The impact of climate change on hops

THE CLIMATE FACTOR | Climate change, which has been predicted for some time, is now clearly visible, in spite of what the doubters say. In this article, weather data from the Hallertau hop growing region are compared with results from hop harvests in order to examine the effects of climate change.

ALTHOUGH REPORTS in the past have presented a number of different relationships between the weather and other phenomena, e.g. the α-acid levels of hop varieties [1-4], there has yet to be a systematic approach to this topic. In particular, there is no clear understanding of the extent to which different varieties of hops react to weather conditions.

Climate change can be explored briefly using the following example. The average temperatures from June to August in Bavaria – the most important window of time for hop growth – yields values for the three time periods shown in figure 1 [5].

In many assessments, the years 1960 to 1990 are presented as the period before climate change became discernibly apparent, which is also supported by this comparison. The ensuing 26-year period posted a temperature increase of 1.35 °C.

Authors: Dr. Adrian Forster (left), Dr. Florian Schüll, HVG Hopfenverwertungsgenossenschaft e.G., Wolnzach, Germany

Climate data for the Hallertau region

The focus of data collection is on the months from June to August, analogous to the comparison above. The weather data reported in Hüll serves as the basis for the comparison [6]. Table 1 lists the average temperatures, the total precipitation and the number of hot days (> 30 °C) for the period from 1961 to 1990, from 2012 to 2018 and two consecutive years, 2015 (hot and dry) and 2016 (moderate).

Over the past seven years, the average temperature during these three months has increased by more than 2 °C compared to the period from 1961 to 1990. Precipitation decreased; however, it should also be noted that heavy rain events increased which led to lower water uptake, relatively speaking. The increase in the number of hot days is also evident. These could very well be linked to disruptions in cone maturation and the formation of bitter and aroma substances. From these simple data it is obvious that climate change has occurred, resulting in higher temperatures and a lower supply of water in summer. This development is likely to be sustained.

The climate data from 2015 and 2016 are of particular interest. It is helpful that two such different years occurred in direct succession, at least for the purpose of evaluating crops.

Collecting harvest data in the Hallertau

The following data are readily available for a growing area:

- amount of area cultivated with a variety, subdivided into older and younger areas, each in ha [7];
- harvested quantity of a variety in t or kg, not subdivided into younger and older areas [8];
- average α-acid content of a variety in all lots harvested [9].

A relevant metric for hops can be determined from these data, namely the amount of α-acids harvested per ha:

$$\frac{[\text{kg}]}{\text{ha}} = \frac{\text{harvested hops [kg]} \times \alpha \text{ content [\% w/w]}}{\text{cultivation area [ha]}}$$

In addition to the quantity of α-acids, the yield per hectare also takes an important

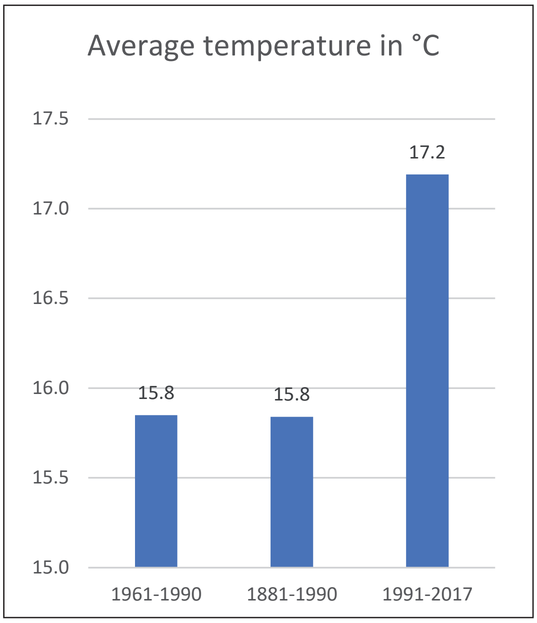

Fig. 1 Average temperatures from June to August grouped into three different time periods

variable into consideration regarding the bitterness and aroma capacity of a single variety.

