Hops

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FACHVERLAG HANS CARL

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Bibliographic Information in the Deutsche Nationalbibliothek (German National Library)

The Deutsche Nationalbibliothek lists this publication in the Deutsche Nationalbibliografie (German National Bibliographic Records); detailed bibliographic information is available on the Internet at http://dnb.ddb.de.

Cover: Christina Schönberger
Translation: McGreger Translations and Consulting, Freising, Germany
Cover design: Echtzeit Medien, Tennenlohe, Germany
Layout and typesetting: Verlagsservice Rohner, Tegernheim, Germany
ISBN 978-3-418-00900-1

Acknowledgements to the Sponsors, Authors and Translators

This book would not have been possible without the full cooperation of the companies listed below, who gave the authors the required permission and set aside time for them to complete the book. The companies also granted the authors access to proprietary research results and rooms, where their numerous meetings were held. For this, Fachverlag Hans Carl would like to extend its deepest gratitude.

We also thank the authors. You have done a masterful job, persevering in spite of scheduling difficulties and remaining motivated in the numerous technical discussions, in which the goal was to find common ground among diverse corporate philosophies.

A special note of appreciation also goes to Nancy and Christopher McGreger, who drew on their substantial experience and expertise in working with brewing texts to translate of this book into English.

Foreword

Dear Ladies and Gentlemen, Hop Lovers, Hop Growers, Hop Processors, Brewers and Those Simply Curious about Hops,

For me, hops are much more than a cultivated plant, despite being known as the "gold of brewers" for economic reasons. My perception of hops is associated with fascinating agricultural practices and processing methods, with empiricism, experience and science as well as with a variety of aroma impressions and sensory experiences.

In my time spent as a quality manager, I enjoyed the hectic days in early autumn collecting samples in the Hallertau as much as I did my travels to American hop production areas where I felt privileged to be given the opportunity to evaluate hops. What I have learned through my contact with the network of experts involved in the hop industry – be it hop growers, hop traders, scientists or hop processors – is their enduring passion for hops.

Hops are also an important field of interest for the European Brewery Convention (EBC). In addition to the active participation of the EBC leadership in the *Gesellschaft für Hopfenforschung* (Society for Hop Research), hops have been the focus of several EBC Symposia in recent years.

Those with a close eye on the brewing scene have observed that over the past several years, not only in the USA but in many countries with a strong brewing tradition, such as Belgium, Germany and the Czech Republic, breweries are becoming increasingly successful at selling specialty beers under very competitive market conditions. In addition to the malt composition, the brewing method and the yeast strain, the use of distinctive hop varieties with pronounced aroma notes is becoming an increasingly important tool for imparting exciting and unique characteristics to these beer styles. As a consequence, hops are gaining markedly in significance, and brewers have begun to perceive them beyond their somewhat limited role as simply a source for alpha acids. Knowledge of varietal characteristics and noteworthy groups of substances in hops such as humulones, polyphenols, xanthohumol and terpene compounds is imperative for distinguishing and further developing individual product attributes, which, in turn, can become significant factors for achieving success in competitive markets.

This thirst for knowledge has now been recognized, and I am very pleased that the group of authors around Adrian Forster has written a unique and comprehensive book concerning all aspects of hops. This team of experts from the hop industry has succeeded in creating a new standard reference for hops. As this book is the outcome of a voluntary collaboration among the authors, it will be evident to readers how much of their free time they have invested in this excellent compendium.

This book on hops is unique, because it communicates and clearly elucidates current scientific knowledge, technological interactions and the principal aspects of the value chain of hops from the seedling to the bottled beer. In each of the individual chapters, you can delve deeply into the world of hop cultivation or the conditions of the hop market. You can gain insight into the agricultural issues facing hop-growers and also tackle topics such as plant protection and hop trade.

Enjoy the great diversity found in the field of hop cultivation over the wide range of existing hop varieties down to the particular attributes of each one.

Discover the huge assortment of hop compounds and quality-enhancing constituents. Put on the hat of a hop researcher and explore the mechanisms by which the broad spectrum of these compounds are formed – flavor and aroma compounds, bitter substances and polyphenols.

For the brewers among you, the overview of hop products allows you to quickly access information regarding technical processes, characteristics and analytical parameters.

The chapter on the hop compounds in beer is of particular interest. It describes the contribution of hops to the characteristics of beer in a distinct and comprehensive form.

You will find in your academic studies that this book far transcends the status of a mere reference work, which is only taken from the shelf for occasionally looking up a specific fact. For those interested in hops, it is much more – reading material that is stimulating and entertaining and also a valued companion on rainy autumn days.

Hops have many facets and are a plant species with fascinating attributes. Their value chain is also very complex. I am certain you will share my enthusiasm and derive a great deal of pleasure from spending many rewarding hours reading about hops in this book.

