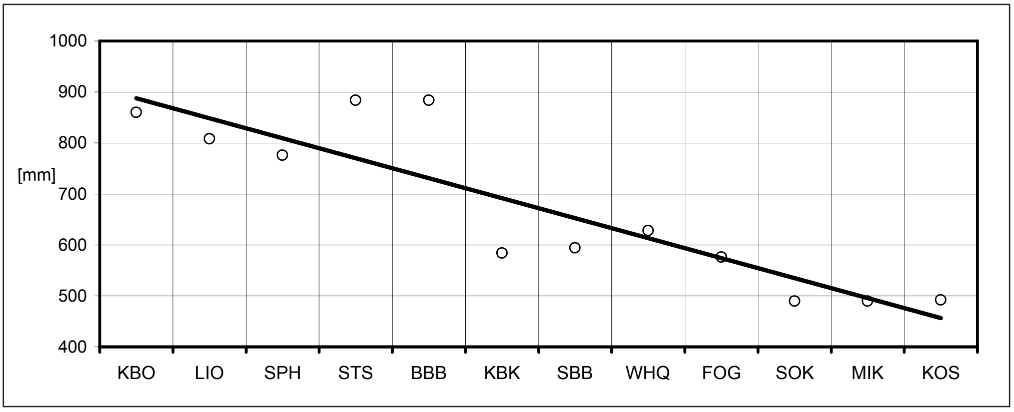

Fig. 3 Mean annual precipitation of the study sites from records of the nearest official weather station (see methods). For site abbreviation see Fig. 1. Sites are arranged from west (KBO) to southeast (KOS). Spearman rank correlation coefficient of precipitation and site sequence: $r_s = -0.842$, $p = 0.001$.

Fig. 3 Mittlerer Jahresniederschlag der Untersuchungsgebiete aus den Aufzeichnungen der nächsten Wetterstation (s. Methoden). Für die Gebietsabkürzungen s. Abb. 1. Die Gebiete sind von West (KBO) nach Südost (KOS) angeordnet. Spearman Rang-Korrelationskoeffizient für Niederschlag und Gebietsreihenfolge: $r_s = -0.842$, $p = 0.001$.

Tab. 1 Topographical features of all sites, both used for long-term microclimate measurements and the one-day measurement campaign (see chapter 2.3). For site abbreviation and site location see Fig. 1.

Tab. 1 Topographische Angaben zu allen Gebieten, an denen langfristige Messungen an Mikroklima-Stationen (Long-term datalogger) und die eintägige Messkampagne durchgeführt wurden (One-day campaign). Für die Gebietsabkürzungen s. Abb. 1.

Site	Elevation [m a.s.l.]	Aspect	Slope [°]	Long-term datalogger	One-day campaign
LIO	250	SSW	15	x	x
KBO	290	-	-	x	
SPH	230	S	45	x	x
BBB	320	SW	16	x	x
STS	290	S	38	x	
HBM	275	SW	12		x
KBK	210	SW	16	x	x
HBR	270	SW	20		x
SBB	295	SE	25	x	x
RSR	270	SW	35		x
WHQ	250	S	22	x	x
FOG	230	SSW	10	x	x
SOK	175	N	24	x	
MIK	205	S	22	x	x
BBK	160	S	24		x
KOS	200	S	18	x	

FER (1973). The resulting species (429) by site (12) matrix was subjected to gradient analysis by unconstrained correspondence analysis (CA). The resulting gradients in species composition were then related *a posteriori* to the monthly temperature and precipitation values obtained from the long-term measurement (see chapter 2.3). All calculations were performed with CANOCO vers. 3.12 (TER BRAAK 1991). Species were not weighted by abundance and no exclusion of rare species was applied. Missing values for environmental factors were interpolated from the next adjacent sites. The results are presented as ordination biplots with sites and environmental variables. Sites are plotted using linear combination (LC) scores as recommended by PALMER (1993). In the graph, environmental variables are scaled by the factor 3.

3 Results

3.1 Microclimate

Fig. 4 shows the average monthly temperature measured at the long-term microclimate stations along the gradient. Temperature variation among sites was highest in winter and lowest during the vegetation period. In contrast to the anticipated gradient in thermal continentality, coldest average temperatures in winter were not observed in the east but in the west (KBO, STS, BBB). However, not all sites followed this general trend. In comparison to neighbouring sites, LIO and SPH were exceptionally warm in winter.

The statistics for differences in daily mean temperature between sites are summarized in Table 2. The most remarkable result emerging from Table 2 is that the pattern of warmest and coldest sites was not consistent over all months. Sites switched from being among the warmest ones to being among the coldest ones (e.g. SBB) or vice versa, from low to high temperatures (e.g. KBO). The most abrupt change in pattern occurred between April and May, evident in different shadings of highest and lowest daily mean temperature values (Table 2). In accordance with expectation, the eastern Kyffhäuser sites had highest

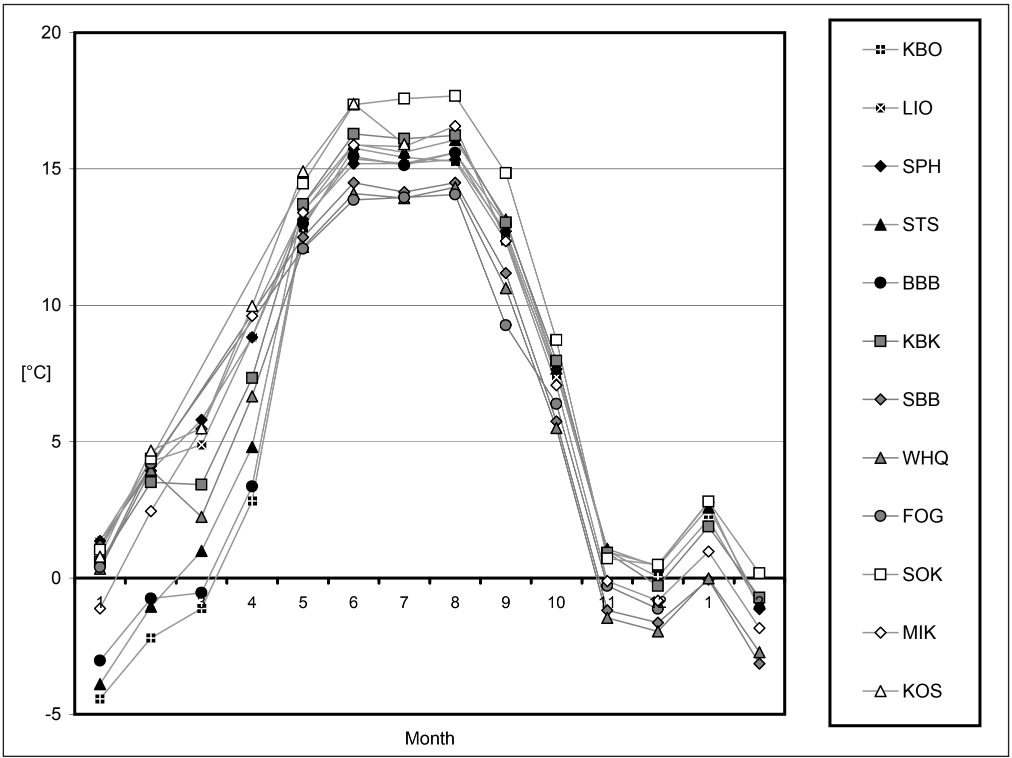

Fig. 4 Average monthly temperatures measured at microclimate stations in dry grasslands from January 1998 to February 1999. For site abbreviation see Fig. 1. Sites are arranged from west (KBO) to southeast (KOS).

Abb. 4 Monats-Mitteltemperatur, gemessen an den in den Trockenrasen eingerichteten Mikroklima-Stationen von Januar 1998 bis Februar 1999. Für die Gebietsabkürzungen s. Abb. 1. Die Gebiete sind von West (KBO) nach Südost (KOS) angeordnet.

temperatures in summer (SOK, MIK, KOS). However, daily mean temperatures in July differed only by 3.6 K from the coldest (FOG) to the warmest site (SOK, Table 2). A similar pattern was also observed for the absolute maximum temperatures (Fig. 5). In particular, the easternmost sites in the Kyffhäuser Mountains were characterized by exceptionally high absolute temperature maxima, especially in spring (KOS, MIK, SOK). In summer, absolute maximum temperatures were above 31 °C at all sites. The highest temperature was measured at the MIK site in the east with 38.5 °C (Fig. 5). This value is higher than the maximum values recorded at official weather stations in this area or at even more continental locations (Döring 2004). However, daily maximum temperatures were not consistently different between sites in the different months, which resulted in less significancies among sites (Table 3). In particular, many sites were assigned to the same statistically homogeneous group with high January and February daily maxima. The absolute minimum temperatures did not vary much among sites (Fig. 6). In February 1998, absolute minimum temperatures were below -14 °C at all sites. The lowest temperature was measured at the westernmost site (KBO) with -20.8 °C (Fig. 6). The pattern in daily absolute minimum temperatures (Table 4) was very similar to the one of the averages (Table 2). In contrast to the macroclimatic gradient, lowest daily temperature minima in winter were encountered for the westernmost site (KBO). In summer, the two sites in Saxony-Anhalt (WHQ, FOG) had lowest daily minima (Table 2).