In the first year, however, younger cultivation areas in the harvested area are to be assessed separately, since they produce significantly lower yields. A correction factor is applied which expresses what percentage of a normal yield can be expected from a younger cultivation area. This factor is determined empirically using grower surveys. For varieties without any changes in growing area, the factor does not play a role, but it is important for new varieties which are just becoming established. Several examples of correction factors for newer varieties of relevance include the following:

- 0.25 (Opal, Smaragd, Hüll Melon);
- 0.3 (Hallertauer Blanc, Polaris, Mandarina Bavaria);
- 0.45 (Herkules).

The production area for determining specific harvest data can be calculated as follows:

production area =
older areas + younger areas × factor

Other variables, such as the location of the hop garden, the age of the hop plants, the time of harvest and post-harvest treatment are not reflected in the calculations.

A comparison of two harvest years

An example shows how the α-yield (kg /ha) can fluctuate from harvest to harvest. The summer of 2015 was hot and dry which resulted in a correspondingly disappointing harvest. In 2016, on the other hand, moderate weather conditions prevailed with only a few hot days accompanied by adequate precipitation (refer to table 1). Table 2 shows the crop data for the two varieties Perle and Magnum for both years as well as a ratio of the data from 2015 and 2016 expressed as a percentage.

First of all, it is notable that Magnum exhibited greater tolerance to fluctuations in the weather conditions than Perle, evidenced by both the yield and the α-acid content. This observation has been previously documented [2-4]. At 60 % of the harvest, Perle accounts for just one-third of the yield, while Magnum comes in at over for over two-thirds in 2015 compared to 2016. This enables a conclusion to be drawn regarding the different effects on varieties simply by comparing data from two crop years.

HALLERTAU: AVERAGE TEMPERATURES, PRECIPITATION AND HOT DAYS

	Temperature / °C	Precipitation /mm	Hot days (> 30 °C)
1961 - 1990	15.85	303	not available
1980 - 2017			5
2013 - 2018	18.3	267	14
2015	19.5	178	36
2016	17.7	334	7

Table 1 *Average temperatures, total precipitation and hot days recorded in the Hallertau between June and August*

COMPARISON OF THE HARVEST VALUES FOR THE VARIETIES PERLE AND MAGNUM

	Perle			Magnum		
	2015	2016	2015/2016	2015	2016	2015/2016
Yield [t/ha]	1.4	2.3	60%	1.73	2.14	81%
α-acids [% by wt.]	4.5	8.2	55%	12.6	14.3	88%
Yield [kg/ha]	63	191	34%	218	306	71%

Table 2 *Comparison of the yield values (quantity harvested, α-acid content and α-yield) for the varieties Perle and Magnum in 2015 and 2016 and the ratio of 2015 : 2016*

RATIO OF THE α-YIELDS FROM 2015 TO THOSE OF 2016, EXPRESSED IN % (REL.)

Flavor	Spalter	28%
	Perle	34%
	Nothern Brewer	36%
	Spalter Select	39%
	Hallertauer mfr.	40%
	Saphir	42%
	Hall. Tradition	45%
	Opal*	45%
	Tettnang Tettnanger	46%
	Hersbrucker	56%
	Smaragd*	66%
	Mean	**43%**

Table 3
*Ratio of the α-yields from 2015 to those of 2016 in % (rel.) for 11 German aroma varieties; data from Tettnanger and Spalter were taken from the corresponding cultivation regions and the remainder from the Hallertau; varieties planted in younger cultivation areas are denoted with **

RATIO OF THE α-YIELDS FROM 2015 TO THOSE FROM 2016, EXPRESSED IN % (REL.)