Dr. Stefan Lustig, President of the European Brewery Convention

Introduction

Around 1900, a number of textbooks on various topics pertaining to hops were available in German. Therefore, it may seem surprising that no comprehensive textbook on hops currently exists in any language.

In 1997, one thousand copies of the EBC Manual of Good Practice, entitled "Hops and Hop Products" were released; however, it has been out of print for years. Since increased attention has been placed on hops in both science and practice, especially in the last ten to fifteen years, the time was right to gather the latest information in the form of an updated book on hops.

Fachverlag Hans Carl publishing house approached hop specialists about a comprehensive up-to-date reference book on hops. Further motivation for writing a book of this nature was to expand the knowledge base of those pursuing higher education. This eventually resulted in the formation of a group consisting of eight people, who are currently active in the hop industry and who approach hops as a raw material from different perspectives. This book is intended for all scientists, brewers and students interested in gaining deeper insight into the exciting world of hops.

The fact that most of the authors are from the Hallertau hop-growing region is for purely practical reasons related to time and expense. The close geographic proximity of the authors was important since more than 40 meetings were held as the book was being written. Moreover, authors from international companies consulted with their colleagues in other countries, thus providing access to global expertise.

Individual hop varieties (chapter 5) could have been described under the topic of hop cultivation (chapter 1) but are first addressed following the chapters "The Hop Market" (chapter 2), "Chemical Compounds in Hops" (chapter 3) and "Quality Assurance" (chapter 4), as the information in these chapters is useful in understanding the details of varietal characteristics.

The outline for chapter 7 "Hops in Beer" posed a particular challenge. Key criteria for structuring the contents were absent. Therefore, three primary topics were chosen: bitter substances, aroma compounds and hop polyphenols in beer. These three topics provide a framework for integrating information on "hop-relevant sensory analysis", "special hopping methods" and "gushing".

Each of the main themes in chapters 1 through 5 was penned by a single author, while chapters 6 ("Hop Products") and 7 were written by three and four authors, respectively. Attentive readers will most likely notice differences in the writing styles among the chapters. All of the authors are ultimately responsible for the content of the entire book, although whole chapters or sections of chapters were composed by individual authors without attribution.

References are provided at the end of each chapter to give readers the opportunity to explore a single topic more extensively. In addition to articles designed to give an overview of the existing body of knowledge, special emphasis has been placed on including the most recent publications on the subject. In the time that has elapsed between the publication of the German edition and its subsequent translation into English, approximately two years have passed. For this reason, the authors have made a small number of changes to the text; among them, statistical results have been updated and any recent scientific findings deemed relevant have been added. Therefore, the German and English editions are not completely identical in content.

The authors would like to express their gratitude to the following people:

- Susanne Rohner (Verlagsservice, Tegernheim) for typesetting
- Karin Schneider (HVG) for the diverse tasks and not always simple job of serving as coordinator for this project
- Thomas Raiser (J. Barth & Sohn) for writing chapter 2

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1 Hop Cultivation

Hops are an indispensible raw material for brewing beer. Numerous hop cultivation regions are scattered across the world's continents. Together, they produce a broad range of hop varieties, easily fulfilling the diverse quality demands of brewers around the globe. Tracking the progression of the average cost of hop additions over time - independent of a general trend towards using smaller quantities of hops - provides a clear indication of the past and current focus of advancements in hop cultivation. For example in 1960, the average cost of hops was 0.80 €/hl of beer; by 2010, it had dropped to merely one quarter of that. However, what has remained unchanged is the insistence by brewers on hops free of pests and disease, that is, healthy hops with good appearance and aroma.

The following chapter provides an overview of the practices and measures employed to reach these goals.

1.1 Biological Classification and Description of Hops

Hops cultivated commercially are classified as *Humulus lupulus* L. and belong to the same taxonomic family as hemp (Cannabaceae) and to the same order as nettles (Urticales).

Hops are perennials, and in the spring, new growth emerges from rootstock. If the plants are well maintained, they are capable of producing uniform crops every season for up to 25 years. In Central Europe and Oregon (USA), hop plants are pruned back after the winter months. The hop vines or bines, as they are known, from the previous season are removed except for the new buds under the soil bed (cultivation system), thereby reducing the presence of the organisms, which cause downy and powdery mildew. A method employed in other growing regions is to mechanically or chemically remove the new shoots emerging from the ground (non-cultivation system), in order to limit initial growth and restrict disease.

Of the many shoots sprouting from the rootstock, only two or three of the strongest are trained onto the wire or twine used for support. Any extra shoots are removed. This is usually performed by hand and marks the period when the workload during the hop-growing season reaches its peak. As climbing plants, hops possess hooked hairs, which enable them to cling to the support, winding around it in a clockwise direction. The bines can grow up to 30 cm in length per day.

Even before reaching the top of the supporting structure or trellis, lateral branches form on the plants where the hop cones will later develop (see fig. 1). Depending on the variety and year, short branches also bearing hop cones may form on the primary bines. After the plant blooms and produces hop cones, the hop plant is completely mature (see fig. 2).