Tab. 2 **Average** monthly temperatures [°C], based on continuous microclimate temperature measurements at a height of 30 cm above ground level every 72 min (20 values a day), from January to December 1998. For site abbreviation and site location see Fig. 1. The sites are arranged from west to southeast. Sites with different letters for a certain month have significantly different daily average temperatures according to ANOVA for tied observations with subsequent single comparisons according to the Scheffé Test ($p < 0.05$). The shadings indicate significantly lowest (black) to highest (grey) values within a certain month. Please note that data from some months were not complete due to logger failure or vandalism and thus were not included in the statistical comparison.

Tab. 2 Monats-**Mittel**temperaturen [°C], basierend auf kontinuierlichen Mikroklima-Temperaturmessungen in 30 cm Höhe alle 72 min (20 Werte pro Tag), von Januar bis Dezember 1998. Für die Gebietsabkürzungen s. Abb. 1. Die Gebiete sind von West nach Südost angeordnet. Gebiete mit unterschiedlichen Buchstaben innerhalb eines Monats haben signifikant verschiedene Tages-Mitteltemperaturen nach der ANOVA für verbundene Stichproben und anschließendem Einzelvergleich nach Scheffé ($p < 0.05$). Die Schattierung gibt die signifikant niedrigsten (schwarz) und höchsten (grau) Werte im jeweiligen Monat an. Es ist zu beachten, dass die Daten für einige Monate nicht vollständig waren aufgrund von Ausfall der Datalogger und Vandalismus und deswegen nicht in die statistische Auswertung eingingen.

	West											East
	KBO	**LIO**	**SPH**	**STS**	**BBB**	**KBK**	**SBB**	**WHQ**	**FOG**	**SOK**	**MIK**	**KOS**
Jan	-4,56 E	1,35 A	1,25 A	-3,90 E	-2,92 D	0,57 BA	1,16 A	0,22 B	0,26 B	0,85 BA	-1,30 C	0,64 BA
Feb	-2,20 E	4,28 BA	3,93 BA	-1,05 D	-0,75 D	3,51 B	4,07 BA	3,96 BA	4,14 BA	4,33 BA	2,45 C	4,67 A
Mar	-1,12 F	4,88 B	5,80 A	0,99 E	-0,55 F	3,42 C		2,24 D			5,47 BA	5,48 BA
Apr	2,83 G	8,85 B	8,82 B	4,80 E	3,35 F	7,33 C		6,66 D			9,61 A	9,97 A
May	12,84 DCE	13,49 C	13,15 DC	13,69 BC	13,00 DCE	13,72 BC	12,52 DE	12,14 E	12,12 E	14,49 BA	13,40 DC	14,91 A
Jun	15,76 CB	15,37 CD	15,19 D	15,92 CB	15,46 CD	16,29 B	14,49 E	14,09 FE	13,87 F	17,36 A	15,88 CB	17,39 A
Jul	15,43 DE	15,20 DE	15,21 DE	15,61 CDE	15,13 E	16,12 CB	14,15 F	13,93 F	13,95 F	17,58 A	15,82 CD	
Aug	15,28 D	15,60 CD	15,34 D	16,07 CB	15,59 CD	16,24 CB	14,49 E	14,33 E	14,07 E	17,68 A	16,57 B	
Sep	12,36 B	12,56 B	12,71 B	13,15 B	13,12 B	13,05 B	11,18 C	10,62 C	9,27 D	14,85 A	12,35 B	
Oct	7,52 CBD	7,37 CD	7,66 CB	7,68 CB		7,95 B	5,75 F	5,50 F	6,40 E	8,68 A	7,07 D	
Nov	0,99 B	4,44 A	0,95 B	1,07 B		0,92 B	-1,19 E	-1,47 E	-0,29 D	0,65 CB	-0,11 CD	
Dec	0,04 BA		0,46 BA	0,41 BA		-0,30 BC	-1,64 FE	-1,96 F	-1,14 DE	0,48 A	-0,84 DC	

Tab. 3 Absolute **daily maximum** temperatures [°C], based on continuous microclimate temperature measurements at a height of 30 cm above ground level every 72 min (20 values a day), from January to December 1998. For site abbreviation and site location see Fig. 1. The sites are arranged from west to southeast. Sites with different letters for a certain month have significantly different daily average temperatures according to ANOVA for tied observations with subsequent single comparisons according to the Scheffé Test ($p < 0.05$). The shadings indicate significantly lowest (black) to highest (grey) values within a certain month. Please note that data from some months were not complete due to logger failure or vandalism and thus were not included in the statistical comparison.

Tab. 3 Absolute **Tages-Maximum**temperaturen [°C], basierend auf kontinuierlichen Mikroklima-Temperaturmessungen in 30 cm Höhe alle 72 min (20 Werte pro Tag), von Januar bis Dezember 1998. Für die Gebietsabkürzungen s. Abb. 1. Die Gebiete sind von West nach Südost angeordnet. Gebiete mit unterschiedlichen Buchstaben innerhalb eines Monats haben signifikant verschiedene Tages-Mitteltemperaturen nach der ANOVA für verbundene Stichproben und anschließendem Einzelvergleich nach Scheffé ($p < 0.05$). Die Schattierung gibt die signifikant niedrigsten (schwarz) und höchsten (grau) Werte im jeweiligen Monat an. Es ist zu beachten, dass die Daten für einige Monate nicht vollständig waren aufgrund von Ausfall der Datalogger und Vandalismus und deswegen nicht in die statistische Auswertung eingingen.

	West											**East**
	KBO	**LIO**	**SPH**	**STS**	**BBB**	**KBK**	**SBB**	**WHQ**	**FOG**	**SOK**	**MIK**	**KOS**
Jan	-2,16 E	4,95 A	5,09 A	-0,04 D	0,95 DC	4,68 A	4,97 A	3,90 A	3,73 A	3,32 BA	1,83 BC	3,90 A
Feb	1,37 C	8,40 A	8,69 A	3,45 B	3,63 B	8,75 A	8,64 A	8,77 A	8,95 A	8,21 A	7,57 A	8,98 A
Mar	2,26 H	9,50 DC	10,42 BC	5,58 F	3,69 G	8,72 DE		7,60 E			10,74 BA	11,62 A
Apr	6,99 E	14,02 CB	14,21 CB	9,92 D	7,70 E	13,37 C		12,85 C			15,26 B	17,36 A
May	18,21 D	20,30 CB	20,45 CB	20,59 CB	19,00 CD	20,95 B	19,70 CBD	19,32 CD	19,89 CB	21,09 B	20,95 B	23,32 A
Jun	21,03 EFG	20,97 EFG	21,48 EFD	22,24 ECD	20,99 EFG	23,05 BC	20,87 FG	20,68 FG	20,06 G	23,90 BA	22,60 BCD	24,76 A
Jul	20,00 D	20,56 DC	21,26 BDC	21,47 BDC	20,37 D	22,33 BAC	20,13 D	20,61 DC	20,14 D	23,36 A	22,50 BA	
Aug	19,90 F	22,19 EDC	22,90 BDC	22,83 DC	21,76 ED	23,55 BAC	21,11 EF	21,95 EDC	19,89 F	24,53 A	24,52 BA	
Sep	16,53 BECD	17,49 BCD	17,92 BC	17,96 BC	16,13 ED	18,18 BA	16,31 ECD	15,99 ED	14,83 E	19,81 A	17,56 BCD	
Oct	10,03 EDC	10,32 BDC	11,03 BAC	10,90 BAC		11,51 A	8,72 F	8,89 EF	9,69 EDF	11,31 BA	10,00 EDC	
Nov	3,00 CB	7,13 A	3,68 B	3,87 B		3,66 B	1,71 C	1,71 C	2,85 CB	2,87 CB	2,91 CB	
Dec	1,92 BC		3,32 A	3,14 BA		3,06 BA	1,58 C	1,48 C	2,00 BC	2,50 BAC	2,20 BAC	

Tab. 4 Absolute **daily minimum** temperatures [°C], based on continuous microclimate temperature measurements at a height of 30 cm above ground level every 72 min (20 values a day), from January to December 1998. For site abbreviation and site location see Fig. 1. The sites are arranged from west to southeast. Sites with different letters for a certain month have significantly different daily average temperatures according to ANOVA for tied observations with subsequent single comparisons according to the Scheffé Test ($p < 0.05$). The shadings indicate significantly lowest (black) to highest (grey) values within a certain month. Please note that data from some months were not complete due to logger failure or vandalism and thus were not included in the statistical comparison.

Tab. 4 Absolute **Tages-Minimum**temperaturen [°C], basierend auf kontinuierlichen Mikroklima-Temperaturmessungen in 30 cm Höhe alle 72 min (20 Werte pro Tag), von Januar bis Dezember 1998. Für die Gebietsabkürzungen s. Abb. 1. Die Gebiete sind von West nach Südost angeordnet. Gebiete mit unterschiedlichen Buchstaben innerhalb eines Monats haben signifikant verschiedene Tages-Mitteltemperaturen nach der ANOVA für verbundene Stichproben und anschließendem Einzelvergleich nach Scheffé ($p < 0.05$). Die Schattierung gibt die signifikant niedrigsten (schwarz) und höchsten (grau) Werte im jeweiligen Monat an. Es ist zu beachten, dass die Daten für einige Monate nicht vollständig waren aufgrund von Ausfall der Datalogger und Vandalismus und deswegen nicht in die statistische Auswertung eingingen.

