HOPS

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Contents

Introduction

It is 25 years since Dr Burgess wrote his invaluable book on hops and in the intervening period there have been very many advances in hop research and hop production techniques. When invited to produce a replacement for that book, therefore, the problem was not finding enough new material but deciding on what to include.

People interested in reading about the hop are likely to fall into very diverse categories. Hop growers will be looking for practical advice on production methods while research workers with specialist knowledge in one field may want detailed information about research in other disciplines. In addition, there are many people for whom hops are of much more general interest and for them a source of basic information about the crop will be required.

The aim has not been to produce a detailed growers' handbook, since techniques vary considerably from district to district and I believe that it is better to obtain advice from neighbouring growers or from specialist advisers than from any book. What I have attempted is to outline the basic principles upon which production methods should be based. At the same time, I have tried to include material that will be of general interest both to those who work with hops and to those to whom they might otherwise remain a complete mystery. In doing this my own personal interests have inevitably played an important part. Since it is difficult for most people to obtain access to historical accounts I have included extracts from those that have fascinated me. In particular, there are several extracts from Reynolde Scot's *Perfite Platforme of a Hoppe Garden*. Reference has, been made throughout, to the second (1576) edition of this book as it includes some material that is not to be found in the first edition of 1574.

One book cannot possibly include all the information that readers may require and in the course of writing it I have become aware of a great deal of literature that was new to me. The attempt to record some of the history of hop growing, the achievements of early workers which might otherwise be overlooked and details of current work has resulted in a very extensive bibliography. By some this may be considered excessive but it is hoped that many will find it a useful source of information.

It was decided not to invite specialists to write individual chapters since this might result in a more disjointed text than one written by a single author. As director of the Hop Research Department at Wye for many years I have been associated with a dedicated team of workers dealing with most aspects of hop research. That certainly does not mean that I am an expert in them all and, in order to avoid gross errors and omissions, most of the chapters have been referred to colleagues for their comments. While most gratefully acknowledging the help of Dr Tony Adams, Dr Colin Campbell, Dr Peter Darby, Dr Greg Lewis, Mr Mike Shea, Dr Philip Talboys, Dr Mike Thresh and Mr Arthur Winfield, I would emphasise that they cannot be held responsible for any errors that may remain.

An exception to the general scheme was made when it was suggested that there should be a section on hop chemistry. This was something which I was not competent to write and Dr Roger Stevens very generously provided a section that is incorporated in Chapter 2. To him, I am particularly grateful.

My thanks also go to Mr Bob Barrar for preparing new drawings for Figures 1.1, 1.2 and 1.3 as well as for permission to re-use Figure 3.10.

The Hop Research Department at Wye and East Malling Research Station have recently been grouped together as part of the Institute of Horticultural Research and illustrations from those sources are acknowledged as from IHR, Wye and IHR, East Malling.

The book has, throughout, had the support of the members of the Scientific Commission of the International Hop Growers Convention and I am most grateful for the encouragement that they have given me.

Hop research is notable for the very close co-operation that exists, not only between workers in the various hop growing countries but also between research workers, hop growers and brewers. It is this friendly and stimulating atmosphere that has made working on the crop such a rewarding personal experience.

Finally I would thank my wife, Lesley, for encouraging me to undertake the task of writing the book and for enduring the consequences.

R.A. Neve

Units and abbreviations

Since the book is likely to be referred to by practical farmers it was decided to use the more everyday units in preference to the SI units which are likely to be confusing for some people. Generally, both metric and imperial units have been quoted, priority being given to metric except when imperial was used in the publication being quoted. The only unit used that may be unfamiliar to some readers is the zentner (zr) which is equivalent to 50 kg and is the standard unit for commercial hop dealings in Europe.

Where initials are used to identify countries these are given according to their own convention. Thus the English form is used for the UK and the USA but DDR is used for the area formerly known as East Germany and BRD, similarly, for West Germany.

CHAPTER 1

Botany

1.1 THE GENUS

The genus *Humulus* consists of three species, *H. lupulus, H. japonicus* and *H. yunnanensis*. The cultivated hop, *H. lupulus*, is indigenous throughout much of the Northern hemisphere between the latitudes of approximately 35° and 70° N. *H. japonicus* is widespread throughout much of China and Japan but has not been recorded elsewhere. Remarkably little is known about *H. yunnanensis* of which there are very few herbarium specimens and no plants in cultivation.

Humulus and *Cannabis* are the only two genera in the family *Cannabinaceae* and there are many similarities between hemp (*Cannabis sativa*) and the cultivated hop. The nettle family is also rather less closely related being in the same order, the *Urticales*. It is possible to produce viable grafts between hops and hemp and it is reported that pollination of hops by hemp, annual nettle (*Urtica urens*) or perennial nettle (*Urtica dioica*) stimulates cone development but only abortive embryos are produced (Schnarf, 1929. Quoted by Davis, 1956).

1.1.1 *Humulus lupulus*

This is a dioecious perennial climbing plant without tendrils, the bines twining round any available support in a clockwise direction with the aid of hooked hairs located on the angles of the stem. Darwin (1882), while ill in bed, watched a hop plant growing on his window-sill and noted that the tip of the bine completed a revolution in two hours. This was later confirmed by Shea (unpublished) using time-lapse photography. Darwin concluded that the twining was brought about by a wave of growth travelling around the shoot in the extending region. Bell (1958) investigated the twining of the hop on supports with diameters ranging from 0.25 in (0.635 cm) to 3 in (7.62 cm) and found that the steepness with which the stem twined diminished with increasing diameter of the support, suggesting that the radius of curvature of its helix remained constant.

The leaves are normally borne in pairs at each node although a tricussate arrangement is sometimes found. The leaves have a toothed margin and the shape varies from cordate to 7-lobed although 3–5 lobes are the most common in mature leaves (Fig. 1.1). Wild American hops generally have more lobes and are more deeply divided than European or Japanese hops and most cultivars.

The flowers of the male plants are produced in loose panicles, and have a perianth of five yellowish-green sepals and five anthers on short filaments. The anthers, which have a furrow in which a few resin glands are located, dehisce to produce large quantities of pollen which is wind-borne (Figure 1.2).

Female flowers occur in inflorescences that consist of a condensed central axis; on each node there is a pair of bracts. Each bract subtends a pair of bracteoles and each bracteole has a small flower enclosed in a fold at the base. The flower consists of an ovary, enclosed in the perianth, with a pair of papillated stigmas. As these inflorescences mature, the central axis elongates and the bracts and bracteoles enlarge to produce the strobiles (commonly referred to as 'cones') which form the commercial product of the plant (Figure 1.3). Flowers that are pollinated develop to form an achene enclosed in the papery perianth and their development stimulates the bracteoles in which they lie to extend much further beyond the bracts than do those bracteoles without seeds. Pollination also results in elongation and thickening of the central strig (Figure 1.4), and the nodes bearing seeded flowers are frequently pigmented. These changes make it easy to distinguish between seeded and seedless cones.

The commercial value of hops lies in the lupulin glands which contain resins (of which the α-acid is the most important fraction) which give beer its bitterness and essential oils which contribute hop flavour. Whereas male flowers develop only a small number of resin glands, these are abundant on the cones of the female plants (Figure 1.5). They are most numerous on the bracteoles with relatively few on the bracts. They are dense on the pericarp and in seeded hops up to a third of the α-acid in the cone is produced there. In seedless cones the pericarp remains vestigial and contributes only a small proportion of the whole. There are great variations between different genotypes in the number and size of the glands in the cones and these differences are commercially very important since it is the glands that contain everything that is of value to the brewer. Neve (1968) investigated the distribution of α-acid on the different parts of seeded and seedless cones of the three cultivars Fuggle, Northern Brewer and Bullion with the results shown in Table 1.1.

Although resin glands were found on the strigs, examination indicated that these had not been formed there but had become detached from other parts during the dissection of the cone and were adhering to the fine hairs which cover the strigs. Resin glands are also produced on the underside of the leaves but are not sufficiently abundant to make the leaves of any value as brewing material.

Thomas (1980a) has published electron microscope photographs showing the stages of development of the glands on cones (Figure 1.6). The separation of the sexes between plants means that self-pollination is not normally possible and consequently hop plants are genetically very heterozygous. Therefore, when plants are raised from seed the progeny are extremely variable and the

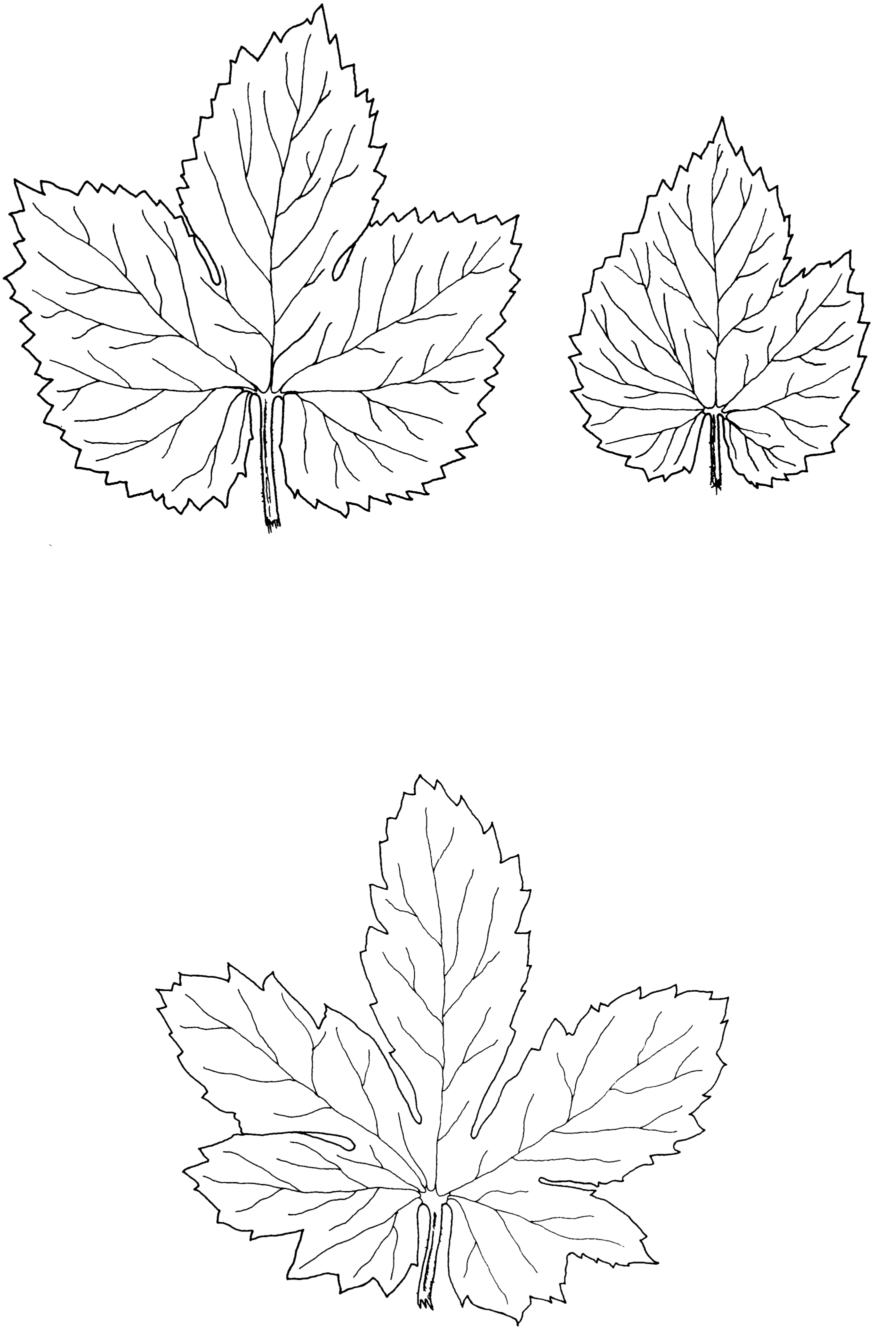


Figure 1.1 Variations in hop leaves (after R. F. Farrar).

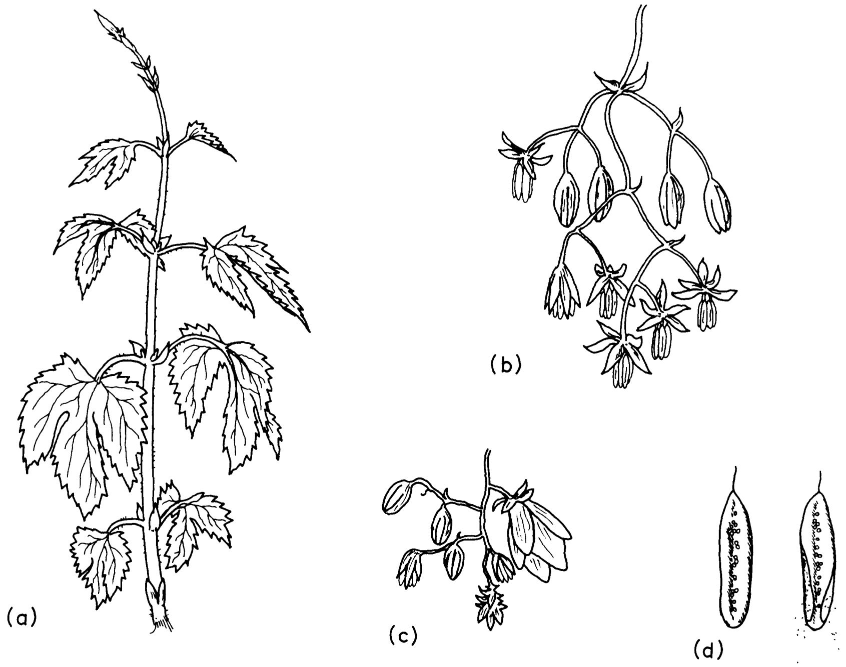


Figure 1.2 (a) Young shoot; (b) male flowers; (c) male and female flowers of monoecious plant; (d) anthers with resin glands in the furrows (after R. F. Farrar).

majority are of little value commercially. For this reason, hop gardens are invariably planted with material that has been propagated vegetatively from one of the established cultivars.

The above-ground parts of the plant die back to ground level each winter but the below ground 'rootstock' is perennial and can survive for very many years. Although referred to as a rootstock the upper part is, in fact, stem tissue (Figure 1.7). In a mature plant the root system can extend downwards for 1.5 m or more and laterally for 2–3 m although the extent of lateral spread is less on deeper soils (Beard, 1943a). There are two types of roots: horizontal roots that are tough, wiry and branching which produce much fibrous growth within the top 20–30 cm of the soil and vertical roots which arise from the crown or from horizontal roots and are fleshy, irregularly swollen and easily broken. The roots do not produce buds and regeneration each spring is from buds on the branched stem tissue which lies below ground level and forms the upper part of the rootstock. These buds produce a mass of shoots in the spring – far more than are needed to grow a crop – so that the grower has to remove most of them. Some buds also develop into runners which can spread sideways, just below ground level, for 1 m or more although most will emerge above ground closer to the rootstock.

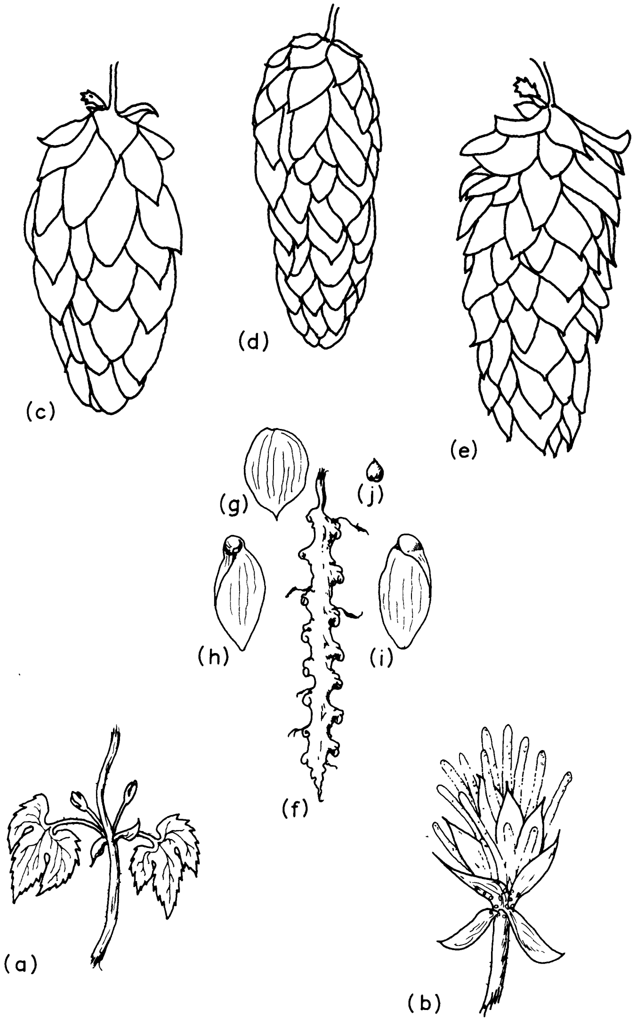


Figure 1.3 (a) 'Pin'; young flowering shoots developing in the leaf axils; (b) 'Burr'; young female inflorescence with papillated stigmas. Mature cones of (c) Fuggle; (d) Wye Target; (e) Yeoman; (f) 'Strig'; central axis of cone; (g) bract; (h) bracteole with enclosed seed; (i) bracteole with seed; (j) removed (after R. F. Farrar).

There are considerable differences between the plants to be found in various parts of the world and botanists have on several occasions suggested that the variation is sufficient to justify classifying them into different sub-species or even into separate species. The wild hops of North America have been named *H. americanus* or *H. neomexicanus* while the type to be found in Japan (and possibly China) with cordate leaves is named *H. cordifolius*. All these forms

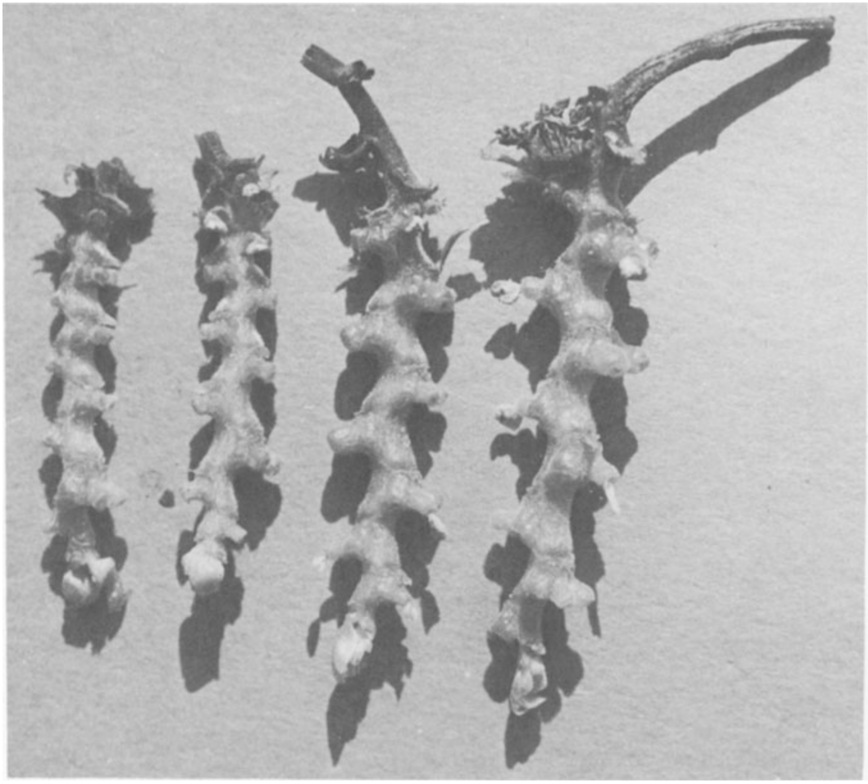


Figure 1.4 Strigs of unpollinated (left) and pollinated (right) cones.

are totally interfertile and most workers do not now separate them. Davis (1957) examined a range of specimens and separated them into three morphological complexes which were represented by English, German–Czech and American (Late Cluster) cultivars. Wild American hops had characters in common with Late Clusters and Japanese wild hops but the variation within the wild Americans was such that further investigation would be necessary before the various forms could be separated.

In the most recent review of the genus, however, Small (1978) has moved in the other direction and proposed dividing the species into five varieties, two of which are new. Under his proposed nomenclature the European hop is *H. lupulus* var. *lupulus*, that of Japan remains as *H. lupulus* var. *cordifolius* and the form native to western North America as *H. lupulus* var. *neomexicanus*. He considers these to be distinct from the plants native to the American Midwest and the eastern part of the United States for which he proposes the names *H. lupulus* var. *pubescens* (var. nov.) and *H. lupulus* var. *lupuloides*

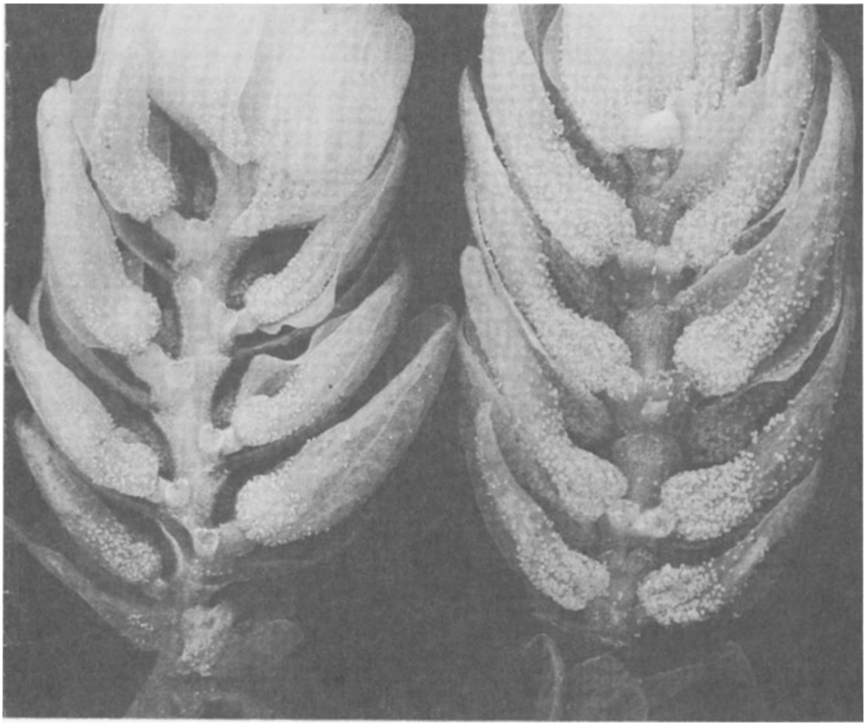


Figure 1.5 Cones of traditional cultivar (left) and high α-acid cultivar Yeoman (right) showing resin glands.

(var. nov.) respectively. Davis (1956), while recognizing differences between the hops of the West, Midwest and East, considered that these differences were too slight to warrant separate names. Moreover, Hampton (personal communication) reports that he was unable to recognize a distinct type when collecting wild hops in the Midwest.

TABLE 1.1 *Alpha-acid in each part of the cone as a percentage of the total.*

	Seeded			Seedless		
	Fuggle	N. Brewer	Bullion	Fuggle	N. Brewer	Bullion
Bract	14.3	14.4	15.0	23.7	21.9	21.8
Bracteole	55.0	66.5	50.2	66.7	74.1	71.2
Seed	28.7	16.6	32.2	5.7	1.8	4.5
Strig	2.0	2.6	3.0	3.9	2.2	2.6

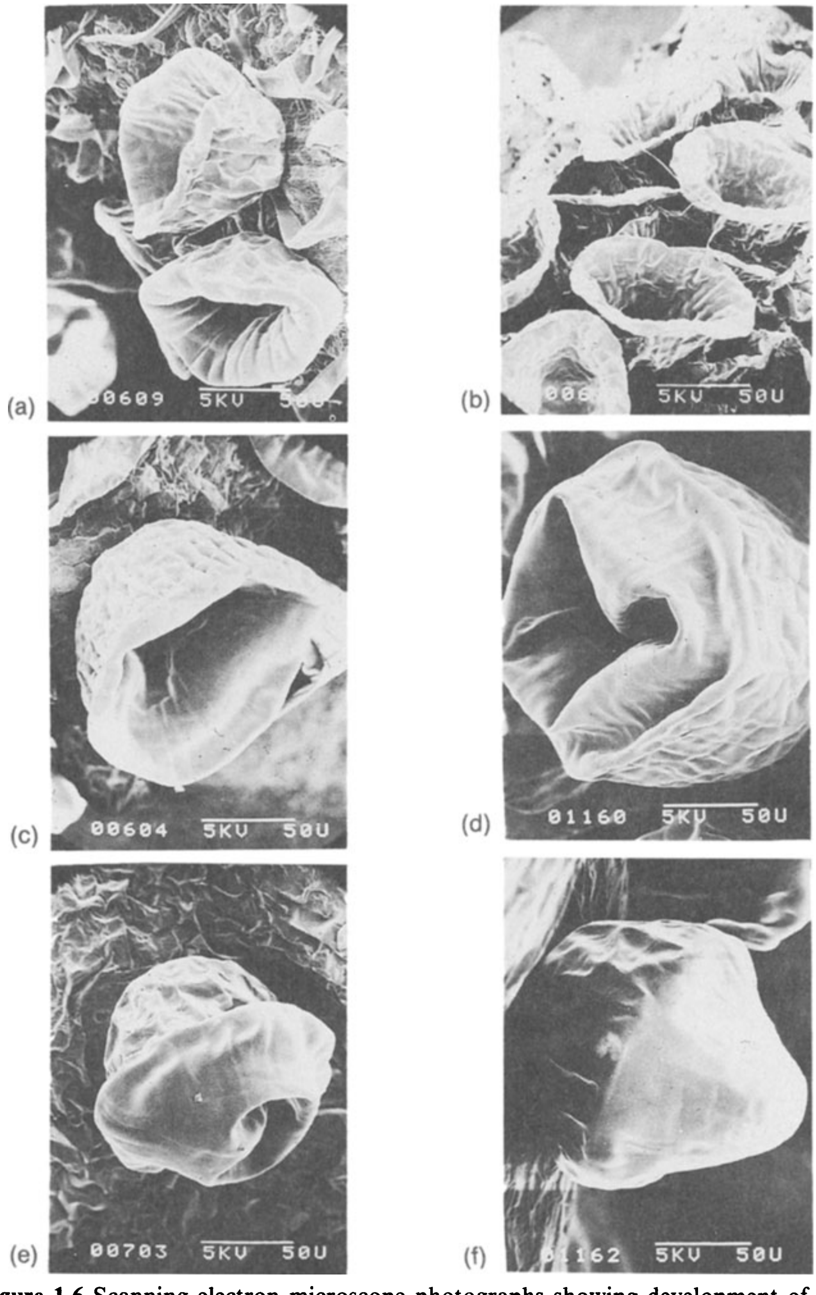


Figure 1.6 Scanning electron microscope photographs showing development of resin glands on the following dates: (a) 30.7; (b) 6.8; (c) 10.8; (d) 29.8; (e) 15.8; (f) 7.9; (Thomas, 1980a).

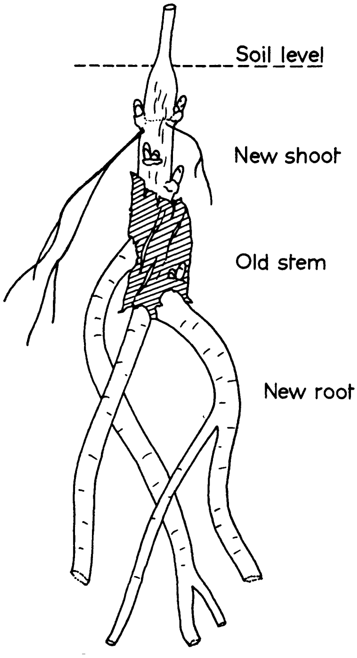


Figure 1.7 Perennial storage organ of young plant consisting of new shoot, old stem of original trimmed sett and new storage roots (Williams, 1960).

1.1.2 *Humulus japonicus*

This is typically an annual species but there are suggestions that it may sometimes survive for more than one season. It is also dioecious and the cones, although similar in structure to those of *H. lupulus*, look quite different, ripen sequentially and have few, if any, lupulin glands. They are therefore of no value as brewing material. The leaves are normally 7-lobed and the plants are covered with very strong hooked hairs which can make them quite painful to work with. It is a strong climber and is sometimes grown horticulturally to provide a leafy screen.

1.1.3 *Humulus yunnanensis*

Attention has been drawn to the existence of this species by Small (1978) but little is known about it apart from a few herbarium specimens. It occurs, apparently, at rather high altitudes in southern China, particularly in Yunnan Province at a latitude of approximately 25°N. Small states that it is not known whether it is an annual or perennial plant but information from China (Jinyu, personal communication) is that it is a perennial. Since it grows at lower latitudes than other members of the genus it could have potential as breeding material to extend the areas in which hops could be grown commercially.

1.2 SEX RATIOS

The fact that female hop seedlings normally occur more frequently than males was first recorded by Winkler (1908) who suggested that it might be due to the production of parthenogenetic seed. Tournois (1914) demonstrated with very careful experiments that no seed was set when pollen was completely excluded, confirming similar reports by Salmon and Amos (1908) and Winge (1914). In a later paper Winge (1923) was the first to suggest that the excess of females was the result of pollen competition.

Dark (1951) reviewed the published results on sex ratios and pointed out that many of the reports gave no indication of germination percentage of seed but that where it was quoted, it was very low. He concluded that this 'must profoundly modify any genetical interpretation of the sex ratios counted in mature families'.

Sex ratios were the subject of PhD theses by Neve (1961) and Smithson (1963) who showed that when germination percentages were low there was a greater preponderance of females and that females tended to germinate earlier then males. If seed was subjected to adequate cold treatment, good germination was obtained; it was then found that pollen competition was the main reason for the excess of females. Even when this was eliminated, however, by diluting the pollen or by placing single pollen grains on the styles, females were still in excess. In most families the ratio was about 2:1 but when the female parent was the Saazer variety it was as high as 4:1. Limited studies indicated that half the male seedlings of the Saazer crosses developed into pagoda dwarfs which survived for such a short time that their sex could only be determined cytologically. This would account for the difference between Saazer and other crosses but, in the absence of evidence to account for the general 2:1 ratio, Smithson could only postulate an incompatability system operating on 50% of the male gametes.

1.3 CYTOLOGY

H. lupulus normally has a diploid chromosome number of 20 in both male and female plants but *H. japonicus* has 16 chromosomes in the female and 17 in the male. Nothing is known of the cytology of *H. yunnanensis*.

Occasional triploid plants have been identified as having occurred naturally in *H. lupulus*. The first report was by Tournois (1914) who examined plants that were basically male but had occasional female flowers at the ends of the laterals and reported that these were triploids. This is the most common form but at least two female cultivars developed from breeding programmes using diploid parents were later found to be triploids. These were AGG8 bred at Wye and Hüller Bitterer from Hüll in Germany.

Both *H. lupulus* and *H. japonicus* have recognizable sex chromosomes and these have been the subject of various investigations. Winge (1923), Derenne (1954) and Jacobsen (1957) working with plants of European origin reported the occurrence of a heteromorphic pair of sex chromosomes in the meiotic divisions of male plants. At the same time the Japanese workers Sinoto (1929a, b) and Ono (1937) were claiming that in the wild Japanese hop they found a chain of four chromosomes that represented a sex chromosome complex while in a later paper Ono (1955) reported on a wide range of male hops in which he found five different sex chromosome types as follows:

1. 'Winge type': a heteromorphic pair with a size ratio of 10:5.2, and nine bivalents;
2. 'New Winge type': a heteromorphic pair with a size ratio of 10:8 and nine bivalents;
3. 'Sinoto type': a quadrivalent with size ratios of 10.0:12.0:14.2:7.2 and eight bivalents;
4. 'New Sinoto type': a quadrivalent with size ratios of 10.0:12.7:10.9:3.4 and eight bivalents;
5. 'Homotype': ten bivalents.

Neve (1958a) studied meiosis in six male plants in which a quadrivalent association occurred together with a heteromorphic pair which he identified as the sex chromosomes. He suggested that this raised doubts about the interpretation by Sinoto and Ono of their quadrivalents as a sex chromosome complex. Ono and Suzuki (1962) examined wild American plants sent to them by Neve and confirmed Neve's interpretation in some plants but in others reported that the sex chromosomes formed part of the quadrivalent.

Neve (1961) found a heteromorphic pair of sex chromosomes corresponding to Ono's 'Winge type' in all the European males that he examined while in males from the USA or Canada there was either a heteromorphic pair corresponding to the New Winge type or an equal sized pair as in the Homotype. Any chains of four chromosomes that he found were in divisions where there was also a sex chromosome bivalent of the New Winge type, identifiable by the unequal lengths of the X and Y chromosomes (Figure 1.8). If a chain of four occurred in plants with homotype sex chromosomes it would be difficult to be certain whether the sex chromosomes were part of the quadrivalent or not. This may account for the different interpretations put forward. Neve did not examine any Japanese wild hops in which Ono and Suzuki (1962) have described tetrapartite and hexapartite sex chromosome complexes.

In all the plants he examined, Neve (1961) found that the X chromosomes could be clearly identified in mitotic divisions by means of the unstained region in the short arm when using pre-treatment with 8-hydroxyquinoline as

Figure 1.8 New Winge type males with and without chain of four autosomes. XY bivalent shaded; (a) male CG24; (b) male 321.

described by Jacobsen (1957) while the Y chromosome in Winge and New Winge types was recognizable as the only one with a short arm ending diffusively (Figure 1.9). The Y chromosome of homotype males was not distinguishable in this way.

1.4 POLYPLOIDY AND SEX DETERMINATION

The use of polyploidy in hop breeding was first reported by Ono (1948) and was subsequently developed by Dark (1953) at Wye. The commercial reasons for this are described in Section 9.7 but the availability of a wide range of polyploid plants provided Neve (1961) with an opportunity to investigate the cytological and genetic basis for sex determination.

Although hops are dioecious, some diploid female plants occasionally develop some male flowers which are infertile. Weston (1960) reported the production of male flowers on the female cultivar Fuggle following treatment with α(2-chlorophenylthio)propionic acid. He did not state whether the male flowers produced any pollen and it is likely that they did not do so. From Australia, three male plants have been reported to occasionally produce female cones with both sexes being fertile (Versluys, personal communication). When grown at Wye College, England, two of these have never produced cones while the third has produced a few cones in some seasons.