Hops are dioecious; therefore, on a single plant they produce either male or female inflorescences. Only female plants are cultivated, because they alone produce hop cones. Botanically, a hop cone is known as a strobilus, consisting of up to 60 individual flowers. Each of these individual flowers can be fertilized by male pollen and produce a seed.

Male plants must be eradicated from the regions where the female plants are cultivated to prevent any pollen from being released there and to preclude the formation of seeds in the female plants. The high fatty acid content in the seeds can negatively impact the foam and flavor stability of beer. Male plants are only needed for the creation of new varieties through crossbreeding.

The hop cone (see fig. 3) consists of a strig and bracts. The structure and shape of the cone represent important botanical criteria for differentiating hop varieties. However, the focus is

Figure 1: Hop cones growing on lateral branches

principally on lupulin, a yellow powder, which is predominantly located on the bracteoles, smaller structures positioned under the bracts and is found in the lupulin glands.

Figure 2: Hop bines on support structures 5.5 to 7.5 m in height

Hops naturally occur in river valleys (flood plains), where both male and female plants are present. For perpetuation of the species, seeds are produced, which mature in autumn. New plants grow from these seeds in the spring.

For commercial hop production, propagation is purely vegetative, meaning that pieces are cut from the rootstock and planted. Buds or "eyes" develop and form new plants. This is the primary

Figure 3: The structure of a hop cone

method used by hop farmers to propagate new plants for their hop yards. Vegetative propagation may also be achieved by cutting young shoots above a layer of leaves and planting them in soil. With vegetative propagation, the genetic composition of the plant or hop variety remains entirely unchanged.

1.2 Support Structures

In their natural habitat, hops require trees or bushes upon which to climb as they grow, whereas those cultivated agriculturally must be supported on wires spanned tautly on wooden or concrete support structures to allow the plants to reach their full height at maturity. In hop-growing regions around the world, such structures can be, for example, 5.5 m in height in the USA and England, 7.0 m in the Hallertau and 7.5 m in Tettnang. These structures are referred to as a tall trellis or wirework. Disadvantages include their high cost, the difficulty associated with applying pesticides and their vulnerability to inclement weather. On the other hand, the yield for the varieties cultivated in this manner is optimal.

In order to eliminate the disadvantages inherent to this kind of structure, a different type of trellis has been developed, one that is only 2.5 to 3.0 m tall (see fig. 4). These structures have been subject to testing for a number of years now. The invention of new techniques for tilling the soil, applying pesticides and harvesting has also been necessary. In order to promote the further use of these so-called low trellises, new varieties adapted to growing on them must be developed. The varieties cultivated up to the present on the low trellises have yielded 30 to 50 % fewer hops. The potential savings in production costs cannot yet be compensated by the lower yield. In China, due to strong north winds, a unique low trellis form has been employed. The climbing support is comparable to an arbor-like structure used in viticulture and requires a substantial amount of manual labor.

Figure 4: A low trellis system 3 m in height

1.3 Cultivation Regions

The central constraint on the cultivation of hops does not involve soil or climatic conditions but rather the light conditions and the length of the day. The shift from vegetative to generative growth (oriented towards sexual reproduction) occurs at a day length of 16 to 18 hours. When the hours of sunlight per day begin to wane again, the plants begin to flower. Such conditions only exist in two belts encircling the globe between 35 and 55 degrees latitude in the northern and southern hemispheres (see fig. 5). On the margins of these two belts, for example in the George cultivation region of South Africa, only very late maturing varieties can be grown.

Since this zone only encompasses the tips of South America, Africa, Australia (Tasmania) and New Zealand (the south island) in the southern hemisphere, the primary hop-growing regions are found in countries located in the northern hemisphere.