	West										East
	KBO	LIO	SPH	STS	BBB	KBK	SBB	WHQ	FOG	SOK	MIK	KOS
Jan	-7,29 F	-1,66 A	-2,11 BAC	-6,82 FE	-5,94 E	-2,93 BC	-2,12 BAC	-3,10 DC	-2,67 BAC	-1,86 BA	-4,26 D	-2,54 BAC
Feb	-5,54 F	1,03 BA	-0,16 BDC	-4,63 FE	-3,86 E	-1,18 DC	0,47 BA	0,05 BAC	0,34 BA	0,72 BA	-1,48 D	1,36 A
Mar	-4,63 D	1,05 A	1,63 A	-3,03 C	-4,07 D	-1,47 B		-2,08 B			1,25 A	0,88 A
Apr	-1,59 E	4,64 BA	4,05 B	0,36 D	-0,40 D	1,44 C		1,59 C			4,84 A	4,55 BA
May	7,04 BA	8,03 A	6,86 BA	7,85 A	7,83 A	6,80 BA	6,06 BC	5,84 BC	5,29 C	7,99 A	7,10 BA	8,10 A
Jun	10,67 BC	10,44 BC	9,50 ED	10,66 BC	10,88 BAC	10,15 DC	8,78 EF	8,27 F	8,01 F	11,64 A	10,18 DC	11,26 BA
Jul	11,07 B	10,63 B	10,45 B	11,19 B	11,23 B	10,59 B	9,17 C	8,62 C	9,00 C	12,63 A	10,83 B	
Aug	9,97 BC	9,89 BC	8,95 DC	10,31 BA	10,66 BA	9,67 BC	8,41 D	7,98 D	8,23 D	11,36 A	10,03 BC	
Sep	8,52 B	8,96 B	8,58 B	9,67 BA	10,59 A	8,67 B	7,24 C	6,54 C	5,34 D	10,80 A	8,79 B	
Oct	4,92 CB	4,71 CB	4,82 CB	5,04 B		5,00 CB	2,93 D	2,54 D	3,16 D	5,78 A	4,32 C	
Nov	-1,12 B	2,30 A	-1,48 CB	-1,14 B		-1,86 CB	-3,67 EF	-4,12 F	-3,00 ED	-1,67 CB	-2,35 CD	
Dec	-2,54 BA		-2,24 A	-2,14 A		-3,34 BC	-4,34 DC	-4,76 D	-3,87 DC	-1,85 A	-3,37 BC	

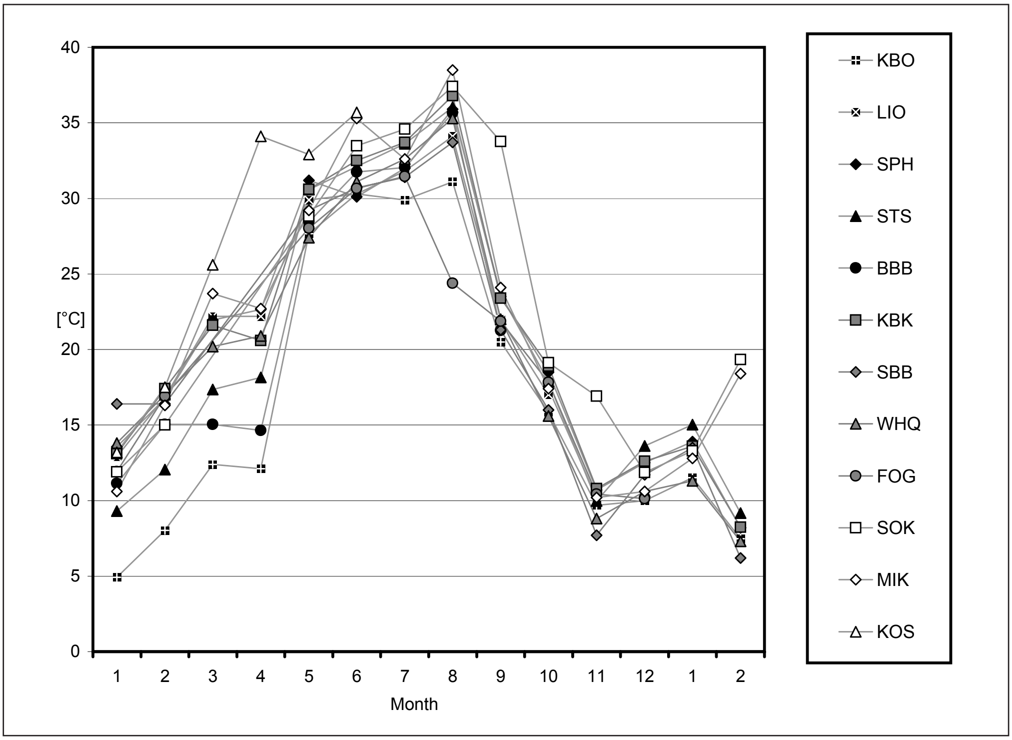

Fig. 5 Absolute maximum temperatures measured at microclimate stations in dry grasslands from January 1998 to February 1999. For site abbreviation see Fig. 1. Sites are arranged from west (KBO) to southeast (KOS).

Abb. 5 Absolute Maximum-Temperaturen, gemessen an den in den Trockenrasen eingerichteten Mikroklima-Stationen von Januar 1998 bis Februar 1999. Für die Gebietsabkürzungen s. Abb. 1. Die Gebiete sind von West (KBO) nach Südost (KOS) angeordnet.

The different seasonal patterns of eastern and western sites resulted in the absence of a significant temperature trend in the annual averages (Fig. 7). However, this failure was also due to missing values of some of the eastern stations with presumably high temperature values.

The mean air temperatures recorded at the measurement campaign on July 20, 1995 showed the importance of measuring heights (Fig. 8). Temperatures recorded 5 cm above the ground level were up to 4.7 K warmer than those measured at a height of 150 cm (at MIK). Averaged over all sites, mean temperature at 5 cm were 1.81 K higher than at 50 cm and 2.34 K higher than at 150 cm. Sites SPH and MIK had extraordinarily high values due to their open vegetation structure and patches of humus-rich bare ground. There was no significant correlation between sequence of sites and mean air temperature (Spearman's rank correlation coefficient 5 cm: $r_s = 0.504$, $p = 0.094$; 50 cm: $r_s = 0.154$, $p = 0.633$; 150 cm: $r_s = 0.070$, $p = 0.829$, Fig. 8). Despite higher temperatures near to the ground, evaporation was higher at 50 cm and 150 cm above ground level (Fig. 9). Averaged over all sites, evaporation was 48 ml at 50 cm and 150 cm above ground level compared to 36.5 ml at 5 cm. This was mainly due to lower air humidity and higher wind speed at greater heights (data not shown). For the heights 5 cm and 150 cm there was no significant rank correlation with site sequence, while the values at 50 cm were marginally significant (Spearman's rank correlation coefficient 5 cm: $r_s = 0.291$, $p = 0.385$; 50 cm: $r_s = 0.601$, $p = 0.039$; 150 cm: $r_s = 0.238$, $p = 0.456$, Fig. 9).

In contrast to temperature, a much clearer gradient was detected for monthly precipitation recorded on the sites along the gradient, with much higher values in the west than in the east, both in winter and sum-

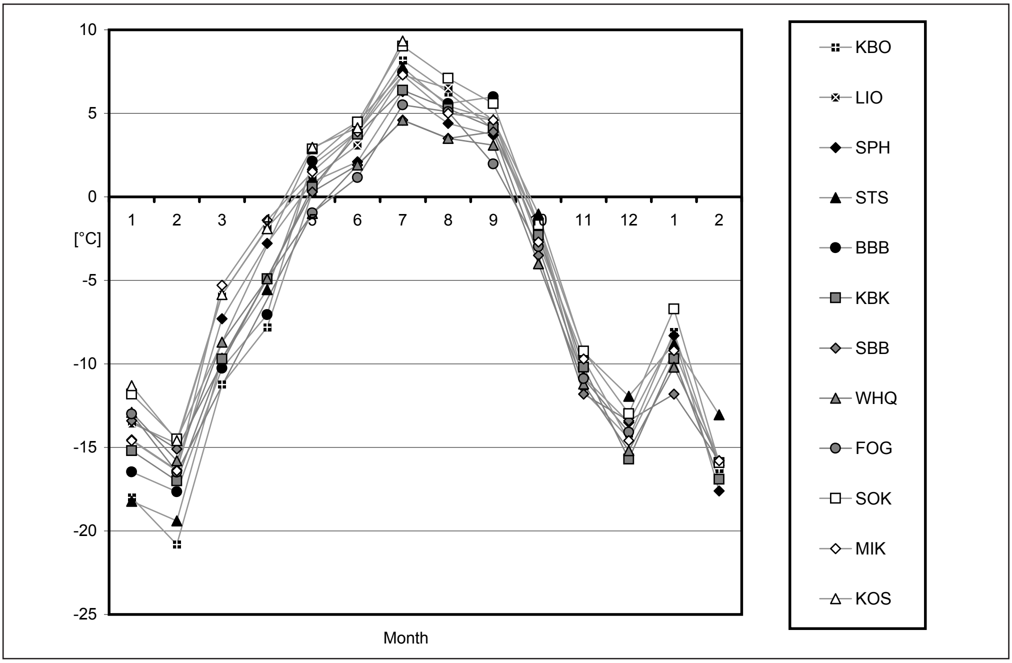

Fig. 6 Absolute minimum temperatures measured at microclimate stations in dry grasslands from January 1998 to February 1999. For site abbreviation see Fig. 1. Sites are arranged from west (KBO) to southeast (KOS).