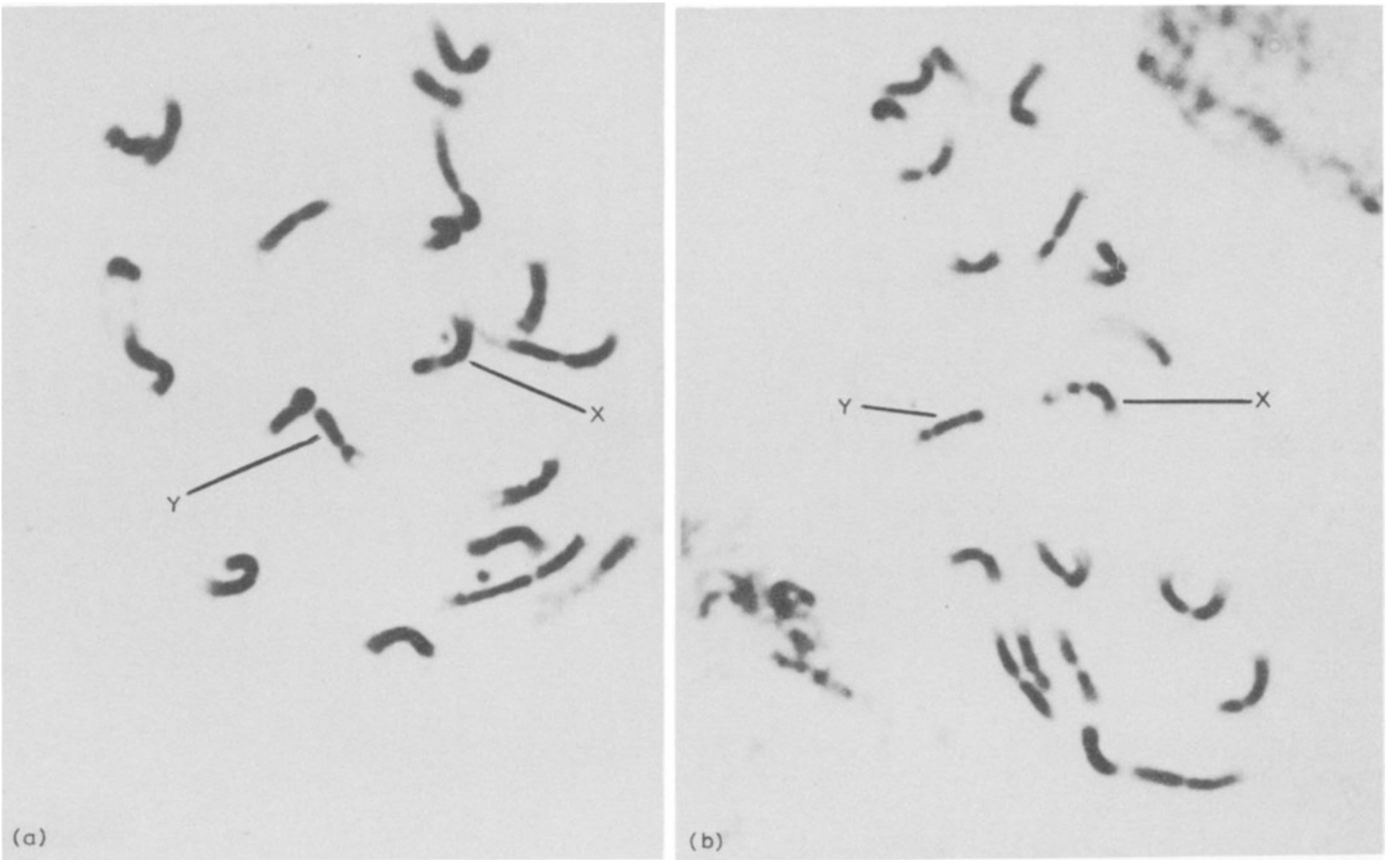


Figure 1.9 X and Y chromosomes in male plants of: (a) Winge; and (b) New Winge type.

—— WE owe to the kindness of Mr. DARWIN the communication of the following, with the specimen to which it refers :—

" I inclose a specimen of the male Hop with apparently female flowers at the tips of the branches, on

FIG. 37.—MONŒCIOUS HOP.

the chance of its having some interest for the naturalist. I observed it this morning, and though accustomed to walk Hop grounds for years I have never seen the two sexes on the same Hop plant before. Perhaps, however, it is but the growth of the flower into a male catkin.

" There are other male plants in the same ground, but I have not seen any other instance of this peculiarity. The whole Hop hill grows in the same way. If we obtain seed, might not it be possible to select a strain of Hops which are uniformly monœcious on the same plant? [Certainly.]

" The Hop ground is in Boughton Monchelsea, facing south, very warm, and of strong rich soil. *L. Lewis, East Farleigh.*"

Figure 1.10 An early account of a monoecious male plant similar to those now known to be triploids with XXY sex chromosomes.

Occasionally, in the progeny of diploid parents, plants are found that are predominantly male with a terminal cone on some of the laterals but differing from the Australian plants in that they shed little pollen. Such plants were described on two separate occasions over 100 years ago (Masters 1852, Lewis 1874, Figure 1.10) and examination of recent examples has shown them to be triploids.

Amongst the progeny of polyploid parents, however, there are many plants with both male and female flowers (Ono, 1959) and the male flowers frequently produce viable pollen. Neve (1961) examined the chromosomes in such plants and established that there was a clear correlation between the sex of the plants and the ratio of X : Y : A (autosome sets). In plants that had complete chromosome sets the relationship was as follows:

Ratio X : Y : A	*Most frequent sexual expression*
1 : 2 : 3	male
1 : 1 : 2	male
2 : 1 : 3	male with occasional female flowers
3 : 1 : 4	approximately equal male and female flowers
2 : 0 : 2	female
3 : 0 : 3	female
4 : 0 : 4	female

This relationship could be interpreted as a balance between X and Y, X and A or Y and A chromosomes. Examination of aneuploid plants (having chromosomes additional to or missing from the sets of 10) indicated that the Y chromosome had little effect upon the sex of the plant and that most of the male determining genes were located on the autosomes. It was the ratio of X:A that was the main determinant of sex. Although the Y chromosome apparently had no influence on the sexual form of the plants, it played an essential role since male plants which lacked any Y chromosome failed to produce viable pollen, development ceasing at the pollen tetrad stage. This is very similar to the situation found in *Drosophila.* Although pairing between the sex chromosomes is very restricted, the normal pairing and crossing over amongst the autosomes allows for genetic segregation of the male-determining genes and this would account for the wide range of sexual expression between plants having similar chromosome complements.

The fact that male hops are of no value for brewing creates problems for hop breeders in selecting males for use as parents in their breeding programmes. Males can be tested for such characters as disease resistance but brewing quality cannot be directly assessed. There would be great advantages if plants that produced hop cones could also be used as sources of pollen. Since some diploid plants produce both male and female organs attempts have been made to induce sex changes by chemical treatment but without any success.

Neve (1965) suggested that tetraploid plants that were both male- and female-fertile could be selected on their cone characters and the best used as male parents. Some work was carried out along these lines but the two stages of having first to breed good tetraploids and then to use them as parents in the commercial programme were too time-consuming to meet the urgent needs of the industry.

Another approach was based on the Australian diploid that was occasionally monoecious. This is cytologically a male plant with XY chromosomes that is presumably deficient in male determining genes in the autosomes. By using this as a parent it might be possible to develop a diploid breeding line in which many of the 'male' plants produced sufficient cones for their brewing quality to be assessed. Since these males would also have XY chromosomes they could produce viable pollen yet their female progeny would not be liable to develop any male flowers. This programme was also commenced but the frequency of the monoecious character was so low that no useful results could have been expected for a very long time (Neve, unpublished).

The female flowers of tetraploid monoecious plants are no longer receptive by the time the male flowers shed pollen so self-fertilization will not normally occur, but Haunold (1972) achieved it by having clonal plants of the same genotype at different stages of development. Extensions of this technique, or of the diploid monoecious material could be used to develop more homozygous lines than are at present available and these could provide useful breeding material.

1.5 CENTRE OF ORIGIN

The occurrence of three species in China suggests very strongly that this area is the centre of origin of the genus. Migration eastwards to America and westwards to Europe would have resulted in distinct populations in these two areas and this conforms with the observations that the Y chromosomes in European hops are different from those in America. This conclusion is supported by Davis's observation of similarity in morphological characters between wild hops from America and Japan.

1.6 PHOTOPERIODIC RESPONSE

The very first reports of flowering in plants being controlled by daylength were in two classic papers by Tournois (1912, 1914) which described this phenomenon in *Humulus japonicus* and the closely related hemp *Cannabis sativa*. He demonstrated that flowering was induced when plants were raised in the winter or when plants growing in the summer were covered to reduce the period of exposure to light. Such plants would now be described as short-day plants. Jackson (1955), who experimented with *H. lupulus* in Kenya, reported that under natural conditions at that latitude the plants slowly died after making only a few inches of growth but that they grew successfully if the natural daylength was extended to 15 hours by using artificial light. He accordingly described the hop as a long-day plant.

Detailed determination of the photoperiodic responses of the cultivated hop was reported by Thomas and Schwabe (1969) who demonstrated that it is a true short-day plant responding to both length of day and light breaks in the dark period. However, if the daylength is too short the plant becomes dormant and fails to flower. A further controlling factor is that bines of less than a critical size, as measured by the number of nodes, are unable to initiate flowering, even in short days. Their results indicated that the Fuggle variety was ripe to flower when 23 nodes were visible while the corresponding node numbers for CC31 (a very early flowering variety) and New York hop (very late flowering) were 12 and 20 respectively. Under experimental conditions (in a glasshouse) the critical daylength for flowering was approximately 16.5 hours for Fuggle and 15.5 hours for New York hop. At lower temperatures the critical daylengths were longer.

In a later publication Thomas (1982a) introduced the term 'minimum' daylength as that below which the plant ceased vegetative growth and formed a dormant terminal bud while he retained 'critical' daylength to describe that daylength beyond which flowering would not be induced. Any daylength between these two would induce flowering but, if it was close to the minimum, initiation would be rapid with few flowers being produced. Increasing daylength resulted in slower initiation but more abundant flowering so maximum cone production was achieved with daylengths slightly shorter than the critical.

Thomas and Schwabe (1970) described how the diameter of the apical buds of plants in the field showed a marked decrease in diameter at about the time that they became ripe to flower. That this was not, however, a morphological indication of ripeness to flower was demonstrated by keeping other plants under long day conditions well past the ripe to flower stage and in these the reduction in diameter did not occur until they were transferred to short days. They concluded that the sudden change in diameter of the meristems indicated the commencement of flower initiation.

Bhat *et al.* (1978) reported that, in Kashmir, early trained hops had two flushes of flowers; one before the longest day and one after. This would be accounted for by the fact that at such latitudes the daylength when such plants became ripe to flower was short enough to initiate flowering but this was then suppressed by the lengthening days and was resumed as the days again became short enough. Under Kashmiri conditions, with the hops grown on high wirework, it would not be feasible to harvest the two crops as the bines would have to be taken down to do so. In China hops are grown on wirework only 2 m high (Chapter 3) and it has been reported that in the southern regions two crops are harvested in the year.

The importance of growing cultivars with daylength requirements suited to the locality was demonstrated in an international variety trial conducted by the

Scientific Commission of the International Hop Growers Convention (Neve, 1983). In this trial three cultivars with a common female parent that had been bred and selected in England, the Federal Republic of Germany or Yugoslavia, at latitudes of 51°, 48° and 46° N respectively, were all grown in those three countries and also in France at 47°.

All three cultivars flowered earliest at the lower latitudes, the difference between Yugoslavia and England being 10–14 days. These differences were reflected in the yield figures. The English and Yugoslav cultivars both showed a steady reduction in yield as the sites became more remote from their place of origin. The results for the German variety were more erratic but the yield was lowest when grown in England.

Hop varieties differ not only in the critical daylength for flowering but also in their minimum daylength requirement for vegetative growth. Neve (1961) described how some seedling plants, on reaching the four-leaf stage, turned dark green, ceased to elongate and developed a swollen hypocotyl. They remained in this condition for a variable length of time but eventually elongation recommenced as the daylength increased. It was also noted (but not published) that plants overwintered in the glasshouse sometimes assumed a similar appearance as a result of commencing growth earlier than they would have done outside and that the cultivar Saaz was especially liable to do so.

Thomas (1968) attributed stunted and slow growth of OT48 (Bramling Cross) in the field to warm conditions in early spring inducing the plants to emerge at a time when the daylength was less than the minimum required by this cultivar.

The flowering dates of male plants are much more variable from season to season than are those of females and Thomas (personal communication) has suggested that males might be daylength neutral. An experiment by Brooks (1963), however, suggests that their basic response to daylength is similar to females'. Early-, medium- and late-maturing males were trained on different dates and, whereas the period from training to flowering of the early clones was little affected by training date, the late clones did not flower until late in the season whenever they were trained. This can be explained on the basis that, whereas the early clones had a long critical daylength and could initiate flowers as soon as they were ripe to flower, the late clones had a short critical daylength so flowering could only occur late in the season when the daylength had shortened.

1.7 DORMANCY

At the end of the growing season hop plants and their seeds both enter a dormant phase which has to be broken before growth can recommence for the next season.

Williams and Weston (1958) reviewed the literature on conditions affecting the germination of hop seeds. Raum (1929), Smith (1939) and Holubinsky

(1941) had shown that some six weeks exposure of moist seed to low temperatures (ranging from -12°to 5° C) were required for good germination to be achieved. Bressman (1931) had increased germination by scarifying the seed but Keller (1953) failed to do so. Paine (1951) obtained rapid germination by chipping the hard testa. Keller and Paine failed to improve germination by chemical treatments. Williams and Weston's own experiments confirmed these findings although they showed that chemical treatment with concentrated sulphuric acid for 9 minutes gave a moderate increase in germination, apparently having a similar effect to scarification, but that it caused damage to the root tips. Other chemical treatments (gibberellic acid, malic acid, potassium nitrate, hydrogen sulphide, bis-cyclohexanoneoxalyldihydrazone, dimethylglyoxime and ethylenediamine tetracetic acid) were ineffective, while thiorea had only a very slight effect. The lack of activity may have been because the chemicals were unable to penetrate the seed coat.

Haunold and Zimmermann (1974) described their techniques for collecting pollen, making crosses and germinating the resulting seeds which included a period of 6–8 weeks under moist conditions in a refrigerator at 2–3° C prior to sowing.

Williams *et al.* (1961) reported that the dormancy of established plants involves two major stages. The first is the 'onset of dormancy' which is complete when the plant will not make new growth even when given good growing conditions. The second stage, the 'breaking of dormancy', involves the gradual removal of growth inhibition and is considered complete when the resting buds will break into new growth when climatic conditions permit.

The onset of dormancy is initiated by changes in the daylength and involves the death of the shoots and the finer root system, the transfer and accumulation of food reserves in the storage roots and the development of relatively large resting buds on the perennating shoot system below soil level.

Experimental plants grown in a warm glasshouse during the winter under artificially extended daylength continued vegetative elongation and developed large fibrous root systems containing little storage material. Plants under the same conditions but exposed to the naturally shortening days of autumn ceased all vegetative growth by early September. The leaves remained viable until late October or early November when the shoot system died completely to near soil level. During this period much storage material, mainly starch, accumulated in the roots which increased in thickness. The fibrous roots died and large dormant buds developed.

By exposing other groups of plants to different temperatures for varying periods before moving them to a growth room at 20° C, it was found that, even in a mild winter, exposure to outdoor temperatures for the whole of November and December was sufficient to break dormancy completely. Plants that had been exposed outdoors only until 2nd December remained dormant. One of the three plants moved to the growth room on 14th December and all three

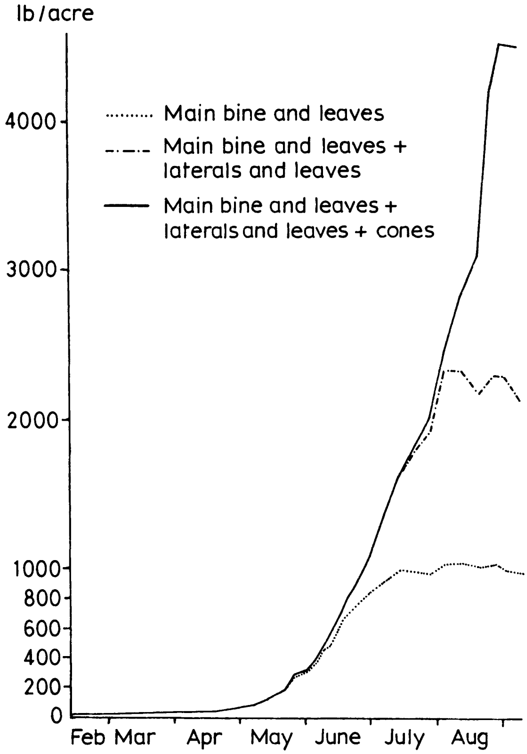


Figure 1.11 Dry matter accumulation of above ground portion of the hop plant lb/acre (Thomas, 1967).

moved on 20th December made some growth but this stopped when the shoots were between 20–40 cm long.

Other plants were placed in a refrigerator at 3°C at the end of October and samples removed at weekly intervals, potted up and placed in the growth room. For the first five weeks these plants made no growth but those moved on the sixth and subsequent weeks all grew strongly.

Hops grown in Kenya where there is no exposure to low temperatures have been found to break dormancy very erratically. Under artificially extended daylength some plants grew vigorously, others made only very limited growth, just like Williams' experimental plants that had insufficient cold treatment, while some made no growth at all (Neve, unpublished). Owino (personal communication) considered that exposure to drought conditions helped to break dormancy.

Thomas (1965) reported that dormancy could also be broken by treatment with gibberellic acid (growth occurring within 14 days of treatment) but that the shoots were often thin and spindly. Attempts by Owino to overcome the lack of low temperatures in Kenya by gibberellic acid treatment have been unsuccessful.

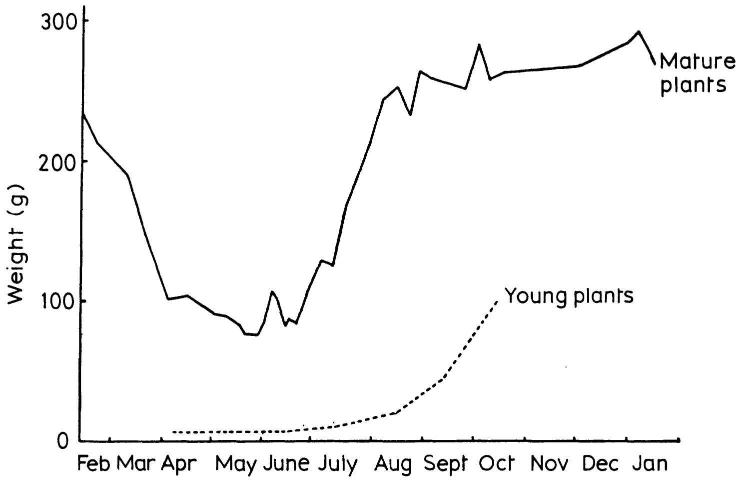


Figure 1.12 Dry weight of rootstock throughout the year (Thomas, 1967).

1.8 PHOTOSYNTHESIS AND CARBOHYDRATE RESERVES

Williams coupled his work on dormancy with studies on the changes in carbohydrate balance. He and his colleagues published their work on young plants (Williams and Weston, 1959; Williams, 1960; Williams *et al.*, 1961; Williams, 1962) while his subsequent work on mature plants was published after his death by Thomas (1967). The results for young and old plants of the cultivar Fuggle were similar in that the carbohydrate in the rootstocks fell from a high level at the end of the winter to a very low level in May. It then commenced to rise in June and July with a more rapid rise from August to mid-October. During the winter months much of the starch component was converted to soluble sugars.

These changes were first associated with the rapid growth in the spring when the plants produce long shoots with little leaf area and are dependent on the reserves in the rootstock. Once the leaves expand, carbohydrates are produced in excess of that required for growth and accumulate in the rootstock, most rapidly during the shortening days of August and September when extension growth has ceased. Although this pattern was the same for both young and old plants, the percentage of starch in old rootstocks during the winter period was considerably lower than young plants, presumably because of the greater accumulation of fibrous material in the mature plants.

Changes throughout the year in the dry weight of the above-ground portion of mature plants are illustrated in Figure 1.11, of the rootstock in Figure 1.12, while Figure 1.13 shows the total starch and soluble sugars contents of mature plants and the total starch of young plants (Thomas, 1967).

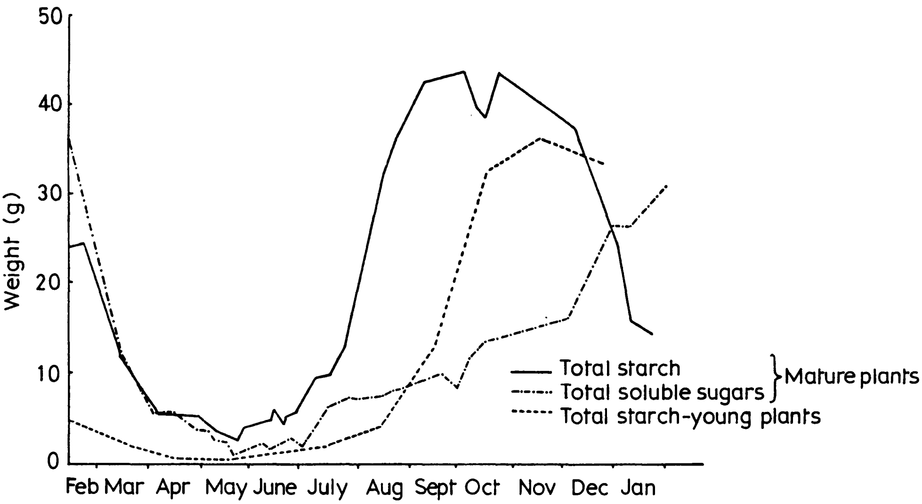


Figure 1.13 Total starch and soluble sugars in the rootstock throughout the year (Thomas, 1967).

From Figure 1.11 it can be seen that total dry matter has accumulated in three phases. Up to the end of June production consisted largely of the main bines and leaves with a total dry weight of about 125 kg/ha. During July growth consisted almost entirely of laterals and their leaves which contributed a further 125 kg to the total. Cones commenced to develop in the third week of July and by the end of August their dry matter amounted to some 250 kg so that they comprised approximately 50% of the total above-ground growth.

Peat and Thomas (1974) measured the carbon dioxide exchange of developing cones and found that, although older cones showed a clear response to light intensity indicating photosynthetic activity, this was negligible in young cones. Stomata in the young leaves of hops are covered by a continuous cuticular membrane which eventually ruptures to form the stomatal pore (Royle and Thomas, 1971b). Such a membrane would permit only very low levels of gaseous diffusion and it is probable that a similar development in the stomata of hop cones accounts for the sudden increase in photosynthetic activity as the bracts and bracteoles commence expanding rapidly. Although older cones were photosynthetically active, this rarely exceeded respiratory loss so made little contribution to their growth.

Kenny and Rohrbach (personal communication) found that leaves more than 75% expanded had maximum photosynthetic potential but that those shaded by the canopy achieved very low rates. They also found that different genotypes varied in their photosynthetic rates.

The carbohydrate reserves of the plant normally accumulate in the rootstock but a feature of hop bines is that any portion of them placed in the dark becomes a storage organ. If the base of a bine is earthed up, or laid along the ground and covered with soil it will accumulate food reserves, thickening up as it does so, while the buds also enlarge. Instead of dying at the end of the season, this swollen tissue becomes perennial and it can be planted the following season. This is the basis of some methods of propagation (Section 3.10). Even sections of the bine at a considerable height above ground can be enclosed in black paper and will behave in this fashion although sections of bine above and below will not be affected.

CHAPTER 2

The cultivated hop

2.1 HISTORY

An early record of the use of hops in brewing is to be found in the Finnish saga *The Kalevala* (Lönnrot, 1963) in which the Beer Lay begins as follows:

The origin of beer is barley, of the superior drink the hop plant,
though that is not produced without water or a good hot fire.
The hop, son of Remunen, was stuck in the ground when little,
was plowed into the ground like a serpent, was thrown away like a stinging nettle
to the side of a Kaleva spring, to the edge of an Osmo field.
Then the young seedling came up, a slender green shoot came up;
it went up into a little tree, climbed to the crown.
The father of good fortune sowed barley at the end of the newly cultivated Osmo field;
the barley grew beautifully, rose up finely
at the end of the newly cultivated Osmo field, on the clearing of a Kaleva descendant.
A little time passed. Now the hop vine cried out from the tree,
the barley spoke from the end of the field, the water from the Kaleva spring:
'When will we be joined together, when to one another?
Life alone is dreary; it is nicer with two or three.'
An Osmo descendant, a brewer of beer, a maiden, maker of table beers,
took some grains of barley, six grains of barley,
seven hop pods, eight dippers of water;
then she put a pot on the fire, brought the liquor to the boil. . .'.

This saga, although it is reputed to go back some 3000 years, was not written down until the 19th century and as it was handed down orally, could have been subjected to considerable alteration or addition. It is, therefore, impossible to judge how old this reference to hops really is.

The earliest written evidence of hop cultivation appears to be that concerning the hop garden of a Wendish prisoner near Geisenfeld in the Hallertau district of Germany, in 736 AD (Linke and Rebl, 1950). The Wends were Slavs and it is thought that the Slav word for hops, 'hmelj', may have a Finnish origin hence the reference in the Kalevala may genuinely indicate that their use originated there. There is further documentary evidence from the 9th–12th centuries for hop cultivation in Bohemia, Slovenia and Bavaria so there seems to be little doubt that this area was the centre from which the practice spread to the rest of Europe and eventually to the rest of the world. Fric (1985) states that 'In a list of goods exported from Bohemia as compiled in the year 1101 we can find also hops. They used to be shipped to Hamburg where they were appraised on the famous *Forum humuli* by specially trained experts'. Fric also states that hop growing declined in Czech countries during the Thirty Years' War and that hop cuttings were used for planting expanding areas in Brandenburg, Silesia, Bavaria, Styria, Baden, Russia and elsewhere. With major concentrations of production in Bavaria and Bohemian Czechoslovakia today it is still one of the most important hop growing regions.

A detailed account of hop growing in Eastern Europe, including its historical background, is given by Strausz (1969). In the Ukraine, Russia, there is an old tradition of hop usage for brewing which may even predate that of Bohemia. Ivan the Terrible passed laws that favoured vodka production over beer – in contrast to the current policy there – and brewing did not develop commercially until the 19th century when both brewing and hop production were, to a large extent, in German hands. Although originally local hop varieties had been grown, these were unpopular with the German brewers and so better quality but lower yielding foreign cultivars were grown almost exclusively.

In Poland there are very early records of hop growing which expanded considerably in the 18th century. In Yugoslavia, too, there are definite references to hops being cultivated from about 1160 but again it did not expand into a significant commercial operation until after 1870.

From central Europe hop growing spread westwards to Flanders during the 14th century where their cultivation was associated with a local specialization in hopped beer as opposed to unhopped ale.

Hops were not cultivated on a commercial scale in England until about 1524 when Flemish planters were brought over to introduce their cultural techniques. This was at a time when the enclosure of common lands was making it more feasible to grow such a crop (Burgess, 1964), but there is some evidence that they were grown on a small scale earlier than that. Baker (1976) believes that hops were grown before the Norman conquest (1066) and refers to Anglo Saxon deeds from Himbleton 'Hymel-tun' in Worcestershire which indicates a hop yard. He also quotes Harrison (1577) as evidence that the 16th century plantings were a revival of hop growing that had lapsed. 'Hops in the past were plentiful in this land: afterwards also their maintenance did cease: and now being revived, where are anie better to be found'.

A so-far unexplained discovery is that of the Graveney boat in England. Graveney is on the north Kent coast and drainage work there in 1970 uncovered the remains of a boat that has been carbon-dated to about 950 AD. The abundant hop remains associated with this boat indicate that these must have been the cargo that it was carrying. There is little evidence that hops were in general use in England at this time although Wilson (1975) refers to documents in Canterbury Cathedral suggesting that they were in use in Kent in the 11th century while Parker (1934) quotes another 11th century document from Westminster Abbey that refers to *hopis de brassio*. Baker (1976) quotes from the Anglo Saxon Herbarium of Apuleius that from the hop 'hymele' was produced a 'wort' which was 'that laudable that men mix it with their usual drinks'. It is possible, therefore, that the hop cargo in the Graveney boat was destined for this country but an alternative explanation could be that the boat was heading for a continental destination and was blown off-course.

Several authors have questioned whether the hop is indigenous to Britain but the discovery of hop fruits in an archaeological dig at Shippea Hill in Cambridgeshire, dated to some 3000 BC (Clarke and Godwin, 1962) and pollen residues from other sites show conclusively that it is a native species.

From Europe the cultivated hop was introduced into North America by the Massachusetts Company in 1629 and was grown for domestic use in New Netherlands and Virginia in the mid-17th century. It did not become an important field crop until the early 19th century, the first commercial hop yard being established in New York in about 1808 (Burgess, 1964). Production was centred in New England until problems with disease led to the industry moving to the west coast where the drier conditions were more favourable.

Settlers were also responsible for the introduction of hops into newly developed countries such as South Africa, Australia and New Zealand. A detailed account of their introduction to Australia is given by Pearce (1976). The early governors of New South Wales were most anxious that a brewing industry should be developed because they felt that beer would be a better and more wholesome drink than the rum which the workforce of convicts seemed to need to enable them to complete even the simplest of tasks. The first attempt to transport hop plants from England, organized by Sir Joseph Banks, was made in 1799 but they failed to survive the voyage because they were 'so constantly exposed, from the smallness of the ship, to the washing of the sea, and other circumstances that tended so much to their hurt'. It appears that the first plants to be grown in Australia were raised from seed in New South Wales in 1803 and 1804 while the first positive record of vegetative material arriving from England is that brought by William Shoobridge, 'an experienced hop cultivator' who left Maidstone in Kent to settle in Tasmania in 1822. There may have been earlier introductions as a result of urgent requests for material, but there are no records of any having arrived.

The variety of hops brought by Shoobridge is not mentioned but there are accounts of subsequent introductions of Canterbury Goldings and Early White Grapes and of 'new kinds of hops'. An intriguing question about such introductions is whether male plants would have been included with them, either deliberately or accidentally. There are plenty of male plants in Australia but these could all have been derived from seedling material and not introduced as imported plants or cuttings.

Although the first attempts at hop growing were made in New South Wales these were never very successful, possibly because of the daylength at latitude 34° S; it was in Tasmania that production was first really successful, to be followed rather later by Victoria.

The growing popularity of beer worldwide led to the further extension of hop cultivation. In Japan hops were introduced to Hokkaido in the 1880s and regular cultivation was begun at Nagano during the 1914–18 war when imports were stopped (Ono, 1959). Hops are said to have been first introduced into China from Japan in 1921 (Zheng and Pen, 1987) although Simmonds (1877) refers to a shipment of 133lb from Chefoo in 1874. However, Neve (unpublished) was once sent a sample of Chinese 'hops' that consisted of seed of an unidentified plant so it is possible there was a similar confusion over nomenclature in Simmonds' reference also. Chinese hop production was on a very small scale until 1949 when the industry spread into Xinjiang, Gansu, Neimeng, Beijing, Shanghai, Jiangxi and Zhejiang. The enterprise was abandoned in the last three areas because low yields resulted from heavy damage by moulds and downy mildew. Since these areas lie between latitudes 27° and 31° it is likely that short daylength was also a major factor.

Problems with availability of foreign currency to buy hops from the traditional producing countries have led to attempts being made, with varying success, to extend production to other areas. In India, a large number of hop cuttings were taken to Kashmir in the 1880s but although the first reports of the experiment were encouraging (Simmonds, 1877) for some reason the crop did not become established there at that time. More recent efforts have been much more successful and India is now largely self-sufficient.

The areas where hops can be successfully grown are limited by the photoperiodic requirements of the plants as described in Chapter 1. The lowest latitudes at which they are produced commercially at present are approximately 34° S in Cape Province, South Africa and 34° N in Kashmir, India. However, even here there are problems because the daylength is too short for optimum yields and in South Africa electric lights are being used commercially to extend the daylength artificially while in Kashmir training has to be delayed to ensure that growth takes place during the period of longer daylength.

In Mexico there are reports of success in breeding varieties that are adapted to latitudes as low as 25° N. These have been described as daylength neutral but since good yields depend upon the inhibition of flowering while the plants make sufficient vegetative growth to bear the crop it is more likely that these plants merely have a shorter critical daylength.

There is interest in hop production at even lower latitudes and it is known that trials are under way in Colombia, Kenya, Zimbabwe and Burma. Earlier attempts at such latitudes have failed and it is now known that this is largely due to the photoperiodic requirements of the plant. These are now being met by using artificial light to extend the natural daylength. There is, however, a further problem as most of these areas lack a sufficiently cold dormant season for normal vernalization to occur and it is difficult to simulate this artificially.

2.2 USE

Although hops are today used almost exclusively for brewing, they were first taken into cultivation for their herbal and medicinal properties. Gerarde (1636), in his Herball says that:

> The buds or first sprouts which come forth in the Spring are used to be eaten in sallads; yet are they, as Pliny saith, more toothsome than nourishing, for they yeeld but very small nourishment.
> The floures make bread light, and the lumpe to be sooner and easilier leavened, if the meale be tempered with liquor wherein they have been boiled.
> The manifold vertues of Hops do manifest argue the wholesomenesse of beere above ale; for the hops make it a physicall drinke to keepe the body in health, than an ordinary drinke for the quenching of our thirst.

The original distinction between unhopped ale and hopped beer should be noted; a distinction that has disappeared since no unhopped ales are now produced.

Culpeper (1653) referred to many virtues:

> It is under the dominion of Mars. This, in physical operations, is to open obstructions of the liver and spleen, to cleanse the blood, to loosen the belly, to cleanse the reins from gravel, and provoke urine. . . . In cleansing the blood they help to cure the French diseases, and all manner of scabs, itch and other breakings-out of the body; as also all tetters, ringworms and spreading sores, the morphew and all discolouring of the skin. The decoction of the flowers and hops, do help to expel poison that any one hath drank. Half a dram of the seed in powder taken in drink, kills worms in the body, brings down women's courses, and expels urine. A syrup made of the juice and sugar, cures the yellow jaundice, eases the head-ache that comes of heat, and tempers the heat of the liver and stomach, and is profitably given in long and hot agues that rise in choler and blood . . . By all these testimonies beer appears to be better than ale.

In Germany, von Mähren (1701) wrote as follows (quoted by Gross, 1900):

> The principal use of hops is for making beer, in which it acts as a saline or aromatic; if, however, too much is used, the beer is too bitter and affects the head. Young hop shoots taken with the food purify the blood, heal the itch, and relieve the liver and spleen. Distilled hop extract cleanses the blood from all impurities, tumours and flatulence, and cures skin diseases and other complaints if taken in regular morning doses of 4 to 5 lothe [the loth = ½oz.].

A somewhat more recent American writer (Mrs Longshore-Potts, 1887) says that, following childbirth, 'If 'after pains' become an annoyance, the application of hot flannel, or steamed hops over the abdomen will be found beneficial, or a draught of warm hop tea.'

Other parts of the plant have been used in various ways. The bines contain fibres similar to those of its close relative hemp and these have been used to make cloth, sacking or paper while an extract of the leaves or bines was used to 'dye woollens a fine cinnamon brown'. The bines and leaves have also been used for 'tanning light skins instead of oak bark' (Lance, 1838). The possibility of using hops as a rather uninteresting, but very permanent, dye will not surprise anyone who has had their clothes disfigured by contact with hop sap!

Gerarde's uses for hops have slightly more relevance to the present day than do Culpeper's since hop shoots are still eaten and hop cones are used in some countries for bread making. In England it is suggested that the young green shoots can be eaten rather like asparagus but it is not a common dish. In Belgium, however, the blanched underground shoots are regarded as a delicacy, and there has been a recent report of a technique for growing hop plants specifically to produce such shoots over a much longer period of the year (Maton, 1986).