Bitter	Taurus	52%
	Nugget	56%
	Herkules*	64%
	Magnum	71%
	Polaris*	77%
	Mean	**64%**
Flavor	Cascade	52%
	Hall. Blanc*	56%
	Hüll Melon*	65%
	Mandarina Bavaria*	71%
	Mean	**61%**

Table 4
*Ratio of the α-yields from 2015 to those of 2016 in % (rel.) for five bitter varieties and three more recently introduced aroma varieties (flavor hops); varieties planted in younger cultivation areas are denoted with **

Therefore, even without any long-term data available, given the present case, it is feasible to include newer varieties, which have only been cultivated since 2013/14, in a comparison of climate tolerance. Table 3 lists the ratios of α-yields (kg/ha) from 2015 expressed as a percentage of those reported in 2016 for the eleven German aroma varieties commonly grown in Hallertau. The data for Spalter and Tettnanger are sourced from their respective growing areas.

CLIMATE FACTORS

	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	Mean
Hallertau	15.8	4.1	14.1	23.9	16.3	16.1	19.0	17.4	24.9	24.7	21.0	13.4	18.8	9.4	18.9	12.5	15.5	16.8
Tettnang	22.1	10.1	16.9	25.3	23.5	28.7	22.4	23.3	35.0	30.5	20.5	15.4	21.5	14.4	29.9	26.6	13.7	22.3
Spalt	14.4	7.3	12.1	17.3	11.4	19.4	11.6	11.6	17.5	16.4	9.0	14.8	15.7	6.8	10.0	16.4	3.9	12.7

Table 5

Climate factors for the three Southern Bavarian hop cultivation regions for 2002–2018 with total values and mean values for 2012–2018; the lower the value, the less favorable were the weather conditions.

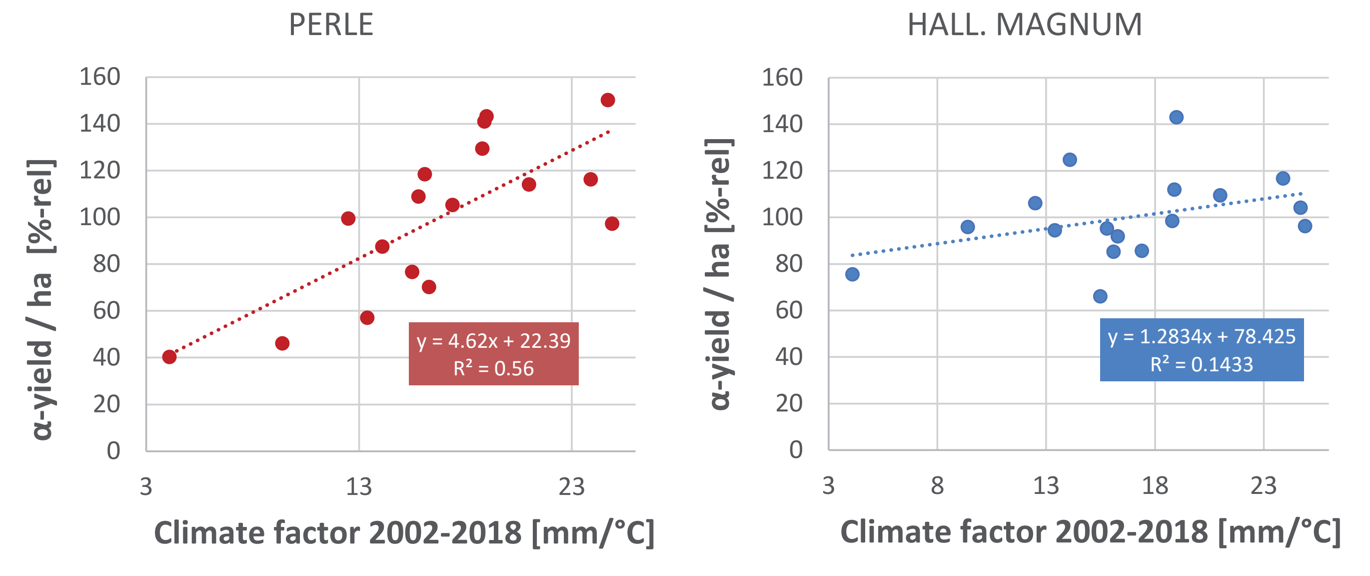

Fig. 2 Relative α-yields for the varieties Perle (left) and Magnum (right) plotted against the climate factors for the years 2002 to 2018; the slope of the line is S = 4.62 (Perle) and S = 1.28 (Magnum)