Abb. 6 Absolute Minimum-Temperaturen, gemessen an den in den Trockenrasen eingerichteten Mikroklima-Stationen von Januar 1998 bis Februar 1999. Für die Gebietsabkürzungen s. Abb. 1. Die Gebiete sind von West (KBO) nach Südost (KOS) angeordnet.

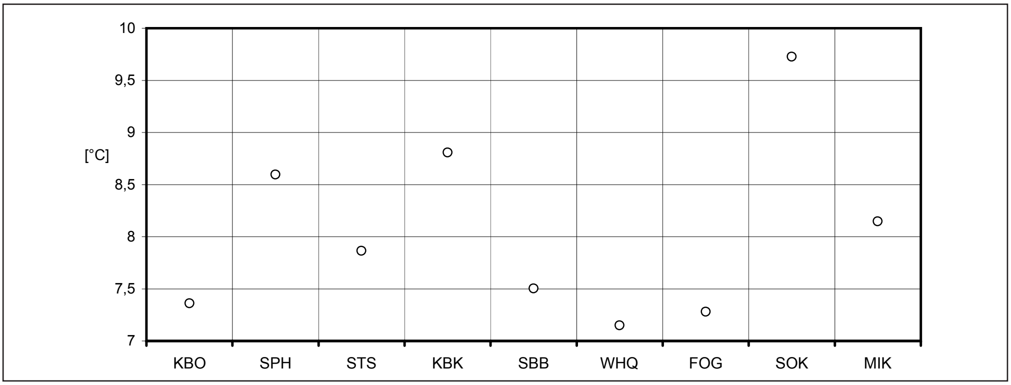

Fig. 7 Annual mean temperature measured at microclimate stations in dry grasslands in 1998. For site abbreviation see Fig. 1. Sites are arranged from west (KBO) to southeast (MIK). Due to datalogger failure three sites were not included and recordings from March and April were omitted. Spearman rank correlation coefficient of temperature and site sequence: $r_s = 0.083$, $p = 0.831$.

Abb. 7 Jahres-Mitteltemperatur, gemessen an den in den Trockenrasen eingerichteten Mikroklima-Stationen im Jahr 1998. Für die Gebietsabkürzungen s. Abb. 1. Die Gebiete sind von West (KBO) nach Südost (MIK) angeordnet. Aufgrund des Ausfalls von Dataloggern wurden drei Gebiete von März bis April nicht in die Auswertung einbezogen. Spearman Rang-Korrelationskoeffizient für Temperatur und Gebietsreihenfolge: $r_s = 0.083$, $p = 0.831$.

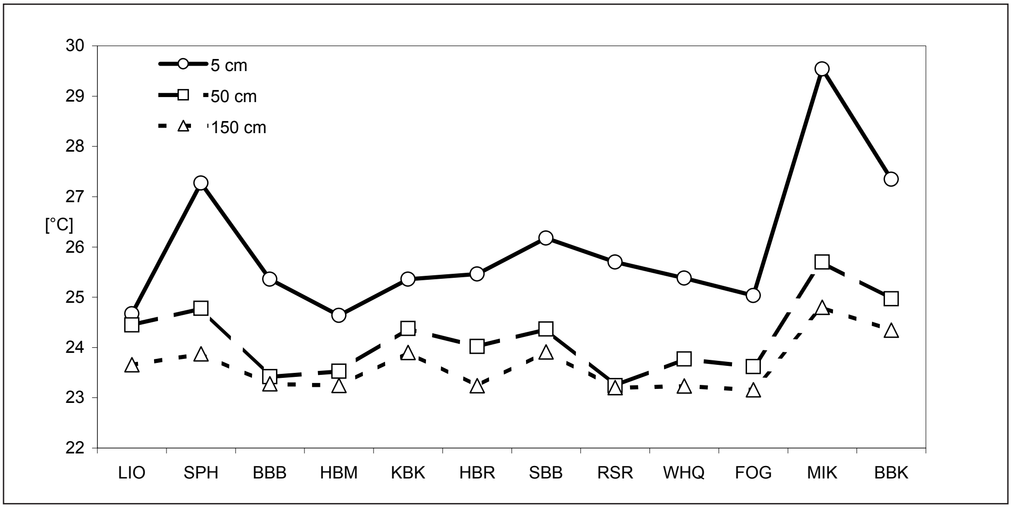

Fig. 8 Average air temperatures measured at different heights on the one-day measurement campaign on July 20, 1995, and averaged over all values from 5 am until 5 pm. For site abbreviation see Fig. 1. Sites are arranged from west (LIO) to southeast (BBK).

Abb. 8 Mittlere Lufttemperaturen, gemessen in verschiedenen Höhen während der eintägigen Mikroklima-Messkampagne am 20. Juli 1995 und gemittelt über alle Werte von 5:00 bis 17:00 Uhr. Für die Gebietsabkürzungen s. Abb. 1. Die Gebiete sind von West (LIO) nach Südost (BBK) angeordnet.

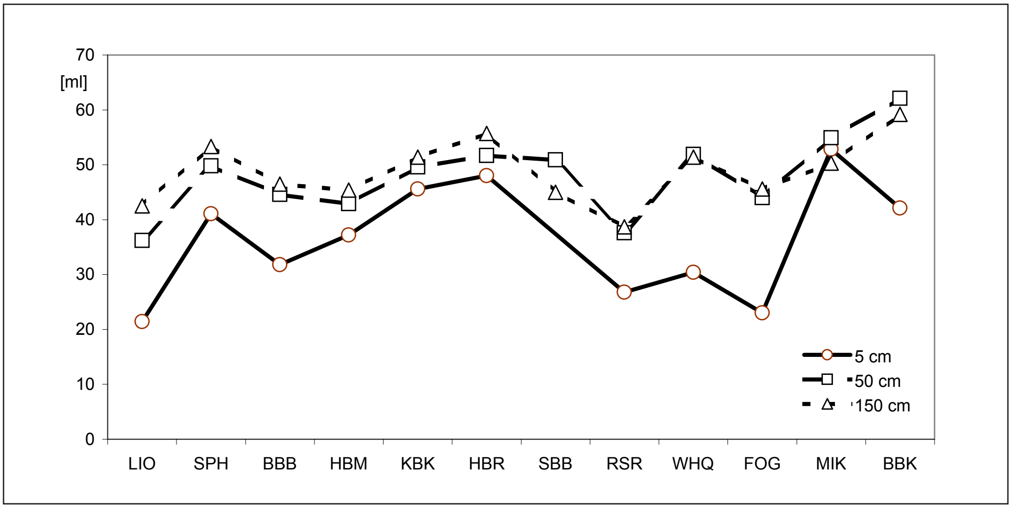

Fig. 9 Piche evaporation measured at different heights on the one-day measurement campaign on July 20, 1995 and summed up from 5 am until 5 pm. For site abbreviation see Fig. 1. Sites are arranged from west (LIO) to east (BBK).

Abb. 9 Evaporation nach Piche, gemessen in verschiedenen Höhen während der eintägigen Mikroklima-Messkampagne am 20. Juli 1995 und summiert über alle Werte von 5:00 bis 17:00 Uhr. Für die Gebietsabkürzungen s. Abb. 1. Die Gebiete sind von West (LIO) nach Südost (BBK) angeordnet.

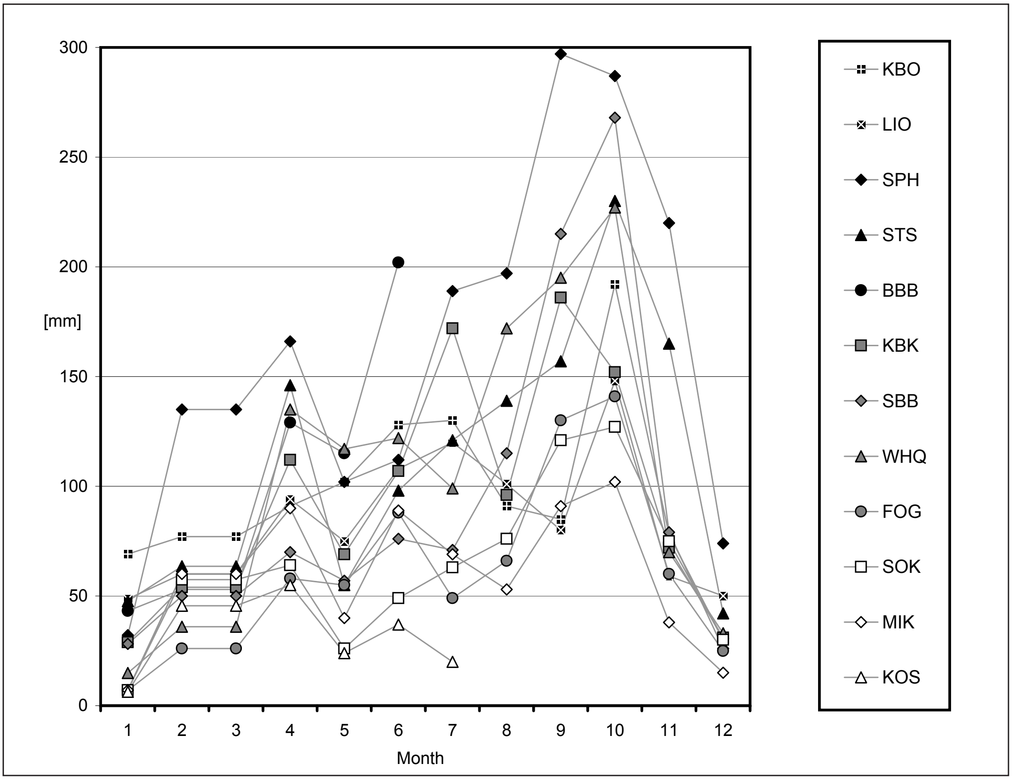

Fig. 10 Monthly precipitation measured at microclimate stations in dry grasslands in 1998. For site abbreviation see Fig. 1. Sites are arranged from west (KBO) to east (KOS). Due to vandalism some sites have missing values. Please note that no measurements were made in February and that March recordings were equally assigned to February and March.