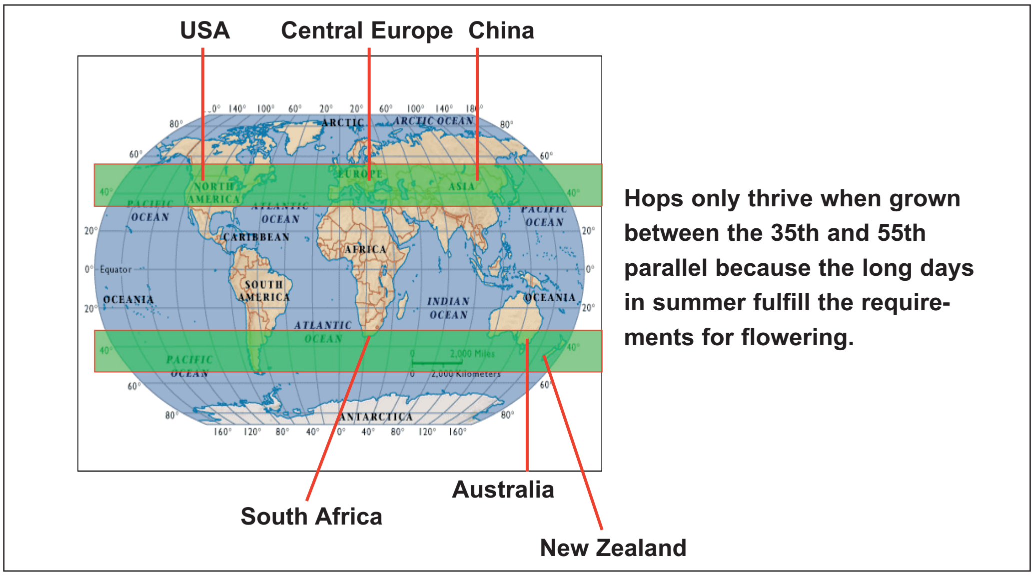

Figure 5: Hop-growing countries in the northern and southern hemispheres (world map from http://www.mapquest.de)

1.3.1 Central Europe

The most extensive hop-growing region in the world is the Hallertau in Bavaria, a southern state in the Federal Republic of Germany. Both the climate and soil there are favorable for hop cultivation. Historically, businesses in the Hallertau were also structured around an agrarian economy. Together these factors have led to a concentration of hop cultivation in the region over the course of two centuries, since the early 19th century. In Germany, there are also other cultivation regions in Tettnang (the Lake Constance region), Spalt (south of Nuremberg), and in the area around the Elbe and Saale rivers. Other significant hop-growing regions in Europe are found in the Czech Republic, Poland, Slovenia, the UK, France and Spain.

In Central Europe, the precipitation needed in the summer for hop cultivation sometimes does not fall. If this is the case, there is a lower yield at harvest and diminished alpha acid production. In the northern hemisphere, the most important factor for good yield and a favorable balance of hop constituents is sufficient rainfall in June, July and August, approximately 100 mm/m² each month.

In the extreme conditions present during the summer of 2003, only 40 % of the average precipitation fell over those critical three months. This had grave consequences for yield and alpha acid production. For instance, instead of the long-standing average values for alpha acid content for the varieties Perle at 7.4 % and Hallertauer Magnum at 13.9 %, in 2003, these values were 3.9 % and 11.7 %, respectively. The optimum for yield and quality was reached in 2008. The amount of precipitation and above all the distribution of rainfall proved to be especially advantageous that year (see fig. 6).

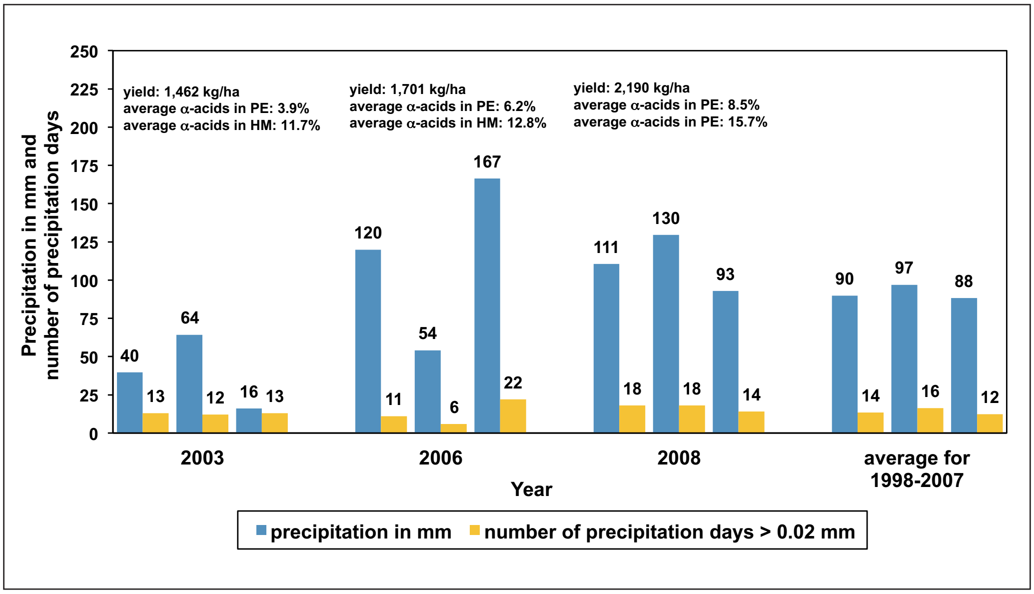

Figure 6: The relationship between crop yield, including α-acid content, and precipitation from June to August for the Hallertau hop varieties Perle (PE) and Hallertauer Magnum (HM) (precipitation data supplied by the agrometeorological station in Hüll, Germany)

In Central European cultivation regions, there are often insufficient amounts of surface and ground water available to irrigate all of the fields where hops are grown. Plans are currently in development to install drip irrigation in at least one third of the hop-growing areas.