The recipes that are to be found for using hops in bread making do not indicate the role that they play but it is probable that they help to keep the yeast cultures free from contamination. Davis (1956) suggests that their use in bread making may have preceded their use in brewing.

Howard (1964) states that 'They were apparently not introduced into England until about AD 1400, and the flavour they gave was sufficiently unpopular to delay complete acceptance until as late as the nineteenth century. Originally they were used by the brewer not because their flavour was liked but because they protected his product against bacterial spoilage'. Reynolde Scot (1576), however, held a different view about their flavour for he says:

> For if your Ale may endure fortnight, your beere through the benefite of the Hoppe shall continue a Moneth, and what grace it yieldeth to the taste, all men maye judge that have sense in their mouths, and if the controversie be betwixt Beere and Ale, which of them two shall have ye place of preheminence: it sufficeth for the glorie and commendation of the Beere, that here in our owne countrie, Ale giveth place unto it, and that most part of our Countrymen doe abhore and abandon Ale, as a lothsome drincke . . . .

There had long been a liking for beers containing bittering or flavouring substances as indicated by de Candolle (1884):

> In the Middle Ages . . . the Kelts, the Germans, other people of the north and even of the south who had the vine, made beer either of barley or of other fermented grain adding in certain cases different vegetable substances – the bark of oak or of the tamarisk, for instance, or the fruits of *Myrica gale*.

The substitution of hops for the various mixtures of herbs (sometimes called gruit) would have provided the preservative action which the other substances lacked although it is said that *Myrica gale* is still used on some farms in Scandinavia. It contains resins similar to those of the hop, but with methyl groups instead of isoprenyl groups, and having some preservative value (Malterud and Faegri, 1982).

One minor, present-day herbal use for hops is in hop pillows, in which they are included for their reputed soporific effect.

Whatever their original purpose, modern brewing techniques rely so heavily upon hygiene and pasteurization to produce a sterile product that the preservative function of the hops is now of little importance and they are used for the bitter taste and hop flavour that they impart. These are derived from the resins and essential oils that are produced in the lupulin glands of the hop cone. The chemistry of these compounds has been recently summarized (Hough *et al.*, 1982).

The traditional method of assessing the quality of hop samples is to examine them for visual defects, to rub them in the hands when the degree of stickiness gives a rough estimate of the amount of resin, and to smell them to evaluate their aroma. There are many brewers and members of the hop trade who are very skilled in this but the value of such organoleptic assessment is probably limited. The essential oil components that predominate in a sample rubbed in the hand will be the most volatile ones and it is these that are most rapidly lost when hops are added to boiling wort, and even the fraction that is not lost is likely to undergo chemical change.

Accumulated experience doubtless makes it possible to examine a sample of an established cultivar and determine the intensity of aroma and whether there are any abnormalities. Such a hop will only have become an established variety if it has been found in practice to produce good beers. For the reasons given above, however, it must be doubted whether it is reliable to predict the suitability of new varieties for brewing simply by smelling them. Trials have shown, in fact, that experimental hops with quite unpleasant aromas have made very satisfactory beers. In spite of the limitations of the technique, simply smelling the cones has the advantage for the hop breeder in that it is a very rapid way of assessing the large numbers of seedling varieties from which to select. It is unlikely that brewers would be interested in using a variety that had an unusual aroma even if it did prove satisfactory in brewing trials, so it is logical to discard them at an early stage on that basis.

Gas chromatographic analysis provides a less subjective method of examining the composition of the essential oils and it will give similar results for samples of the same cultivar even when these have been grown under widely different conditions. Figure 2.1 shows gas chromatograms of three different cultivars and it is apparent that there are major differences between them. There is some variation between samples of the same variety depending upon the stage of ripeness at which the hops were picked, particularly in the height of the myrcene peak as this is synthesized most rapidly as the crop nears maturity. Nevertheless, by comparing the ratios of the other major peaks it is generally possible to identify the cultivar from which the oil sample was obtained (Green, 1986).

Traditionally hops are boiled with wort for 1½–2 hours during which

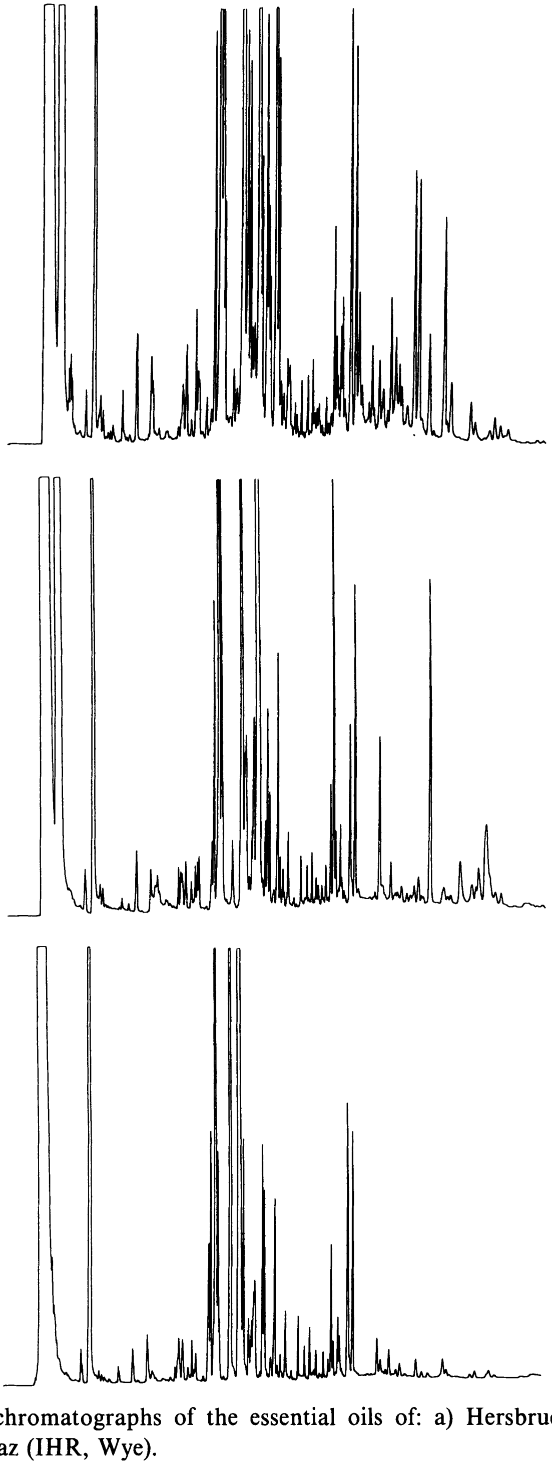


Figure 2.1 Gas chromatographs of the essential oils of: a) Hersbruck; b) Pride of Ringwood; c) Saaz (IHR, Wye).

time some of the resins go into solution to provide the bittering principles of beer but the bulk of the essential oil constituents are evaporated. To overcome this loss of essential oil flavour some brewers reserve a portion of choice 'aroma' hops and add them late in the boil, 15–20 minutes before copper casting. British brewers may add 'dry' hops to unconditioned beer, either in cask or tank, to introduce more essential oil components into the beer. The flavours introduced by 'late' hops or by 'dry' hops can be distinguished and either can be reproduced by using appropriate fractions of the essential oil. Hops added at the start of the boil, rich in resin but with a poorer 'aroma', are sometime referred to as 'alpha' or 'bitter' hops, but there is no clear distinction between these and 'aroma' hops.

2.2.1 Hop resins

The hop resins are peculiar to the hop and have not been found in any other plant species. The lupulin glands consist largely of a mixture of soft and hard resins. From the brewing point of view it is the soft resins, soluble in hexane, that are important. These consist of the α-acids, β-acids and the so-called uncharacterized soft resins. It is the α-acids that are the precursors of the bitter principles of beer, the iso-α-acids. The α-acids are a mixture of analogues, humulone (*1a*), cohumulone (*1b*) and adhumulone (*1c*) which differ only in the nature of the acyl side chain R. The β-acids are a similar mixture of analogues, lupulone (*2a*), colupulone (*2b*) and adlupulone (*2c*), as are the deoxyhumulones (*3*), the probable biological precursors of the α- and β-acids. Both the α- and β-acids can exhibit tautomerism and exist as a mixture of readily interconvertible structures. Those given are thought to represent the principal tautomers.

Neither the α-acids nor the β-acids are very soluble in water. At 25°C the solubility of humulone is 6 mg/l and lupulone 1.5 mg/l. They are more soluble at the boiling point but any extra that is dissolved will precipitate out on cooling. However, during wort boiling, the α-acids are isomerized into the iso-α-acids which are much more soluble. The β-acids, being much less soluble, are largely unchanged during wort boiling. The iso-α-acids now have two chiral centres and so exist as a mixture of *cis-(4)* and *trans-(5)* isomers. The bittering principles of beer thus consist of at least six compounds: *cis-* and *trans-*isohumulone, *cis-* and *trans-*isocohumulone and *cis-* and *trans-*isoadhumulone. The overall level in beer is 20–50 mg/l. *Cis-* and *trans-*isohumulone have similar bitterness and it is thought that the other analogues have similar intensity. Further hydrolysis of the iso-α-acids gives *trans-*humulinic acids (*6*), which lack bitterness, but this transformation occurs to a negligible extent in the brewers' copper. The proportion of cohumulone in the α-acids can vary from about 20%–50%. At one time it was thought that cohumulone was better utilized (converted into isocohumulone) than the other α-acids and that a high

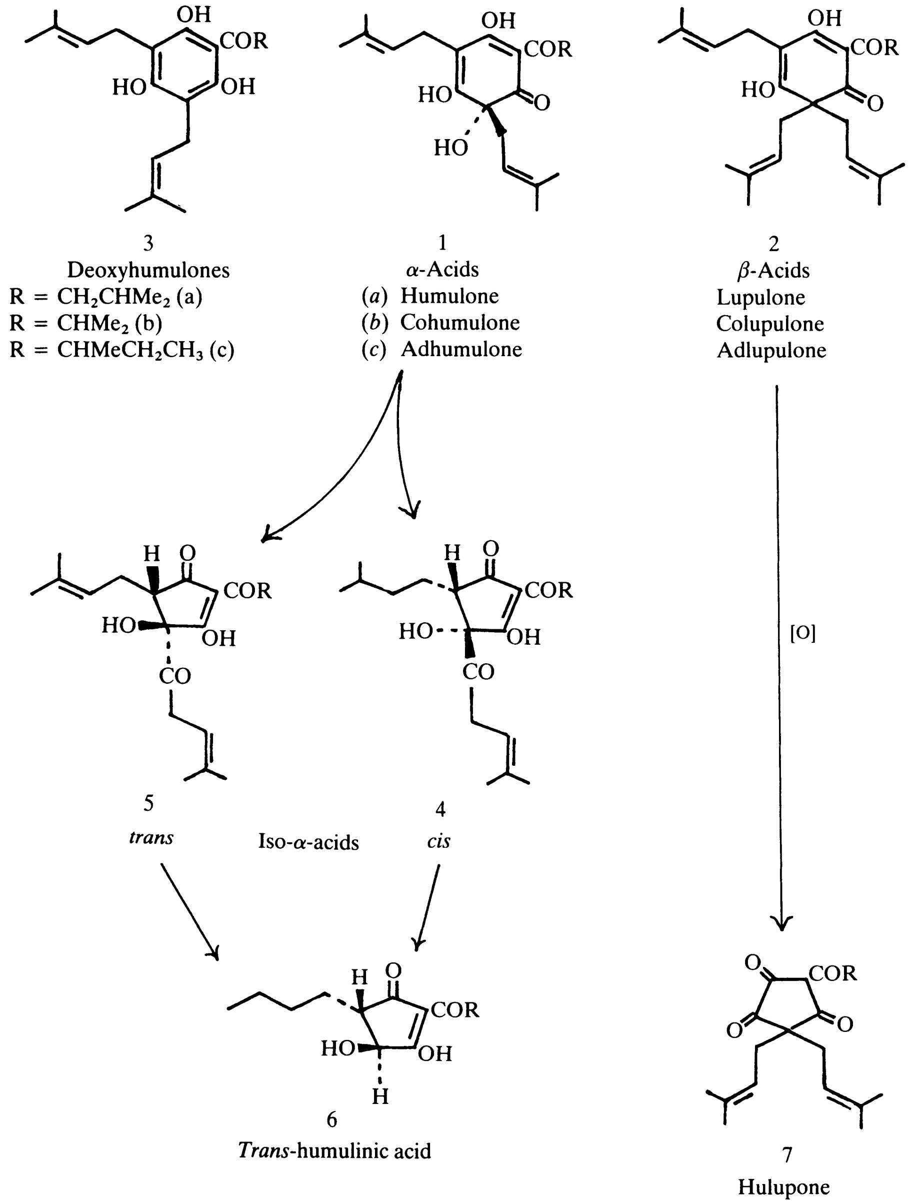


Figure 2.2 Hop resins and their transformation products.

proportion of it was, therefore, desirable. This was subsequently questioned and it was later claimed that cohumulone produced less acceptable beers than the other analogues (Rigby, 1972) but this is not everywhere accepted (Laws *et al.,* 1976).

The ability of hops to give a bitter taste to the beer is their principal function and many hops are bought solely for this purpose. Their α-acid content is then of prime importance and this can vary from as low as 3% in traditional cultivars to as much as 14% in the newer sorts now in production while even higher levels are to be expected from breeding programmes now under way. It is now common practice for the contract price for such 'bitter' hops to be based on the weight of α-acid they contain rather than the weight of the hops themselves. Accurate analysis of the α-acid content is, therefore, commercially important. Since different methods of analysis frequently give different results it is important that the method used should be specified.

Three properties of the α-acids are commonly used for their estimation: (a) lead salt formation; (b) ultraviolet light absorption; and (c) optical rotation. The β-acids do not form insoluble lead salts, do not rotate polarized light and absorb ultraviolet light at different wavelengths from the α-acids. When a 4% solution of lead acetate in methanol is added to a methanolic solution containing α-acids, a yellow salt is precipitated. Originally this was weighed but now it is more usual to follow the electrical conductance of the solution during the titration as this changes dramatically when excess reagent is present. Since uncharacterized resins and oxidation products may react with the lead acetate, the result of the analysis is usually termed the lead conductance value although with fresh hops the result is very close to the percentage α-acids. This is the most common method for the estimation of the α-acids in Europe and is recommended by the European Brewery Convention (EBC) as the basis for commercial transactions.

In the USA however, the measurement of ultraviolet light absorption is the method of choice. Most hop resins absorb ultraviolet light at a characteristic wavelength which also depends on whether the solution is acidic or basic. In the method recommended by the American Society of Brewing Chemists (ASBC), measurements are made in alkaline solution at 325 nm (λ_{max} for the α-acids), 355 nm (λ_{max} for the β-acids) and 275 nm (λ_{min} for both α- and β-acids – background reading) and regression equations applied to calculate the percentage of both α- and β-acids. This is the only simple method to give a value for the percentage of β-acids. The regression equations assume that the hop resins are a mixture of pure α- and β-acids with a constant background. This assumption may be fairly true for fresh hops but does not apply when they are old. From the results of this analysis, Likens *et al.* (1970) proposed that the ratio of optical density at 275 nm to that at 325 nm should be used as a hop storage index (HSI). The ratio increased from 0.24 in fresh hops to 2.5 in completely oxidized lupulin. Over several seasons the regression equation

$$\%(\alpha + \beta) \text{ lost} = 110 \log(\text{HSI}/0.25)$$

was arrived at and used to compare the storage characteristics of many commercial cultivars.

Ultraviolet light absorption is the only easy method for estimating the iso-α-acids in beer. In the internationally agreed method, degassed, acidified beer (10.0 ml) is extracted with iso-octane (2,2,4-trimethylpentane) (20.0 ml) and, after centrifugation, the absorbance of the iso-octane layer is read at 275 nm in a 1 cm cell against a blank of pure iso-octane. The result is expressed in Bitterness Units (BU) (= 50 × absorbance). In beers brewed with fresh hops the bitterness units are almost equivalent to mg/l iso-α-acids. This analysis would be interfered with by unisomerized α- and β-acids but these are not normally present in beer.

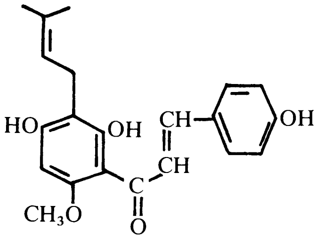
The optical rotation method depends upon the fact that α-acids rotate the plane of polarized light and can thus be measured by polarimetry. The difficulty is to prepare a solution of hop resins that is sufficiently transparent to enable a reading to be taken. The chlorophyll and degradation products must be removed without removing any α-acid but suitable grades of charcoal are usually satisfactory. A more serious disadvantage is that on storage, or in the preparation of hop extracts, the α-acids may racemize and not be detected by this method although racemic α-acids are still capable of bittering beer.

More detailed analyses are now obtained by high pressure liquid chromatography (HPLC). Individual analogues can be separated, though with varying degrees of precision. It is more difficult, for example, to resolve humulone from adhumulone than to resolve these isomers from cohumulone. In the method recommended by the Institute of Brewing (1988) four peaks are resolved: cohumulone, humulone + adhumulone, colupulone and lupulone + adlupulone.

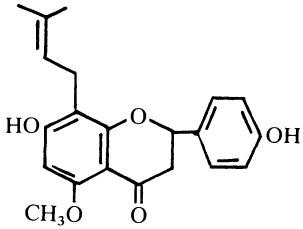
Hops undergo oxidation and degradation during storage, some cultivars more rapidly than others. Since they are only harvested at one season of the year, part of each crop needs to be stored for at least 18 months before use unless supplies are imported from the other hemisphere. To minimize deterioration many brewers either keep their hops in cold store or have them processed into pellets or extract.

As a result of oxidation the amount of soft resins decrease while the hard resins (insoluble in hexane but soluble in ether) increase. It is possible that even more bitter products that are insoluble in ether but soluble in water are formed but these would be more difficult to detect. Compounds present in the hard resin of fresh hops include xanthohumol (*8*), iso-xanthohumol (*9*) and the flavone (*10*) but these have no known brewing value.

Oxidative cleavage of the acyl side-chains of the α- and β-acids is manifest in the 'cheesy' aroma, in old hops, of the isobutyric, isovaleric and 2-methylbutanic acids. No oxidation products of the α-acids have been characterized as bittering agents in beer but oxidation of the β-acids gives hulupones that are bitter. When hops are boiled in the copper using traditional brewing methods, the loss of bitterness of the α-fraction during storage is partly compensated by the gain from the β-fraction. The utilization of the β-acids is probably most significant when hops are boiled with the wort more than once, as in stout



8
Xanthohumol



9
Iso-xanthohumol

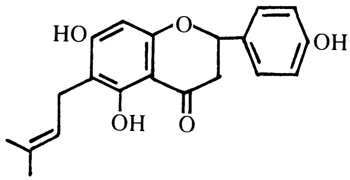


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Figure 2.3 Constituents of the hard resins of hops.

brewing. In the first boil the molten β-acids spread over the surface of the hop cones as a thin layer and are readily oxidized during the air rest between boils. Procedures have been described for utilizing the β-acids by these routes with improved yields in commercial trials (Moir, 1988) but they are not yet widely used.

Whereas newer cultivars have much higher α-acid contents than older sorts, there has not been a corresponding increase in the β-acids. Whether this is simply because there has been no selection for the β-acids or whether there is competition between α and β for a common precursor as suggested by Likens *et al.* (1978) is not clear.

Because of the high proportion of β-acids: α-acids in the old cultivars the changes in storage did not greatly reduce the bittering power of the hops when used in the copper, but with the modern, bitter varieties the proportion of β-acids: α-acids is much lower and so the losses of bittering power are greater. Storage stability has, consequently, become a much more important criterion for hop breeders when making their selections. It is even more important if the hops are to be used for extraction when, at present, only the α-acid is required. Cultivars that store well can be processed economically over a longer period after harvest thereby enabling the capital cost of the processing equipment to be better utilized.

It was reported by Warmke and Davidson (1944) that hop scions grafted onto *Cannabis* stocks produced cannabinoid resins and this led to interest in the technique as a means of producing such material while avoiding legal restrictions (Drake, 1970). An observation that soil applications of carbamate insecticides appeared to reduce α-acid levels in treated hop plants also suggested that rootstocks might have an influence on resin production. However, trials by Crombie and Crombie (1975) involving *Humulus*/*Cannabis* grafts failed to show any change in the type of resins produced as a result of such unions, while Neve (1973) made grafts between hop cultivars with high and low α-acid contents and these too showed no influence of the stock on the resin production of the scions.

2.2.2 Essential oils

The other important hop product is the essential oil which is also produced in the lupulin glands and normally represents about 0.5–1.5% of the weight of the dried cones. Some cultivars contain more than others while seedless hops have a considerably higher content than seeded cones of the same cultivar and contents as high as 3–4% have been reported in some situations.

Whereas the hop resins give beer its bitterness, the essential oil gives it aroma and flavour. Although the chemistry and value of the resins are well understood, there is still much to be learned about the essential oil which is a complex mixture of 200 or more components. These components can be separated by gas chromatography and many of them have been identified but this has by no means provided a complete understanding of their use in the brewery.

By definition the essential oil is volatile in steam and is estimated by steam distillation, the oil being retained in a trap while the condensed aqueous phase returns to the boiler; a process known as cohobation. In the Institute of Brewing method, steam distillation is carried out for three hours. Commercial hop oil, prepared by this process, has been available for many years and used by some brewers to impart a hop flavour to finished beers, but most brewers can distinguish between beers that have been late hopped, dry hopped or those treated with such hop oil. Some changes occur during cohobation and hop oil preparations obtained by steam distillation under high vacuum at low temperatures, or by liquid carbon dioxide extraction, give flavours more akin to those obtained by dry hopping. Liquid CO_2 extracts can be fractionated to provide preparations that give mainly late hop flavour (floral and citrus) or dry hop flavour (resinous, spicy and citrus) to beers.

It appears that hop flavours are due to synergistic mixtures of compounds rather than single impact compounds. The essential oils can be divided into three classes of compounds: (a) hydrocarbons; (b) oxygenated derivatives; and (c) compounds containing sulphur. In most cultivars the hydrocarbons predominate but they are the most volatile and few survive wort boiling, even with late addition, but they will be slightly more soluble in the dilute alcoholic solution of beer and traces will dissolve during dry hopping.

The main hydrocarbons in the essential oil are the monoterpene (C_{10}) myrcene (*12*) and the sesquiterpenes (C_{15}) caryophyllene (*24*) and humulene (*23*). Other sesquiterpenes, such as farnesene (*22*) and *β*-selinene (*26*) are found in some cultivars but not in others. The ratios of humulene:caryophyllene and humulene:selinene appear to be characteristic of cultivars and are useful for their identification (Green, 1986). The essential oil of the 'aroma' hop, Hersbrucker, contains several sesquiterpenes not found in other cultivars (Tressl *et al.,* 1983).

Current biogenetic theory suggests that the terpene hydrocarbons are formed from oxygenated intermediates and in the ripening hop oxygenated compounds are found before the hydrocarbons. Of the hydrocarbons, the cyclic sesquiterpenes are found before farnesene and myrcene. As the hop ripens the synthesis of myrcene appears to be the dominant pathway. Myrcene and other monoterpenoids are thought to be formed from geranyl pyrophosphate (*11*). Many of these intermediates are now thought to contribute to the hoppy flavour of beers. Figure 2.4 shows the relationships of some of these compounds, the flavour they produce and their concentrations in beers (Sharpe, 1988). Another compound in hop oil giving a floral flavour to beer is undecan-2-one (15 ppb). This compound is not terpenoid in nature and presumably is formed as a by-product of fatty acid biosynthesis. Smaller amounts of related methyl ketones such as tridecan-2-one also occur in hop oil.

The sesquiterpenes are formed in a similar manner to the monoterpenes from farnesyl pyrophosphates (*20*) but cyclization of the farnesyl cation can lead to many cyclic structures such as the monocyclic humulene (*23*), the bicyclic caryophyllene (*24*) and the tricyclic aromadendrene (*25*) found in Hersbrucker hops (Figure 2.5).

Oxygenated compounds can also be formed from hydrocarbons during storage (Figure 2.6). Oxygen can add to carbon–carbon double bonds to form cyclic epoxides. The epoxides of caryophyllene (*24*) and humulene (*23*) have been detected in hop oil and beer. Humulene can form three monoepoxides (*28–30*) and each of these, and diepoxides, have been found. Reductive ring scission of the epoxides gives rise to alcohols such as humulol (*31*) and humulenols I (*32*) and II (*33*) found in oil and beer. It is possible that epoxides and ketones in wort could be reduced to alcohols during fermentation. Similar transformations to those given in Figure 2.5 occur with other sesquiterpenes but, although many of the oxygenated products have been detected in hop oil and beer, it is not known, with the possible exception of humulenol (see below), what flavours they contribute to beer.

By fractionation of a liquid carbon dioxide extract of hop oil, two fractions were obtained, one rich in ketones such as undecan-2-one and the other rich in alcohols, especially linalol and humulenol. Both imparted late hop characteristics to beer. The ketone-rich fraction was the more floral but also contributed some spicy/mouthfeel and astringent characteristics. The alcohol-rich fraction

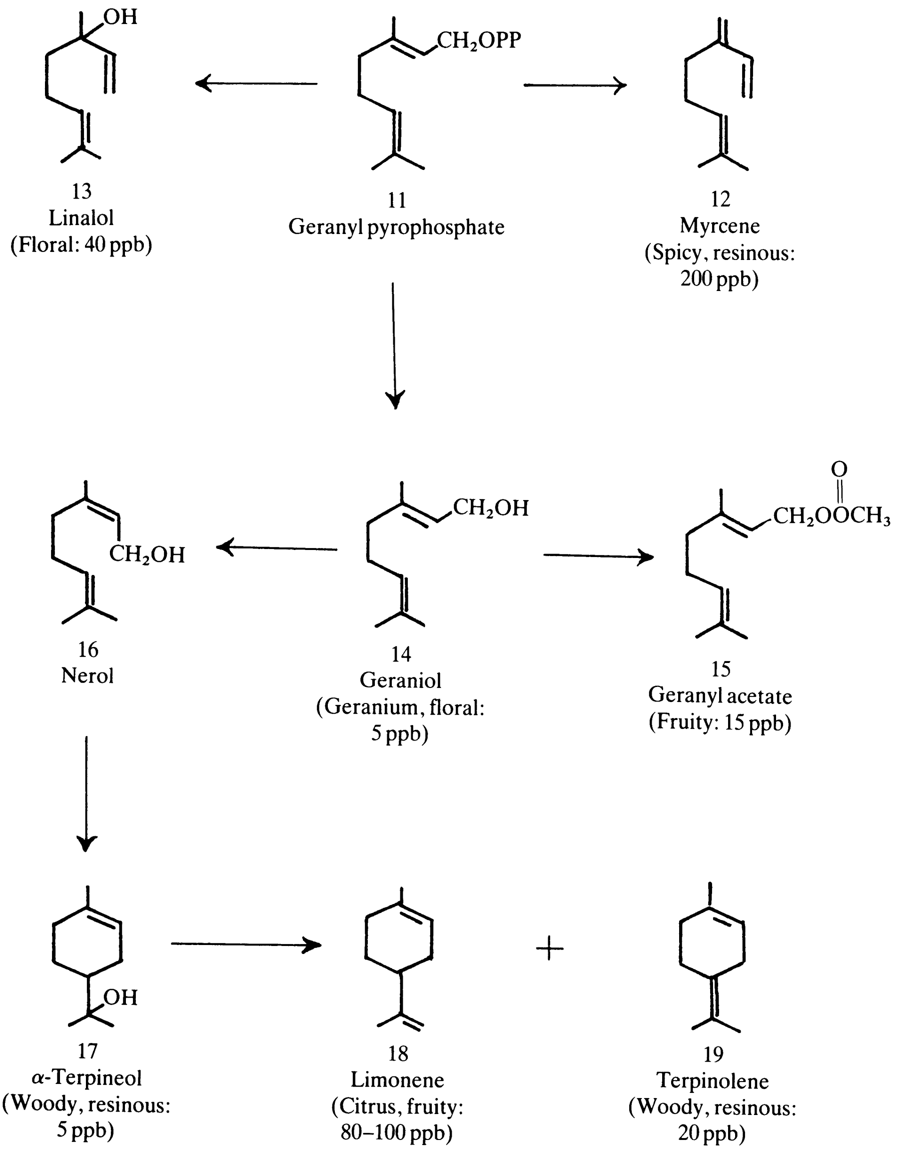


Figure 2.4 Monoterpenoids in hop oil and beer (after Sharpe, 1988).

was less floral but exhibited more of the spicy/mouthfeel and astringent characteristics. Both fractions produced a similar degree of grapefruit character in the beers and contributed to the body (Murray *et al.,* 1987).

The essential oil of hops contains only trace amounts of sulphur compounds but since these have potent aromas they may influence the overall flavour of the essential oil and beer. Hops in the field may be treated with elemental sulphur to control mildew and it used to be a common practice to burn sulphur

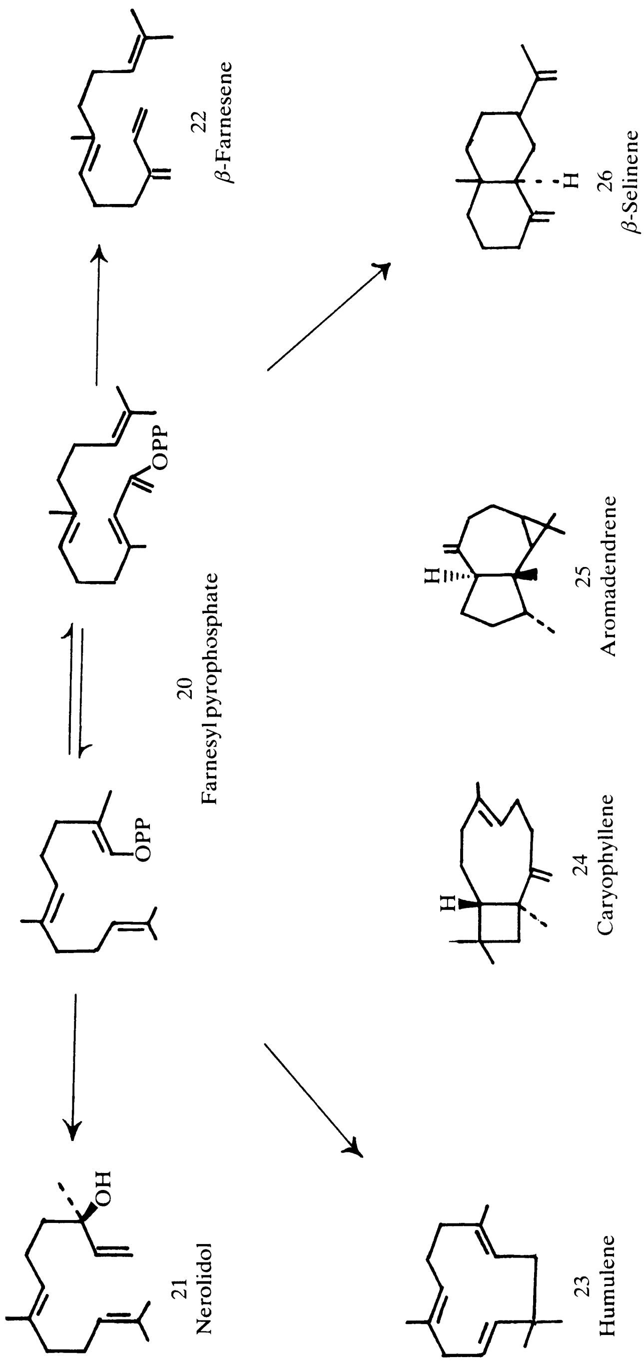


Figure 2.5 Sesquiterpenoids in hops.

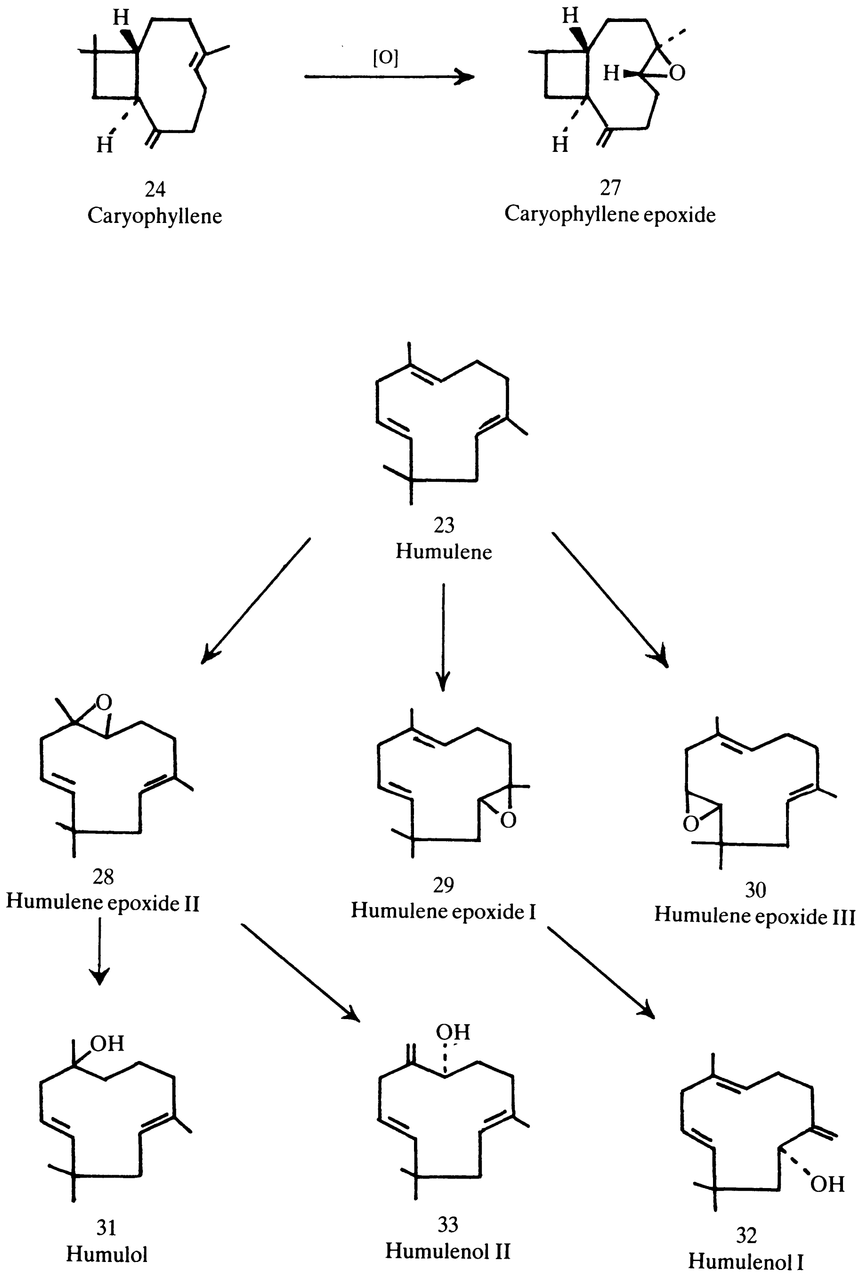


Figure 2.6 Transformation of sesquiterpenes.

in the oast to bleach the hops. Both of these treatments may alter the spectrum of sulphur compounds in the oil. For example, the sesquiterpenes caryophyllene (*24*) and humulene (*23*) react with elemental sulphur under mild conditions to form episulphides (as *27–30* but with sulphur replacing oxygen). The essential oil contains polysulphides such as CH_3SSSCH_3, $CH_3SSSSCH_3$, and $CH_3SSCH_2SCH_3$, which are formed from *S*-methylcysteine oxide, $CH_3SOCH_2CH(NH_2)COOH$, during steam distillation. This intermediate is largely destroyed when sulphur is burnt on the kiln but slowly regenerates during storage. Thioesters are also present in hops and hop oil (‹1000 ppm) and some of these, such as *S*-methyl 2-methylbutanethiolate, are introduced into beer by dry hopping.