Abb. 10 Monatliche Niederschläge, gemessen an den in den Trockenrasen eingerichteten Mikroklima-Stationen im Jahr 1998. Für die Gebietsabkürzungen s. Abb. 1. Die Gebiete sind von West (KBO) nach Südost (KOS) angeordnet. Aufgrund von Vandalismus zeigen manche Gebiete fehlende Werte. Es ist zu beachten, dass im Februar keine Messungen vorgenommen wurden und die März-Niederschläge zu gleichen Anteilen den Werten des Februar und März zugeordnet wurden.

mer months (Fig. 10). The annual course of precipitation also shows exceptionally dry conditions in May 1998. The sequence of sites showed a highly significant rank correlation with total precipitation (Spearman's rank correlation coefficient $r_s = -0.875$, $p = 0.001$, Fig. 11). However, no gradient was found for the ratio of winter to summer precipitation ($r_s = 0.176$, $p = 0.627$).

3.2 Relationship between microclimate and macroclimate

There was no correlation between the calculated annual average temperature measured at our microclimate stations in 1998 and the long-term interpolated averages from the global dataset (Fig. 12). There was also no correlation between all but one of the monthly temperature averages of microclimate and macroclimate (data not shown). The only exception was April ($r_s = 0.848$, $p = 0.004$).

In contrast to temperature, precipitation measured in 1998 on the sites was significantly related to macroclimate (Spearman's $r_s = 0.687$, $p = 0.028$, Fig. 13).

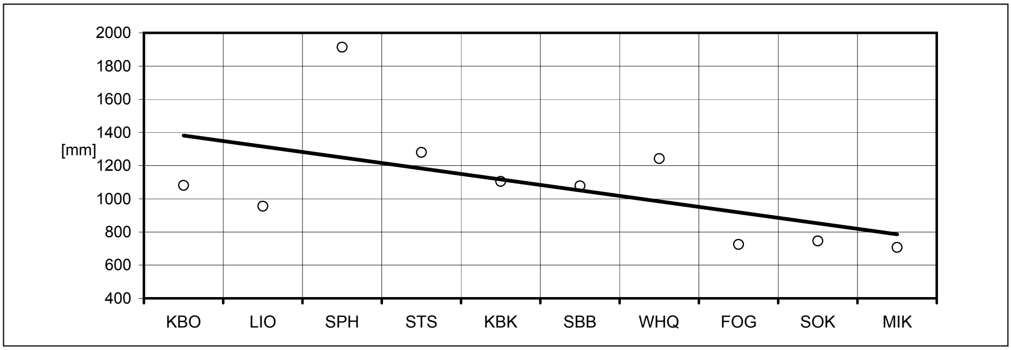

Fig. 11 Annual precipitation measured at microclimate stations in dry grasslands in 1998. For site abbreviation see Fig. 1. Sites are arranged from west (KBO) to southeast (MIK). Due to vandalism two sites were not included. Spearman rank correlation coefficient of precipitation and site sequence: r_s = -0.875, p = 0.001.

Abb. 11 Mittlerer Jahresniederschlag, gemessen an den in den Trockenrasen eingerichteten Mikroklima-Stationen im Jahr 1998. Für die Gebietsabkürzungen s. Abb. 1. Die Gebiete sind von West (KBO) nach Südost (MIK) angeordnet. Aufgrund von Vandalismus wurden zwei Gebiete nicht in die Auswertung einbezogen. Spearman Rang-Korrelationskoeffizient für Niederschlag und Gebietsreihenfolge: r_s = -0.875, p = 0.001.

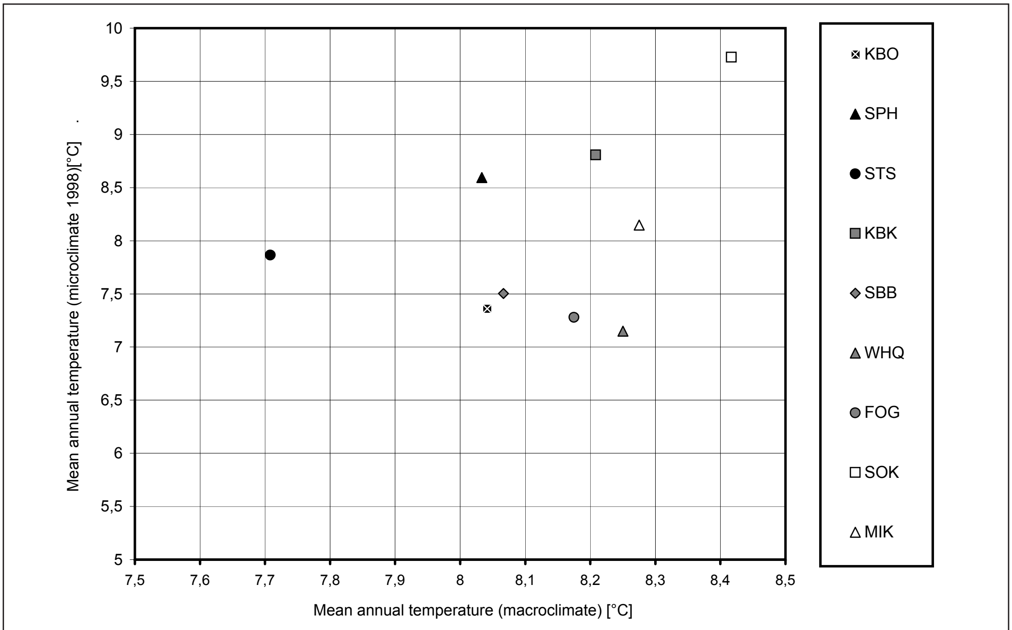

Fig. 12 Mean annual temperature measured at microclimate stations in dry grasslands in 1998 as a function of mean annual temperature (long-term averages 1930 to 1990) interpolated from the WORLDCLIM dataset (Hijmans et al. 2005). For site abbreviation see Fig. 1. Sites are arranged from west (KBO) to southeast (MIK). Due to datalogger failure three sites were not included. Spearman rank correlation coefficient: r_s = 0.217, p = 0.576.

Abb. 12 Jahres-Mitteltemperatur, gemessen an den in den Trockenrasen eingerichteten Mikroklima-Stationen im Jahr 1998, als Funktion der Jahres-Mitteltemperatur (langfristige Mittelwerte 1930 bis 1990), interpoliert aus dem WORLDCLIM Datensatz (Hijmans et al. 2005). Für die Gebietsabkürzungen s. Abb. 1. Die Gebiete sind von West (KBO) nach Südost (MIK) angeordnet. Aufgrund des Ausfalls von Dataloggern wurden drei Gebiete nicht in die Auswertung einbezogen. Spearman Rang-Korrelationskoeffizient: r_s = 0.217, p = 0.576.

3.3 Relationship between microclimate and floristic composition

The dry grassland species pool for all twelve sites where long-term microclimate measurements were carried out is listed in Table 5. While only a few species are restricted to the western and central part of the gradient, many species are confined to either the eastern half or, in particular, to the Kyffhäuser region. Species with a western distribution in the study area (e.g. *Potentilla neumanniana, Carex flacca, Thymus pulegioides*) are typical of subatlantic dry grasslands, (Mesobromion, Gentiano-Koelerietum), while Kyffhäuser species (e.g. *Scabiosa canescens, Poa bulbosa, Inula germanica*) are typical of continental dry grasslands (Festucion valesiacae, Festucion pallentis). The largest group of species has a regional distribution boundary near to Nordhausen in western Thuringia (e.g. *Stipa joannis, S. capillata, Allium montanum, Koeleria macrantha*). There is also a group of dealpine species (e.g. *Parnassia palustris, Cardaminopsis petraea, Carex ornithopoda*) with most occurrences at the westernmost site (KBO) but some scattered occurrences elsewhere.