1.3.2 USA

The first hops to be cultivated in the USA were planted on the East Coast. Later, hop farming moved to the western states of Washington, Oregon and Idaho. Now, the primary hop-growing region is situated in the Yakima Valley, southeast of Seattle. Irrigation systems were put in place decades ago to offset the lack of natural precipitation in the area. Secure water rights have been the cornerstone of hop farmers' existence in this region. From year to year, they ensure conditions to provide the basis for consistent yield and reliable quality.

Long periods of elevated temperatures approaching 40 °C are not conducive for developing aroma in hops. Thus, bitter and high alpha varieties are predominant in the Yakima Valley. In Oregon and Idaho, the climate is somewhat milder. High levels of rainfall and more moderate temperatures are better suited for the cultivation of a greater proportion of aroma varieties in these states.

1.3.3 China

China's hop-growing regions are located along the edge of the Gobi Desert in the northeast. Strong winds blow across the area, preventing construction of tall trellises. Relocating the hop-growing region to the south where there is less wind is not feasible because it is below 35 degrees latitude, and the days are too short. Therefore hop farmers have no choice but to use low trellis systems. As the world's largest beer-producing country, China grows its hops almost exclusively for domestic use.

1.4 Changes in Cultivation Area

Table 1 shows the reduction in land dedicated to hop cultivation from 1990 to 2012. This demonstrates that the overall area shrinks if prices are too low to earn a profit or if production cannot be secured at fixed prices through forward contracts. Hop farmers faced with such situations around the world react by planting alternative crops or allow their land to lie fallow. For brewers, this means that the area under cultivation must be monitored on an annual basis, to ensure a constant supply of hops through forward contracts, especially for less cultivated varieties.

		1990	1995	2000	2005	2008	2009	2010	2011	2012
World	ha	91,271	86,786	58,991	50,273	57,297	57,108	52,772	49,069	46,041
Germany	ha	20,113 **	21,930	18,594	17,161	18,695	18,485	18,386	18,228	17,124
percentage of total:										
aroma hops	%	63	62	58	59	56	53	53	54	56
bitter hops*	%	37	38	42	41	44	47	47	46	44
USA	ha	14,357	17,490	14,627	11,924	16,551	16,076	12,647	12,147	12,467
percentage of total:										
aroma hops	%	31	30	24	39	35	25	26	28	32
bitter hops	%	69	70	76	61	65	75	74	72	68
Czech Republic	ha	11,807 ***	10,074	6,108	5,672	5,335	5,305	5,187	4,744	4,435
percentage of total:										
aroma hops	%	100	100	100	99	99	99	98	98	98
bitter hops	%	0	0	0	1	1	1	2	2	2
China	ha	~8,500	6,550	4,930	3,486	5,683	7,200	5,100	4,390	3,531
percentage of total:										
aroma hops	%	~5	4	4	11	13	13	12	9	8
bitter hops	%	~95	96	96	89	87	87	88	91	92

*includes high alpha varieties
**former West Germany before reunification
***former Czechoslovakia

Table 1: Changes in the area under cultivation in the largest hop-growing countries from 1990 to 2012

Table 2 shows fluctuations in the area under cultivation in selected countries and provides an overview of the most important hop-producing nations. Approximately 62 % of the cultivated area is divided between two countries: Germany and the USA. The percentage rises to 75 % if based solely on alpha acid production. A large number of varieties exhibiting a wide array of characteristics and containing a diverse range of hop constituents are grown around the world. However, the ten most significant varieties occupy about 95 % of the area under cultivation in Germany and roughly 85 % in the USA.

	Area under cultivation (ha)		Change
	1991	2012	+/-
Germany	22,567	17,124	-5,443 ha (-24 %)
USA	16,018	12,467	-3,551 ha (-22 %)
Czech Republic	10,201	4,435	-5,766 ha (-56 %)
China	8,000	3,531	-4,449 ha (-56 %)
Poland	2,225	1,400	-825 ha (-37 %)
Slovenia	2,388	1,160	-1,228 ha (-51 %)
England	3,527	999	-2,528 (-72 %)
Spain	1,387	510	-877 ha (-63 %)
South Africa	587	492	-95 ha (-16 %)
Ukraine	7,300	470	-6,830 ha (-93 %)
World	**91,409**	**45,041**	**-45,368 ha (-50 %)**

Table 2: Changes in the area under cultivation for selected hop-growing countries from 1991 to 2012. The countries are listed according to the area cultivated in 2012.

A comparison of the area devoted to the cultivation of aroma hops versus bitter hops is presented in table 1.

1.5 Environmentally Friendly Hop Production

Hops are a natural product and can exhibit a high level of variability in their quality characteristics in response to seasonal variation. Even with effective production techniques, weather-related factors can impact not only the appearance of the hop cones but also the quality of the substances they contain.