Sharpe (1988) describes how hop flavour is added to some commercial beers by the addition of CO_2 extracts post-fermentation and identifies the key components of the essential oil and their flavour characteristics. Thus, much is known about the composition of hop oil and its effect upon beer flavour, but this is still not enough to enable the plant breeder to make selections on this basis.

2.2.3 Tannins

The tannins are a group of water soluble polyphenolic compounds which react with proteins in the wort or beer to form insoluble precipitates. Those precipitated during wort boiling or cooling are known as the hot break and cold break respectively and are removed by filtration. Some protein and polyphenol materials still remain, however, and these will continue to react to produce a haze which can make the beer cloudy and unacceptable. Much of this haze can be induced to form by conditioning the beer at low temperatures and filtering it off but, even after this, haze formation can continue in the finished beer, the shelf life of which is largely determined by how soon the cloudiness develops.

Normally about 70–80% of the polyphenols in the wort come from the malt and only 20–30% from the hops. Opinions differ among brewers as to whether the hop contribution is important and this uncertainty is reflected in the fact that some of those who use hop extracts require them to contain the water soluble fraction, that contains the tannins, while others do not.

The most reactive of the polyphenols are the proanthocyanidins. These are made up of catechin units (Figure 2.7). Procyanidin B-3 (*35*), for example, contains two such units while procyanidin C-3 (*37*) contains three. On treatment with acid they yield catechin (*34*) and the pigment cyanidin (*36*). Other procyanidins contain additional hydroxyl groups and give delphinidin etc. on treatment with acid. Recent barley breeding work by Carlsberg has developed cultivars that are free of these. Brewing with malt from these barleys produces beers with a considerably extended shelf life and if all the malt is of this type the proanthocyanidin content of the hops used may become important. Determinations made by Carlsberg of the amounts present in

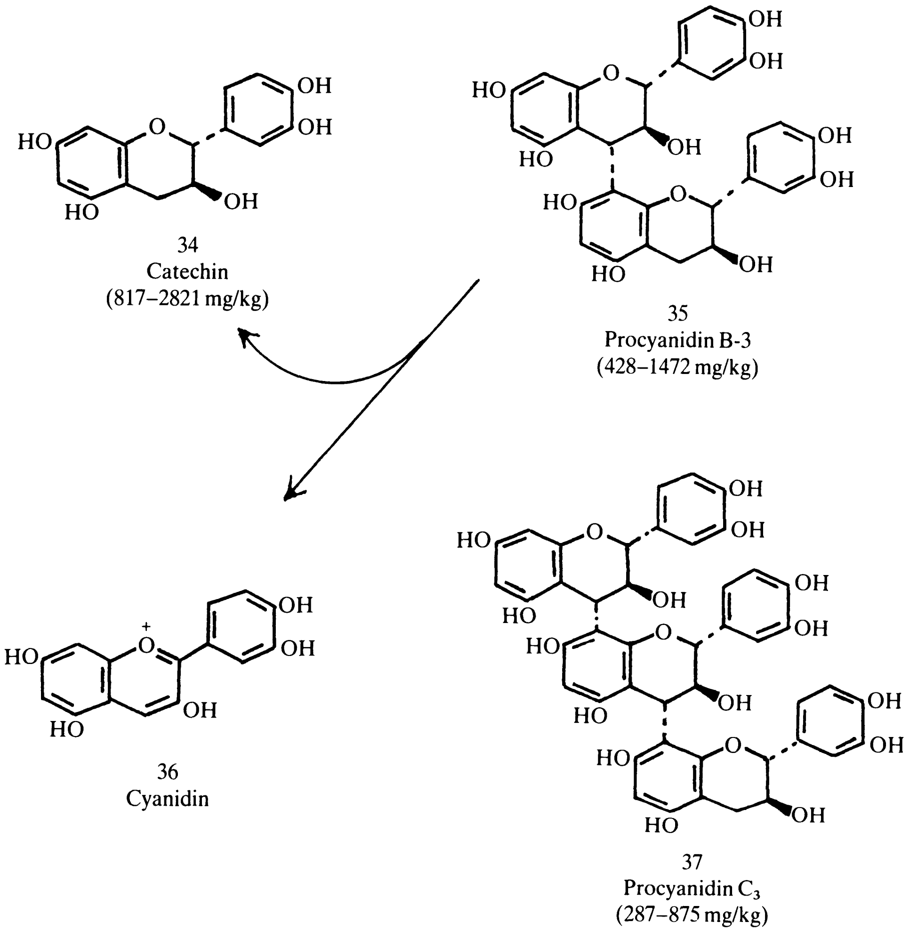


Figure 2.7 Flavenoids in hops: Alsace Record, Hallertauer, Tettnang, Saaz (after Jerumanis, 1985).

various hop cultivars have shown considerable differences (Table 2.1). It is not only the proanthocyanidin content that is important but also the amount of α-acid. This is because the weight of hops added would be calculated from the quantity of α-acid required and so it is the ratio of proanthocyanidin:α-acid that matters.

The proanthocyanidin-free barleys so far in production are probably not commercially acceptable for other reasons but these objections are likely to be overcome. Once such improved barleys are available it can be expected that some brewers, at least, will be looking for hop cultivars that have low P:α ratios and this is another factor that hop breeders need to anticipate.

TABLE 2.1 Determination of proanthocyanidin content of a number of hop cultivars

Cultivar	Proanthocyanidin	α-acid	Ratio
	%	%	P:α
Yeoman	1.2	5.6	0.2
Target	3.9	12.6	0.3
Northern Brewer	3.1	7.1	0.4
Fuggle	2.9	5.1	0.6
Saaz	5.1	3.5	1.5

Alternatively, brewers could use CO_2 extracts which are very low in proanthocyanidins.

Jerumanis (1985) describes a method for quantitative analysis of flavanoids in hops using HPLC and in limited trials found that (+)-catechin and procyanidin B_3 were the most representative followed by procyanidin C_2. The values he found for these three major components in Saaz hops totalled about 5000 mg/kg (0.5%) which is only one-tenth of the total value recorded for that cultivar by the Carlsberg workers.

2.3 HOP PROCESSING

Hops pressed into the conventional bales or 'pockets' are bulky to store and they gradually lose α-acid and aroma through oxidation which can be slowed, but not eliminated, by cold storage. Various methods of processing hops which help to overcome these disadvantages have been developed.

The first of these is the use of organic solvents such as hexane, methanol, methylene chloride or trichloroethylene to extract the brewing materials from the hops. The solvents are then evaporated and during this process the more volatile essential oils are lost. The finished extracts are green viscous liquids containing as much as 50% α-acid.

These extracts are packed in cans which are far less bulky than an equivalent quantity of baled hops and they are very stable in storage. Although they are useful as a source of α-acid they have lost a great deal of the essential oils and some breweries are reluctant to use them in case they contain residues of the solvent used. The cost of the extraction process is compensated by the elimination of storage losses and by a small increase in the utilization of α-acid in the copper.

A process that retains most of the character of the hop cones is to grind them to a powder which is then compressed into pellets. Packing the pellets in vacuum or inert gas ensures they have a long shelf life with limited losses in brewing value. Again they are far less bulky than whole hops and are much easier to handle. They are particularly well suited to whirlpool separators, the use of which has been stimulated by the use of high α-acid hops. With traditional cultivars sufficient hops are added to the copper for them to form a filter bed when the wort is run off from the hop back. With high α-acid hops much smaller quantities are required and the bed is too thin to provide an effective filter. Whirlpools perform better in this situation and work more effectively with pellets than with whole hops. Systems have also been developed that enable pellets to be loaded automatically into the copper.

By suitable blending during processing, pellets can be produced with a standard α-acid content, again making them far easier to use than baled hops which require an α-acid analysis of each batch so that the bitterness levels of the beer can be controlled. The α-acid content can be adjusted by blending hops with different alpha contents, discarding some of the cone material that is free of lupulin or by sieving out lupulin from one batch of hops to add to another batch to produce enriched pellets.

In recent years a better method of extracting hops has been developed by using carbon dioxide as the solvent. One method uses liquid CO_2 at 5–15° C at about 50 atmospheres pressure. Above the critical temperature of 31.1° C the gas will not liquefy at any pressure and the second, supercritical method uses CO_2 gas at a temperature of 45–50° C and pressures as high as 400 atmospheres. Supercritical CO_2 is a more powerful solvent but the liquid process is more selective and produces an extract containing α- and β-acids together with the essential oils but without the hard resins, polyphenols, fats, waxes and chlorophyll which are found in supercritical extracts (Laws *et al.,* 1977). With either process, there are no objectionable solvent residue problems.

A further advantage of CO_2 extraction is that it is possible to collect separate fractions that are rich in either the essential oils or the α-acid. Other methods of collecting the oils waste the α-acid. The latest development has been to separate further the essential oils into fractions that can be added to beer after fermentation to give results similar to either late hop addition or dry hopping (Haley and Peppard, 1983).

Because liquid CO_2 extraction produces the purest source of α-acid, it makes an excellent starting point for the preparation of pre-isomerized extracts. As already mentioned, the utilization of hops or hop products added to the copper is low but this can be overcome by pre-isomerizing the α-acids by treatment with dilute alkali and adding this material to the beer after fermentation. In this way almost 100% conversion to isohumulone can be achieved and the losses on yeast are avoided. Small losses do occur in the process but an overall utilization of about 85% can be achieved. A review of the different types of processed hops and their characteristics is given by Moir (1988).

The most recent development has been a report from the Brewing Research Foundation (1988) that extrusion cooking of hops prior to addition to the copper converts substantial quantities of α-acids into iso-α-acids and that overall utilization of hops for the bittering of beer is greatly enhanced. The process has been patented.

With any of these methods of processing hops the costs are the same for a given quantity of hops regardless of their α-acid content. High α-acid cultivars, however, yield a more valuable product and it is only economic, in general, to process these. More than 60% of the world hop crop is now processed in one way or another and this has played a large part in the increased demand for the new high α-acid selections.

These comments are true for the bulk of the crop that is bought simply for its bittering value. Some of the crop, however, is more highly valued for the fine quality of its aroma and such hops command a premium on the market at the present time. For brewers who demand such cultivars and also want the benefits of processed hops the costs of processing may be justified but this represents only a small proportion of the hops that are processed.

2.4 *IN VITRO* PRODUCTION

Various attempts are at present being made to produce plant products by means of cell or tissue culture techniques and some work has been done using these methods for α-acid production from hop cell cultures. Heale *et al.* (1988) have reviewed this work which has not, so far, given any positive results. It is suggested by Robins *et al.* (1985) that this failure may be due to peroxidase activity degrading any α-acid that is produced in hop suspension cell cultures. Support for this suggestion came from the rapid disappearance of exogenous α-acid that was added to the suspension. The possibility of selecting cell lines that would not degrade the α-acid has been considered.

The possibility of brewers obtaining their hop material from cell cultures in rather the same way that they maintain yeast cultures probably has some attraction. Such a source should be more reliable as it would not be subject to the vagaries of the weather or market fluctuations but it would first have to be shown that it was a suitable replacement for whole hops. As a source of α-acid for pre-isomerization it would presumably be adequate but it might not contribute all the constituents of the hop, such as the essential oils and tannins, that are utilized when hops are added to the copper.

There would also be a major difference in scale between maintaining a yeast culture and producing the quantity of α-acid that is required. *In vitro* techniques are only likely to be economically, as opposed to technically, viable when the product has a very high commercial value and it is doubtful whether α-acid would fall into this class. The developments already achieved in hop research, especially in the production of new varieties, have led to a big reduction in the price of α-acid grown on the farm and further advances can be expected so it will be increasingly difficult for cell culture to prove competitive.

CHAPTER 3

Production methods

3.1 SUPPORTING STRUCTURES

The hop is a climbing plant and in order to bring it into cultivation it is necessary to provide a support for it. Originally this was done by providing each plant with a pole or poles up which it could climb. These were pulled from the ground at harvest time and stored until the beginning of the following season. In the earliest description of hop growing in England written by Reynolde Scot (1576) it is said:

> . . .if your hylles be distant three yardes a sunder, provide for every hyll foure Poales, if you will make your hylles nearer togither, three Poales shall suffice . . . Your Poales maye not be above, xv, or xvi, foote long at the most, except your ground be very riche or that you have added there unto great labour in raysing up your hylles, or else except your hylles stande too near togither: if anye of these chance to be, or if all these three thynges meete in one Garden, the best waye of reformation, is to set the fewer Poales to a hyll, or to let them remain the longer. Otherwise the hoppes will growe from one Poale to another, and so overshadowe your Garden, the fault thereof being especially to be imputed to the nearnesse of the hylles. Therefore chiefly you must measure your Poales by the goodnesse of youre grounde.

Since the end of the 19th century it has become standard practice to provide a permanent structure of poles and wire to which each year string or thin wire is attached to provide support for the hop bines. The height of such wirework structures varies from country to country. In continental Europe it is usually 7–8 m, in England rarely more than 5 m, while in the USA an intermediate height is normal.

Originally all poles were, of course, wooden but there has, during the past 30 years, been some change towards steel or concrete poles. Concrete has been quite widely adopted in Eastern Europe because of shortage of suitable fir poles (Gjurov and Christov, 1963; Kiss, 1965) but it is much more expensive than wood (Gerber, 1966) and has been rarely used elsewhere.

When low-tensile wire is used with short spans between poles the wires are strained quite tight so that there is little sag. Systems that use high-tensile wire with wide spans achieve greater strength by leaving the wires lightly strained so that they sag in a catenary. Attaching the string or wire supports directly to

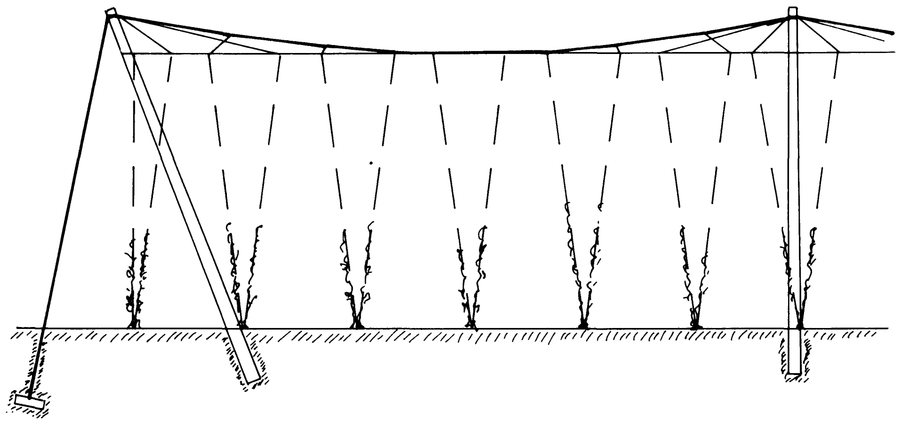


Figure 3.1 Wide span wirework system showing horizontal stringing wire suspended from the sagged load-bearing wire (after Kamm, 1969).

the catenaries would mean that the bines were of varying length and this would complicate the harvesting process. A second horizontal wire is therefore suspended from the catenary by supports of different lengths to hold it level (Figure 3.1).

In the 1960s there was a series of papers presented at the meetings of the Technical Commission of the European Hop Growers Convention describing the new developments in wirework systems and these included calculations of the various stresses which needed to be considered in designing the systems developed in the following countries: Gjurov and Christov (1963) for Bulgaria, Bailey (1963) for England, Kamm (1965 and 1969) for BRD, Kiss (1965) for Hungary, Gerber (1966) for France, and Thomas (1967) for Belgium.

In England coir string is used for the hops to climb and this is attached at the bottom to a ground peg at each hill and, at the top, to hooks clamped onto the top wires. Stringing is carried out from the ground using a continuous length of string and a pole long enough to reach the top wire (Figure 3.2). In continental Europe cut lengths of thin, soft iron wire are commonly used and these are attached to the top wire by means of a device called a cuckoo (Figure 3.3) and dibbed into the soil beside the hop hill. In the USA and Australia, cut lengths of string are tied to the top wire by workers standing on a tractor-drawn platform and also dibbed into the ground.

In continental Europe the rows of plants were traditionally close together (1.6 m) with 1.4 m between plants in the row and one wire provided for each plant. These narrow rows meant that only very narrow tractors and implements could be used so more recently there has been a change to a distance of

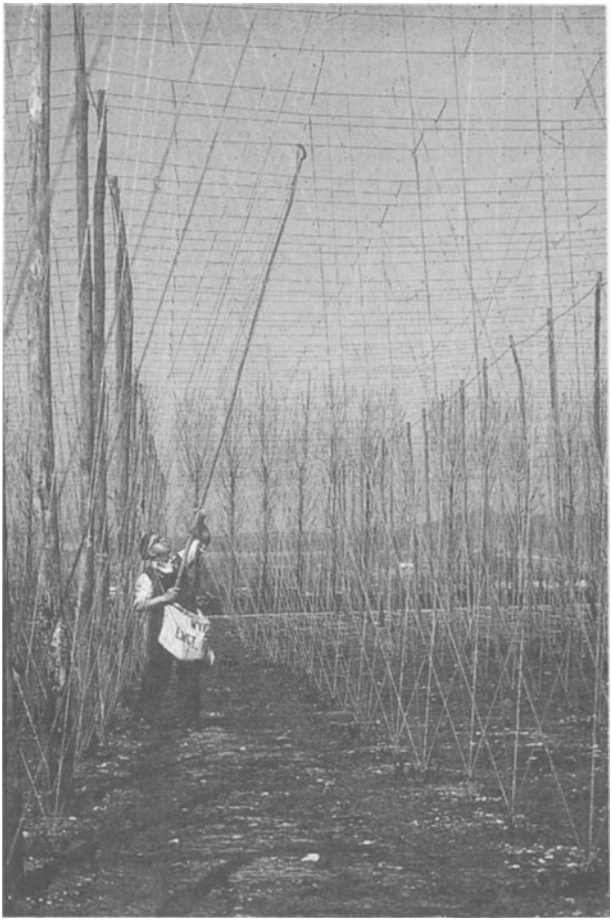


Figure 3.2 English hop stringing (IHR, Wye).

2.8–3.2 m between rows. With a spacing of 1.5 m between hills within the row each plant is provided with two wires or, if the spacing is halved, then only one is used.

In England also there has recently been a change to wider spacing. The traditional layouts were either the umbrella system with 2 m between and within the rows and four strings to each plant, or the Worcester system with wider rows (up to 3 m), approximately 1 m within the row and only two strings per plant. In the USA the spacing has remained fairly constant at about 2.25 m between and within the rows and two strings per plant.

These variations in spacing result in big differences in the number of strings (and hence the number of bines) per hectare. The results of experiments in

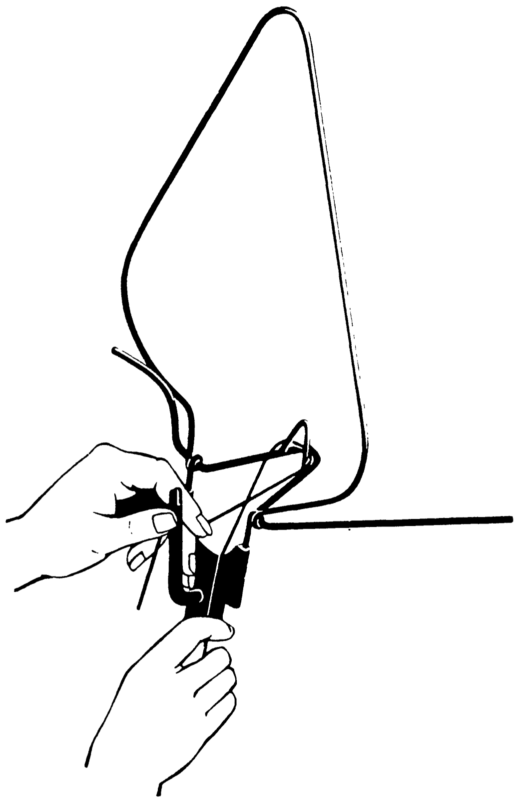


Figure 3.3 'Cuckoo' used for attaching training wires to the top wire in Germany.

England at Wye and Rosemaund have been summarized by Thomas (1979). These trials included wirework of 14 ft, 16 ft and 18 ft (4.3, 4.9 and 5.5 m) heights, and it was found that Bullion performed best at 18 ft but Fuggle and Northern Brewer were best at 16 ft. All cultivars produced the highest yield per plant with the widest spacings but the yield per hectare was greatest with the closest spacings. In Czechoslovakia, Stranc *et al.* (1979) obtained the highest yield per plant at a spacing of 3 m × 1 m and 3 bines up a single string while the highest yield per hectare was obtained from a 3 m × 0.75 m spacing with 2 bines on each of two strings per plant.

To calculate which spacing would give the best economic return is quite complicated since it is necessary to determine the costs that are related to the number of plants and strings (such as planting, stringing, training and harvesting costs) and those related to the area of the garden (ground rental, wirework, manuring and spray materials).

Examination of the growth on the different heights showed that the bending over, or breaking, of the bines at the top wire stimulated lateral development.

Since this happened earlier on the lower wirework the amount of head development was greatest at 14 ft and least at 18 ft. The growth on the 18 ft system was most suitable for machine picking as there were fewer tangled laterals but the reduced lateral development gave lower yields except for the very vigorous cultivar Bullion.

It is worth noting that Reynolde Scot had anticipated this finding in 1576 with the following comment:

> The hoppe never stocketh kindlye, untill it reache higher than the Poale, and returneth from it a yarde or two, for whylest it tendeth climbing upwarde, the branches which growe out of the principall stalke (wherein consisteth the abundance of encrease) growe little or nothing.

The various heights and spacings in the Wye experiments resulted in the strings having different angles of slope and yields were highest on the flattest slopes. In a more detailed study on the effect of slope Thomas (1969) compared growth on strings inclined at 45°, 65° and 85° from the horizontal. The flatter the slope, the slower the rate of growth and the shorter the internodes on the main bine. The highest yields were obtained from the 65° slope as it had the greatest number of laterals which were also the longest and had the most cones. A similar study in Germany (Rossbauer and Christl, 1979) indicated that a slope of 72–8° was best for the cultivars Hallertauer, Hersbrucker, Hüller and Brewer's Gold but that Northern Brewer was best when grown on vertical strings.

A recent development in the USA has been a system of growing hops on wirework only 3 m high and without any supporting wires running across the rows and in England there are plans for a similar system using dwarf cultivars (see section 3.7).

In China a totally different method of supporting the hops is employed. The wirework structure is only 2 m high and the top wires are only about 30 cm apart. The plants are grown in rows 3 m apart with 1 m spacing within the row. Two bines from each plant are trained up a vertical wire and on reaching the top they are trained horizontally in opposite directions in such a way that they and their lateral shoots form a complete canopy. All side shoots are stripped from the vertical growth, so that the cones are formed entirely upon the horizontal area with the majority of them on the upper surface but with some below. Under this system mechanization is practically impossible but this is not a problem in a country where plenty of hand labour is available.

3.2 CULTURAL OPERATIONS

When establishing a new hop garden it is important that the site is well drained and that the ground has been deep-ploughed and well cultivated to ensure that it is clear of perennial weeds. Since the hop plant is perennial and remains in the ground for many years, soil cultivations in established gardens are concerned principally with controlling weeds, incorporating manures or fertilizers, and controlling the growth of the rootstock.

If left untended, hop hills will spread extensively by means of underground runners with the result that many shoots emerge in the spring too far from the strings to be trained satisfactorily. The traditional method of dealing with this problem was to plough one or two furrows away from the hop row on each side during the winter and then to dig around the hill by hand in the spring to expose the rootstocks so that they could be trimmed with a knife, cutting back the old shoots to below ground level and removing runners and side shoots, leaving the hills neat and compact. A series of cultivations with tined or disc harrows during the spring and summer then moved the soil back over the rootstocks and kept weeds under control. Such cultivations could be quite deep at the beginning of the season but the depth would be reduced later so as to avoid damage to the fibrous feeding roots that developed as the season progressed.

It was also a common practice, half way through the season, to 'earth-up' the hop hills by using a pair of mould boards to sweep the top soil from the centre of the alleys over the hop rows. This helped to control weed growth in the rows while the covered bases of the bines produced additional roots and thickened up so that they could be cut off in the winter to provide 'strap cuttings' for further plantings. Every effort is made today to reduce the amount of hand labour required and various machines have been developed to cut the hills mechanically, the commonest comprising two overlapping disc coulters. This operation is not suited to English conditions because of the permanent soil pegs that are used for holding the strings.

3.2.1 Non-cultivation

The majority of hops in England are now grown under a non-cultivation system which has also been adopted to some extent in Australia and New Zealand. Under this system weeds are controlled by herbicides and the hills are left undisturbed so that a strong root system develops near the surface (Figure 3.4). This greatly reduces the labour requirement and has been found to have the added advantage that after rain tractors can travel much sooner on uncultivated than on cultivated ground. Under non-cultivation, cracks develop in most soils and these provide drainage channels down which surface water soaks away far quicker than on cultivated ground where such channels are constantly being destroyed. Some silty soils form a cap after rain which prevents such drainage, resulting in run-off and soil erosion. It has then been found useful to run a sub-soiler down the middle of the alleys in the winter to provide an alternative drainage channel.

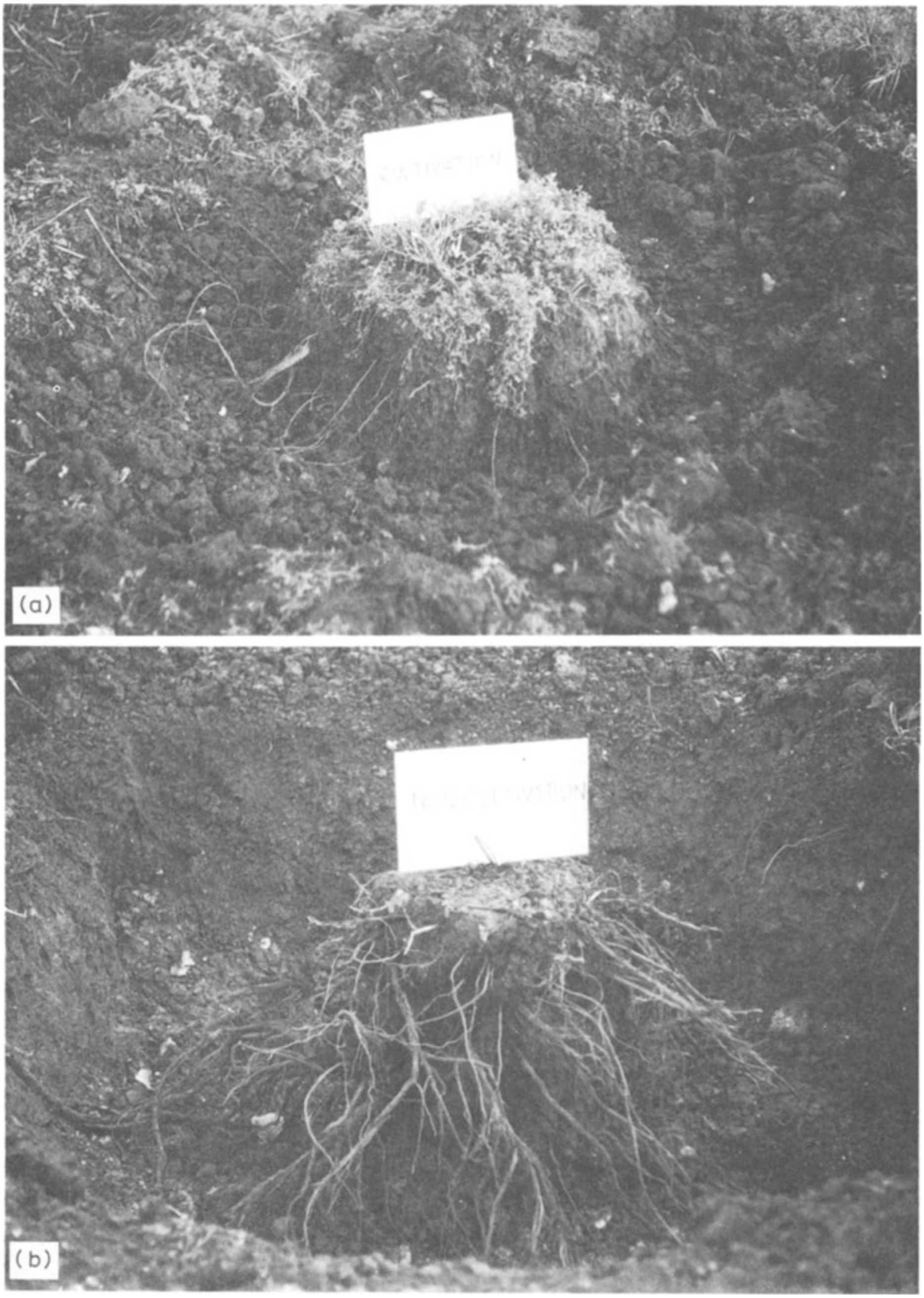


Figure 3.4 Root system of a) cultivated; and b) non-cultivated hop hills (IHR, Wye).

Trials have shown that yields are at least as good, and frequently better, under non-cultivation and as soil cultivations have been shown to be a very important cause of verticillium wilt disease spreading within an infected garden (Keyworth, 1939). There has been considerable incentive for growers quickly to adopt non-cultivation in the areas affected by this problem. Although most rapidly adopted in the wilt-infected areas it is now widely used in all districts.

The frequent soil cultivations of the traditional systems destroyed soil structure and heavy dressings of bulky organic manures were required to counteract this. There were fears that the inability to incorporate such manures under non-cultivation would lead to a breakdown of soil structure but this does not appear to happen. Since the soil is not disturbed the hop root systems extend throughout the soil profile and help to provide structure while there are none of the mechanical operations which are the main cause of damage.

Non-cultivation does, however, have the disadvantages that powdery mildew disease is more difficult to control and that the spread of runners from the hills can be a problem. In order to control runners a technique was introduced of planting hop setts in sleeves which, being open at the bottom, allowed the roots to emerge but checked the runners which develop from the upper part of the rootstocks (Thomas and Farrar, 1976, 1977). This method was first observed in Czechoslovakia where rigid pipes were being used but in trials at Wye these were found to be too restricting and polythene tubing was found to be much better.

The standard treatment with herbicides in the non-cultivation system consists of an application of paraquat in the autumn, to burn off any weeds that may have developed during the latter part of the season, followed by simazine in the spring to prevent the establishment of new seedlings. This controls most weeds but alternative herbicides may be required to deal with such problems as docks (*Rumex* spp.), perennial nettles (*Urtica dioica*), creeping thistle (*Cirsium arvense*), cleavers (*Galium aparine*) or couch grass (*Agropyron repens*). Difficulties have also started to arise with simazine-resistant strains of weeds such as groundsel (*Senecio vulgaris*) that were originally susceptible.

3.2.2 Training

In general two or three bines are trained up each of the supporting strings or wires as this produces the optimum density of growth for high yield and good quality. The bines are trained when they are about 0.5 m long and it is usually found to be best not to select the most vigorous of all. Under the English system in which there are four strings to each hill, there may not be the required 8–12 shoots of the right type at the first training and a second round is then necessary. Established plants eventually produce many more shoots than are needed and once training is completed it is necessary to remove the surplus.

This can be done by hand by the trainers but more commonly the unwanted growth is burned off by chemical defoliants. Leaving the excess shoots to form a dense growth around the base of the plants would create a major disease problem since the conditions would be ideal for the mildew diseases to develop there.

Training is one of the most labour-demanding operations and there have been several attempts to simplify or eliminate it. Various training aids that can be placed around the hill to direct the shoots towards the strings have been tried but not found to be economical. The idea of planting the setts in containers was initiated in Czechoslovakia with the intention of simplifying training by ensuring that all the shoots emerged close to the supporting wires and it was found to be effective. In England a series of trials were carried out at Wye and Rosemaund to see whether the bines could be left to self-train. The conclusion at Rosemaund was that hand training consistently produced higher yields than 'assisted self training' (Anon, 1984). The Wye report was more encouraging though it pointed out that much depended upon the habit of growth of the cultivar concerned. The upright-growing variety Early Bird when given assisted self-training, or even complete self-training, gave yields not far short of hand-trained controls. On the other hand few bines of Wye Challenger climbed the strings when left to self-train, although assisted self-training was quite successful (Thomas and Farrar, 1975). Assisted self-training consisted of initially putting a handful of bines between the strings and later furnishing any empty strings.

After training, some cultivars will climb the supports less successfully than others and, especially under windy conditions, many bines may fall away from the strings or wires, necessitating more hand labour to retrain them. If they can still be reached from the ground the work is not too difficult but if the trouble occurs later it is necessary to use a forked stick to reach them or else the trainers may be driven through the garden on a trailer that is high enough for them to reach.

3.2.3 Stripping

In addition to removing all the excess shoots it is normal practice to strip the leaves and laterals from the lowest part of the bines. If left unrestricted these provide an excellent site for downy and powdery mildews or red spider mites to become established and then spread upwards into the main canopy. Stripping is usually started when the bines are about 2 m high and is carried on later in the season as required. The height to which it is done depends upon the circumstances. On young plants it is kept to the minimum so that some leaves will be left on the basal part of the bines that is left attached to the plant after harvest. This allows some additional photosynthetic activity to continue which helps to build up food reserves in the rootstock. Past experience of disease

Figure 3.5 Basal growth removed by chemical defoliation (IHR, Wye).

problems in each garden can modify the amount of stripping that the grower considers necessary. The introduction of bine-pulling machines at harvest has required that bines be stripped to the height at which they are cut. Because of these various factors, bines may be stripped to anything between 1–2 m high.

Stripping was originally a hand operation but today it is much more commonly done by spraying with a chemical defoliant (Figure 3.5). This was first done in the USA using dinoseb as the defoliant whereas the material used in England for many years was tar oil, sometimes mixed with sodium monochloracetate, but this was then largely superseded by dinoseb until the use of this was banned. After the bines have reached the top wire it is usually safe to use diquat or paraquat but these materials can cause damage if applied to young bines. In Germany much use has been made of concentrated solutions of nitrogenous materials such as ammonium sulphate or urea, generally mixed with defoliants such as bromfenoxim or diquat. In England it is usually necessary to spray three or four times in the season to cope with the renewed flushes of growth.

In Australia and New Zealand, where there is no need for early-season application of fungicides or pesticides, sheep are often put into the hop gardens to graze and defoliate the bottoms of the bines.

3.3 SOILS

Although hop growing is concentrated in relatively small areas of each producing country, soil type has probably been only one of the factors leading to this localization. Hop plants will thrive on a wide range of soils although different cultivars do appear to be better suited to some areas than others. Even light, sandy soils can produce good crops provided the water supply is augmented by irrigation and manuring is adequate. Hops will grow well on heavy clay soils but these create real difficulties for the cultivator when he is faced with the work of digging round the hills and dressing them in a wet winter or cultivating in a dry summer. However, for hop production to be economically viable the grower needs to keep costs down and yields high and this can only be achieved on land that is easy to manage and suited to the cultivars that he wishes to grow.