Fig. 14 shows the correspondence analysis for all 429 species and all 12 sites. Floristic variation explained by the first two axes is 32 % (eigenvalues of 0.356 and 0.244 for axis 1 and 2 related to the sum of all eigenvalues 1.894). The sites form a gradient from the western Lower Saxony site (KBO) on the right to the southeastern Kyffhäuser site (KOS) on the left. In addition, the sites were arranged in three main groups: the Kyffhäuser sites (KOS, MIK, SOK), the sites in western Thuringia and in Saxony-Anhalt (KBK, WHQ, SBB), and the western sites in Lower Saxony (LIO, SPH, STS, BBB). The eastern site FOG

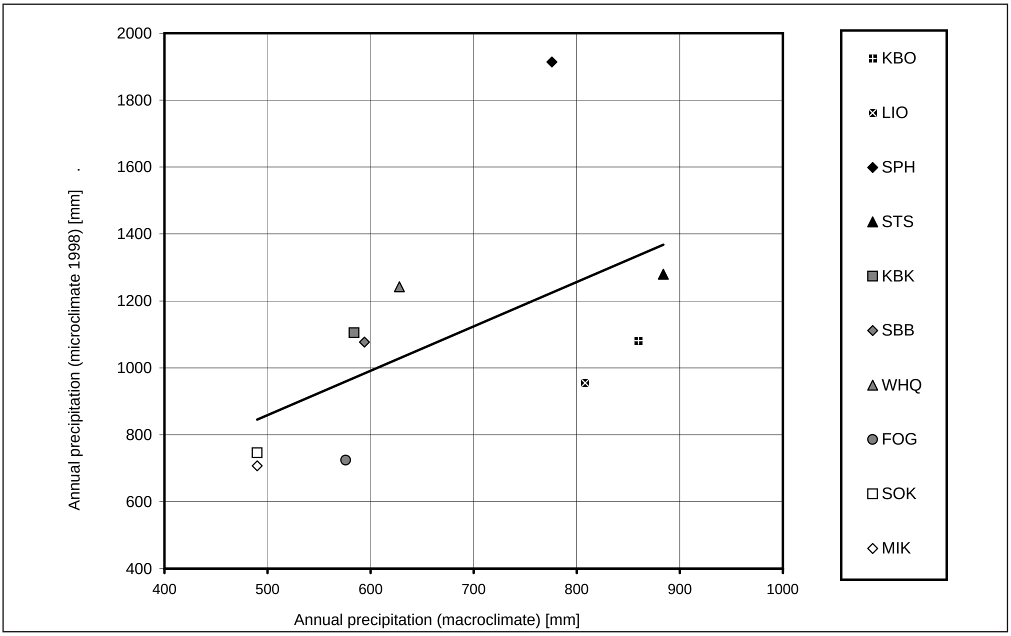

Fig. 13 Annual precipitation measured at microclimate stations in dry grasslands in 1998 as a function of long-term averages of precipitation recorded at the nearest official weather station. For site abbreviation see Fig. 1. Sites are arranged from west (KBO) to southeast (MIK). Due to vandalism two sites were not included. Spearman rank correlation coefficient: $r_s = 0.687$, $p = 0.028$.

Abb. 13 Mittlerer Jahresniederschlag, gemessen an den in den Trockenrasen eingerichteten Mikroklima-Stationen im Jahr 1998, als Funktion der langfristigen Mittelwerte des Jahresniederschlags aus den Aufzeichnungen der nächsten Wetterstation. Für die Gebietsabkürzungen s. Abb. 1. Die Gebiete sind von West (KBO) nach Südost (MIK) angeordnet. Aufgrund von Vandalismus wurden zwei Gebiete nicht in die Auswertung einbezogen. Spearman Rang-Korrelationskoeffizient: $r_s = 0.687$, $p = 0.028$.

in Saxony-Anhalt was exceptional as it clustered with the western sites in Lower Saxony. The prevailing community at this site is the Gentiano-Koelerietum (Mesobromion), which explains the floristic relatedness to the western sites. In the CA, the westernmost site (KBO) was separated from the other western sites, mainly due to the concentrated occurrence of dealpine species.

Environment completely explained the floristic composition of sites, which, however, was due to an overdetermined set of environmental variables. The best correlation with axis 1 was found for January precipitation (r = 0.843), indicated in Fig. 14 by the longest arrow running almost parallel to the first axis. In this context, it is remarkable that January precipitation was collected to a large portion as snow. Similarly, all other environmental variables related to precipitation point at the same direction, i.e. towards the western sites. In contrast, almost all temperature variables point at the eastern sites (Fig. 14). Highest correlations with the first axis were detected for the spring temperatures in March (Tmin r = - 0.882) and April (Tmin r = -0.726). Although not attaining high correlation coefficients, the western sites were characterized by high temperature maxima in November (correlation coefficient with axis 2 r = -0.429) and December (correlation coefficient with axis 1 r = 0.399 and with axis 2 r = 0.257).

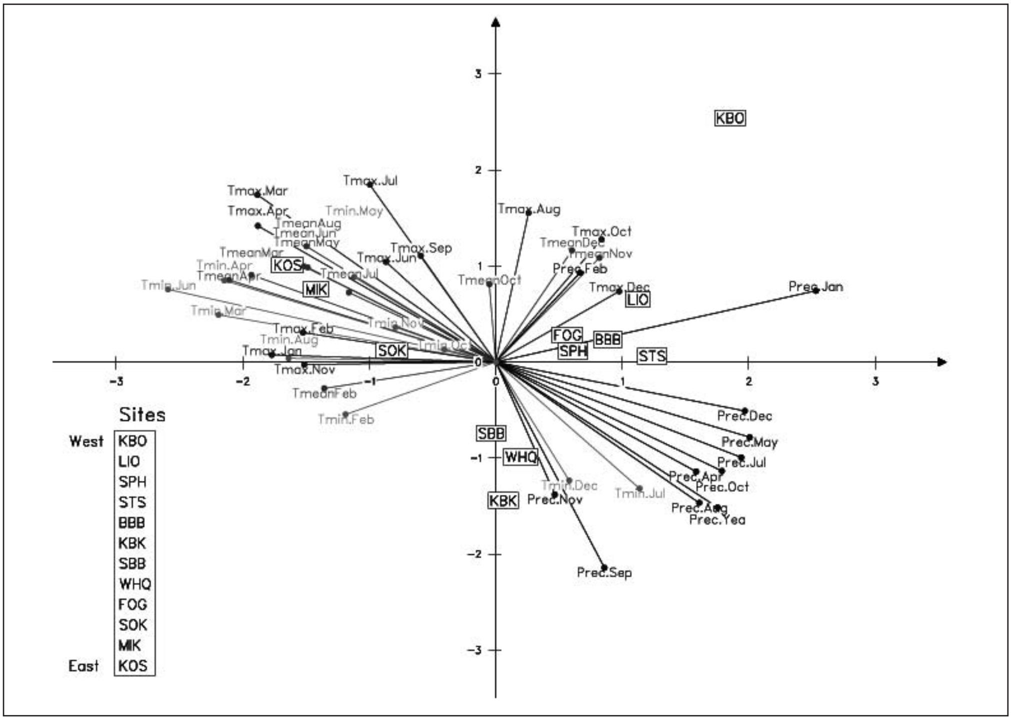

Fig. 14 Correspondence analysis of the floristic data of Table 5 and all monthly averages of variables recorded at the microclimate stations in 1998. Tmean = monthly average temperature, Tmin = absolute minimum temperature of that month, Tmax = absolute maximum temperature of that month, Prec = precipitation of that month. For site abbreviation see Fig. 1. Eigenvalues were 0.356 and 0.244 for axis 1 and 2, respectively. The legend shows the sequence of sites from west (KBO) to southeast (KOS).

Abb. 14 Korrespondenz-Analyse der floristischen Daten aus Tabelle 5 und alle monatlichen Mittelwerte der in den Trockenrasen eingerichteten Mikroklima-Stationen im Jahr 1998. Tmean = Jahres-Mitteltemperatur, Tmin = absolute Minimum-Temperatur des jeweiligen Monats, Tmax = absolute Maximum-Temperatur des jeweiligen Monats, Prec = Niederschlag des jeweiligen Monats. Für die Gebietsabkürzungen s. Abb. 1. Die Eigenwerte betrugen 0.356 für Achse 1 und 0.244 für Achse 2. Die Legende zeigt die Gebietsreihenfolge von West (KBO) nach Südost (KOS).

Tab. 5 Synoptic table of the flora of the twelve sites with long-term microclimate measurements. Data were compiled from JANDT (1999, Table 18). Only selected species are listed (108 out of a total of 429). For site abbreviation see Fig. 1. L-S = Lower Saxony, Tw = western Thuringia, S-A = Saxony-Anhalt, T-K = Thuringia-Kyffhäuser. Sites are arranged from west to southeast, species are arranged according to their regional distribution boundaries.

Tab. 5 Übersichtstabelle der Flora der zwölf Gebiete mit langfristigen Mikroklima-Messungen. Die Daten wurden aus JANDT (1999, Table 18) zusammengestellt. Es werden nur ausgewählte Arten aufgeführt (108 von insgesamt 429). Für die Gebietsabkürzungen s. Abb. 1. L-S = Niedersachsen, Tw = West-Thüringen, S-A = Sachsen-Anhalt, T-K = Thüringen-Kyffhäuser. Landnutzung N = Brache, G = beweidet. Die Gebiete sind von West nach Südost angeordnet, die Arten nach regionalen Verbreitungsgrenzen.