CLIMATE SENSITIVITY OF 13 HOP VARIETIES GROWN IN THE HALLERTAU

Hall. Magnum	1.3
Herkules*	2.3
Taurus	2.5
Nugget	2.7
Hall. Tradition	3.1
Hersbrucker	3.9
Spalter Select	4.1
Smaragd*	4.2
Hallertauer Mfr.	4.2
Opal*	4.3
Perle	4.6
Saphir*	4.8
Northern Brewer	4.9

Table 6
Slopes of the curves for 13 hop varieties grown in the Hallertau; the higher the slope, the greater the climate sensitivity.
**data from 2006-2018, all others from 2002-2018*

For varieties denoted by *, the younger cultivation areas were evaluated as previously described. The variety Spalter (28 %) is particularly sensitive to climate conditions, while Smaragd (66 %) is the most tolerant. On average, these eleven varieties only had a 43 percent α-yield in 2015 compared to 2016.

Table 4 names the five most important bitter varieties that appear to be more climate-tolerant than the aroma hops. These bitter varieties had an average of 64 percent α-yield in 2015 compared to 2016, which also corresponds to the value for the bitter variety Herkules, the dominant variety in the area under cultivation. Table 4 also includes three newer aroma varieties (often referred to as flavor hops), Hallertau Blanc, Hüll Melon and Mandarina Bavaria, which are comparable to the bitter varieties in their α-yield.

Bitter varieties and newer aroma varieties are mostly crossed with North American varieties which possess a stronger level of heat resistance. It follows that the traditional aroma varieties that are still in high demand on the market are precisely the ones which react most sensitively to the weather.

Comparison over an extended period

The goal of this research was to sort through the multitude of climate data, in order to identify a simple metric that would correlate with the harvest results. Ultimately, the climate factor (CF) emerged as the result of this effort:

$$CF = \frac{\text{total precipitation June to August [mm]}}{\text{mean temperature June to August [°C]}}$$

A high CF is positive for hop growth; conversely, a lower value is detrimental. The climate factors from 2002 to 2018 and their averages can be found in table 5 for the Hallertau, Tettnang and Spalt growing regions. Although the three regions are located only a few hundred kilometers apart, the CF values differ significantly.

Tettnang has the highest CF and Spalt has the lowest. In all three cultivation areas, the CF has shown a tendency to decrease, hence the existence of unfavorable CF values in recent years based on a comparison of the overall average over the past seven years.

In the next step, the α-yields (kg/ha) are plotted against the CF values. The individual harvest yield data are divided by the average yield obtained over the period from 2002 to 2018 to generate a graph that is comparable across all hop varieties. The calculation is as follows:

$$\% \text{ relative yield} = \frac{\text{yield in one harvest}}{\text{mean yield}} \times 100$$

Figure 2 illustrates the relationship between the relative yields and the CF values for the varieties Perle (left) and Magnum (right). As previously discussed in the comparison of harvests in 2015/2016 (table 2), Magnum exhibits a significantly lower response to the CF than Perle. The regression line increases with a higher CF, but with a less pronounced slope (S = 1.28) and without significant correlation.

Perle, on the other hand, has a slope S of 4.62, which is over 3 ½ times steeper. The line plotted indicates a significant correlation exists.

For all of the varieties examined in this investigation, the slope of the line serves as an indicator for the climate tolerance of the variety. The lower the slope of the line is, the less sensitive the variety is to weather conditions. Conversely, a line with a high value for the slope corresponds to a high sensitivity to fluctuations in climate. In general, this correlation becomes more significant as the slope of the line increases.

The slopes for each of the varieties commonly grown in the Hallertau are provided in table 6. Data for Herkules, Smaragd, Opal and Saphir were only available starting in 2006. Of the hop varieties reviewed, Magnum fared best while Northern Brewer was the least tolerant with regard to climate conditions.