The main requirements for good yields are probably a sufficient depth of soil for this deep-rooted plant and an adequate supply of moisture without any danger of waterlogging. It has been suggested that a high water table during the winter can kill off the lower roots and that the plants suffer during the following summer, especially if there is a shortage of water then. The importance of a well-developed root system has been noted in the breeding garden at Wye in dry summers when two-year old seedlings have been checked much more than three-year olds. In wet summers there has been little difference between the two age groups.

Although hop production is restricted to areas where the soils are suitable there are many other areas with similar soils where hops are not grown. One of the reasons for such localization used to be the availability of sufficient labour for harvesting by hand and in England this restricted production to places with good access to the major cities of London and Birmingham. Although labour is no longer drawn from those sources, production has not spread from the traditional areas, largely because the necessary expertise and equipment are not readily available elsewhere.

3.4 MANURING

Hops do not thrive under acid soil conditions and liming should be carried out when necessary to prevent the pH from falling below 6.5.

Although hops require higher levels of fertility than many other crops, recent fertilizer trials have shown that there is little if any benefit from the very high levels of fertilizers that have frequently been advocated. Brown (1980) records that Burgess's recommendation for the Guinness farm in 1934 was for 336 kg N, 230 kg P_2O_5 and 224 kg K_2O per ha, in addition to 37 tonnes of farmyard manure or 2.5 tonnes of shoddy. In the years 1934–7 the rates of artificial fertilizer applied were considerably in excess of the recommendation averaging 432, 1132 and 342 kg/ha respectively although very little farmyard manure was used.

There can be considerable advantages on some soils of heavy dressings of bulky organic manures that improve the moisture-holding capacity of the soils and maintain soil structure and this may have led to the assumption that high levels of artificial fertilizers are also needed. Under non-cultivation systems however, trials have shown only small benefits, if any, from applications of dung or straw mulches. Heavy straw mulches can be disadvantageous since they keep down soil temperatures in the spring, delaying the growth of the plants and increasing the risk of verticillium wilt.

3.4.1 Nitrogen

In spite of numerous fertilizer trials, there are still considerable differences of opinion as to the levels of manuring that are required, especially for nitrogen. In England, Burgess (1950) reported that maximum yields were obtained from 300 kg/ha N but at present the official recommendation is considerably lower, ranging from 150 kg/ha if there have been frequent applications of farmyard manure in previous seasons, to 225 kg/ha when no FYM has been used for several years (Ministry of Agriculture, 1985). However, several trials have shown little response to applications of more than 135 kg/ha even in the absence of FYM.

In Germany the recommended rates have been based upon the quantities of nutrients removed by the crop each year and the figure quoted for nitrogen with a crop yield of 37 zr/ha is 120 kg N. Since the plants only utilize some 65% of the nitrogen applied it is calculated that such a crop requires 185 kg/ha while for a crop of 45 zr/ha this needs to be increased to 224 kg/ha (Kohlmann and Kastner, 1975). More recently however, growers have been encouraged to adopt the N_{min} system whereby nitrogen applications are based on soil analyses which are interpreted with reference to the cultivar and its expected yield to calculate the minimum application of nitrogen that is required (Rossbauer and Zwack, 1989). The use of this method can lead to reductions of 50–80 kg N for some cultivars.

The previous standard rates are considerably higher than those suggested for the Yakima Valley in the USA where the recommendations are based upon the soil test values for nitrogen in the soil. Even for the lowest nitrogen soils the suggested rate is only 140 lb/acre (160 kg/ha) while for the highest nitrogen soils no further application is advised (Roberts *et al.*, 1985). Since verticillium wilt disease is more severe when heavy applications of nitrogen are used it is recommended in England that 135 kg/ha is the maximum that should be applied when this disease is present but some growers prefer to apply even lower rates.

A further reason for keeping nitrogen manuring at as low a level as possible is the increasing concern about the quantities of nitrates that are consumed in food and drink. Provided that brewers take steps to reduce the nitrogen content of the brewing water, hops are the major source. Although more work needs to be done to establish all the factors determining the nitrogen level in hop cones it does appear that it increases with higher rates of nitrogen fertilization.

The manurial recommendations in different localities may differ because nitrogen is sometimes not a factor limiting yield. As the vigour of hop plants increases, yields will initially increase also, but if the growth is too strong the increased shading effect will have an adverse effect. It is to be expected therefore that plants that are widely spaced would respond to higher nitrogen levels than plants that are more closely planted. Since English hop gardens usually have a much higher density of bines than other countries the nitrogen requirement may also be lower. For the same reason it has been found that the less vigorous cultivars may require heavier applications while the supply needs to be restricted on the most vigorous sorts in order to avoid excessive growth.

3.4.2 Phosphate and potash

After several years of manuring hops at much higher rates than those used for most arable crops, soil analyses can show very high residual values for phosphate and potash. The application rates recommended in England for these elements therefore vary according to the soil analysis. For phosphate the maximum advised is 300 kg/ha P_2O_5 but for most established gardens it would be only 50–100 kg/ha. For potash the maximum is 450 kg/ha K_2O but in most cases only 75–150 kg/ha. With the highest residual values no additional phosphate or potash is considered necessary.

In Germany the levels recommended are again based upon the quantities of each element removed by the crop and the recommendations for a crop of 45 zr/ha, are 225 kg P_2O_5, and 270 kg K_2O.

The recommended rates for soils in Yakima with the lowest soil test values are very similar to the German figures but lower rates are suggested for the more fertile soils and again no additional treatment is advised for the soils with the highest soil test figures.

Although a deficiency of phosphate will result in a progressive reduction in yield there are no visual symptoms to identify the cause. Phosphate is particularly important for the stimulation of root development and it is therefore necessary to ensure an adequate supply for newly planted hops.

Deficiency of potash also results in poor growth and reduction in yield which is associated with a bronzing of the interveinal areas which later become necrotic. Excessive levels of potassium should be avoided as these lead to magnesium deficiency.

3.4.3 Magnesium

At one time the magnesium requirements were supplied by the heavy dressings of farmyard manure or crude potash fertilizers such as kainit, but without them it is frequently necessary to include magnesium in the fertilizer programme. Deficiency is recognizable as chlorotic yellowing of the interveinal areas followed by necrosis and some cultivars are more liable to show these symptoms than others (Marocke *et al.*, 1979). Soil analysis should indicate the need for additional magnesium before the symptoms occur and applications of 30–100 kg/ha Mg are recommended.

3.4.4 Trace elements

Various trace element deficiencies occur in some areas. Perhaps the commonest is zinc deficiency which is quite common in Europe and the USA. The problem is known in Czechoslovakia as kaderavost and in Germany as Kräuselkrankheit (= curling disease) and was for many years thought to be due to a virus infection. The leaves become light yellow in colour with upward cupping, are sharply toothed and have an elongated middle lobe. In severe cases the teeth wither and the leaves are brittle to touch.The condition can be improved by spraying with fungicides that contain zinc but as these go out of use it is necessary to spray with zinc sulphate.

In the USA zinc deficiency occurs most frequently in the heavily irrigated desert areas such as the Yakima valley but has been much reduced since growers included zinc in their fertilizer programmes (Roberts *et al.*, 1985).

The other trace element deficiency that has been quite widely reported is boron. It occurs in Germany and has also been reported from New Zealand where the symptoms were described as delayed development of new shoots accompanied by crinkling, often causing malformation of the leaves. The internodes were short, laterals developed at an early age and the growing point was killed (Askew and Monk, 1951). In England, Cripps (1956) further described a rigidity of the young tips of the bines which had small leaves, large stipules and short internodes. These symptoms were described as 'fluffy tip'.

3.5 IRRIGATION

Hops require a good supply of water during the growing season to produce high yields but in western Europe this is normally provided by natural rainfall. In the drier regions of the world, however, irrigation is essential for hop production, not only because of the low rainfall but also because under hot, dry conditions the hop plants have a higher water requirement. It is reported (Evans, 1985) that their requirement in Yugoslavia and the Willamette Valley of Oregon is between 450–500 mm (18–20 in) whereas in the Yakima Valley in

Washington State they require nearly 760 mm (30 in). The Yakima Valley and the Xinjiang Region of China, which lies at the western end of the Gobi desert, are two of the most arid areas where hops are grown. In both these areas the water for irrigation is provided by melting snow from the nearby mountain ranges and it is distributed in the hop gardens by furrow irrigation rather than overhead sprinklers. The combination of a controlled water supply and hot sunny weather provides some of the best conditions for hop production.

Between these two extremes there are areas where hops can be grown without irrigation but will not give economic yields. Pearce (1976) describes how Australian growers, who initially used the methods with which they had been familiar in Europe, suffered heavy losses from dry summer conditions until a visit to Tasmania in 1840 by the Polish Count Strzelecki, who had travelled widely in North America, did much to encourage the use of irrigation. This was initially done with furrow irrigation but later was replaced largely by overhead sprinkler systems.

In the Backa area of Yugoslavia conditions are dry enough for irrigation to be a standard requirement and it is provided by overhead sprinkler systems. Kisgeci (1980) reported on physiological changes to hops in irrigation trials carried out there. Measurements of osmotic pressure showed only a low correlation with soil moisture in the top 60 cm layer. It was concluded that this was because the hops were deep rooted and were able to obtain water from greater depths but there was a good response to irrigation because most of the soil nutrients are in the top layer which irrigation made available. Irrigation is also used in some parts of Czechoslovakia and other eastern European countries.

In England some growers have used overhead systems of irrigation in dry seasons but various trials have indicated that this only occasionally increased yield significantly. Because of the expense of moving and maintaining the equipment the system has largely lost favour although it is still used occasionally on young hops during spells of dry weather. The development of trickle irrigation systems, where plastic lines remain down permanently and less water is needed, presented a new possibility and trials were commenced at Wye in 1973 (Thomas and Farrar, 1975). The first trial on Fuggle hops gave increased yields in two years out of four but when the plants were grubbed it was found that the hills from the irrigated plots were smaller with a peat-like mat of fine fibrous roots close to the crown. A subsequent trial with the cultivar Wye Saxon gave no significant increases in yield.

Evans (1985) suggested that trickle irrigation is probably the most efficient method of irrigating hops but there were problems if the emitters become blocked while pipes that were laid on the surface interfered with cultural operations. Nor were underground systems to be recommended because of maintenance problems. Wample and Farrar (1980) found that trickle irrigation with fertilizer injection provided several crop management advantages but required changes in cultural practices. In the second year of their trial they obtained the highest yield from trickle plots which received the least water, fertilizer or labour.

Following reports that yields of fruit trees could be increased by the use of intermittent overhead sprinkling with water in order to reduce moisture stress, a similar treatment was tested at Wye (Thomas, 1981). In some treatments the sprinkler treatment was combined with trickle irrigation. Measurements of leaf water potential and stomatal conductance showed that, after sprinkling, the water stress fell and the stomata were more open than in control plants. Increased photosynthesis and increased growth and development were expected to result. Non-significant yield increases were recorded from both sprinkling and trickle irrigation except in 1982 when yields were lower in the sprinkled plots than in the controls. This was attributed to either the excessive ('housey') growth or to the downy mildew which was evidently encouraged by the humid conditions (Thomas and Farrar, 1983).

3.6 SPRAYING

The very serious damage that can be inflicted on hops by various pests and diseases makes it essential, in nearly all countries, to carry out regular and efficient spraying operations. The crop does not provide an easy target for spraying, at least during the later stages of growth. Not only is it grown at heights of up to 7 m, but as the growth becomes more dense it is increasingly difficult to achieve penetration of the spray to all areas. Although some chemicals are now available with systemic action it is necessary in most cases to achieve good cover of all parts of the plant to ensure good control of the various pests and diseases.

Most sprayers in use today rely on fans to carry the spray droplets to the necessary height (Figure 3.6) but some growers in continental Europe still rely on purely hydraulic systems with the nozzles placed at varying heights on a vertical boom in order to reach the crop at all levels.

Without air assistance the droplets must be relatively large in order that they should travel far enough to reach the target but this is not necessary when they are transported in an air stream. One of the problems with hop spraying is that the use of large volumes of water means the sprayer has to return to the filling point frequently, thus wasting a considerable amount of time. By reducing droplet size it is possible greatly to reduce the total volume of spray that is required so some air-assisted sprayers will work with very small droplets at very low volumes.

In England the majority of growers use high volume, air-assisted sprayers and apply from 600 l/ha (50 gal/acre) at the start of the season to a maximum of 2200 l/ha (200 gal/acre) when the plants are fully grown. In Germany

Figure 3.6 Fan-assisted sprayer (IHR, Wye).

volumes as high as 3300 l/ha are recommended for this type of sprayer and as much as 5000 l/ha for hydraulic sprayers.

A few growers in England have changed to low volume application with rates of only 280 l/ha (25 gal/acre) and are satisfied that they are achieving good control. In some cases an electrostatic charge is induced on the droplets as they leave the sprayer so that they are attracted to the leaf surface but there is little evidence so far to show how effective this modification may be. With any sprayer there are difficulties, in a crop like the hop, in achieving a uniform distribution of spray between the leaves close to the spray output and those further away so there are advantages in providing outlets at different heights.

Figure 3.7 American mobile harvester on 3m high wirework (Hopunion, USA).

When weather conditions are bad there is frequently only a limited period in which spraying can be carried out and speeding up spraying operations not only reduces costs but is also necessary to ensure that the whole crop can be sprayed at critical times. Whereas a high volume sprayer may only cover a half hectare at each filling, a low volume sprayer can cover up to eight times as much. Transporting heavy loads of water through gardens when the ground is wet can cause a lot of soil compaction and low volume spraying is better in this respect also.

Whichever system of spraying is used, it is essential that the sprayer is well maintained and correctly adjusted with the appropriate nozzles and pressure and with the tractor driven at the correct speed. In many cases where the grower complains that the sprays are not working effectively, the problem lies in the way in which the spraying has been carried out.

3.7 LOW TRELLIS

A system has been developed in the USA of growing the normal cultivars on wirework that was at first only 2 m high but it was found necessary to increase this height to 3 m. Mobile harvesters have been constructed which straddle the row (Figure 3.7) and these appear to be far more successful than the mobile harvesters that have been used on normal, high wirework (Figure 3.8).

Figure 3.8 American mobile harvester for traditional high wirework (IHR, Wye).

Since the crop is harvested *in situ*, the bines remain attached to the wirework and it has been found that these can be used to support the next season's growth, thus eliminating the need for restringing each year. The harvester should pick the hops from the laterals as cleanly as possible so there is no need to complicate the machine by adding a lateral picker. The laterals are then left attached to the main bines and when the next year's shoots start to climb they frequently grow out along these laterals instead of going upwards. It is therefore necessary to remove the old laterals during the dormant season.

Very little training is required and hops on low trellis offer a much better target for spraying to control pests and diseases, reducing spraying costs and producing cleaner crops.

Figure 3.9 Prototype harvester picking dwarf hops on 2m high wirework (IHR, Wye).

It was found in England that the standard cultivars were not suitable for growing under low trellis and a breeding programme is in progress to develop dwarf types that should be more successful. It was intended that these would be grown on 2 m high wirework (Figure 3.9) but it now appears that it may also be necessary to increase this to about 2.5 m in order to achieve economic yields. Whereas most hop yards in the USA are quite level, many English hop gardens are on sloping land and the extra height may create difficulty with stability of a harvester that has to be high enough to straddle the row.

Low trellis offers considerable cost savings on such operations as stringing, training, spraying and harvesting so efforts are likely to continue in developing a commercially acceptable system.

3.8 SEEDED AND SEEDLESS HOPS

Since the male and female flowers of hops are produced on separate plants, the females will only be pollinated and produce seed if there are male plants sufficiently close for the wind-borne pollen to reach them.

Many brewers insist that the presence of seed is undesirable, usually with no explanation, on the grounds that oxidation of the seed fat can give rise to rancid flavours. There is little experimental evidence to support the objection to seed although Zattler and Krauss (1970) found that lager brewed with seedless hops was preferred after storage for six weeks. Several other investigations have failed to detect such differences (BIRF Ann. Report, 1984; Harrison, 1971; Pfenninger *et al.*, 1978; Neame *et al.*, 1980) but brewery demand remains such that, in most countries, hops are grown seedless by ensuring that all male plants in the hop growing areas are destroyed. In Germany, for example, there are regulations that require all wild hops to be cut down or, where possible, grubbed by 15th June at the latest (Kohlmann and Kastner, 1975).

In Europe the seed content of dried hops has to be below 2% for them to be classed as seedless while in the United States the limit is 3% but this is equivalent to 4.2% when determined by the same method as in Europe.

Salmon and Amos (1908) published a report indicating that the yield of hops was considerably higher when grown seeded and they encouraged English growers to plant males by offering to supply them free of charge. Until then there had been no definite policy regarding the use of male plants but from that time on English hops were invariably grown seeded. Brewers in Britain did not share the dislike of seeded hops that German brewmasters had advocated as they spread their influence around the world. Since the English hops were bought mainly by British brewers there was every advantage to be gained by the grower from planting male hops in the gardens.

The development of high α-acid varieties in England offered an opportunity for the export of such hops and in 1963 an experiment at Wye again indicated that yields of seedless hops were reduced (Neve, 1964a). There was a further stimulus to overseas trading as a result of Britain's entry into the European Economic Community and this led to more accurate experiments being started in 1971 (Thomas and Neve, 1976). These showed that a reduction in yield of up to 30% resulted from growing hops seedless but that there was, with the high α-acid varieties in particular, an increase in α-acid content that largely compensated for this since the price of such hops is based upon their α-acid analysis. With the traditional cultivars Fuggle and Golding there was no increase in α-acid (nor would such an increase enhance the price of these aroma hops) and it was therefore uneconomic to consider growing them seedless.

In the USA too it proved uneconomic to grow Fuggle seedless so males had to be planted in this variety whereas it is standard practice to grow other hops seedless. This stimulated the breeding of cultivars with similar qualities to Fuggle that could be grown economically without seeds.

One breeding technique which could do this was the production of triploid cultivars which is described in section 9.7. Triploids are very infertile and although, if fully pollinated, their seed content may exceed the European limit of 2% for seedless hops, this limit can be achieved without very stringent elimination of male plants from the garden and its surrounds.

The ordinary diploid hop cultivars vary considerably in the amount of seed that they set when pollinated and it has been found the English high α-acid cultivar Wye Target has a low seed content so by removing males from gardens of this hop the European limit of 2% seed can be readily achieved, even when neighbouring farms still have male plants in their hop gardens.

An alternative to breeding infertile female cultivars is to use male plants whose pollen will stimulate cone development but will not produce seed. Davis (1959) found that the annual species *Humulus japonicus* when used in this way stimulated the development of bracts, bracteoles and internodal length though to a lesser extent than ordinary male hops and he said that its commercial practicality had not been tested. This method is currently being tried in England (Gunn, personal communication).

Another method, initiated by Haunold (1975), was to use triploid male plants of *H. lupulus*. Because of irregularities in the meiotic divisions leading to pollen formation in such males, many of the gametes which they give rise to are not viable and so only empty seed cases develop. In field trials (Haunold and Nickerson, 1979) the overall seed content of hops pollinated by triploids was 4% compared with 2% in an adjacent yard which contained no males and the yield was 30% higher. In the females close to the triploid males, however, the seed content was much higher, averaging 10.3%. Although the reduction in seed weight may be sufficient to qualify for the seedless limit of the USA it would be less likely to meet the more stringent European standard.

3.9 GROWTH SUBSTANCES

Seeley and Wain (1955) attempted to stimulate cone development by applying synthetic growth substances or pollen extracts to early or fully developed burr. They reported that 2-naphthoxyacetic acid and α(2-naphthoxy)propionic acid caused a marked initial stimulation of cone growth but the effect did not persist. After 20 days the control cones were as large as those that had been treated while at harvest both the cone weight and α-acid content of the treated hops were lower. There was no effect from pollen extracts.

Weston (1960) found that α(2-chlorophenylthio)propionic acid applied to female hop plants induced the formation of some male flowers. The earliest applications (2 and 4 July) had most effect with fewer male flowers from the 6 July treatment. He did not report that any viable pollen was produced.

Nash and Mullaney (1960) reported in Australia that applications of gibberellic acid at a concentration of 12.5 ppm to hops when the stigmas were ⅛ in (3 mm) long advanced the maturity of the developing cones by 10 days and increased the yield by 40%. However, the α-acid content was reduced from 10.16% to 1.8% so the treatment was not commercially beneficial. Roberts and Stevens (1962) repeated the treatment in England on the cultivar Bullion and found that, although the treated hops were initially more advanced, by the time of harvest the differences had disappeared and the yields were lower than the untreated controls and the α-acid contents were the same. They suggested that their results might have been different from those in Australia because of the different environmental conditions. They did not suggest another explanation, that the Australian hops were harvested at an earlier stage of maturity before the untreated hops had time to catch up with the treated ones.

Zimmermann *et al.* (1964) treated Fuggle hops in America with gibberellin A_3 at various stages of growth. They agreed with the British workers that application at the burr stage did not influence maturity date but that the treated hops were liable to shatter badly when harvested. However, a concentration of 5 ppm applied at the 1.5 m (5 ft) stage resulted in a large set of small cones and a 25% increase in yield. Hartley and Neve (1966) tried the same treatment on Fuggles in England and found that the treated plants also produced a greater number of smaller cones but that there was no increase in yield. They suggested that the different result might be related to the fact that in England the plants were spaced 2 m × 2 m (6.5 ft × 6.5 ft) with four strings to each plant compared with the American system of 2.4 m × 2.4 m (8 ft × 8 ft) and three strings per plant. With the denser plant in England there could be a limit to the ability of the plants to support the development of the increased number of cones.

Further trials in England (Thompson and Thomas, 1971) demonstrated no increase in yield of similar treatments to Fuggle, Eastwell Golding or Bullion but the yield of Northern Brewer was sometimes significantly increased and never, apparently, reduced. There was an additional benefit that the number of leafy cones ('cock' hops), which are an undesirable feature of this cultivar, was frequently reduced. The treatment was therefore recommended for Northern Brewer and later for Wye Northdown which is a seedling of Northern Brewer.

Thomas and Goldwin (1976) tested mixtures of growth substances that were effective on apples on hops. The most effective mixture consisting of GA_3 (5 ppm), NN′-diphenylurea (3 ppm) and 2-naphthoxyacetic acid (0.4 ppm) applied at cone formation gave small but significant yield increases. Responses differed with cultivars, Northern Brewer showing yield increases of 9–12% while Wye Challenger only gave 4–5% increases. A subsequent report (Thomas and Farrar, 1979) indicated little benefit from the treatment in a range of trials.

There have been a number of trials with growth retardants, mainly with the object of reducing the excessive growth of some cultivars. The retardants (2-chloroethyl)trimethyl ammonium chloride (CCC) and N-dimethylamino succinamic acid (= daminozide, B9 or Alar) were tested for several years at Wye. Both compounds caused shortening of the internodes but the effect lasted for only about 10 days (Hartley, 1966). Repeated applications led to a general shortening of the internodes but yields were much reduced (Hartley, 1967). Thomas (1968) reported that B9 could induce flowering in plants growing under continuous light. In natural daylength it reduced yield but increased

α-acid content. The final conclusion (Thomas, 1973) was that this material was of doubtful value. Only on Fuggle had increased yields of α-acid been recorded; on other cultivars the increased α-acid content had not compensated for the reduced yield.

Similar transient shortening of the internodes has been recorded with paclobutrazol (PP333 or Cultar) applied as a foliar spray but yield was reduced. When applied as a soil drench there was no effect until the bines reached the top wire when the intermodes and laterals were shortened. Both sprays reduced α-acid content and yield. The effects of the soil treatment persisted into the following season, initial growth being slower although by harvest differences had disappeared (Thomas, 1982b, 1983). One trial indicated that early application of paclobutrazol delayed shoot development but that growth was vigorous when the effect of the treatment wore off. It was thought that this could be a useful management tool to hold back the development of some hops on a farm so that everything did not require training at the same time (Thomas, personal communication).

3.10 PROPAGATION

Hop gardens are invariably planted with clonal material of one of the standard cultivars and this has to be produced by vegetative propagation. This can be done very easily by taking cuttings from established plants in commercial gardens. In England this was traditionally done by earthing up the bines during the latter part of the growing season, inducing the covered bases to thicken and develop perennial buds. These bine bases could be cut off from the hills in the winter to provide 'strap cuts' which would be planted directly into a hop garden, usually putting 2 or 3 at each hill position. Alternatively they could be grown on in a nursery for one year to produce 'bedded setts' which would establish quicker than strap cuts (Figure 3.10).

In the USA the corresponding technique was to remove underground runners from the stock during the winter and plant several of these at each hill position.

The spread of verticillium wilt in England resulted in a demand for large quantities of planting material as resistant varieties became available and this led to the development of more rapid methods of propagation.

Instead of earthing up the base of the bine more cuttings could be obtained by lowering the bine from the top wire, laying a length of it along the ground and covering this with soil, while the tip was retrained upwards along another string, usually that of the next hill in the row. In this way the whole of the layered portion thickened up and could be cut up into single-node sections to provide several layer cuts (Figure 3.10). Plants in a commercial garden could be layered in this way, provided that cultivations were to be carried out in one direction only, but an alternative was to establish permanent layer beds on full

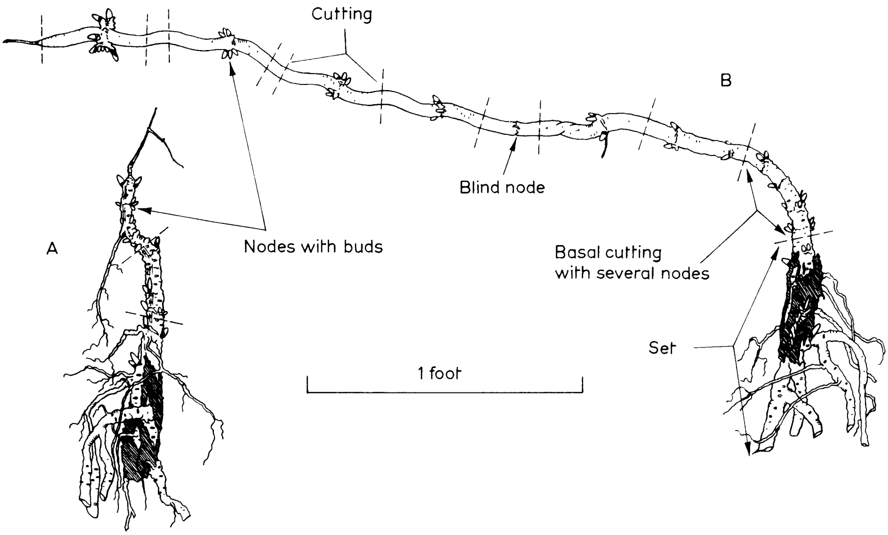


Figure 3.10 a) Bedded sett; b) layered bine. Dashed lines indicate suitable positions for dividing into cuttings (drawn by R. F. Farrar).

height wirework and to use these solely for propagation (Keyworth *et al.*, 1948).

An alternative to layering, which is termed air layering, has been suggested by Vasek and Tassell (1984). The technique consists of placing black polythene sleeves (20 cm diameter, 60 cm long) round the plants in the spring and, once the bines reached the top wire, filling the sleeves with pulverized bark to a height of 50 cm. By treating up to ten bines per hill in this way they were able to produce 40–50 one-node cuttings which were superior to those obtained from layering below ground.

Permanent layer beds had the disadvantage that there was a delay of a whole season during which the plants were becoming established. A more rapid system was to plant strap cuts or bedded setts in nursery rows, under 2 m high wirework, and to layer the bines that they produced in the first season. A technique was devised using two top wires, one of which could be lowered when the bines had made sufficient growth, so that a length of each bine lay on the ground where it could quickly be covered with soil (Keyworth and Wilson, 1948).

A more rapid multiplication would be achieved if it were possible to root soft-wood cuttings quickly during the growing season; this was also attempted at East Malling by Beard and Wilson (1946 and 1947) who concluded that the methods they used were not of wide application.

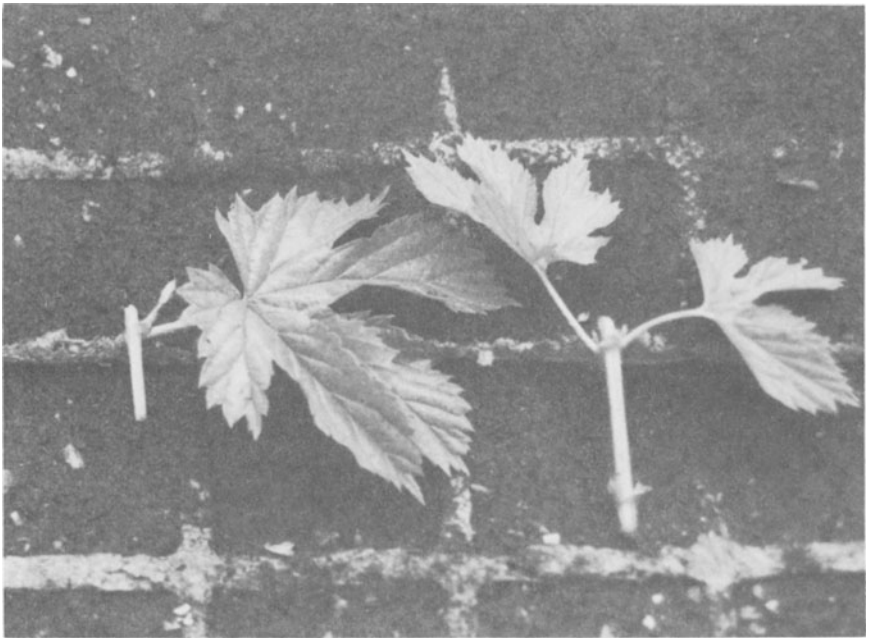


Figure 3.11 Cuttings prepared for mist-propagation (right) two-node cutting; (left) half-node cutting (IHR, Wye).

Soft-wood propagation became a very practical proposition following the work of Williams and Sykes (1959) in which they adapted the mist-propagation system for use with hops. In their paper they suggested that existing methods were adequate for commercial propagation and that the more rapid multiplication made possible by the new technique would be useful mainly for research projects.

Cuttings rooted in a mist bench (Figure 3.11) will rapidly make sufficient growth to provide approximately ten further cuttings within 4–6 weeks. Since cuttings are only in the mist unit for 10–14 days, two or three batches can be put through in each 4–6 week period. Quite soon the factor limiting the rate of multiplication is the capacity of the mist bench rather than the number of soft wood cuttings available.

The advantages of this form of rapid multiplication were soon appreciated. New cultivars can be bulked up for large-scale planting much more rapidly than was previously possible and this is extremely important at times when growers have an urgent need to change varieties. Since only small nuclear stocks are required to commence the process each season it is possible to ensure that these are true to type and, even more importantly, that they are free from infection with the various virus diseases that can severely affect productivity (Chapter 8).

When cuttings were taken from plants in a commercial hop garden there was no check on their virus status and this resulted in considerable spread of such diseases. With the adoption of mist propagation of virus-tested stocks there was a rapid improvement in the situation. In England for example, a survey showed that all the available stocks of the established cultivars were 100% infected with prunus necrotic ringspot virus but this changed very rapidly as a result of large-scale planting of new varieties that were available free from this virus. Over the two seasons 1973 and 1974 some 25% of the total English hop area was replanted with healthy stocks and the process has continued at a slower rate since then. It was calculated that in 1976 the value of the English crop was increased by £1 million as a direct result of the virus-free status of the newly planted material (Thresh, 1979).

Another possible method of rapid propagation could be by tissue culture which has been adopted on a commercial scale in South Africa but elsewhere it offers little advantage for a crop that can be multiplied so rapidly and successfully by mist propagation.

3.11 FACTORS AFFECTING QUALITY

The quality of hops is assessed by a combination of chemical analysis and evaluation of appearance and aroma. The appearance of a sample can be adversely affected by damage from pests or diseases, by wind bruising, by the presence of extraneous matter or by faulty drying methods. These topics are dealt with in the relevant chapters.

Chemical analysis is concerned principally with the α-acid content of the sample and there have been several investigations into the factors that might be responsible for the considerable variations in α-acid that occur in samples of the same cultivar between farms and between years.

It has been difficult to relate quality to different cultural practices other than effective control of pests and diseases. Burgess (1935) showed that omitting any of the major nutrients from experimental plots for 10 years resulted in considerable reductions in yield but that quality was not affected. Keller and Magee (1952) found that applications of nitrogen in excess of normal practice resulted in significant lowering of the total soft resin and ß-fraction but not of the α-acid contents. There was no significant correlation between yield and resin content. Thompson and Neve (1972) reviewed the evidence on manuring and concluded that only small effects of manuring on α-acid content had been demonstrated. Where there had been a response, the most consistent effect had been a decrease in α-acid with increased nitrogen applications whereas high potash usually had the reverse effect.

Thompson (1957) reported largely inconsistent effects of height of wirework or plant spacing on α-acid content of four cultivars in 1954 and 1955 while a subsequent height and spacing trial also indicated negligible effects (Thompson, 1967). In both these trials there were significant differences in yields of cones between treatments and these led to corresponding differences in the yields of α-acid per hectare.

One cultural treatment that does have a considerable effect upon hop quality is the elimination of male plants in order to produce seedless cones as described above (section 3.8).

The effects of replacing hand picking by picking machines have been investigated and at Wye Thompson and Neve (1972) reported α-acid contents from 7–11% lower in machine-picked samples. The lower values were partly due to dilution of the cone material by leaf and stem extraneous matter but was mainly due to loss of lupulin from whole and apparently undamaged cones. More recent experience with the cultivar Yeoman has shown that the belts of picking machines working on seeded hops rapidly become coated with thick layers of lupulin whereas this does not happen with the less open cones of seedless hops. In Yugoslavia, Spevak and Kisgeci (1982) reported losses as high as 20% in machine-picked hops compared with those picked by hand.

The major factors affecting quality are undoubtedly environmental conditions. Burgess (1964) quotes Méneret and Svinareff (1955, 1956) who concluded that α-acid content depended upon the amount of sunshine during the development and ripening of the cones but that it might also be influenced by the amount of rain during maturation. Zattler (1960a) had shown that shaded hops had a lower resin content than unshaded ones and that those produced in a glasshouse had a higher content than those grown outside at a lower temperature. Zattler and Jehl (1962) concluded that a hot, dry summer with much sunshine during cone formation gave lower resin contents than a moist summer with lower temperatures and a normal amount of sunshine.

Burgess himself examined data for the English crop and found strong indications that total soft resin content increased rapidly with higher August temperatures with no falling off at the highest temperatures. There appeared to be a similar increase in α-acid but with a lessening response at the higher temperatures. July temperatures did not appear materially to influence either total soft resin or α-acid levels.

Smith (1970) examined data relating to several cultivars grown in various European countries and concluded that there was convincing proof that mean air temperature over the last 40–60 days before maturity exercised a strong influence on the α-acid content. He also suggested that very high temperatures (over 26°C) had an adverse effect. Lyashenko (1985) found that temperatures as high as 18°C reduced α-acid content.