The requisite production techniques for hop cultivation, harvesting practices and the application of fertilizers and pesticides cannot be discussed in full detail here. Most important is that healthy hops are available to the brewer, which do not contain residues of prohibited pesticides or other inadmissible compounds. Descriptions of the fundamental aspects of production-related techniques, which guarantee environmentally friendly and sustainable hop cultivation, are discussed below. These techniques were based upon field trials conducted over several years, and the results have been subsequently applied through agricultural advisory boards. The following chapters describe the production process as it is carried out in Central European hop-growing regions.

1.5.1 Soil Management and Protection

Soil quality is an essential factor in the cultivation of hops. Preserving the fertility of the soil over the long-term must be a high priority. As mentioned above, hops are perennials and are therefore planted as a permanent crop. Throughout the world, hops are planted in rows, spaced 2.7 to 4.2 m apart. Hop plants do not offer any protection against erosion between the rows.

In the past, the entire hop yard was kept free of other plants. Now, intertillage crops are planted to cover the surface of the soil for as long as possible. Crops such as winter oilseed rape, winter turnip rape, fodder radish or rye are sown between the rows of hops.

Undersowing crops (see fig. 7) not only reduces erosion but also has a positive effect on soil fertility:

Figure 7: Undersowing crops between the hop rows to preserve soil fertility

- Such crops improve the soil structure through intensive root penetration.
- They contribute to an enhanced humus balance through the creation of organic mass.
- By binding nitrogenous substances, they prevent nitrates from being leached out of the soil in winter, thus protecting water resources.
- They enhance the biological activity of the soil.

The rows where the hops grow are maintained so they are free of other plants to eliminate competition for water.

1.5.2 Nutrient Supply According to Soil Analysis

Only a balance among the primary nutrients of lime, phosphate, potash and magnesium ensures healthy plant growth and high yield. The level of nutrients present in the soil and whether or not any supplementary nutrients should be added is determined through analysis. The soil analysis provides the hop farmer with information regarding how much fertilizer must be applied to the soil at that time.

Hops also require trace elements. They need high amounts of boron and zinc, as do other crops. As the need arises, trace elements can be added directly through foliar feeding to avoid stunted growth.

Nitrogen occupies a special place among these nutrients. If there is a shortage of nitrogen, hop plants react with a precipitous decline in yield. On the other hand, excess nitrogen results in the following:

- the promotion of leaf growth and increased susceptibility to diseases
- the pollution of groundwater through runoff
- elevated nitrate content in hop cones

In long-term field trials with fertilizer, the quantity of nitrogen and the time it should be applied were established for a number of hop varieties, so that hop cones low in nitrates can be produced in an environmentally sound manner.

By law, results from soil analyses and the quantities of fertilizer applied to hops must be documented by farmers and archived for a minimum of seven years.

1.5.3 Pesticide Usage According to Early Warning Systems and Action Thresholds

Every year, hops are attacked by pests and diseases and must therefore be protected against the harm caused by these organisms. The objective behind any measures taken to protect hops should be to keep the plants healthy until the harvest; however, excessive use of pesticides should also be avoided, due to increased costs and damage to the environment.

For all intents and purposes, hop production is not possible without some means of protection, even with so-called "organic" hops. Work is being carried out at hop research institutes and universities to improve forecasting models and to better understand how to implement action thresholds. This research assists consultants and hop farmers in making decisions regarding whether or not and, if so, when it is necessary to take action against specific diseases and pests. The action threshold is reached when the expected damage is greater than the cost of the product required to combat the pest or disease, including the cost of application.

1.5.3.1 Weighing the Resistance of Hop Varieties

The resilience of hop varieties against harmful organisms is referred to as "resistance". The attributes giving rise to resistance are genetically determined and are therefore inherent to a variety. In breeding new varieties, the selection for resistance to diseases must be the primary objective.

New varieties from breeders around the world must be evaluated in field trials and compared directly with one another to determine their resistance and their susceptibility to the diseases most relevant for hop cultivars (see table 3).

	Parasite	Scientific name
Diseases	wilt	*Verticillium albo-atrum*
	downy mildew primary infection secondary infection	*Pseudoperonospora humuli*
	powdery mildew	*Podosphaera macularis*
	botrytis	*Botrytis cinerea*
Pests	two-spotted spider mite	*Tetranychus urticae*
	hop aphid	*Phorodon humuli*
	alfalfa snout beetle	*Otiorhynchus ligustici*
	hop flea beetle	*Psylliodes attenuatus*

Table 3: The most important harmful organisms affecting hops

Unfortunately, the resistance of hop varieties is constantly under threat and therefore does not endure. All organisms are subject to natural selection. For pathogenic organisms in particular, it is vital that through changes to their genetic make-up they develop ways to guarantee their continued survival by overcoming the resistance of their hosts. Thus, assigning hop varieties to resistance groups is provisional and must be adjusted as results from research trials and observations from the field are documented and continuously updated.