Column	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Site	KBO	LIO	SPH	STS	BBB	KBK	SBB	WHQ	FOG	SOK	MIK	KOS
Bundesland	L-S	L-S	L-S	L-S	L-S	Tw	Tw	S-A	S-A	T-K	T-K	T-K
Land use (N=no use, G=grazed)	N	N	N	G	G	N	N	GN	N	G	N	N
Total species number	101	91	68	111	101	218	167	290	93	144	162	194
Species with distribution in the west of the study area												
Potentilla neumanniana	*	*	*	*	*	*	*	*	*	.	.	.
Carex caryophyllea	*	*	*	*	*	*	.	*	*	*	.	.
Carex flacca	*	*	*	*	*	*	.	*	*	.	.	.
Thymus pulegioides	*	*	*	*	*	.	*	*	*	.	.	.
Festuca ovina	*	*	.	*	*	.	.	*	.	.	.	.
Helianthemum numm. ssp. *numm.*	.	.	*	*	*	.	.	.	.	.	.	.
Thesium pyrenaicum	*	.	.	.	.	.	.	.	.	.	.	.
Dealpine species												
Parnassia palustris	*	.	.	*	.	.	.	.	.	.	.	.
Solorina saccata	*	.	.	.	.	.	.	*	.	.	.	.
Cardaminopsis petraea	*	.	.	.	.	.	.	.	.	.	.	.
Carex ornithopoda	.	.	.	.	.	*	.	.	.	*	.	.
Species with distribution limit in Lower Saxony (L-S)												
Medicago falcata	.	.	*	.	.	*	*	*	*	.	*	*
Potentilla heptaphylla	.	.	*	*	.	*	*	*	*	*	*	.
Fragaria viridis	.	.	*	*	*	*	*	*	*	*	*	*
Euphorbia cyparissias	.	.	*	*	*	*	*	*	*	*	*	*
Galium verum	.	.	*	*	*	*	*	*	*	*	*	*
Thymus praecox	*	.	.	.	.	*	*	*	*	*	*	*
Acinos arvensis	.	.	*	*	*	*	*	*	.	*	*	*
Catapyrenium squamulosum	.	.	*	.	.	*	.	*	.	*	.	.
Inula conyza	.	.	*	.	.	.	*	*	*	*	*	*
Helianthemum ovatum	.	.	.	.	*	*	*	*	.	*	*	*
Hippocrepis comosa	.	.	.	.	.	.	*	*	.	*	*	*
Asperula cynanchica	.	.	.	.	.	*	*	*	*	*	*	*
Carex humilis	.	.	.	.	.	*	*	*	.	*	*	*
Reseda lutea	.	.	.	.	.	*	*	*	.	.	*	.
Potentilla arenaria	.	.	.	.	.	*	*	*	.	*	*	*
Cladonia foliacea	.	.	.	.	.	*	*	*	.	*	*	*
Cladonia rangiformis	.	.	.	.	.	*	*	*	.	*	*	.
Potentilla subarenaria	.	.	.	.	.	*	*	*	*	*	.	.
Cornicularia aculeata	.	.	.	.	.	*	*	*	.	*	*	*
Species with distribution limit in western Thuringia (Tw)												
Salvia pratensis	.	.	.	.	.	*	*	*	*	*	*	*
Rosa elliptica	.	.	.	.	.	*	*	.	.	.	*	*
Bupleurum falcatum	.	.	.	.	.	*	*	*	.	.	*	*

Column	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Site	KBO	LIO	SPH	STS	BBB	KBK	SBB	WHQ	FOG	SOK	MIK	KOS
Bundesland	L-S	L-S	L-S	L-S	L-S	Tw	Tw	S-A	S-A	T-K	T-K	T-K
Land use (N=no use, G=grazed)	N	N	N	G	G	N	N	GN	N	G	N	N
Total species number	101	91	68	111	101	218	167	290	93	144	162	194
Holosteum umbellatum	.	.	.	.	.	*	*	*	.	*	*	*
Veronica praecox	.	.	.	.	.	*	*	*	.	.	*	*
Festuca valesiaca	.	.	.	.	.	*	*	*	*	*	*	*
Fumana procumbens	.	.	.	.	.	.	.	.	.	.	*	*
Tanacetum corymbosum	.	.	.	.	.	.	.	*	.	.	.	.
Geranium sanguineum	.	.	.	.	.	*	.	.	.	.	.	*
Galium glaucum	.	.	.	.	.	.	.	.	.	.	*	*
Polygonatum odoratum	.	.	.	.	.	*	.	*	.	.	.	.
Allium montanum	.	.	.	.	.	*	.	*	.	*	*	*
Hypochoeris maculata	.	.	.	.	.	.	.	.	.	.	.	*
Astragalus danicus	.	.	.	.	.	*	*	.	.	*	*	*
Koeleria macrantha	.	.	.	.	.	*	*	*	*	*	*	*
Onobrychis viciifolia	.	.	.	.	.	.	*	*	.	.	.	.
Gypsophila fastigiata	.	.	.	.	.	*	*	*	.	*	*	*
Falcaria vulgaris	.	.	.	.	.	*	*	*	*	.	*	*
Origanum vulgare	.	.	.	.	.	*	.	*	.	.	*	*
Cerastium semidecandrum	.	.	.	.	.	*	.	*	.	*	*	*
Centaurea stoebe	.	.	.	.	.	*	.	.	.	*	.	*
Asperula tinctoria	.	.	.	.	.	*	.	.	.	.	.	*
Lithospermum officinale	.	.	.	.	.	*	.	.	.	.	.	*
Achillea pannonica	.	.	.	.	.	*	*	*	.	*	*	*
Medicago minima	.	.	.	.	.	*	*	*	.	*	*	*
Stachys recta	.	.	.	.	.	*	*	.	.	.	*	*
Stipa joannis	.	.	.	.	.	*	.	.	.	.	*	*
Viola rupestris	.	.	.	.	.	*	.	.	.	*	*	*
Viburnum lantana	.	.	.	.	.	*	.	.	.	.	*	*
Allium oleraceum	.	.	.	.	.	*	.	*	.	.	.	*
Veronica spicata	.	.	.	.	.	.	.	.	.	.	*	*
Veronica verna	.	.	.	.	.	.	.	.	.	*	*	*
Anthericum ramosum	.	.	.	.	.	.	*	.	.	.	*	*
Cuscuta epithymum	.	.	.	.	.	.	.	*	.	.	*	*
Stipa capillata	.	.	.	.	.	.	*	.	.	*	*	*
Psora savizcii	.	.	.	.	.	.	.	*	.	*	.	.
Rhytidium rugosum	.	.	.	.	.	.	.	*	.	.	*	.
Pleurochaete squarrosa	.	.	.	.	.	.	.	*	.	.	*	*
Thlaspi perfoliatum	.	.	.	.	.	.	*	*	.	.	*	.
Viola arvensis	.	.	.	.	.	.	*	.	.	*	*	.
Pulsatilla vulgaris	.	.	.	.	*	.	*	.	.	*	*	*
Hornungia petraea	.	.	.	.	.	.	*	.	.	*	*	*
Anthericum liliago	.	.	.	.	.	.	.	.	.	.	*	*
Arabis auriculata	.	.	.	.	.	.	.	.	.	*	*	*
Thesium linophyllon	.	.	.	.	.	.	.	.	.	.	*	*
Dianthus carthusianorum	.	.	.	.	.	.	.	*	.	*	*	*
Phleum phleoides	.	.	.	.	.	.	.	*	.	.	*	*
Orobanche caryophyllacea	.	.	.	.	.	.	.	.	.	.	.	*
Species with distribution limit in Saxony-Anhalt (S-A)												
Eryngium campestre	.	.	.	.	.	.	.	*	*	*	*	*

Column	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Site	KBO	LIO	SPH	STS	BBB	KBK	SBB	WHQ	FOG	SOK	MIK	KOS
Bundesland	L-S	L-S	L-S	L-S	L-S	Tw	Tw	S-A	S-A	T-K	T-K	T-K
Land use (N=no use, G=grazed)	N	N	N	G	G	N	N	GN	N	G	N	N
Total species number	101	91	68	111	101	218	167	290	93	144	162	194
Alyssum montanum	.	.	.	.	.	.	.	*	.	*	*	*
Artemisia campestris	.	.	.	.	.	.	.	*	.	.	.	*
Aster linosyris	.	.	.	.	.	.	.	*	.	.	*	*
Adonis vernalis	.	.	.	.	.	.	.	.	.	*	*	*
Thalictrum minus	.	.	.	.	.	.	.	.	.	*	*	*
Onobrychis arenaria	.	.	.	.	.	.	.	.	.	.	.	*
Tragopogon orientalis	.	.	.	.	.	.	.	.	.	.	*	*
Pterygoneurum ovatum	.	.	.	.	.	.	.	.	*	.	*	*
Species with distribution limit in the Kyffhäuser in Thuringia (T-K)												
Scabiosa canescens	.	.	.	.	.	.	.	.	.	*	*	*
Silene otites	.	.	.	.	.	.	.	.	.	.	*	*
Teucrium chamaedrys	.	.	.	.	.	.	.	.	.	.	*	*
Poa bulbosa	.	.	.	.	.	.	.	.	.	*	*	*
Teucrium montanum	.	.	.	.	.	.	.	.	.	.	*	*
Senecio integrifolius	.	.	.	.	.	.	.	.	.	*	.	.
Inula hirta	.	.	.	.	.	.	.	.	.	.	*	*
Inula germanica	.	.	.	.	.	.	.	.	.	*	*	*
Asparagus officinalis	.	.	.	.	.	.	.	.	.	.	*	*
Stipa tirsa	.	.	.	.	.	.	.	.	.	.	*	*
Stipa pulcherrima	.	.	.	.	.	.	.	.	.	.	*	*
Oxytropis pilosa	.	.	.	.	.	.	.	.	.	*	*	*
Scorzonera purpurea	.	.	.	.	.	.	.	.	.	.	.	*
Cotoneaster integerrimus	.	.	.	.	.	.	.	.	.	.	.	*
Achillea setacea	.	.	.	.	.	.	.	.	.	.	*	*
Lappula squarrosa	.	.	.	.	.	.	.	.	.	*	*	*
Myosotis stricta	.	.	.	.	.	.	.	.	.	*	.	.
Nonea pulla	.	.	.	.	.	.	.	.	.	*	.	.
Orobanche loricata	.	.	.	.	.	.	.	.	.	.	.	*
Pulsatilla pratensis	.	.	.	.	.	.	.	.	.	.	.	*
Astragalus exscapus	.	.	.	.	.	.	.	.	.	.	.	*