Farrar (1971) carried out a survey of several gardens of Bullion hops in England during 1969 and 1970 but was unable to identify any factor that was of practical value in helping a grower to improve or maintain the α-acid level of the hops. He concluded that any small effects of changes in management would be masked by climatic and geographical considerations that would be beyond the control of the grower. However, there was little correlation between the α-acid contents of each site in 1969 and 1970 which is difficult to explain in terms of climate or geography since they were all located within a relatively small area.

Thomas (1980b) submitted the analyses of the whole of the English crop for the years 1971–1978, which were available from the laboratory of the Hops Marketing Board, to multiple regression analysis in an effort to establish which weather factors were related to α-acid content. He found a high correlation with the mean temperature from 24 May–21 June whereas temperature or sunshine during the cone-ripening period of August appeared to be of secondary importance. Lewis and Thomas (1982) investigated the variations in α-acid content within the same cultivar and found they were due to differences in the ratio of resin gland numbers per unit weight of cone material and/or differences in the α-acid content of the glands themselves.

The correlations found from the 1971–8 seasons were used to predict the α-acid levels of the 1979–83 seasons. Whereas good predictions were made in 1979, 1980 and 1982, there were wide divergences in 1981 and 1983 (Thomas and Darby, 1984). This led to the proposition that the final α-acid content could be the result of a series of interacting weather factors which they listed as follows:

1. factors affecting cone weight;
   (a) during flower initiation;
   (b) during pollination (seeded crops only);
2. factors affecting resin gland numbers per cone;
3. factors affecting resin gland size;
4. factors affecting the percentage of resin in the glands.

The final α-acid content would result from a combination of these and possibly other factors. A mathematical model was constructed which assumed, amongst other things, that these factors combine in a multiplicative rather than additive manner. This model was used and indicated some highly significant associations which supported the contentions of Thomas that May/June weather and of other workers that the cone-ripening period were of crucial importance. It is unfortunate that this hypothesis has not been tested in subsequent seasons.

Versluys (1982) examined Australian data and found low levels of correlation from applying Thomas's hypothesis. He found that minimum and maximum temperatures during January and February fluctuated less in years when α-acid contents were high and deduced that there were high and low temperature thresholds which, if exceeded, depressed α-acid synthesis. He calculated the best fit of these two limits with α-acid content were when he chose a critical period from 18th January–7th February and threshold temperatures of 10.4°C and 23.1°C. That critical period coincided with the flowering stage of the main Australian cultivar. He introduced, as an additional factor, the fluctuations of minimum and maximum temperatures during the critical period and developed a formula to fit the data for the years 1973–80 which he then used successfully to predict the α-acid content of the 1981 crop.

He applied his method to English data for the two cultivars Northern Brewer and Bullion with similar results except that there was no negative effect of temperatures above a threshold maximum. When he examined the limited German data he decided that the temperature effects were the same as in Australia.

Diseases can also have very significant effects upon the α-acid content of infected plants. Royle (1969) reported that increasing severity of infection with downy mildew significantly reduced α-acid content. Virus infections, especially with prunus necrotic ringspot virus, have been shown to have a very important effect upon α-acid content. This is described in more detail in section 8.5.

CHAPTER 4

Harvesting

4.1 PICKING

Possibly the most economically important development in the methods of hop production was the transition from picking hops by hand to the use of machines. Mechanical harvesting commenced in the USA in the early part of the 20th century but did not become normal practice until labour shortages during World War II accelerated its adoption. The Productivity Team Report (1951) states that by 1951 more than 85% of the USA hops were picked by machine.

The American lead in this was followed by England when an American machine was imported in 1922 but proved unsuccessful. In 1935 the first English machine was installed and by 1952 some 10% of the crop was harvested by machine. This figure had increased to 65% by 1958 and 90% by 1963.

In the Federal Republic of Germany, the first picking machine was one imported from England in 1955 but thereafter locally produced machines were installed very rapidly and by 1963 they were being used on 85% of the crop. There were similar developments in other countries. In Czechoslovakia too the first machines were imported but much effort was then put into developing their own equipment.

4.1.1 Hand picking

Over the years there have been many changes in the way hops have been grown and these have sometimes necessitated corresponding changes in harvesting methods.

Because most hop cones are produced out of reach from the ground, the bines need to be lowered in order that the hops can be picked. When the bines were trained up poles, the poles themselves had to be lowered. However since they were firmly embedded in the ground it was necessary first to raise them clear. The method was described by Reynolde Scot (1576)

And bicause, when the hylles are made great, and raysed high; you can neyther easily pull up any, nor possiblye pull up all your Poales except you breake them . . . I thought good to shewe you an Instrument wherewith you shall pull them up without disease to your selfe, destruction to your Poales, or expence of your money, the charge beinge onelye fourtene or fiftene pound of iron wherewith the Smith will make you a paire of Tongues . . . or Pynsers, of the fashion here set downe.

The pole was gripped by tongs (Figure 4.1) and prised out of the ground using a block of wood as a fulcrum. First, however, the bine had to be cut at the base to separate it from the rootstock so that the pole around which the bine was tightly twined was free to be lifted.

With the introduction of permanent wirework systems, in which the bines were trained up either string or thin wire, it was possible to lower the bines in order to pick them without having to sever them from the rootstock (Figure 4.2) and they could be left attached until after harvest was completed. Hall (1902) suggested that leaving the bines uncut might benefit the plants in the following season by allowing additional nutrient reserves to be translocated to the rootstock. In 1897 and 1898 one plot had been grown on poles and the crop in 1898 and 1899 was below that of the rest of the garden where the hops were under wirework. In 1899 the system was changed and the previously poled plot was left uncut at harvest. There was a partial recovery of yield in 1900 and this was complete by 1901.

Once the bines had been lowered to the ground the cones could be picked off by hand. This required the services of large numbers of people and the availability of an adequate supply of such temporary labour was one of the factors limiting the districts in which hops could be grown. Most of this labour for southern England came from London and for the west Midlands from Birmingham. Farmers had to provide shelter for the pickers during their stay on the farm though this was usually of a very poor standard. Nevertheless, in the days before paid holidays, hop picking provided the only opportunity that most of the pickers ever had to visit the countryside and the work was popular for that reason.

In England the members of the same family or a group of friends might pick as a team. The hops were picked into bins or baskets. Some leaves would inevitably collect amongst the hops, and pickers were expected to remove these in order to obtain as clean a sample of hops as possible. At the end of each day the hops were measured out by volume on which payment was based. In the USA, on the other hand, pickers were paid by the weight of green hops (Productivity Team Report). This difference in procedure is possibly accounted for by climatic differences; in England the weight of the hops would be greatly affected by heavy dew or rain but these would not have had so much influence under the drier conditions in the USA.

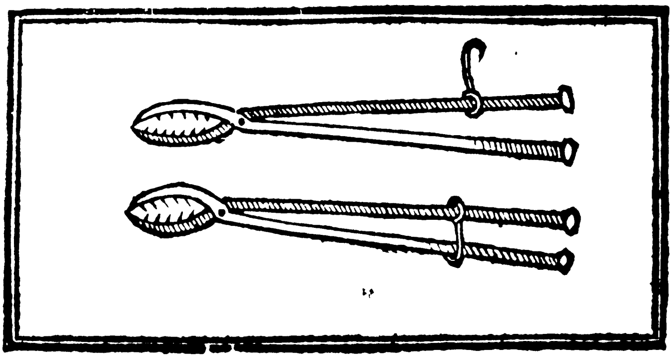
In the days when many hop pickers in England were illiterate the quantities of hops they had picked were recorded by means of wooden 'tallies', the two parts of which were laid together and marked with a file. Alternatively, the farmer would issue 'tokens' which were usually similar to coins that were locally made of a design unique to each farm (Burgess, 1964).

22 *A perfite platforme*

ſtake beſide the broken Poale, and to tye the broken Poale to the ſame, which maye vpholde the ſaide broken Poale, and preſerue the Hoppe. If the Poale be only broken at the nether ende, you maye ſhoue the ſame Poale againe into the hill, and ſo leaue it.

Of pulling vp Poales.

AND bicauſe, when the hylles are made great, and rayſed high; you can neyther eaſily pull vp any, nor poſſiblye pull vp all your Poales except you breake them. &c. eſpecially if the wether or the ground be drie, or elſe the Poales olde or ſmall, I thought good to ſhewe you an Inſtrument wherewith you ſhall pull them vp without diſeaſe to your ſelfe, deſtruction to your Poales, or expence of your money, the charge beinge onelye foure-tene or fiftene pound of I-



ron, wherewith the Smith ſhall make you a paire of Tongues, or (rather you maye call them) a payre of Pynſers, of the faſhion here ſet downe, the which maye alſo be made with woode if you thinke good.

Figure 4.1 'Pynsers' for pulling up hop poles (Reynolde Scot, 1576).

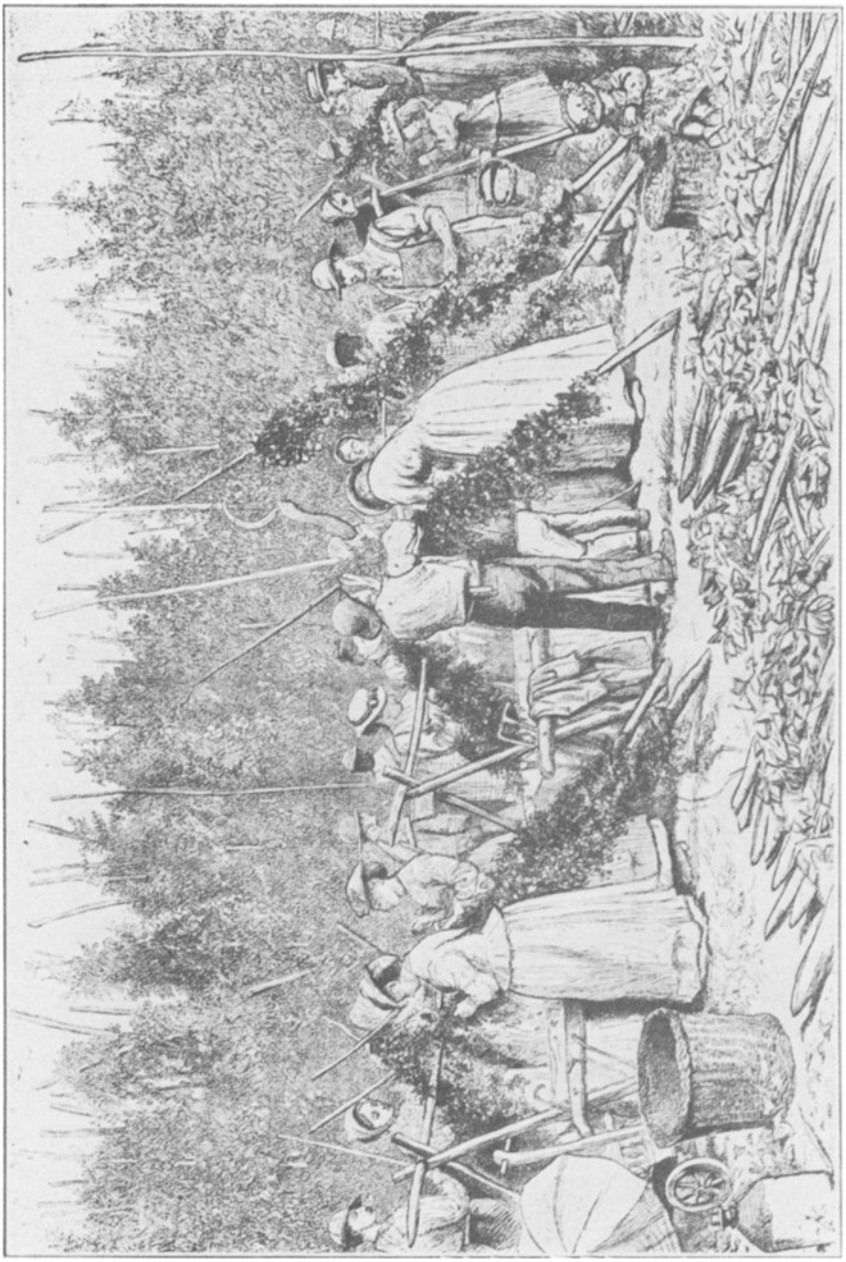


Figure 4.2 Hop pickers at work, 1874.

Figure 4.3 Hop pickers resting (drawn by 'Phiz').

Hand picking has been very largely abandoned in favour of machine picking in most countries, partly because of the cost but also because it has become increasingly difficult to recruit sufficient casual labour to do the work. One exception is China where there is not only sufficient labour available but the wirework system would not be suitable for mechanized bine collection.

4.1.2 Machine picking

Although there have been experiments with mobile mechanical harvesters that could pick the hops *in situ* as with hand picking, only static machines have so far proved of any importance and these require the bines to be cut in the field and transported to the picker. This again raised the question of the effects of cutting the bine on yield in the following season and led to fresh investigations.

Thompson (1959) reviewed six years of trials which showed that overall any loss of crop was negligible. He pointed out, however, that all the hops were harvested when fully ripe and suggested that the time of harvest might have an important influence. This comment is supported by observations in commercial practice where it is frequently necessary to start picking a cultivar before it is fully ripe in order that it is not too over-ripe by the end. Experience of many growers is that the first-picked gardens do suffer in the following season and this is particularly noticeable with the earlier maturing cultivars.

Williams (1962) carried out an experiment on hop plants in their first growing season to test the effects of stripping the leaves to a height of 1 m in late May and up to 1.5 m in early June, and also of cutting the bines at a height of 1.5 m at the end of the first week of September. Both stripping and cutting reduced yields in the following season and these were more than halved by the combination of both treatments. The reduction in yield was closely correlated with the starch reserves in the rootstocks at the end of the first season.

The Productivity Team Report (1951) described the types of picking machine then in use and there have been only relatively minor modifications since then. It was during the 1950s that attempts were made to develop the Harvestex machine which employed a totally different mechanism. Brown (1980) describes it as designed to operate by sucking the hop cones into circular orifices of special design; round the circumference of each rotated a knife which cut off the hops. The hops fell onto a belt while the leaves were carried away in the airstream. Although originally thought to be a promising idea several years' work failed to produce an effective machine.

Although such alternative mechanisms have been tried, all the machines in commercial use are equipped with a system that removes the cones from the laterals by means of wire loops (or 'fingers') which are usually mounted on rotating drums. The bines are transported past these, either hanging upside down between two banks of fingers or drawn horizontally, base first, over a line of picking drums.

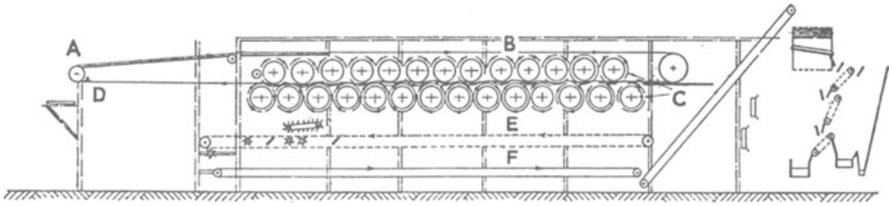


Figure 4.4 Layout of horizontal hop picking machine (Productivity Team Report, 1951),

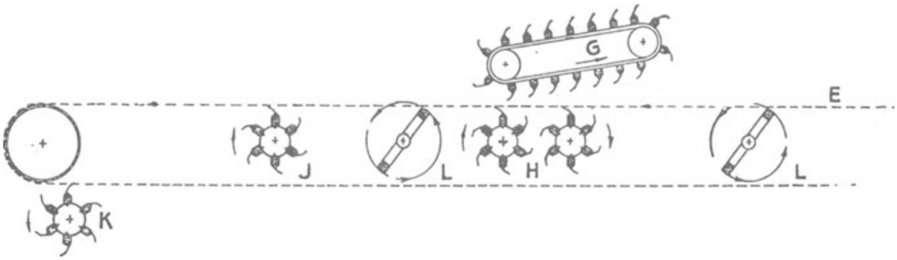


Figure 4.5 Layout of lateral picker (Productivity Team Report, 1951).

The earliest American machines had horizontal pickers (Figure 4.4) but in the 1950s vertical pickers were developed and these then became dominant (Riel, 1970). In Europe vertical pickers have been most widely used, the only exception being the Allaeys machine which had a horizontal unit.

In practice some laterals, with cones still attached, are stripped from the bines in the picking unit and these have to pass through a 'lateral picker' (Figure 4.5). The picked material then has to undergo a cleaning process to separate the hops from pieces of leaf, stem or other extraneous material. This is done by a combination of coarse mesh conveyors and spaced rollers through which the hops will fall while large pieces of leaf and bine will be carried to waste. This is followed by fan cleaners which suck leaf material onto a wire mesh, and then by inclined belts, travelling upwards, down which the cones will roll while flatter waste products are carried upwards and away (Figure 4.6). In many cases there is also a visual inspection on the final conveyor belt.

The bines are carried through the picking mechanism on a continuous bine track which is fitted either with clamps into which the bine bases are fixed or with hooks around which they are twisted. After they emerge from the picking unit the clamps are triggered to release the picked bines or a blade cuts the bines close to the hooks. The spent bines may then be chopped up and blown onto the waste heap or carried away unchopped.

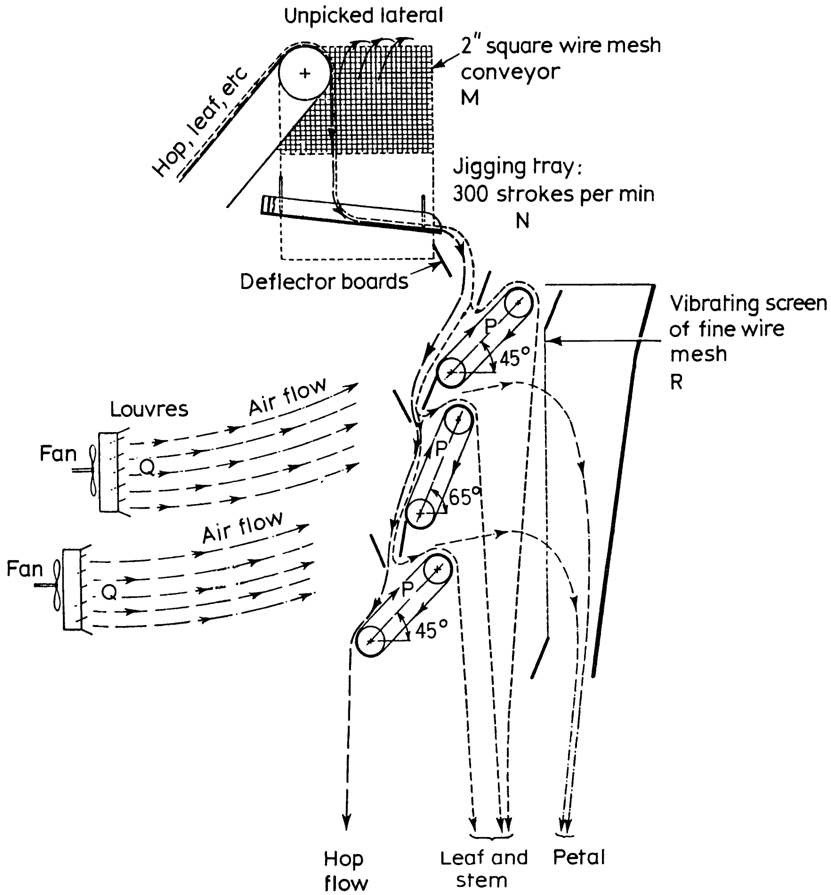


Figure 4.6 Layout of fan cleaner and inclined belts (Productivity Team Report, 1951).

Although the basic design of the picking machines has not changed there have been several modifications to ensure more efficient working. The most significant has been the installation of magazines which hold a reserve of clamps ready loaded with bines. This helps to smoothe out any irregularity in the supply of bines to the machine from the field.

The magazines can only guard against minor interruptions in supply and much attention has therefore been paid to the methods of collecting the bines from the field. They have first to be cut to separate them from the rootstock and this is usually done at a height of about 1–1.5 m since there are few, if any, hop cones below this point and the length of bine to be dealt with by the machine should be kept as short as possible. The bines then have to be detached from the top wire and the least sophisticated way of doing this is simply to pull them, from the ground, hard enough to break the supporting string. The bines are then thrown onto a trailer which carry them to the picking machine. This is hard work, not only pulling the bines down but also picking them up from where they have fallen and throwing them up onto the trailer.

The work has been greatly simplified by using portable crows nests which could be fitted into a socket on each trailer while it was being loaded and then removed and used on the next trailer. A worker climbs into the crows nest and cuts the strings close to the top wire and the bines fall into the trailer. The butts of the bines would mostly be laid between upright posts at the end of the trailer so that they were readily available for loading onto the picking machine without tangling. In the USA the crows nest was more commonly replaced by elevated tractor-mounted frames (Shea, 1980) (Figure 4.7).

Whereas in Europe it was normal to load the bines onto tractor-drawn trailers (Figure 4.8), in the USA trucks were frequently used, especially for long hauls which involved travel on public highways (Productivity Team Report).

More recently in the USA the operation has been mechanized by means of a reciprocating or rotating blade positioned to cut the bines just below the top wire by means of an hydraulically operated arm that is mounted on the front of a tractor which pushes the collecting trailer or truck along the row.

Alternatively in Europe, mechanized bine pullers have been introduced that cut the base of the bine and grip the severed end. As the machine moves further along the row it pulls the bines from the top wire and they fall onto a trailer which is towed behind the bine puller. In one system a single unit is attached to the tractor which serves a number of trailers while another system uses a considerably cheaper device, one of which is mounted on each of the trailers.

Labour costs for bine collection and transport to the machine are a major item for consideration and it is for this reason that so much attention has been paid to mechanization of the process. A better solution would be a machine that would harvest the hops in the field, thereby eliminating the need for bine collection entirely. Shea (1980) described mobile harvesters that had been developed in the USA. These picked the hops but did not clean them so they had to be transported to the static machine for this operation to be carried out. He reported that the picking machines were little used and attributed this to their capital cost and difficulties with maintenance.

Mobile harvesters are, however, the only suitable method for picking hops grown on the low trellis system. This wirework is low enough for the machines to straddle the rows and pick the hops by means of a bank of picking fingers on each side of the row. Because the bines are not inverted, as they are when loaded onto a static machine, the picking fingers work in an upward direction. Such a machine is in production in the USA to work on the 3 m high low trellis developed there while a prototype machine is being used in England for the dwarf hops growing 2 m high.

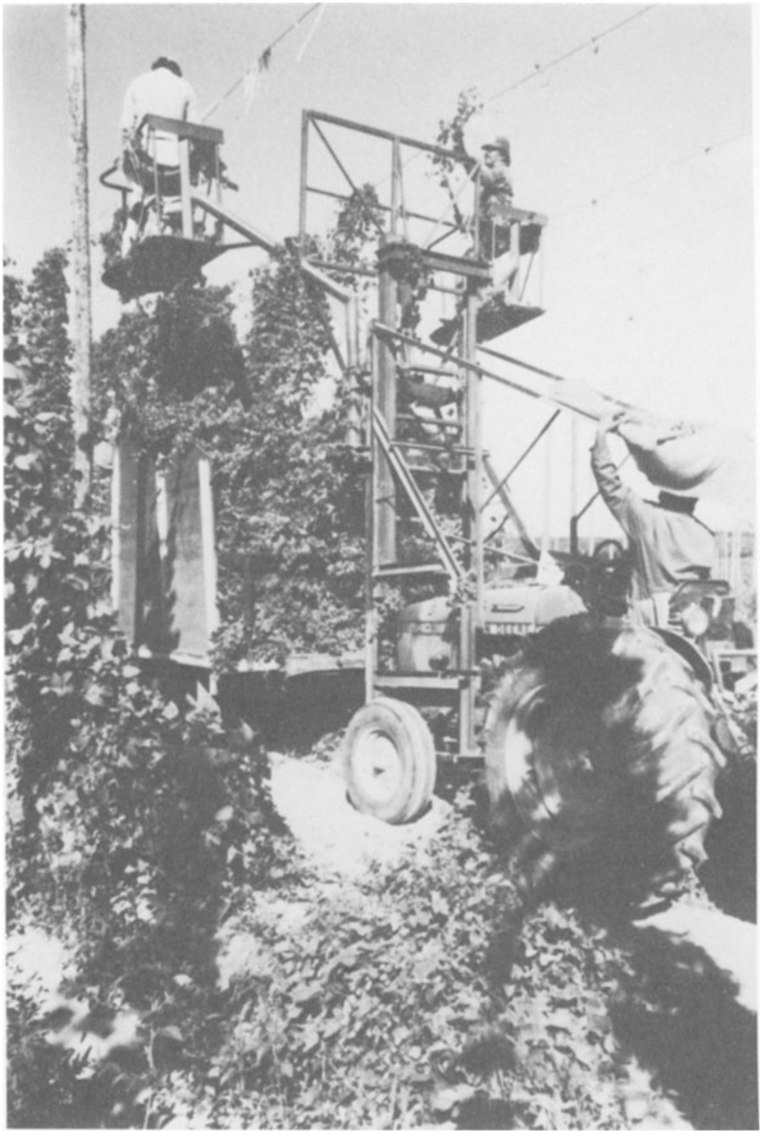


Figure 4.7 Tractor-mounted crows-nest in USA (Hopunion, USA).

Far greater economies would be achieved if the hops could be not only picked but also cleaned in the field and a machine has been developed in the Federal Republic of Germany which will do this. To ensure that the cleaning operation is successful this machine has a self-adjusting hydraulic system to keep it level and this contributes to the considerable size and weight of the

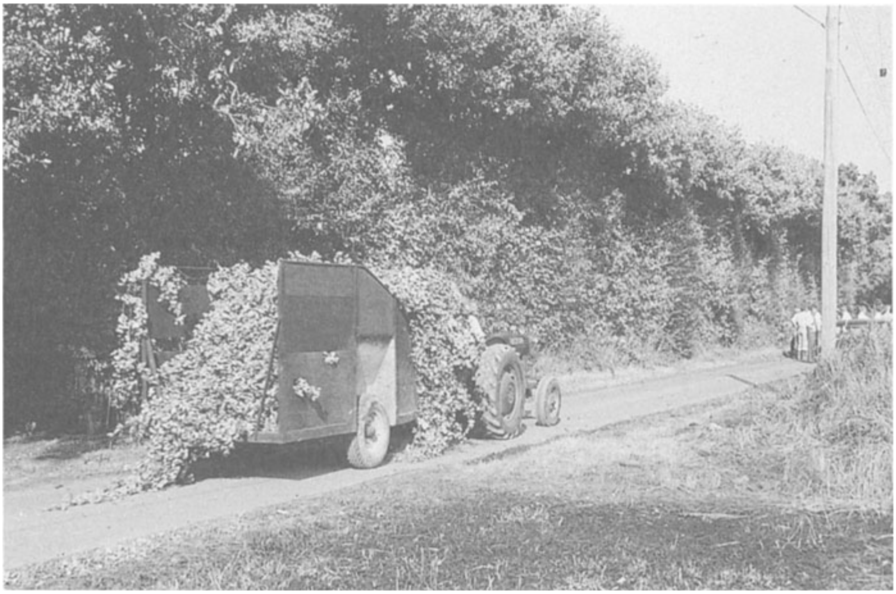


Figure 4.8 Hop bines transported by tractor-drawn trailer in England (IHR, Wye).

machine (12 tonnes). Trials with the two machines that were built showed that harvesting costs were reduced by 27% (from 3000 to 2200 DM/ha) but this advantage was offset by the high cost of the machine. The limited potential market for it meant that there was no scope to automate the manufacture and it would have to be constructed entirely by hand (Richtsfeld and Gmelch, 1982). So far it does not appear to have attracted much support in Germany where most hop farms are too small for its use to be justified and it is understood that the machines are now working in Czechoslovakia where the large collective farms are more suitable for it.

Another mobile machine which both picked and cleaned the hops was developed in England using a novel picking mechanism in which the bines were propelled round the inside of a large drum past the picking fingers. It was not so heavy as the German machine and it was claimed that its more compact form and design allowed it to turn within the hop garden, thereby eliminating the need for wide headlands (Catchpole, 1982). A prototype and one production model were produced but the results were not entirely satisfactory and production has now ceased.

4.2 DRYING

Hop cones at harvest have a moisture content of nearly 80% and this needs to be reduced to no more than 12% or the hops will not keep in good condition in storage. Apart from the risk of the hops going mouldy, Maton (1982) has recorded considerable losses of α-acid in hops dried to final moisture contents of more than 11% while Henderson (1973) has reported evidence of spoilage with moisture contents above 10.5%. To allow for variations within a batch of dried hops it is safer to aim for a maximum of 10%. In continental Europe the drying and packing of the hops is not completed on the farm where they are only dried to a maximum of 14% and loose packed for movement to a merchant's warehouse. At the warehouse several lots of the same variety and similar quality are blended, re-dried, sulphured to improve their appearance and baled. In other countries the whole procedure of drying and packing is carried out on the farm.

Makovec *et al.* (1978) described how in Czechoslovakia hops were, until the 19th century, dried with cold air in lofts and other such spaces. Houses built with such drying lofts are still to be seen in Europe, notably in the town of Spalt. These authors state that hot-air drying did not become the normal method until the end of the 19th and beginning of the 20th centuries. This is surprising since, in England, Scot (1576) described how to build and use an oast for drying with hot air which was based upon '*such an Oste as they drie their Hoppes upon at Poppering*' and the use of hot air appears to have been standard practice since then in England. As an appendix to his thesis Baker (1976) includes *An Account of Hopps by a Kentish Gentleman* which was probably written between 1707 and 1712. This account states that:

> The best way of drying hopps is with a charcoal fire on an oast or kiln covered with a hair cloth, of the same form and fashion which is used to dry malt on, which every carpenter or bricklayer, in countries where hopps grow or malt is made, knows how to build.

Makovec describes how the first kilns were very simple and consisted of a single layer on which the hops were spread and states that this type survived in the UK and Belgium whereas in Czechoslovakia this was replaced, as early as 1880 in some places, by several layers fitted with tilting, louvred floors so that the hops could be dropped from one layer to the next as drying proceeded. Such multitier kilns (Figure 4.9) became standard in central and eastern Europe but have only more recently been introduced in England.

The air was at first heated by burning charcoal but replaced later by coal. Since the hot air from the fire passed directly through the hops care had to be taken that it was free from contaminants. The fire had to be carefully stoked to produce the minimum of smoke while in England it was also necessary to use coal that came from selected pits where the arsenic content was extremely low. This followed the appointment of a Royal Commission in 1901 to inquire into cases of arsenical poisoning in Lancashire although the investigation found that the quantities of arsenic found in hops had in all cases been minute (Select Committee, 1908).

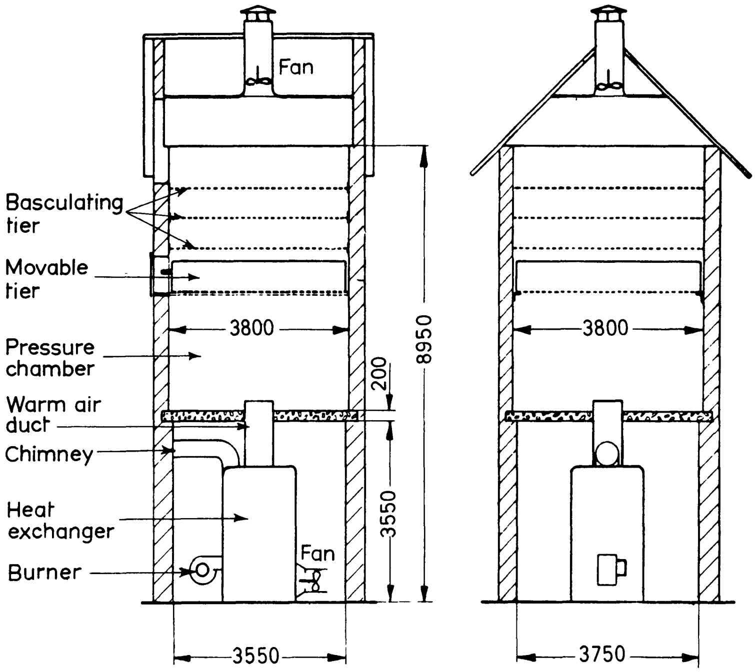


Figure 4.9 Layout of three-tiered kiln (Zeisig, 1970).

Contamination can be avoided by the use of heat exchangers which transfer the heat from the exhaust air to fresh air. Although Burgess (1964) states that a patent was granted as early as 1635 for a kiln in which the products of combustion did not come in contact with the hops, heat exchangers were first introduced on coal-fired kilns in America. Today most kilns are heated by oil and it is especially important to ensure that the hops are not contaminated by unburnt oil. In many countries heat exchangers avoid this risk but where they are not used, great care has to be taken with the setting of the oil burner to ensure efficient atomization of the fuel and sufficient air for complete combustion of the oil.

In the older systems the air flow through the hops depended upon natural draught and the traditional cowls of the English hop kilns turned with the wind to maximize the air flow. Burgess (1964) quotes air flows measured in such kilns as ranging from practically nil to a maximum of 19 ft/min (0.1 m/s). At a later stage electric fans were installed and these made it possible to dry deeper loads of hops and gave more control over the air flow through them.

There have in recent years been several investigations into ways of improving the efficiency of hop drying. When oil was cheap a major consideration was to reduce the labour requirement either by mechanization of the operation or by reducing drying times so as to minimize overtime payments to

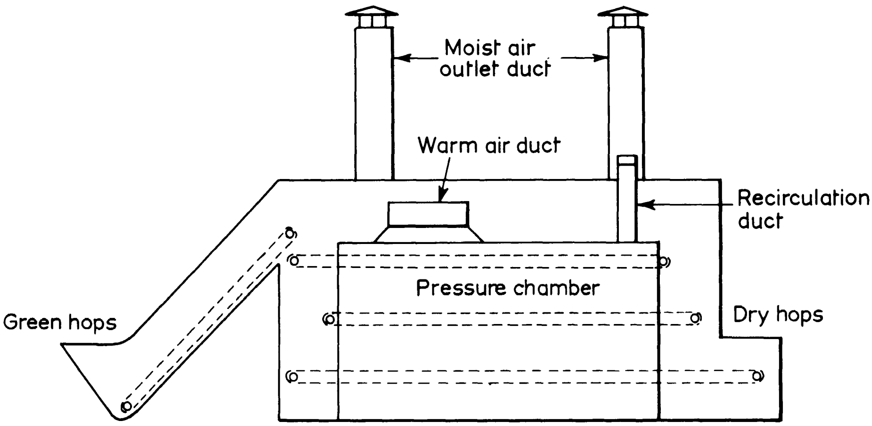


Figure 4.10 Layout of three-tier continuous drier (Zeisig, 1970).

the staff. Although shorter drying times could, in theory, allow growers to increase their drying capacity without additional capital cost, in most cases this would not happen because the time saved would be insufficient to allow for an additional drying cycle before picking started again the next day.

Following sharp rises in oil costs however the emphasis swung towards saving fuel, rather than labour. The most heat-efficient system would be one in which, after passing through the hops, the exhaust air would always be close to saturation. Single-tier batch drying is inefficient in the final stages because, as drying proceeds, the quantity of moisture removed becomes less and the exhaust air has only a relatively low moisture content. With multi-tier systems, fresh green hops are loaded onto the top tier each time that dry hops are removed from the bottom tier and this ensures that the exhaust air is at all times more nearly saturated so that less heat is wasted. The capital costs of such systems are, however, higher than those of single-tier systems.