1.5.3.2 Early Warning Systems for Peronospora (Pseudoperonospora humuli)

There are early warning systems for Peronospora (downy mildew, see fig. 8) in almost every hop-growing region on the globe. The Bavarian State Research Center for Agriculture (Bayerische Landesanstalt für Landwirtschaft) has established a Peronospora early warning system in Bavaria. In the past, this disease was combatted on a weekly basis, 15 to 17 times per season.

Figure 8: Peronospora-infected hop cones - damaged hop leaves and cones are no longer marketable

Since the early warning system has been in place, hops with a high tolerance to downy mildew only need to be sprayed three to four times per season, and those with less resistance, five to six times.

At four to five stations in the Hallertau and at one each in the Spalt and Hersbruck regions, the number of zoosporangia in the air is counted daily using spore traps (see fig. 9).

Weather data from over ten measurement stations, which are integrated and evaluated in weather data processing systems, provide additional information regarding the probability of a Peronospora infection. Due to the diverse nature of the data collected, the Peronospora early warning system makes daily announcements over both the telephone and the Internet about the severity of the Peronospora threat at that time. Should the four-day sum for the zoosporangia count rise above 30 before flowering commences (50 for tolerant varieties), or after the flowering period has commenced - over 10 (20 for tolerant varieties) with concurrent precipitation over several hours - then an announcement is made to spray the varieties belonging to the relevant resistance groups.

Daily announcements via the telephone service or the Internet allow hop farmers to spray only when there is threat of infection, given that the following is taken into consideration as well:

Figure 9: Spore traps in a hop yard for determining the number of zoosporangia; pictured in the foreground is the weather station

- Crops should be continuously monitored for signs of disease.
- Spraying is performed within a minimum of two days after notification of an infection has been received.
- Wild hops should be removed from the area, because they are usually infected with Peronospora and endanger any nearby hop yards.
- Properly handling the first infection of the spring (primary infection) is a prerequisite for spraying according to the early warning system.

1.5.3.3 Early Warning Systems for Powdery Mildew (Podosphaera macularis)

This disease is not present in all hop-growing regions and does not cause an outbreak among cultivated hops every growing season. Figures 10 and 11 show the typical signs of an infection on hop leaves and cones. Different varieties of hops also vary in their levels of resistance to this organism.

The life cycle of *Podosphaera macularis* is very complex. Forecasting models for effectively managing this disease are still in development. In the hop-growing regions of the USA, there has been an early warning system for powdery mildew since 2003. Due to the farming methods practiced there, the forecast assumes that for less resistant varieties - beginning when flag shoots appear in the spring - that infection is probable, and therefore the hops are sprayed regularly. Depending on the amount of precipitation and the pesticides used, the intervals between spray treatments can vary from seven to 18 days.

In the Hallertau, the introduction of forecasting models is in development. In the beginning, the model was based on field trials, which provided the initial orientation, followed by reproducible, scientifically verifiable tests conducted in the laboratory and in the field from 2007 to 2009. Taking into consideration the most up-to-date findings about the biology and epidemiology of the species of powdery mildew infecting hops, the forecasting model was introduced

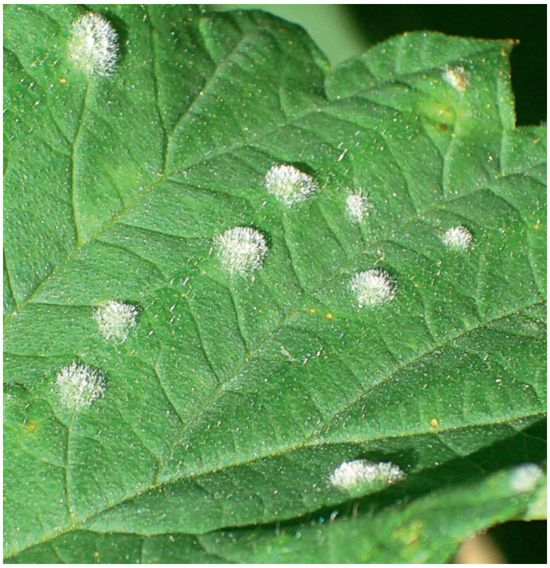

Figure 10: Damage to a hop leaf caused by powdery mildew - fungal mycelium destroys the leaf tissue, thus reducing crop yield

Figure 11: An extreme powdery mildew infection on hop cones

across the entire Hallertau in 2009. Data available on the Internet concerning weather conditions are collected on a daily basis from weather stations and entered as an index value (0 or 1) into an equation (see fig. 12, black curve). Over the vegetation period, a curve is generated and compared to action thresholds. If the infection curve is above the threshold, then action must be taken to combat the powdery mildew. In the example depicted in figure 12, on May 14th an announcement was made to spray all hop varieties. By contrast, on July 9th and August 13th only the red line was intersected; therefore, only hop yards needed to be treated where an infection had been previously identified through visual examination of the hops. However, if the curve intersects the green line, then varieties susceptible to powdery mildew must be treated as well, even if no infection is evident on the hops at the time.