Several rules apply to both methods (comparison of 2015/2016 and calculation with CF):

- These results do not take into account selected locations, growers or lots; instead it represents an average of the total harvest in the Hallertau.
- Preferably, outliers in individual results due to disease, hail damage, location, etc. will be balanced with varieties grown in higher proportions.
- In the case of varieties cultivated over a smaller area, unusual figures may have to be examined more closely. For example, in 2013, hail ruined the crop of Nugget hops – a small amount overall – but in a region that mainly cultivates this variety.
- It can be assumed that there will be outliers. For example, the 2018 crop of Smaragd hops had unusually low yields and content.

An additional aspect

Figure 3 is a graph of the α-yields in kg/ha for seven aroma varieties and four bitter varieties plotted against the climate factors. The polynomial curve, flattening towards the back or even falling regression curve appears more logical than a linear regression, since very high volumes of precipitation usually occur with less sunshine, essentially suppressing the growth of hop plants. Nevertheless, years with a lot of rain and little sunlight and the corresponding low temperatures are likely to be the exception in the future.

Comparing methods

In essence, the ability to compare two very different crop years in 2015/2016 was a random occurrence. Heat and drought characterized 2015, whereas the weather was moderate in 2016. A direct comparison of the α-yields (kg /ha) reveal distinct differences: -28 percent for Spalter and 77 percent for Polaris from the year 2015 to 2016. A special advantage associated with these two years is that newer varieties could also be evaluated since long-term data for them was not available. Of course, there is a risk drawing unsubstantiated conclusions from just two groups of data.

The second method, involving the plotting of the relative α-yields against the climate factors and determining the slope of the line, allows consideration of data spanning many years. This should contribute to its scientific validity, but it does have the dis-

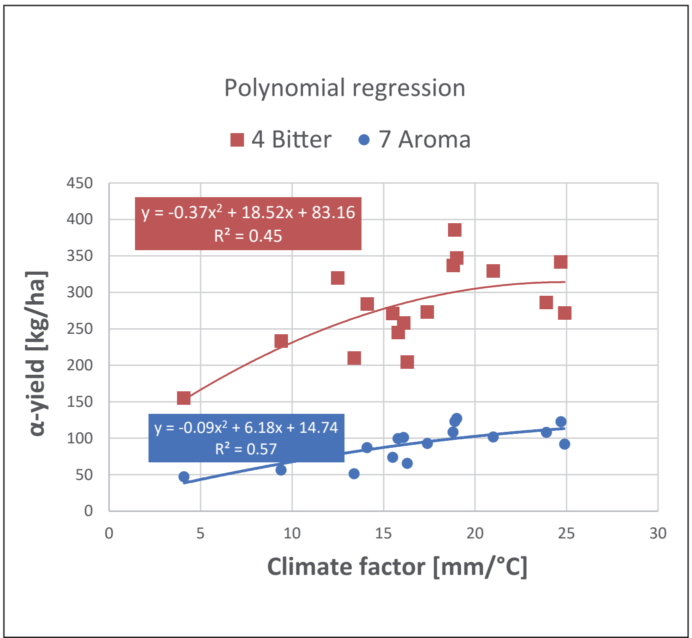

Fig. 3 Relationship between α-yields and weather conditions for 7 aroma hop varieties and 4 bitter hop varieties