A modification of the multi-tier system is the continuous drier in which the hops pass through the plant on three tiers of moving belts, falling from the ends of the upper and middle belts onto the one beneath (Figure 4.10). Driers of this type were developed in Germany, Czechoslovakia and Yugoslavia. The capital costs of such driers are again high and there can be rather more difficulty in controlling the system so that the hops emerge with the desired moisture content but they have the advantage that very little labour is required.

Burgess worked for many years on the principles of drying and the results of his and other work are summarized in his book (Burgess, 1964). Because the time taken for the hops in a load to dry depends upon their position in the load he introduced the concept of minimum time of drying as that required to dry

TABLE 4.1 Minimum times of drying at different temperatures. Mean values for a range of air speeds. (Summarized from Burgess, 1937).

Maximum temperature (°F)	Minimum time (min)
104	1072
122	532
140	329
149	265
158	237
176	123
194	82
212	56

an infinitely shallow layer of hops – which in practice meant a layer one cone deep. The additional time required to dry loads of greater depth was found to be proportional to the depth of the load and he called this the 'extra time'.

The relationship that he found between the temperature of the drying air and the minimum time of drying is shown in Table 4.1. Air speed had little effect upon the minimum time but the extra time was inversely proportional to the air speed within the bed of hops (Burgess, 1937).

The thermal efficiency of drying can be greatly modified by adjustments to the air speed and temperature. As the heated air passes through the hop bed and evaporates some of the moisture in the cones, its temperature will fall and its moisture content will increase. Its drying capacity will be greatest as it passes through the hops at the bottom of the bed and least when it reaches the top layer. If the input temperature is high and the air speed is low, so much moisture may be extracted from the lower layers of hops that the air becomes saturated before reaching the top and may then deposit moisture onto the cooler hops at the top of the load causing them to be discoloured – commonly referred to as 'stewed' or 'reeked'. For this reason it was traditional to commence drying at a lower temperature and raise it once the risk of such condensation was over.

Care must be taken that the temperature is not raised to the point where damage is done to the hops. Burgess (1931) carried out trials in which the air temperatures ranged from 40–100° C and found that the α-acid content of the finished hops fell steadily as the air temperature increased. At 100° C the α-acid level was little more than half that of the hops dried at 40° C. The colour of the hops also deteriorated as the temperature was raised. In most cases the adverse effect of the high temperatures on α-acid content continued in the subsequent storage period.

The hops being dried do not, however, reach the same temperature as the air with which they are in contact because they are cooled by the evaporation of moisture from them. This cooling effect is greatest at the commencement of drying when the hops contain the most moisture and the temperature differential decreases as drying proceeds. It should therefore be possible to use hotter air at the beginning of the drying cycle without heating the hops to the point where damage occurs but this would also require higher airspeeds to avoid reeking.

Zeisig (1970) showed that increasing the air speed through a 30 cm (12 in) deep bed of hops at 60° C could only reduce drying time by about 20% and that it had practically no effect once the moisture content of the hops had fallen below 45%. He therefore carried out experiments using temperatures ranging from 60–120° C (140–248° F) and air speeds from 0.28–1.27 m/s (55–101 ft/min) and found the drying time at the lowest temperature was 11.5 times as long as at the highest temperature and air speed. He realized that there would be damage to the hops under some of these treatments and added a curve to indicate the boundary of what he judged to be acceptable conditions.

A further problem was that as the air speeds were increased above 0.3 m/s (60 ft/min) the hops were lifted by the air stream and because of uneven loading they would be blown around causing damage and loss of resin glands.

He therefore suggested a design for a three-tier belt drier in which the air speeds would be high enough to lift and hold the hops to the underside of the belt above them, the top belt being provided with a mesh screen above it to restrain the hops. This required avoiding air speeds from 0.3–0.5 m/s (60–100 ft/min) since within this range the hops would not be stable on either the belt below or above them. Moreover, he advocated that for a bed of hops 27 cm (11 in) deep the distance between the top of that bed and the belt above it should be not more than 5–7 cm (2–2.75 in). By introducing a second air stream at a higher temperature to the green hops on the first section of the top belt he was able to recommend a two-stage regime with air for the green hops at around 100° C (212° F) at a speed of 1.45 m/s (285 ft/min) with the second stage operating at about 75° C (167° F) and 0.9 m/s (177 ft/min). In this work Zeisig was assessing the efficiency of the kiln in terms of drying time and thus the quantity of hops that could be processed in a given time and did not include any estimates of fuel consumption.

Maton (1982) dried hops at temperatures ranging from 50–75° C at two air speeds - 0.2 and 0.1 m/s (44 and 22 ft/min.) and found that at the lower air speed α-acid losses increased greatly as the temperature increased but at the higher speed there was little loss of α-acid at any temperature.

Shea (1971) carried out high temperature drying runs which started with air at 96° C and 0.6–0.8 m/s (120–60 ft/min) which was reduced in two stages to 71° C at 0.4–0.5 m/s (80–100 ft/min). The following season he carried out another series of experiments at temperatures between 60–100° C which were held constant throughout drying, again using high air speeds (Shea, 1972). In neither of these series was there any significant loss of α-acid although the appearance of the samples was seriously affected.

In order to operate at these high air speeds it was necessary to restrain the hops by means of a thin wire mesh laid on top of the bed otherwise the hops would have entrained in the air stream. Bailey (1958) found that dried bracts were moved by air speeds between 0.4 and 0.5 m/s (80–110 ft/min) while dry whole hops moved at about 0.76 m/s (150 ft/min). In practice it is not possible to operate with air speeds as high as this because uneven loading of the kiln results in spots with lower resistance through which the air speed is greater than average and these can become 'blow holes'. The problem is greater with deep loads and towards the end of the drying cycle. Thompson *et al.* (1985) have reported that hops can lift with air speeds as low as 0.15 m/s (30 ft/min) but this figure is surprisingly low and the limit of 0.3 m/s (60 ft/min) suggested by Henderson and Miller (1972) agrees with that recorded by Zeisig and is more realistic.

The air speeds that are quoted in these experiments are the averages but the speeds through different parts of the bed will differ as the loading can never be completely uniform and the resistance to air flow will vary as a result. With very shallow loads the resistance is so low that there can be only very small differences across the bed. With deep loading there is much more resistance with correspondingly greater variability.

The danger of blow holes developing as the hops dry and become less dense is not, however, only due to uneven loading but may also result from the shrinkage that takes place in the bed. This is very noticeable in the depth of the bed but it also occurs in the horizontal plane although this is not so obvious. One consequence of the lateral shrinkage is that a small gap develops between the hops and the kiln wall thus the air speed increases in this area and a significant amount of heat is wasted. This can be overcome by blanking off a 15–20 cm strip all round the edge of the floor. Cracks also tend to develop within the bed itself and, as the air accelerates through these, the surrounding hops begin to lift, the resistance to air flow decreases still further and blow holes can develop.

Various workers have used computer modelling to calculate the most efficient system for hop drying. Doe (1984) concluded that with a bed of 1.0 m (3.3 ft) depth the optimum air speed would be 0.194 m/s (38 ft/min) at 75°C.

Kranzler *et al.* (1984) used a computer simulation to compare various drying programmes and concluded that the most efficient would be MAT (Modified Airflow and Temperature) which commenced with a temperature of 82°C and airflow of 0.3 m/s (60 ft/min), these conditions being reduced to 70°C and 0.1 m/s (20 ft/min) as drying proceeded. They comment that this method would require a more sophisticated control system as well as fan and furnace modifications. The next most efficient system was one in which some of the exhaust air was recirculated once the low-humidity air had broken through the drying bed. They suggested that this would require additional ductwork and fans but Ellis and Winch (1983) have reported that it will work successfully with a cheap type of ducting leading from the kiln wall above the hop bed down to the main fan. The difference in pressure between these two points is sufficient to ensure recirculation and no additional fans are necessary.

The drier advocated by Zeisig introduced additional hot air to the green hops so that they could be dried at a higher temperature than those with a lower moisture content. A similar system is used on a few multi-tiered kilns. In most cases, however, it is the driest hops that are exposed to the hottest air. There could therefore be advantages in developing a system in which the hops and the air move in the same direction instead of the usual counter-current arrangement. This was one of the features of the prototype auto-continuous drier, designed to achieve short drying times at high temperatures with the minimum of labour, developed at Wye (Shea and Sykes, 1981). In spite of some promise the project suffered from many technical problems and was eventually abandoned.

Another development in recent years has been the conditioning of hops after drying. When hops are unloaded from the drying kilns there are considerable variations in their moisture content. Not only do the hops from the bottom of the load have a lower average moisture content than those from the top but there are also variations within the cones themselves. Whereas the bracts and bracteoles (the 'petals') dry quickly, the central strigs are sheltered within the cones and dry more slowly. Watson (1954) recorded moisture contents of 15% in the strigs of Fuggle hops at the end of drying when the bracts contained only 4.5%.

Bracts with such low moisture contents are very brittle and shatter badly if the hops are baled in this condition. If the dried hops are left in heaps on the cooling floor there will be a redistribution of moisture between and within the cones so that they reach a more uniform moisture content and will suffer less damage when pressed up. There will, in addition, be some transfer of moisture between the hops and the surrounding atmosphere, depending upon the relative humidity of the air and the extent to which the hops are exposed to it.

Skilled workers could manipulate the conditions on the cooling floor to some extent by covering or uncovering the heaps of hops or by opening and closing windows at times of the day to suit the ambient conditions. This was not only rather unreliable but the time required to achieve uniformity through the load could run into days, requiring more cooling space than was generally available. More rapid results can be achieved by blowing air at the correct RH through the hops and this process is referred to as conditioning and was first adopted commercially in Czechoslovakia (Vent and Makovec, 1970).

Henderson and Miller (1972) suggested using steam to bring the RH of conditioning air to 72–4%, which would bring the moisture content of the hops to 10–11% while Henderson (1973) published results of experiments to establish the equilibrium relationship between the relative humidity (RH) of

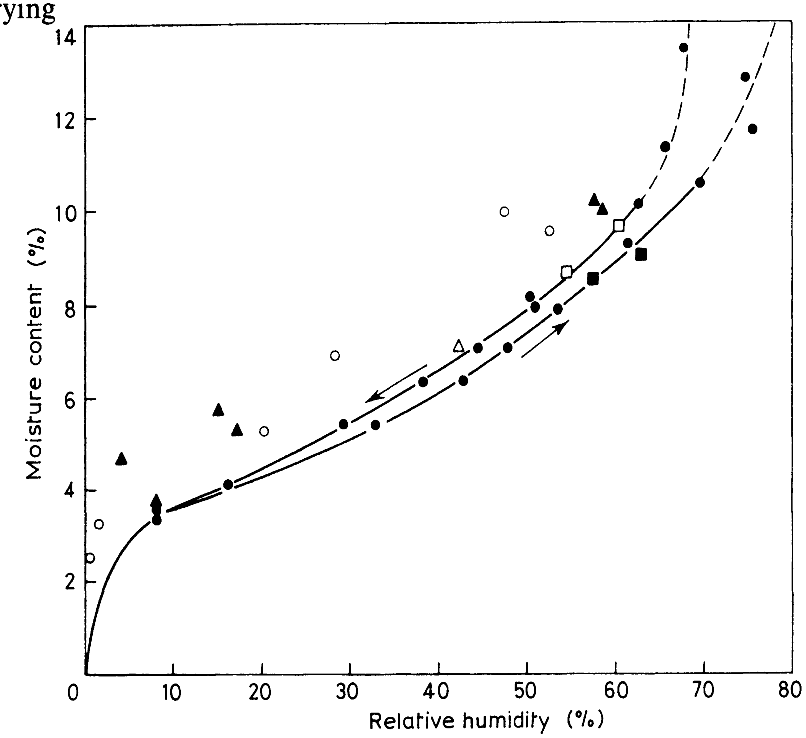


Figure 4.11 Equilibrium conditions for hops when drying, etc. (Henderson, 1973. Courtesy of *J. Agric. Eng. Res.*)

the atmosphere and the moisture content of hops exposed to it (Figure 4.11). His results suggested that a moisture content of 10.5% was the maximum that would avoid spoilage and this would be in equilibrium with air at 69% RH.

When freshly dried hops are exposed to such air the bracts will mostly absorb moisture while the strigs will generally lose it. Moreover, as with the drying process the bracts will respond more quickly than the strigs and will reach the equilibrium moisture content while the strigs are still too moist. If the hops are baled in that condition there would be a serious risk of spoilage. If conditioning was continued long enough the strigs would also reach the desired moisture content but this would take too long. In practice it is generally necessary to dry hops that are to be conditioned to a lower mean moisture content than those which will be left to equilibrate on a cooling floor with restricted exposure to the atmosphere. Conditioning has the advantages that the hops can be ready for baling in a matter of one or two hours after drying, without requiring cooling floor space, and the final moisture content can be close to the intended limit so that there is the maximum weight of hops for sale.

The large-scale hop enterprises on the state farms of Eastern Europe were especially suited to the introduction of mechanized harvesting and drying and Vent and Macovec (1970) described the development of the picking machines and multi-tiered drying and conditioning equipment that was developed in Czechoslovakia.

Figure 4.12 American hop kiln with automatic loading (IHR, Wye).

Although the principles of hop drying have been well researched and the fuel-saving benefits of multi-tier driers are well understood, they have not been adopted everywhere, probably because of the capital cost while single-tier operations can be operated very efficiently. This is particularly true in the USA where the very large hop farms are concerned to achieve a very rapid throughput with the minimum of labour.

Shea (1980) has described how some of the American ranches operate with large, single-tier units comprising five or six separate 'floors' each measuring 13.4 m × 13.4 m(32 ft × 32 ft) (Figure 4.12). These are loaded automatically and the even way in which the hops are spread makes it possible to dry deep loads with high air speeds without risk of the blowing through less dense spots in the load. It also results in more even drying so that the process does not have to be extended to deal with dense patches that dry more slowly.

Loads are 0.76–1.0 m (30–40 in) deep and the air temperature is 60–65°C (140–150°F). The hops are also unloaded mechanically by winding the hessian floor cloth onto rollers so that the dried hops fall either onto a conveyor or directly into a deep silo for cooling. Cooling times are not more than 24 h and are sometimes only 2 h. The hops are frequently cooled on the kilns with ambient air slightly heated by passage through the fan furnace unit. Since a large volume of air is drawn through the furnace unit, the lightly constructed walls of which retain little heat, the conditioning air soon resumes a relative humidity high enough to condition the hops.

In Belgium, Maton (1982) developed a fully automatic three-tiered kiln using an air speed of 19 m/s (63 ft/min) at a temperature of 65° C which gives a drying time of approximately 6 h. When the hops on the bottom tier are dry the fan and burner are switched off, and switching on a timer then automatically carries out the reloading sequence. The hops on the bottom tier are dropped onto a mesh belt which then conveys them through the kiln wall to another conveyor outside. The other two tiers are then dropped to the layer below. A container outside the kiln is loaded by blowing hops from the storage bin into it through a telescopic tube fitted with a distributor at the end. This container, which also has a louvred floor, is then wheeled into the kiln and the floor actuated to drop the hops in an even load onto the top floor of the kiln. At the end of this programme, which takes about 13 min, the fan and burner are switched on again.

Davey (1982) described the kilns that were in operation in Scottsdale in Tasmania. This is a four-tiered kiln with another loading floor above which can be ready filled with hops so that when required its solid, louvred floor can be operated to drop the hops onto the top floor of the kiln.

The objective with this operation is to achieve good fuel economy by trying to maintain the exhaust air completely saturated and to do this its RH is monitored by a direct-reading recorder. In practice the air cannot be maintained at 100% RH constantly and the floors are changed when the RH has dropped to 70% but the change from 100% RH to this level only takes 5 min or less. The best depth of load for fuel efficiency and throughput has been found to be 30 cm (12 in). The airspeed used is 0.5 m/s (100 ft/min) and the air temperature is maintained at 72° C (162° F).

This kiln is probably unique in having a pelleting plant in line with it. The hops are dried to approximately 6% moisture content and then moved to conveyors on which they can be conditioned by blowing moist air through them to bring them up to about 8.5% moisture content, thereby helping to equalize the moisture contents of the strigs and petals to aid hammer-milling the hops prior to pelleting.

In Czechoslovakia a great deal of work has been devoted to developing drying equipment and Fric *et al.* (1985) have described the TPD-3-K model which has a capacity of 1500 kg/h. It has a regulator which can control drying periods of 4–9 h and conditioning times of 1–2 h. Drying is carried out at 50–65° C (122–149° F) and the hops are dried to a moisture content of 7% which is brought back to 11% by conditioning.

Hops are sometimes exposed to the fumes of burning sulphur or to SO_2 to improve their appearance and possibly to improve their storage stability. It is particularly effective in removing some of the brown discoloration of hops that have been damaged by wind, pests or diseases.

In England and the USA the burning of sulphur in the plenum chamber of hop kilns during drying was a standard practice. It was abandoned first in the

USA but was continued in England until quite recently even though it made working in the kilns very unpleasant and it caused a lot of corrosion of metal fittings and equipment. Growers were reluctant to refrain from using it in case their hop samples appeared inferior to those of other growers who did use it. Eventually the brewing industry produced evidence that sulphured hops were inferior from their point of view and the practice was abandoned. In the merchants' warehouses in Europe some sulphuring is still carried out when the hops from the different farms are bulked, blended and redried.

In countries where the processing of hops is finished on the farm the dried hops are pressed into 'pockets' or bales. Pockets are the traditional pack used in England and to fill these it was necessary to fill the pocket with loose hops and press these several times before the pocket was full and could be sewn up. Today, many farms have installed bale presses with which a rectangular shaped bale can be filled with only two charges. This speeds up the operation and the bales take up less space in storage.

In Europe, where the hops are to be reprocessed by the merchant, they are only lightly pressed into large sacks on the farm so that they can be unpacked at the warehouse without too much breakage of the cones.

CHAPTER 5

Pests and diseases: historical review

Hops are subject to attack by several pests and diseases and the most serious of these, if not controlled, will reduce the crop to a level at which it is not worth harvesting. The few cones that might be produced would probably be themselves so discoloured that they would be unmarketable.

Because there was in England, for very many years, a tax on hops, there are nearly complete records since 1711 of the quantities harvested while since 1807 the acreage has also been recorded. From the latter date therefore it is possible to calculate the average yield for the country (except for 1862–5) (Table 5.1, Figure 5.1). These figures demonstrate tremendous fluctuations in yield from season to season. In 1825, for example, the average yield for the country was only 2.69 zr per hectare while in the following season it was up to 27.72 zr. In 1854 there was another bad year with an average yield of 4.09 zr, again followed by a very good year with 32.19 zr.

The unpredictability of the crop led during the 19th century, to the amount of tax collected each year becoming a popular subject for gambling. A book written by Lance in 1838 introduced the subject by saying: 'The gentlemen who anticipate the amount of duty while the crop is growing, and make wagers on what that amount will be, may find some assistance from the following table . . .' There followed two pages which include a table showing the amount of duty that would be raised from a range of average yields with comments which conclude as follows:

> The speculations on the duty, and the spirit of gambling which it inculcates, and which is so prevalent amongst the growers, dealers, and others, in the neighbourhood of hops, is by some considered to have an injurious effect, and appears to be the most dangerous attendant on hop growing, in nowise according with the sober meetings and habits of British farmers, who are in general industrious thoughtful husbandmen.

The main pest and disease problems that Lance described were flea beetles, aphids and mould (powdery mildew). From his and other accounts it is clear that the aphids were the most important cause of the damage which led to the great fluctuations in yield, though mould could also have serious effects. It is therefore remarkable that the only reference by Reynolde Scot in 1576 to pests or diseases is what appears to be a description of the flea beetle:

TABLE 5.1 English hop yields from 1807 to 1986. From 1946 the Hops Marketing Board included headlands in the area recorded as being under hops. This reduced the calculated yield by up to 10%.

Year	zr/ha	Year	zr/ha	Year	zr/ha
1807	13.6	1847	21.3	1887	18.1
1808	33.9	1848	21.8	1888	12.1
1809	8.5	1849	9.8	1889	21.6
1810	9.8	1850	27.9	1890	13.1
1811	21.1	1851	15.6	1891	19.6
1812	4.0	1852	24.9	1892	18.3
1813	17.3	1853	14.3	1893	18.1
1814	17.8	1854	4.0	1894	26.9
1815	15.1	1855	32.4	1895	23.6
1816	5.3	1856	22.8	1896	21.1
1817	7.3	1857	20.8	1897	20.3
1818	21.1	1858	24.9	1898	18.1
1819	24.6	1859	33.6	1899	32.1
1820	14.8	1860	5.5	1900	17.1
1821	17.6	1861	11.3	1901	31.9
1822	24.1	1862	no record	1902	16.3
1823	3.3	1863	no record	1903	22.1
1824	17.8	1864	no record	1904	14.8
1825	2.5	1865	no record	1905	35.7
1826	27.6	1866	13.3	1906	13.1
1827	14.6	1867	9.5	1907	20.8
1828	18.3	1868	18.3	1908	30.4
1829	3.5	1869	11.0	1909	16.6
1830	9.8	1870	29.1	1910	23.1
1831	19.1	1871	20.8	1911	24.9
1832	15.3	1872	25.9	1912	26.9
1833	16.6	1873	21.3	1913	17.8
1834	19.1	1874	11.5	1914	34.6
1835	22.6	1875	25.4	1915	18.3
1836	18.8	1876	15.8	1916	24.6
1837	16.3	1877	16.3	1917	33.4
1838	16.1	1878	24.6	1918	23.9
1839	20.3	1879	6.0	1919	28.1
1840	4.0	1880	16.6	1920	30.1
1841	16.6	1881	17.6	1921	23.9
1842	20.1	1882	4.5	1922	29.6
1843	16.1	1883	20.6	1923	23.3
1844	16.3	1884	15.3	1924	45.4
1845	17.1	1885	17.8	1925	33.9
1846	24.4	1886	27.9	1926	32.6

TABLE 5.1 *Continued*

1927	27.9	1947	32.9	1967	28.2
1928	25.6	1948	30.1	1968	27.9
1929	37.7	1949	28.4	1969	31.5
1930	32.6	1950	41.7	1970	34.7
1931	21.8	1951	35.9	1971	32.7
1932	28.6	1952	31.9	1972	26.0
1933	32.1	1953	31.1	1973	30.9
1934	36.1	1954	29.6	1974	31.2
1935	34.1	1955	31.6	1975	25.8
1936	34.6	1956	23.1	1976	26.9
1937	32.6	1957	32.9	1977	24.4
1938	34.9	1958	35.9	1978	32.1
1939	38.4	1959	27.4	1979	36.2
1940	36.4	1960	31.1	1980	34.1
1941	36.4	1961	25.9	1981	32.2
1942	35.7	1962	32.9	1982	35.1
1943	37.4	1963	33.1	1983	30.3
1944	32.6	1964	30.4	1984	31.0
1945	35.4	1965	31.4	1985	27.4
1946	29.4*	1966	28.2	1986	24.0

* Change to 'board acres'

The Hoppe that lykes not his entertaynment, namely his seate, his grounde, his keeper, his dung, or the manner of his setting, commeth up greene and small in stalke, thicke and rough in leaves, very like unto a Nettle, which will be commonly devoured, or much bitten with a little black flie, who also will do harme unto good Hoppes where the Garden standeth bleake, or the Hoppe springeth rath, but be not discomforted herewith, for the heate of the Summer will reforme this matter, and the later springs will be little annoyed wyth this flie, who (though she leave the leafe as full of holes as a nettle) yet she seldome proceedeth to the utter destruction of the Hoppe.

With such a detailed description of the flea beetle it is most unlikely that he would not also have commented upon aphids or mould if they had been prevalent at that time so it is interesting to enquire when these were first reported. An invaluable source of references for this is Parker (1934) who provides an exhaustive historical review.

The earliest account of either of these problems appears to be in a book by Worlidge (1669) who said of hops: 'They are the most of any plant that grows subjected to the various mutations of the Ayr, from the time of their first springing, till they are ready to be gathered; over-much Drought, or wet, spoyles them, mill-dews also sometimes totally destroys them.' Although this is a clear reference to powdery mildew there is still no reference to anything resembling aphids.

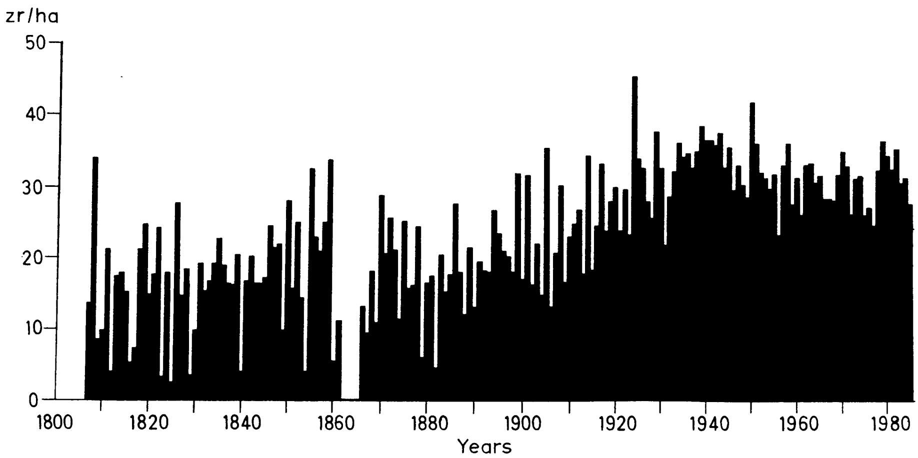


Figure 5.1 English hop yields from 1807 to 1986. (See Table 5.1.)

Leonard Meager (1697) referred to the attacks of insects: 'If you perceive the Flies, or any other Insects that bite and affect them, sprinkle the Vines with Water wherein Wormwood has been boiled, and it will preserve them.' This appears to be the first reference to control measures but is not very helpful in identifying the insects involved which are probably, again, flea beetles.

The earliest recognizable reference to aphids in England comes from Ellis (1750) who described the problems affecting the hop as follows:

Lice, Fly, Worm, Blight and the Mould or Dwindle. Lice are bred by Mill or Honeydews or Fogs. At a greater age its called the Collier Fly because it turns black and will then feed on the Sap of the Vines and Hops . . . Put Stone Lime on each Hill and the first rain will cause a fume that will do Service . . . Or you may make Use of the Dutch Squirt that casts its Water twenty Feet high and thereby washes off the Breed of Lice, Lady Bird and Slug or Snail that are bred and nourished by the Honey-dews.

A few years later, Mills (1763) described a disastrous attack of mould (or fen) in 1723 when the most flourishing and promising hops were all infected. He quoted the authors of the *Journal Oeconomique* on this disease:

. . .no other remedy from nature against this mischance, except rain sufficient to wash the plant, and clear it entirely from this fatal dew: but as rain seldom comes quite seasonably to the relief of the plant thus affected, artificial means have been sought for insuring it against this accident. Some have surrounded their hop-grounds with hogs dung; others have employed persons to go through the ground with vessels full of beech ashes, and to throw them upon the hops while the mildew was falling; and both sides . . . have even proceeded so far, as that each affirm their's to be the only remedy. Those who use hog dung say, that the ashes may probably hinder the action of the dew upon the plant; but that they must, at the same time, stop up its pores, and deprive the soil of its humidity . . . The partisans of the ashes say, that they cannot comprehend how hog dung laid around the hop-ground in the spring, should preserve such virtue as to destroy the bad quality of this mildew in the summer.

He also quoted an account of the 1725 season by Mr Austen of Canterbury, . . . 'who was a very great planter and an accurate observer'. According to this account the hops were infested with flies towards the end of April and, since this would be too early for migrant aphids, it probably refers to flea beetle. But then about the 20 May: . . . 'the flies appeared upon the leaves of the forwardest vines . . . About the middle of June the flies increased, yet not so as to endanger the crop; but in distant plantations they were exceedingly multiplied' and this is most probably a reference to the hop aphid.

Mills referred elsewhere to honeydew which is a common feature, from this time onwards, in reports on aphids and its seems unlikely that earlier writers would not also have noted it if aphids had been a pest of hops in their time. It does seem likely, therefore, that they did not become a problem until sometime in the 17th or early 18th centuries.

While there is no definite date for the first appearance of hop aphids in Europe, their arrival in North America appears to have been accurately recorded. Parker (1913) stated that they first appeared in New York in 1863 and that they reached the Pacific coast in 1890. It is very unlikely that live aphids would have been carried to America on fresh hop material and it is much more likely that they were introduced as eggs on shoots of *Prunus* which is their winter host.

Honeydew was the subject of considerable disagreement in the 19th century, some maintaining that it was excreted by aphids, others asserting that this was not true. Lance, for example, said that:

The strange notion is entertained, that this matter is the excrement of aphides when in reality it is a disease of the vegetable occasioned by their attacks. . . Bonnet has asserted that the juice emitted by this vine fretter, plasters over the upper side of the leaf, and this idea has been taken up by all writers on entymology since his time, without examining, or reflecting on the subject.

He then proceeded to argue that 'juice' from the aphids could not be distributed in the way that the honeydew was but, not surprisingly, he quoted no experimental evidence to support his view. He did however make more worthwhile comments upon the activities of the ladybird as a predator of the aphids (describing it as 'the principal antidote') and there are other dramatic accounts at that time of how the appearance of ladybird larvae (or 'niggers' as they were commonly called) saved the day when the crop was apparently doomed by heavy infestations of the aphids.

In the early 19th century efforts were made to control aphids but these were not very effective. Lance again: 'When once the leaves of hops are infected by aphides, it is almost useless to attempt a cure.' But a little later he said, 'Means have been tried, and sometimes with good effect, to destroy them in the progress of their growth, by fires and fumigating with sulphur and tobacco, which, when burnt immediately under them, is sure to occasion their destruction.'

It was not until spraying with a solution of soft soap was started about 1865, to which quassia was added a few years later, that any worthwhile control was achieved and such spraying did not become general until about 1883 (Burgess, 1964). The subsequent introduction of nicotine as an insecticide and the widespread adoption of sulphur to control powdery mildew resulted in a marked improvement in yields. The last really bad crop was in 1882 with a yield of 4.5 zr/ha. Since then the yield has never fallen below 13 zr whereas this had happened 19 times in the preceding 72 years.

Cousins (1895) described the use of soft soap and quassia but advocated as a better alternative the use of 'Paranaph' Soap which was a mixture of paraffin, naphthalene and soft soap which had been patented. The details of the mixture were not given and growers were warned that they needed a demonstration of how to make the mixture as it could cause serious scorching if prepared incorrectly.

Some early writers showed a remarkable appreciation of the way that spraying to destroy aphids could upset the ecological balance and they questioned whether the destruction of natural predators did not outweigh the direct benefit achieved by spraying. Any attempt to produce hops today without the use of insecticides results in even greater losses than those of the prespraying era, presumably because the widespread use of non-selective insecticides over the past 100 years has seriously depleted the predator populations.

Blattny and Osvald (1950) described the importance of predators as follows:

> Nature, which is superior to us, looks after both the increase and decrease of aphids. She enables the species to survive and she also created the natural enemies. Those predators do not permit the aphids to have control over hop plants and so over the hop growers. These natural enemies are helpmates in the struggle with aphids. The most important of them are the seven-spotted and the two-spotted ladybirds. We can say that without ladybirds and the other natural enemies we should have to spray against aphids every year.

It was not until the latter part of the 19th century that the life history of the aphid, overwintering on *Prunus* and migrating to hops in the summer, was understood. Ormerod (1890) says:

> It does not seem now to be open to doubt that a great part of the yearly attack of Hop Aphis, or 'Fly', comes on the wing from Sloe, Damson, or plants of the Plum tribe. This was long ago stated by German entomologists, also laid down by at least some of our Hop-growers . . . In 1887 Prof Riley set the matter of migration from Plum to Hop

beyond doubt by his observations of which a part was read before our own British Association.

It is understandable that the available records do not indicate when the long-established pest and disease problems first attacked the crop. In many cases the knowledge available at the time was insufficient to understand the cause of the symptoms observed. Even today the cause of some abnormalities is not known while, in the case of prunus necrotic ringspot virus, it is only recent research that has indicated the existence of a symptomless disease that seriously affects production.

In the 1920s, however, a new problem arose in Europe which was immediately identified and reported. This was downy mildew which had first been recorded in Japan in 1905 and later on wild hops in the USA in 1909. It was first observed and identified in Europe by Salmon and Wormald (1923) who found it in October 1920 at Wye on young plants raised from Italian seed. It could not be found in 1921, which was a dry year, in spite of a careful search, but 1922 was a wet year and it reappeared in the same garden on a number of plants in September. In 1924 it was reported as being endemic on wild hops in the south of England (Salmon and Ware, 1924) and by the autumn there was a heavy epidemic on cultivated and wild hops in several southern counties (Salmon and Ware, 1925). Because it occurred on wild hops at localities far from any known source of infection, the authors thought this indicated that the disease was indigenous and not introduced from abroad.

In 1924 there was a severe outbreak at Württemberg in Germany (Lang, 1925) and it was also present in Belgium (Marchal and Verplancke, 1926). In 1925 it was severe in Belgium (Lindemans, 1925), was widespread in France (Rials, 1926), made its first appearance in Bavaria (Korff, 1925) and caused some browning of cones in Czechoslovakia (Blattny, 1925). It was also reported in Yugoslavia from both the Vojvodina (Vrbovsky, 1928) and Savinja Valley (Terzan, 1927a) regions. In Germany the disease is referred to as 'Falscher Mehltau' (False Mildew) to distinguish it from the old powdery mildew which is now called 'Echter Mehltau' (True Mildew).

By 1926 it had been discovered in Italy near Perugia (Curzi, 1926) in Poland (Siemaszko, 1927) and on wild hops in north-west Russia (Naoumoff, 1928) while in Bavaria it devastated 60% of the crop (Sgd, 1927).

In 1927 it was reported on wild hops in Sweden (Juel, 1928) while in Russia it was found chiefly on wild hops in several widely separated localities, including the Caucasus '. . . in virgin forest, scarcely penetrated by man'. In 1928 a systematic search revealed its presence in several districts of West Prussia (Jaczewski, 1929).

This apparent spread throughout Europe led Salmon and Ware (1926) to change their mind about its origin and to conclude that it probably had been introduced from abroad and was not indigenous. Although this is now generally accepted, the rate of spread over such wide areas is quite remarkable, especially for an organism whose spores are only short-lived (section 7.1.2). It is interesting to note too that many of the records report it first on wild hops far from areas where the crop was cultivated.

The original account of the disease from Japan (Miyabe and Takahashi, 1905–6), as quoted in Salmon and Wormald (1923), states that it was first noted on cultivated hops at the Hokkaido Experimental Station in the early summer and that by mid-June it had spread to an alarming extent through the field. In view of this rapid spread it is surprising that they inferred that the disease had been present there for many years without attracting attention. It was also found on wild hops in Japan and Miyabe concluded that the mildew was, without doubt, indigenous to the country and had found the cultivated hops introduced from America and Europe to be a more congenial host (Salmon and Wormald, 1923).