The following is of particular significance:

- The forecasting model for powdery mildew is designed to prevent an initial infection. If pustules are found, which have for example been borne by wild hops, it is nearly impossible to completely eradicate the disease.
- Combatting the disease in the spring is crucial. Since the plants are still small at this point, much can be achieved with minimal effort.
- Spraying when there is no risk of infection is ineffective.

Production techniques and preventative measures (e.g. less nitrogenous fertilizer usage) also contribute to reducing powdery mildew infections.

1.5.3.4 Early Warning Systems for Pests

Thresholds also play an important role in combatting the most destructive pests. All farmers must personally monitor their hops, in order to determine the extent of the infestation. It should be noted that an existing infestation cannot in any way be compared to the conditions present during the previous growing season. For this reason, it is essential that hop farmers monitor their fields prior to taking any measures to protect their crops.

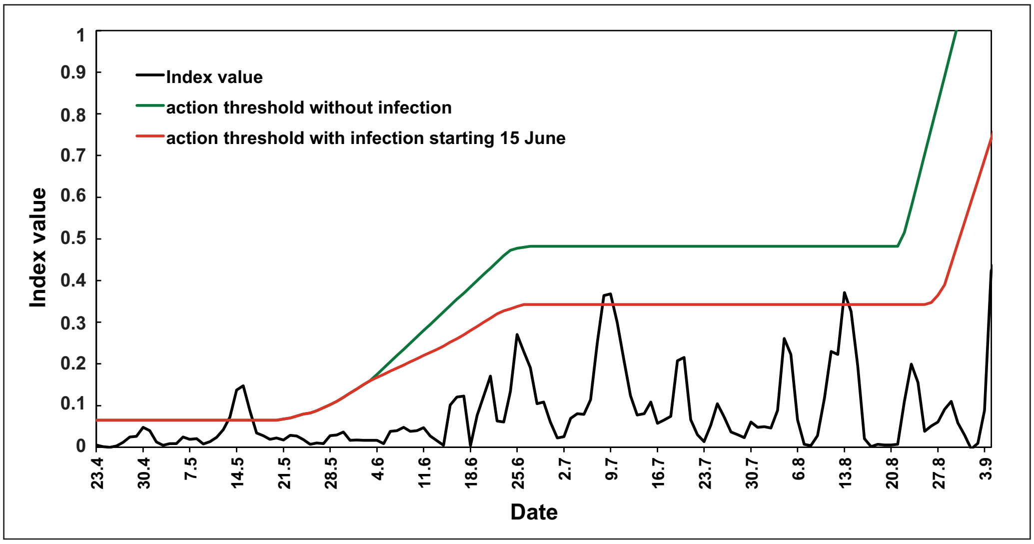

Figure 12: Forecasting models for combatting powdery mildew in the Hallertau. An index (black curve) is calculated using weather data. If the action threshold is exceeded, an announcement is given that spraying should be carried out.

Two-spotted Spider Mite (Tetranychus urticae)

This pest (see fig. 13) must be monitored in at least two ways. The number of red spider mites on a minimum of 20 individual leaves per hectare of cultivated hops is normally determined by simply counting them using a magnifying glass. An index value is defined for every leaf according to the information in table 4. Averaging 20 values per hectare yields the infestation index for the inspected hop yard. If the control threshold (see fig. 14, thick dotted line) is exceeded, then treatment is necessary. A general rule of thumb during the first inspection of a hop yard: if slight traces of spider mites are perceptible on every other leaf, then treatment is required.

It is imperative that the second inspection occurs 25 to 45 days prior to the harvest. If at that point the control threshold has not been exceeded, spider mites cannot reproduce quickly enough - even under optimal conditions - to amass a sufficiently large population able to pose a threat. Later treatment with pesticides is usually not possible, since complying with the pre-harvest interval - the mandatory time period between the last possible application and the harvest - is no longer feasible. Studies concerning yield have shown that up to 70 spider mites per leaf are tolerable at harvest, because this number and fewer per leaf have no adverse effect on either the yield or the alpha acid content. Numerous trials have even revealed that a slight spider mite infestation causes the alpha acid content to rise.

Figure 13: Two-spotted spider mite - the light yellow areas indicate that spider mites have been feeding on the underside of the leaf, robbing the plant of nutrients. Similarly affected hop cones appear brown.

	Estimated number of mite eggs			
Mites	0	<30	30 to 300	>300
0	0	1	2	3
1 to <10	1	1	2	3
10 to <50	2	2	3	3
50 to <100	3	3	3	4
100 to <1000	4	4	4	5
>1000	5	5	5	5

Table 4: Determining the control threshold for two-spotted spider mites