4 Discussion

Our results show that the twelve dry grassland sites from west to east in the southern Harz and Kyffhäuser Mountains form a gradient in microclimate. This gradient is clearly apparent in precipitation, but much less in temperature. Although eastern sites showed the tendency to have higher daily mean temperatures in summer, this difference was not very profound (3.6 K in July). Such differences in mean temperatures are easily encountered within a single site with different slopes or aspects (GEIGER 1965, MAHN 1985, BECKER 1998), different structure (e.g. DIERSCHKE 1974) or even within the same plot, when comparing temperatures at different heights above ground level (up to 4.7 K in our study). These results provide an explanation why dry grassland communities occur from west to east Europe in a similar structure and even with a basic set of common species. For example, British and west German grasslands can still unequivocally be assigned to the same alliance (Mesobromion) (DUCKWORTH et al. 2000). It can be assumed that differences in macroclimate are at least partly compensated for by particular microclimate conditions, e.g. by a steeper slope or more southern aspect, as already described by PERRING (1959, 1960). Our measurements corroborate this view, however, only for temperature, not for precipitation. One possibility to compensate for differences in precipitation in dry grasslands is varying soil depth. LEUSCHNER (1989) has shown that within the same site (and thus the same amount of precipitation) depth of the top soil layers decide about xerophilous (Xerobromion) and mesophilous communities (Mesobromion) in Alsace (France). He found water shortage in summer to be the main environmental factor discriminating between these two communities. In general, in all types of dry grasslands, water storage capacities of soils in summer are quickly exhausted and soil moisture is mainly dependent on precipitation. Hennenberg & Bruelheide (2003) found a remarkable correspondence between soil moisture gradient and precipitation measured at official weather stations when they studied the performance of *Hippocrepis comosa* in dry grasslands along a north-south gradient at the species' northwestern distribution boundary in Germany. Although we have not included soil moisture and amount of available soil water in long-term microclimate measurements, our plot selection with similar slopes, aspects, and most important, the same Zechstein bedrock with only shallow soils, let us assume that differences in precipitation along the studied gradient will not be fully equalised by soil factors. This is also because the gradient was much steeper in precipitation (by a factor 2 to 3 from west to east) than for temperature. The minor importance of temperature along the gradient is also apparent from our one-day microclimate measurement campaign. We conclude from this that the most relevant factor along the studied gradient is precipitation rather than temperature. Dry grasslands in the southern Harz and Kyffhäuser Mountains encounter more or less the same microclimatic conditions with respect to temperature but differ considerably in precipitation.

This conclusion would not have been possible with data on macroclimate alone. For macroclimate, both temperature and precipitation show clear gradients from west to east in the study area, and thus, might be considered equally important drivers for a floristic gradient. Actually, all studies on dry grassland flora and vegetation in this area have always argued simultaneously with precipitation *and* temperature.

Our second objective was to analyse the correspondence between microclimate and macroclimate. We demonstrated this correspondence for precipiation but failed to find a significant relationship for temperature. Of course, this failure might be due to temperature anomalities in this particular year or methodological problems. Nevertheless, given the strong macroclimate gradient in temperature, we should have detected it in microclimate even with our coarse methods. We do not believe that measurements with more sites and finer resolution will bring new knowledge because we expect temperature variation within sites to be larger than between sites.

Finally, we aimed at relating microclimate to the floristic inventory of our study sites. Although we used not plot data but the whole species set of dry grasslands, we found similar gradients in species composition in the CA analysis as in studies using plot data at much finer spatial scales, at the scale of individual plants (Austin 1968a, b; 0.1 to 10 m), at local scale (Gittens 1965; 100 to 200 m), but also at much broader scales (Duckworth et al. 2000; Ejrnæs & Bruun 2000; 100 to 500 km).

In accordance with many other studies that have been carried out along environmental gradients in grasslands we found stronger correlations for precipitation than for temperature or other climatic variables. For a comprehensive dataset of seminatural Danish grasslands, Ejrnæs & Bruun (2000) found the main floristic gradient to be strongly related to annual precipitation. However, under the more humid Danish conditions precipitation was also associated with a strong gradient in pH, which in contrast to our study might have superimposed the vegetation pattern. Similarly, in a study on the relationship between vegetation and environment for calcareous grasslands from western Spain, France, Britain and Ireland, Duckworth et al. (2000) described April precipitation as the highest correlating environmental factor with vegetation (correlation coefficient with axis 2 r = -0.734). This pattern is also often observed in studies outside Europe. For example, in a vegetation study along a climatic gradient in the loess plateau in China, Zhang et al. (2006) found annual precipitation to be the most significant factor in the multivariate analysis.

However, in all these multivariate approaches mentioned above there is always also a high correlation with temperature, as it was also the case in our CA analysis, which makes it difficult to decide which is the most important significant climate factor related to floristic composition. At this point of covarying environmental factors with similar correlation coefficients, correlative studies come to the limit of their range of applicability. Disentangling the effects of temperature and precipitation requires manipulative experiments.

The trend of changing temperature, and in particular precipitation, as predicted in the 2007 report of the IPCC (AR4WG1_Pub_TS.pdf at http://ipcc-wg1.ucar.edu/wg1/wg1-report.html, www.ipcc.ch) will be of utmost importance for the vegetation of dry grasslands in the study area. While mean temperatures are predicted to rise about 1.75 K from 1990 to 2050 (MITCHELL et al. 2004), the predictions for precipitation diverge widely and are still uncertain. However, changes in preciptation patterns are already detectable for the study ara, as was shown by FABIG (2007) for the regions leeward of the Harz Mountains. Comparing different observation periods in the 20th century, FABIG (2007) found a shift to more humid conditions in winter and drier conditions in summer. For Sangerhausen in the eastern part of our gradient (Fig. 1), there is a trend from 1902 to 2000 of about -20 % for summer precipitation and +70 % for winter precipitation. This means that the climate shows a tendency of becoming more mediterranean in the eastern part of the study region. Extrapolating this trend into the future would mean an even greater accentuation of precipitation as the predominant site factor for the differentiation of dry grassland vegetation.

5 Zusammenfassung

BRUELHEIDE, H.; JANDT, U.: Die Beziehungen zwischen Trockenrasen-Vegetation und Mikroklima entlang eines West-Ost-Gradienten im mittleren Deutschland. – Hercynia N.F. **40** (2007): 153-176.

Im Südharz und Kyffhäuser kommen Trockenrasen auf kalkreichen Böden und Gipsgestein entlang eines steilen Klimagradienten vor. Durch die nur geringfügigen Unterschiede in Bodenbedingungen und Landnutzung kann das Klima als der ausschlaggebende Faktor für das Auftreten der verschiedenen Trockenrasen-Vegetationstypen angesehen werden. Normalerweise stehen für Gradientenuntersuchungen auf breiterer Skala nur Klimadaten von offiziellen Wetterstationen zur Verfügung, die das Makroklima repräsentieren. Da das Mikroklima, dem die Pflanzen an einem spezifischen Wuchsort ausgesetzt sind, sich erheblich von den Aufzeichnungen von Wetterstationen unterscheiden kann, greift dieser Artikel die folgenden Fragestellungen auf: (1) Ist ein Gradient im Untersuchungsgebiet auch im Mikroklima festzustellen? (2) Spiegelt sich das Makroklima im Mikroklima wider? (3) In welchem Maße erklärt das Mikroklima den floristischen Gradient im Untersuchungsgebiet.

Klimadaten wurden für zwölf Gebiete entlang eines Nordwest-Südost-Gradienten auf ungefähr gleicher Meereshöhe auf drei verschiedenen zeitlichen Skalenebenen zusammengestellt: (1) langjährige Mittelwerte von offiziellen Wetterstationen, (2) stündliche Temperatur-Aufzeichnungen über ein Jahr mittels automatischer Datalogger sowie monatliche Niederschlagsmessungen, und (3) halbstündliche Temperatur-, Luftfeuchte- und Evaporationsdaten über einen Tag im Rahmen einer an allen Orten zeitgleich durchgeführten Messkampagne.

Die Ergebnisse zeigen, dass sich der Mikroklimagradient deutlich im Niederschlag, nicht aber in der Temperatur abzeichnete. Die Trockenrasen im Südharz und im Kyffhäuser erfahren mehr oder weniger dieselben mikroklimatischen Temperaturbedingungen, unterscheiden sich aber deutlich in den Niederschlagsverhältnissen. In Folge dessen wurde auch keine Korrelation zwischen Mikro- und Makroklima für Temperatur, sondern nur für Niederschlag festgestellt. Die floristische Ausstattung der Untersuchungsgebiete zeigt einen klaren West-Ost-Gradienten, der sich deutlich im Mikroklima widerspiegelt. Von allen gemessenen Variablen wurden höhere Korrelationen von Artenzusammensetzung mit Niederschlag als mit Temperatur festgestellt. Die Schlussfolgerung hieraus ist, dass der prägende Klimafaktor für die Differenzierung von Trockenrasenvegetation entlang des untersuchten Gradienten Niederschlag und nicht Temperatur ist.

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Anschrift der Autoren:
Prof. Dr. Helge Bruelheide, Dr. Ute Jandt
Institute of Biology / Geobotany and Botanical Garden
MartinLutherUniversit Halle-Wittenberg, Am Kirchtor 1, 06108 Halle
e-mail: helge.bruelheide@botanik.uni-halle.de