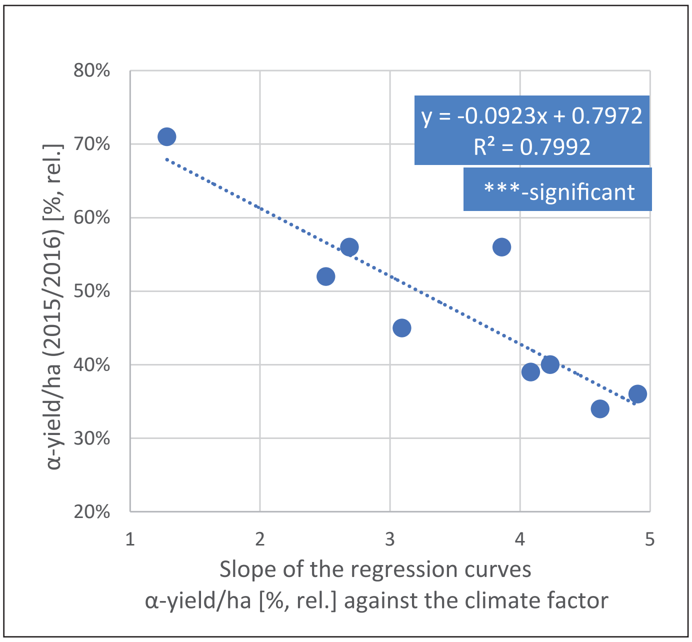

Fig. 4 Two year comparison (2015 : 2016) of the α-yields plotted against the slope of the regression curves (relative α-yields against climate factors) for 11 hop varieties

advantage that it cannot be used to evaluate new varieties.

The correlation depicted in figure 4 is generated by plotting the data sets used in the two methods together in one graph. This encompasses the data calculations for the eleven varieties and indicates that there is a *** statistical significance between the two methods. It follows that a comparison of two harvest years occurring in close succession with different weather conditions can provide valuable information regarding the degree of sensitivity of a variety to climatic events.

Summary

Climate change is already in full swing. The fact that it has an impact on the growth of hop plants has become especially evident in recent years. It has also been established empirically that individual hop varieties react differently to weather conditions. In this article, the authors endeavor to describe this influence in a more systematic manner. By simply comparing the harvest data from two different years, 2015 (bad) and 2016 (good), findings indicate that traditional aroma varieties are significantly more climate-sensitive than bitter hops or the newer aroma varieties.

Critics may find that calculating a climate factor based on the total volume of precipitation and the average temperature over the primary growing season from June to August to be a bit simplistic. Of course, a more complex mathematical, statistical model could yield better results. However, it is questionable as to whether any other "groundbreaking knowledge" will be revealed. After all, it was possible to derive a reasonably certain connection between the weather conditions and harvest results and to delineate varietal differences. Both methods can be applied to arrive at findings which correlate well with one another.

This information also allows brewers to rethink their current hop portfolio. Consideration should be given to whether varieties will have to be substituted. If substitution is necessary, they can determine which other varieties are good options and what steps are necessary to accomplish this. Recommendations for substitutions are beyond the scope of this article but will be addressed in a separate article.

Climate change continues, and no viable solution has been found for countering it at this time. In the interim, the focus has now shifted to the following questions:

- Should the range of hop varieties, as it currently stands, be maintained over the mid-term or long-term?
- Should the current system of forward contracts be retained, at least for key varieties?
- Does irrigation represent a long-term solution? Water is becoming an increasingly scarce commodity.
- How can hop breeding make a contribution? Should knowledge of climate tolerance for different varieties be considered when selecting partners for making crosses?

Climate change is a global problem and its consequences can only be mitigated to a limited extent. ■

Literature

1. Forster, A.: "Spezifische Probleme der deutschen Hopfenernte 1994", BRAUWELT No. 44, 1994, pp. 2309-2314.
2. Forster, A.: "Die Hallertauer Hopfenernte 2003 – Probleme und Perspektiven", BRAUWELT No. 17, 2004, pp. 487-491.
3. Forster, A.; Schüll, F.: "Die deutsche Hopfenernte 2015 – eine Herausforderung für Brauer", Brauindustrie No. 1, 2016, pp. 30-33.
4. Forster, A.; Schüll, F.: "Die Deutsche Hopfenernte 2017 – mit einem blauen Auge davongekommen", Brauindustrie No. 1, 2018, pp. 14-17.
5. Source: Deutscher Wetterdienst (DWD), 7.5.2018.
6. Hüll climate data: https://www.am.rlp.de
7. https://www.deutscher-hopfen.de/de/Hopfen-Info/Anbauflaechen
8. https://www.hallertauerhopfen.de/de/Hopfen-Infos/Marktbericht-und-EU-Bericht
9. https://www.brauwelt.com/de/