The first American record on wild hops in Wisconsin in 1909 was by Davis (1910) who found it again in 1920 (letter quoted by Salmon and Wormald, 1923) and did not doubt that it was indigenous there. It was not recorded on cultivated hops anywhere in North America until 1928 when Salmon and Ware (1929) described how it was prevalent on cultivated hops at Sardis, British Columbia in 1928 and surmised that it was present in 1927 and possibly earlier. Since the disease was unknown in hop gardens in the USA they assumed that it had been introduced on setts imported from Europe. In the same year it was reported for the first time on commercial hops in the USA on a Bavarian hop farm in Otsego County, New York where '. . . it was evidently of recent introduction' (Dunn, 1929). In 1929 it appeared in the Willamette Valley, Oregon (Barrs, 1930) and in the same year Heald (1930) reported it in western Washington while it had spread to California by 1934. Although found on ditchside hops in eastern Washington in 1937 it did not affect commercial hops in the Yakima Valley until '. . . the calamitous year of 1947' (Romanko, 1964a).

This evidence suggests that the disease was so uncommon in America before 1920 that it is very unlikely to have been introduced in Europe from there (although Japan remains as a possible source). On the other hand, it was quite possibly introduced into American commercial production from Europe in a more virulent form than the indigenous disease reported by Davis.

A curious fact is that Salmon observed the disease in Wye in 1920 but did not report this until 1923. In the meantime the disease had been included in the Destructive Insects and Pests Order of 1921 on the grounds that it had been introduced from Japan to the USA and was there spreading but that it had not yet reached Britain. It had, in fact, reached Britain and there appears to be no evidence of it having been introduced into America from Japan nor of it spreading in the USA at that time.

Several of the sources quoted above suggest that the pathogen was present in Europe prior to the first reports. Rials thought that it had probably existed in the south of France for some years. Because of its widespread distribution and the fact that there had been no hop plants introduced, Jaczewski believed that it had a ubiquitous origin of long-standing on wild hops in Russia and that the various epidemics were brought about by unascertained ecological conditions. Curzi noted that the first report at Wye was on plants raised from Italian seed and suggested that the disease had existed previously in Europe. Moreover Baudys (1927) thought that it had been present for some time in Czechoslovakia without attracting attention and that it was definitely present on wild hops near Weisskirchen (Moravia) in 1924.

Marchal and Verplancke considered that it could have been introduced to Belgium on plants imported from England but nowhere else was movement of hop plants suggested as a possible source of infection while Lang states that there had been none to account for the first outbreak in Germany.

The most remarkable report of all is that the first serious occurrence of the disease was as early as 1894 in Vojvodina at the manor of Graf Kotec in Old Futog when it reduced the yield of the hops by a half (Terzan, 1927a, b, 1928). If this report could be confirmed it would certainly support the suggestions that the pathogen was indigenous and it would then be necessary to explain what could have led to the sudden epidemic throughout Europe. Romanko (1964a) suggested as several possibilities: the mutation of existing mild forms, hybridization of mild forms brought together by planting imported rootstocks, a shifting of the general world climate or changes in production practices. Hybridization would only lead to new forms if the resulting oospores were able to germinate and infect hop plants. As described in Chapter 7, oospore germination appears to be very infrequent. Could it be that hybridization had occurred throughout Europe before 1920 but that it was not until then that there was a year, or years, that were particularly favourable for oospore germination?

Once established, the disease caused dramatic reductions in yield in Germany in some seasons, Zattler (1928) reporting that in 1926 the average yield was only 2.15 zr/ha but that with an energetic spraying programme in 1927 it increased to 8.2 zr/ha. Magie (1942) reported that American growers in New York State who did not spray lost at least one-third of their crop in the average year. The damage caused by downy mildew was largely responsible for a shift in hop cultivation away from the Eastern States to the drier conditions of Washington and Idaho in the west (Skotland, 1961) but powdery mildew was also a contributing factor. Powdery mildew was first reported in New York State in 1909 and then gained steadily in importance (Blodgett, 1915). Whereas both diseases caused serious losses in the eastern states, downy mildew is much less of a problem in the west while powdery mildew does not occur at all.

In England, Beard and Derbyshire (1957) recorded a marked decline in yields of a garden of Golding hops over a seven year period during which most of the rootstocks became infected. Coley-Smith and Beard (1962) working in the same garden showed that the yield of infected hills was 27.7% lower than healthy plants. It is surprising, therefore, that the English yield figures do not indicate any general decline following the appearance of the disease in the 1920s. This may be because the other varieties being grown were not as susceptible as the Goldings. Fuggles, in particular, were noted as being highly resistant, not only in England but also in Europe where they were called Goldings, a confusing nomenclature that persists until now in Yugoslavia.

Although downy mildew has spread through all the hop growing areas of the northern hemisphere (with the possible exception of some of the Chinese regions), and also into South America, it has been excluded from South Africa and Australasia by strict quarantine measures. Salmon and Ware (1931) give a fascinating account of how these quarantine precautions were initiated in Australia:

> Hearing that a consignment of hop roots from this country was being sent (with the sanction of the Ministry of Agriculture and Fisheries) to Australia, we wrote to the official mycologist and to Dr E.J. Butler, Director of the Imperial Bureau of Mycology in this country, pointing out the great danger of this importation. Thanks to the prompt help given by Dr Butler, and to the action taken locally by the mycologist and agricultural authorities, a Proclamation was issued prohibiting the importation of hop plants into the Continent of Australia. Although the hops were landed, the Proclamation was just in time; the cases were never opened, and were eventually destroyed. It is very possible that the introduction of Downy Mildew into Australia has thus been prevented. It is satisfactory to know that New Zealand has recently legislated to the same effect.

Because Professor Salmon believed that he was responsible for the introduction of downy mildew to Europe on material imported from the USA, he was only too conscious of the potential danger to the Australian hop growing industry of that consignment of planting material.

Whereas in most countries the response to the outbreaks of downy mildew was to concentrate upon chemical control, in Germany there was also a more positive approach with the establishment at Hüll of a research institute having the primary objective of breeding varieties that were resistant to the disease (section 7.1.6).

Although the history of verticillium wilt also seems to be well documented there are increasing doubts about how this disease developed in England. It was first recorded in England near Tonbridge in 1924 (Harris, 1927) but it seems that this was merely the first time it had been identified and that it was already widespread in the hop growing areas but not sufficiently serious to attract attention. In 1938 it was noted that there were two types of attack which were either mild ('fluctuating') or severe ('progressive') in character (Keyworth, 1939). This was later shown to be due to mild and virulent strains of the fungus but more recent work has shown that there is now a range of strains of varying pathogenicity and it is thought possible that the original mild strain has changed to a more pathogenic form on more than one occasion.

No chemical control measures are available for the control of this disease and growers have to exercise careful hygiene to prevent its spread or, if that fails, plant cultivars that are resistant to it. Had it not been for the successful breeding of such cultivars, the virulent strains of the fungus would have devastated the English hop industry. Even so, there have been considerable losses in production though these have been due less to the direct damage to the hop gardens, which have usually been grubbed before too many plants were affected, than to losses caused by replanting with new cultivars and the delay before these were in full production. Many gardens in south-east England have had to be replanted more than once as the first of the resistant cultivars were superseded by newer selections that were either more acceptable to brewers, or able to withstand the attacks of the more virulent strains of the pathogen which developed.

In 1952 verticillium wilt was first recorded in the Hallertau district of Germany where it spread rapidly through the whole of the area and subsequently into the Jura and Hersbruck districts (Kohlmann and Kastner, 1975). The strains found there are not as virulent as the worst of the English types and the impact has not been so serious as in England. Even so there have had to be great changes in the types of hop that could be grown in the affected areas.

Although Australia and New Zealand have escaped most of the diseases that are found in the northern hemisphere, they have suffered considerable problems with black root rot caused by *Phytophthora citricola*. No effective control measures are available against this disease and it, too, has been countered by breeding programmes that have produced resistant cultivars.

Considerable confusion surrounds the history of the virus diseases of hops and this is not surprising since the very existence of viruses was for so long unrecognized while the understanding of individual virus problems has frequently involved years of research.

The best example of this confusion is to be found in nettlehead disease which was first recognizably described by Percival (1895) who gave it the alternative name of 'skinkly disease' and attributed the cause to damage by eelworms. It is considered by some people that Reynolde Scot's 'unkindly Hoppe' that 'commeth up greene and small in stalke, thicke and rough in leaves, very like unto a Nettle. . .' is a description of nettlehead disease but it could also be a description of shoots that had gone dormant (see section 1.6), especially as Scot added that 'the heate of the Summer will reform this matter. . .'. In 1925 Duffield found that eelworm was not the cause of nettlehead but it was not until some 40 years later that it was shown to be associated with infection by arabis mosaic virus (Bock, 1966).

There was further confusion between nettlehead and the 'curling disease' (called Kräuselkrankheit in Germany and kaderavost in Czechoslovakia) which were at one time thought to be the same. More recent work has indicated that the curling disease is not due to a virus but is a symptom of zinc deficiency (Schmidt *et al.*, 1973).

Nettlehead causes severe damage – reducing the yield of infected plants by over 75% (Legg, 1959b) – and it became so widespread that it was difficult to find any gardens that were free of it (Keyworth, 1945) and some growers found it necessary to abandon hop growing completely (Ogilvie, 1939). It must therefore have had a considerable effect upon the national yield figures. The spread of Verticillium wilt was of some benefit to this problem since the extensive replanting was mostly done with virus-free stocks and this contributed to a decline in the incidence of nettlehead.

There was also some confusion between nettlehead and hop mosaic which was first described by Salmon (1923). The symptoms of mosaic and nettlehead are not dissimilar and Salmon's old records can now be interpreted to show that as far back as 1906 he was describing mosaic-infected plants as suffering from nettlehead. MacKenzie *et al.* (1929) recorded that cuttings imported from Germany by a grower between 1904–8 appeared to have been carriers of the virus and to have caused widespread infection in the Golding hops amongst which they were planted. It is probable that Salmon introduced the virus to Wye in a similar way but because the infected plants were grown in a garden containing both susceptible and 'carrier' varieties the source was not as apparent as it was in the grower's garden. It seems certain that the virus was not present in England previously but it is not possible to estimate how widely distributed it was on the continent because few of the cultivars grown there are as susceptible as the English Goldings.

The methods used to control the virus diseases are described in section 8.4.5 but the most important precaution has been to ensure that only virus-free material is used when planting up a new hop garden. To achieve this several countries have organized supervised propagation of virus-tested stocks. The earliest was the 'A-Plus' Certificate set up in England in 1954. At that time the Ministry of Agriculture was operating, for other crops, an 'SS' (Special Stock) Certificate which indicated that the stocks had been tested and shown to be virus-free. In 1954 there was insufficient knowledge for such a standard to be applied to hops. Only nettlehead and mosaic could be tested for with any confidence so the A-Plus Certificate was introduced as a compromise that ensured that growers could obtain the best material that could be produced in the existing state of knowledge (Jary, 1955). In America, Skotland organized the propagation of selected clones of the Cluster hops and more recently a similar scheme has been set up in the Federal Republic of Germany. Research into hop viruses has also been actively pursued in the German Democratic Republic in order to ensure that planting material is of the highest quality.

In view of the new pest and disease problems with which growers have been faced it is a tribute to the efforts of pathologists, hop breeders and the chemical industry that it has been possible not only to maintain but to see increases in hop yields. The weight of hops harvested is, of course, only one part of the story. When the enhanced content of brewing material in modern cultivars is taken into account it is clear that there has, as described in Chapter 8, been a massive increase in production.

CHAPTER 6

Pests

6.1 DAMSON-HOP APHID: *Phorodon humuli*

Description

This pest is a problem in all the hop growing districts of the Northern Hemisphere except, according to reports, some areas in China. If uncontrolled it is capable of completely destroying the crop and even when control measures are taken they may not be entirely successful. The aphids feed by inserting their long stylets into the phloem strands of the leaf veins and can severely weaken the plant and cause defoliation. The main problem arises after cone formation because at that stage the insects feed within the cone and present a much more difficult target for spraying. It is at this time, also, that they cause the most damage. Even quite light infestations can seriously affect the commercial value of the hops because sooty mould grows on the honeydew produced by the aphids. This shows up when the dried hops are valued and causes them to be down-graded. More heavily invested cones turn brown and limp and many of them will be lost on the picking machine. Those that survive into the final sample can make it unsaleable.

The aphid is also of importance as a vector of virus diseases. It has been especially so in England where the Golding cultivars are unusual in being susceptible to Hop Mosaic Virus whereas other cultivars are symptomless carriers. It is important that the Goldings are grown sufficiently far-removed from other hops to prevent the aphids transmitting the disease from one to the other. The aphid is also reported to be a vector of American Hop Latent Virus.

The aphid overwinters on various species of *Prunus*, principally on sloe (*P. spinosa*), but also on damsons (*P. insititia*) and plums (*P. domestica*). The eggs are laid in the axils of the buds in the autumn (Figure 6.1) and hatch out in the spring to produce wingless females (virginoparae) that feed on the *Prunus* leaves and reproduce asexually, giving birth to living young. After one or two generations they then produce winged females (alatae, Figure 6.2) which migrate to the hop only when the flight threshold temperature of 13°C is exceeded (Muir, 1968). Soon after arrival the migrants commence producing the first of several generations of wingless, asexual aphids (apterae) which

Figure 6.1 Eggs of the damson-hop aphid overwintering on buds of *Prunus* sp. (IHR, East Malling).

build up in large numbers throughout the summer unless controlled (Figure 6.3).

Most aphids are attracted more to objects that are yellow than to those that are green and aphid traps are, for that reason, usually coloured yellow. Muir (unpublished) found that *P. humuli* was an apparent exception as he trapped more of them in green than in yellow traps. Campbell (1984) compared the numbers of aphids alighting on the normal green form of the cultivar Brewer's Gold and a yellow mutant of the same cultivar. Contrary to expectations, about 1.5 times more aphids settled on the yellow-leaved form and laboratory experiments showed that this was not due to differences in palatability.

A report from East Malling (Anon, 1969a) describes how practically all the aphids which settle to feed and reproduce are found on the rapidly expanding leaves at the top of the bine. They may alight directly on these leaves or else on the older ones lower down and walk up to the apex. When a barrier was placed below the fifth node, the numbers of alatae removed from the tip each day was 50–70% less than on control plants. The numbers were further reduced by half on plants from which all leaves below the fifth node were removed.

Campbell (1977a) found that 100% more migrants were found on strings with two bines than on those only having one bine and that there was a positive

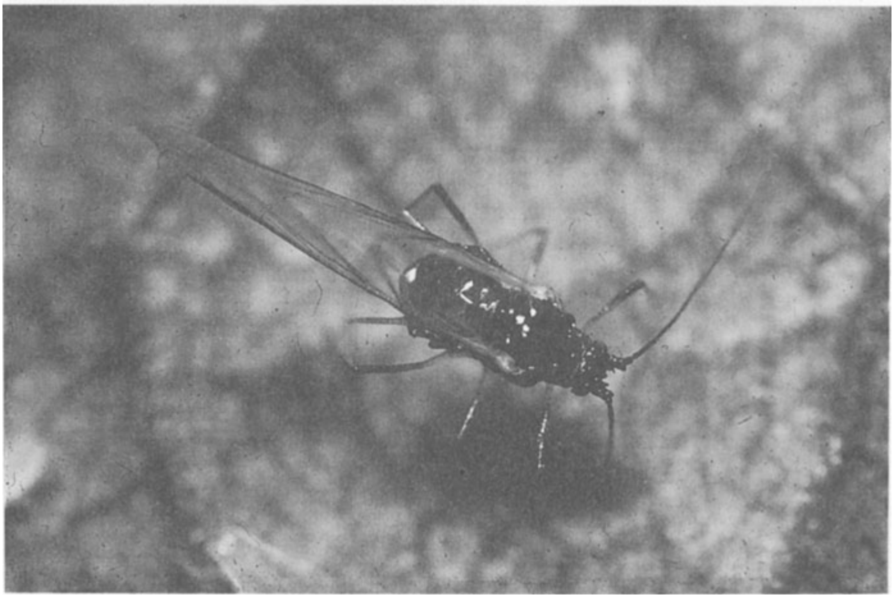


Figure 6.2 Winged migrant female of damson-hop aphid (Crown copyright).

correlation between bine height and aphid numbers. Plants next to poles were more heavily infested than those not at poles and migrants were more abundant on leeward than windward orientated strings. By comparing the numbers of alatae on hops with the numbers caught in a nearby aphid trap he estimated that most infestation was by aphids from sources within one hour's flying time.

The migrant alatae may not settle on the hop plant on which they first alight but any subsequent flights are short and will only be to plants close to the original one. At East Malling, workers marked newly arrived alatae and found that half a day later only 20–40% remained on the original plant (Anon, 1968). This report made no reference to the cultivar involved and it is probable that varietal preference is important in relation to the amount of post-arrival movement that takes place. Campbell (1977a) found that fewer migrants settled on the variety Tolhurst than on Northern Brewer and that Fuggle was intermediate. In this experiment the aphids had the possibility to move from an unpopular cultivar to one that they preferred but most commercial gardens are planted with a single variety and though the amount of movement from plant to plant may reflect the aphids' preference they will finally be forced to settle on that variety and in such circumstances preference may have little effect upon the migrant numbers.

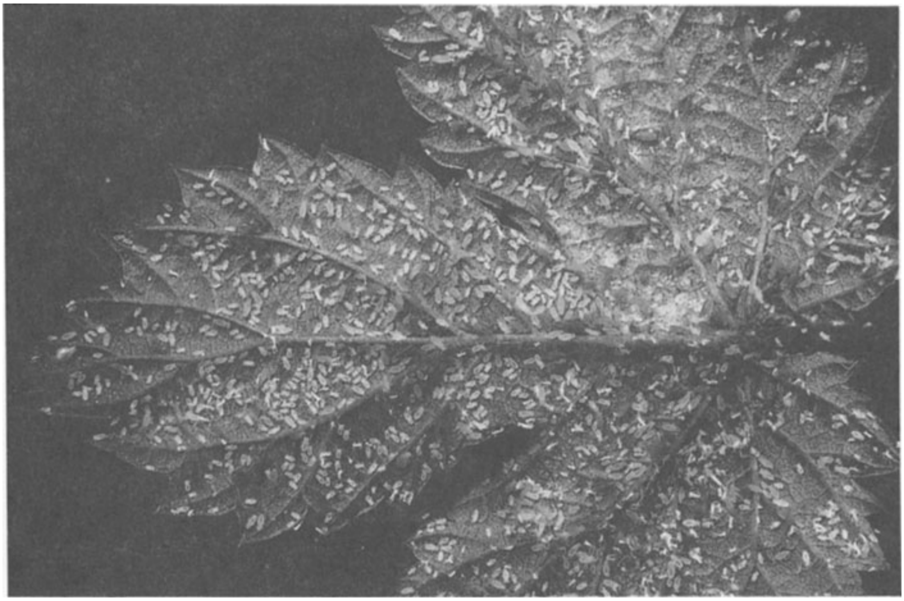


Figure 6.3 Leaf of unsprayed hop plant showing heavy infestation of apterae of the damson-hop aphid.

Differences in post-arrival movement are probably important in relation to the role of aphids as vectors of virus diseases since movements are likely to be more frequent in gardens planted with unpopular cultivars and this would increase the rate of spread of viruses (section 8.1). Most workers agree that the aphids on the hop produce no winged forms (alienicolae) that will move to other hops and Campbell (1984/5) concluded that, even if the few claims that such a morph has been observed could be confirmed, it would be such an infrequent event that it was of no economic significance. It is, therefore, only the aphids migrating from *Prunus* that are important as virus vectors.

Although preference may not, in practice, affect the size of the migrant population that settles on a cultivar it would be related to the subsequent multiplication rate if preference reflected the suitability of each cultivar as a food source for the aphids. Such a relationship is indicated by the results of Campbell (1983) who raised apterae on the same three cultivars and found that their capacity to increase was greatest on Northern Brewer and least on Tolhurst except at the lowest temperature when the positions of Fuggle and Tolhurst were reversed.

The migration to the hop commences in late May or early June but some wingless forms continue to be produced on the *Prunus* and these remain as a source of winged migrants until as late as July or early August. Campbell *et al.,* (1987) found that aphid populations persisted longer on cultivated plums than on hedgerow blackthorn or myrobalan. In September and October migration back to the *Prunus* winter host takes place. The wingless viviparous females switch from producing more of their kind to producing winged migratory females when the light period falls below about 13.5 hr/day although the critical daylength varies inversely with the ambient temperature (Campbell, personal communication).

The first winged forms to move from the hops (gynoparae) produce wingless females (oviparae) on the *Prunus* and these are then ready to mate with winged males which follow from the hops rather later. The males locate the oviparae by means of a pheromone released from glands in their hind legs. The fertilized females then lay the overwintering eggs on the *Prunus*.

It is of considerable importance to growers to know when the migration onto the hops will start and, more importantly, will end since the effective timing of control measures depends upon this. Extensive data on the migration periods have become available from a series of suction traps sited in different parts of Britain for the Rothamsted Insect Survey. Thomas *et. al.* (1983) investigated the relationship between the beginning and end of migration over a number of years with various weather parameters. They found that the commencement of migration was earlier when the maximum temperatures in late March and early April were higher and using this single parameter they were able to predict the starting date with considerable accuracy. Although it appeared that there was some association between dry weather in mid-January and, more particularly, early April, the prediction was not improved by including this factor. The end of migration was accelerated by high temperatures and sunshine hours in June but predictions based on this were only moderately successful.

According to Kriz (1966) the end of the migration does not depend upon the completion of a particular number of generations on *Prunus* since the number varies from year to year. It is affected by the ratio of total nitrogen to carbohydrate in the leaves; only the young ones being suitable in this respect for the continued production of apterae. As the production of young leaves diminishes and the diet changes, alatae are formed which migrate to the hop.

The annual migration to hops varies, not only in the time at which it starts and finishes, but also in the numbers of aphids that migrate, and the intensity of the infestation makes a great deal of difference to the control measures that are required. Control depends upon the use of chemical pesticides but in recent years there has been considerable interest in developing biological control. Although this has been primarily a response to difficulties with purely chemical methods, it has also been encouraged by increasingly strict regulations about pesticide residues in the hop cones.

6.1.2 Chemical control

The earliest materials used to control the aphids by spraying were soft soap, quassia and nicotine. Of these nicotine was the most effective and became the standard treatment until TEPP and schradan were introduced in 1946 followed by parathion in 1950 and demeton-*S*-methyl in 1952. There was then a period of about ten years during which control was based almost exclusively upon the organo-phosphorus (OP) insecticides demeton, demeton-*S*-methyl, parathion and thiometon applied as foliar sprays, and dimefox applied as a drench to the base of the bine (its high mammalian toxicity made it unsafe to use as a spray). These materials were so effective that for several years control of the aphids did not present a problem.

In the early 1960s, however, the first signs appeared of aphids that were resistant to these chemicals. Hrdy and Zeleny (1966) reported resistance to thiometon in Czechoslovakia while Muir (1979) found that by 1966 aphids from hop gardens in Kent were ten-times more resistant to demeton-*S*-methyl than those collected from the north of England where they were remote from spraying. By 1974 this level of resistance had doubled and by 1976 it had increased to 50 times that of the susceptible stock. Since the first signs of resistance to these aphicides, there has been a continuing problem of new chemicals being introduced and new, resistant strains appearing.

Initially it was possible to find new organo-phosphorus materials that were more effective than their predecessors. These included acephate, diazinon, dichlorvos, dicrotophos, disulfoton, mephosfolan, methidathion, methamidophos, mevinphos, omethoate, orthen, phorate and phosdrin but most of these are now of little value due to resistant strains developing. The rather surprising exception is mephosfolan which has been used for many years as a soil-applied material in England where it is still proving to be the most effective chemical available although increasing reliance upon it does mean that there is more danger of resistant strains arising.

There was hope of overcoming the resistance problem with the introduction of other groups of chemicals such as the carbamates (propoxur and methomyl), an organochlorine (endosulfan) and most recently the synthetic pyrethroids. Although the pyrethroids have been in use for only a short time there are already very high levels of resistance developing. Kremheller (1988a), for example, reported that resistance to cypermethrin increased 40-fold between 1980 and 1985. Numerous other accounts of the resistance problem are given in the Proceedings of the Working Group *Integrated Pest and Disease Control in Hops* (Hrdy and Hrdlickova, 1981 and 1984; Campbell and Hrdy, 1988) and this development leaves growers in a very serious situation.

The onset of resistance has been most rapid in European countries where the aphids are a very serious problem and where spray applications are frequent. Selection pressure is greater than in the USA, for example, where the aphids are less of a problem and some chemicals are consequently still effective in the USA although they have had to be abandoned in Europe.

There are differences, too, in the reported effectiveness of the same materials on different farms and it is widely believed that these reflect the efficiency with which the spraying operations are carried out. It is most important that spraying machines are checked to ensure that everything is in good order and that the nozzles and settings of the machines are correct.

6.1.3 Biological control

Mohl (1924) described how in Czechoslovakia ladybirds, lacewings, hover flies and birds were able to save growers from the ravages of the aphid if temperatures were high and there was plenty of sunshine. If, however, the nights were cool and high temperatures only lasted for a few days the aphids were dominant.

The important effect that predators had upon aphid populations there was stressed by Blattny and Osvald (1950) who pointed out that there were never two consecutive years of severe aphid damage because after one such year a large predator population carried over to the next season. Little attention was paid to predators for some years after that account, presumably because the newly developed insecticides gave such effective control. As the aphids have become resistant to many of these chemicals there has been renewed interest in predator activity.

Zeleny *et al.* (1981) studied the occurrence of predators and parasitoids over a 15-year period. Ladybirds (*Coccinellidae*) were the most common predator but many more species were recorded, some in significant numbers. An important observation was that it was only when aphid populations reached 50 or more per leaf that permanent colonization and reproduction by the predators occurred. With smaller aphid populations the predators only occurred sporadically.

Ruzicka *et al.* (1986) also stated that ladybirds are the most important predator. They reported a trial in which an attempt was made to control a population of aphids in a hop garden without using insecticides. The 0.9 ha hop garden was surrounded by a 52 ha pea field and several rows of mustard were planted inside the plot to attract predators. Conditions that season were favourable for the development of ladybird populations but not so good for the aphids. The aphid population declined sharply in July when large numbers of adult ladybirds migrated into the garden from the surrounding field and it may only have been the combination of such a migration and the favourable weather conditions that led to this successful result.

Hrdy (1981) reviewed the problem of resistance to pesticides in hops and drew attention to the potential effect on the environment of the increased quantities of chemicals being used. In the Bohemian hop-growing region this had increased in the period of 1967–77 from 3.5–8.3 kg active ingredient per hectare. He suggested that the problem could be reduced by, among other measures, ceasing to use an insecticide as soon as resistance to it developed and changing to one with a different mode of action. In addition only using them when absolutely necessary and using selective materials which would not be toxic to predators. Unfortunately there has rarely been an adequate choice of products to put these measures into effect.

Knan and Kremheller (1984) found that average populations of 200 aphids per hop leaf did not cause any damage before flowering and that it was only necessary to commence control measures when this threshold was reached. In England an infestation of this magnitude would be considered to be out of control.

The increasing problems with strains of aphids resistant to chemical control have focused attention upon non-chemical ways of controlling the pest. There had been early reports of differing susceptibility of hop cultivars to aphid attack (Gross, 1900; Hampp and Jehl, 1937) but these were of no importance at a time when chemical control was very effective. When evidence of resistance to OP insecticides began to emerge however, a start was made at Wye in 1965 to look for hop selections that showed resistance to the attacks of the aphids (Neve, 1966) but not until 1968 did this work show any promise. In that year the aphid migration started slowly and the most resistant cultivar in the trial, Tolhurst, survived the whole season without any insecticide treatment and was almost free from any infestation at harvest time. This was attributed to predators multiplying sufficiently quickly to control the smaller population of aphids that had built up on this cultivar (Neve, 1969).

It was thought from this experience that the predators were probably of greater importance than the rather low level of resistance that had been found within the hop population and for some years the research effort was directed towards methods of promoting the effectiveness of the predators. Some selection of resistant plants continued, however, the results of field trials being confirmed by laboratory experiments. Darby and Campbell (1988) identified one female and five male genotypes which were consistently less heavily infested than the standard varieties. A laboratory feeding experiment with these six genotypes and three control cultivars showed that four of the selections had marked antibiotic effects on the reproductivity of two strains of aphids although the OP resistant strain had a greater reproductive capacity than the other strain on all genotypes (Campbell *et al.*, 1987).

These resistant genotypes have been used as parents in a breeding programme, and testing of the progeny in 1988 indicated that the resistance is hereditary and not, apparently, sex-linked. The level of resistance in some of the progeny was better than that of either parent, especially when both parents were resistant (Darby, personal communication).

In the USA a similar search for resistant genotypes has been carried out by Dorschner and Baird (1988) by measuring the rate of increase of aphids caged on leaves of a wide range of material from the US Germ Plasm Collection growing under growth-room conditions. The most susceptible and the most resistant genotypes were plants collected from the wild, while less wide-ranging differences were recorded between commercial varieties, the aphids having low rates of increase on the German cultivar Perle and the American Chinook.

In Germany a collection of 125 male or female hops, collected from the wild, have been planted in a garden that receives no chemical control and are being recorded for the level of infestation with both aphids and spider mites. In 1987, 11 of the wild hops and the Yugoslav cultivar Atlas were recorded as aphid free (Kremheller, 1988b). Although Perle was recorded by Dorschner and Baird as showing resistance it is interesting that this was not mentioned in Kremheller's report although it is likely to have been tested. This might be a result of the different methods of testing since aphid preference for different genotypes could affect the size of the initial population on a mixture of plants in the field but not in the controlled experiments in the growth-room where the varieties were grown in isolation.

Romanenko (1985) reported that the polyphenol content of the leaves of hop plants was an objective criterion for measuring resistance to the aphid.

Campbell (1977b, 1978) reported that *Anthocoris nemorum, A. nemoralis* and the earwig *Forficula auricularia* were the most abundant predators of aphids on hops in East Kent and found in laboratory trials that each anthocorid would kill about 200 aphids during its nymphal development and about 35 per day during its adult life. During the latter part of the season he compared the populations of aphids that developed on bines where the aphids were exposed to predation with those on bines from which predators were excluded by sleeve-cages. In the absence of predators, aphid numbers increased rapidly but where predators had access they were very effective in reducing the numbers.

Aveling (1981a) extended this work by setting up plot trials to test Campbell's technique of controlling aphids during the early part of the season, before predators arrived in the hop gardens, by a soil drench of mephosfolan and observing the effectiveness of predators thereafter. Anthocorid bugs, especially *A. nemoralis*, were the most abundant predators and in the first two years aphids in the cones were controlled. In the third year aphids did build up in the cones but not to damaging numbers. When predators were excluded the cones were heavily infested.

If this was to be a practical technique for achieving integrated control it was important to know the extent to which the mephosfolan which was systemic within the hop plant would be toxic to the anthocorids. Aveling (1981b) reported that there was no evidence of toxic effects on anthocorid larvae or adults fed on aphids that had been killed by feeding on mephosfolan-treated hop plants. He did record increased mortality of eggs laid in the leaves of treated plants and this was greatest when the eggs were laid near the leaf margins where the concentration of mephosfolan was thought to be highest.

Because the aphids migrate to the hop crop before predators are present in any numbers, it is essential to provide some chemical control, at least during the early part of the season. Ideally, a selective insecticide should be used which is toxic to aphids but not to predators. Unfortunately materials that can be used in this way against other aphids are not effective against the damson-hop aphid. For this reason selective action has had to rely upon the use of soil applied materials such as mephosfolan that are taken up systemically by the hop plants. In this way the predators do not come into direct contact with the pesticide. Winfield (1981 and 1984) carried out field trials from 1977–83 to determine whether predators could control the aphids following an early-season mephosfolan drench but with only limited success. There were six hop gardens in the trials but in only two did the system work successfully in some years. Although anthocorids were the key predators in these trials, hover flies (*Syrphidae*), lacewings (*Chrysopidae*), earwigs (*Forficula* spp) and, in some years, ladybird beetles (*Coccinellidae*) were also common (Figure 6.4)

Although predator activity following mephosfolan treatment did not provide adequate commercial control of the aphids, it may well have contributed to the fact that this chemical, alone amongst the organophosphate materials, is still effective since resistant aphids that survive the chemical are liable to be destroyed by predators.

At present there does not appear to be an integrated control programme that will operate successfully but there are possible developments that could help to achieve this. Most promising amongst these is the breeding programme to develop the resistance of the hop plant to the aphid. It appears unlikely, at present, that this would provide complete protection by itself but it should greatly increase the possibility of predators providing an effective control.

Another possibility is that of artificially rearing predators that can be released into the crop to supplement those arriving naturally. Parker (1981) has published a method for artificially rearing anthocorids but it appears that, unless an artificial diet can be developed, the feeding requirements with live prey are likely to make the technique too labour-intensive for it to be commercially viable. The artificial rearing of lacewings, however, is more feasible and their release into a low trellis garden at Wye in 1990 gave good control with or without an early mephosfolan treatment. An alternative approach has been an attempt to attract egg-laying female lacewings to hops early in the season by spraying the plants with artificial honeydew just before the aphids were due to arrive from their winter host.This failed to work in 1987 because prolonged rain delayed spraying until the middle of June but it showed more promise in 1988 (Campbell, personal communication).

Whereas predators have been shown to be of considerable importance in controlling aphid populations it does not appear that parasites are likely to have a significant effect, even when natural populations are supplemented artificially. Campbell *et al.* (1987) released 10 000 adult *Aphidius matricariae* into each of two 48 hill hop gardens three weeks after the start of aphid migration and a further release of the same number about three weeks later. These releases had no detectable influence on the development of the aphid populations and very few parasitized aphids were found and the trials were abandoned.

There have been trials with the fungus *Cephalosporium* (*Verticillium*) *lecanii* as a pathogen of the aphid (Figure 6.5) but although it worked well in pots under glass it gave poor results in the field (Cranham and Firth, 1984).

Campbell *et al.* (1985) reported on trials with the aphid alarm pheromone (E)-β-farnesene which, when released by the aphids causes dispersal of other aphids feeding nearby. This compound substantially reduces the numbers of aphids settling on other crops but it did not noticeably affect the settling of damson-hop aphids when applied to hops. It did, however, cause the aphids to stop feeding and walk over the leaf surfaces. This activity would increase the likelihood of aphids coming into contact with any insecticide on the leaf surface and when leaves were sprayed with the pheromone, immediately followed by a spray of Thiodan (endosulfan) the mortality of adult apterae was 87% compared with 76% when Thiodan was sprayed without the pheromone.

Dawson *et al.* (1984) reported that hops are readily colonized by aphids even though the plants themselves contain this compound and they found that another sesquiterpene component of the essential oils, (−)-β-caryophyllene, inhibited the effect of the farnesene in the hops so that it did not act as a deterrent to colonization.

A possible method of reducing the aphid population would be to spray the sex-attractant pheromone, by which males are attracted to oviparae, in places where there were none, thereby reducing the chances of the oviparae ever being fertilized. The pheromone has recently been shown to be a nepetalactol and an effective attractant (Campbell *et al.*, 1990/91).

The prospects for continuing control of the aphid by purely chemical means are not good. Resistance to all groups of aphicides is already either well-established or showing clear signs of developing and no new types of aphicide appear to be forthcoming at present. The problem is being aggravated further by the refusal of some countries to permit the import of hops containing residues of pesticides not registered there. Because different countries have different pest and disease problems, the pesticides that they need to use (and which are registered) also differ and this is creating major problems for the international trade of hops. There is, therefore, likely to be great emphasis given in the near future to any technique which will reduce the dependence of hop growers upon chemicals for the control of this extremely damaging pest.

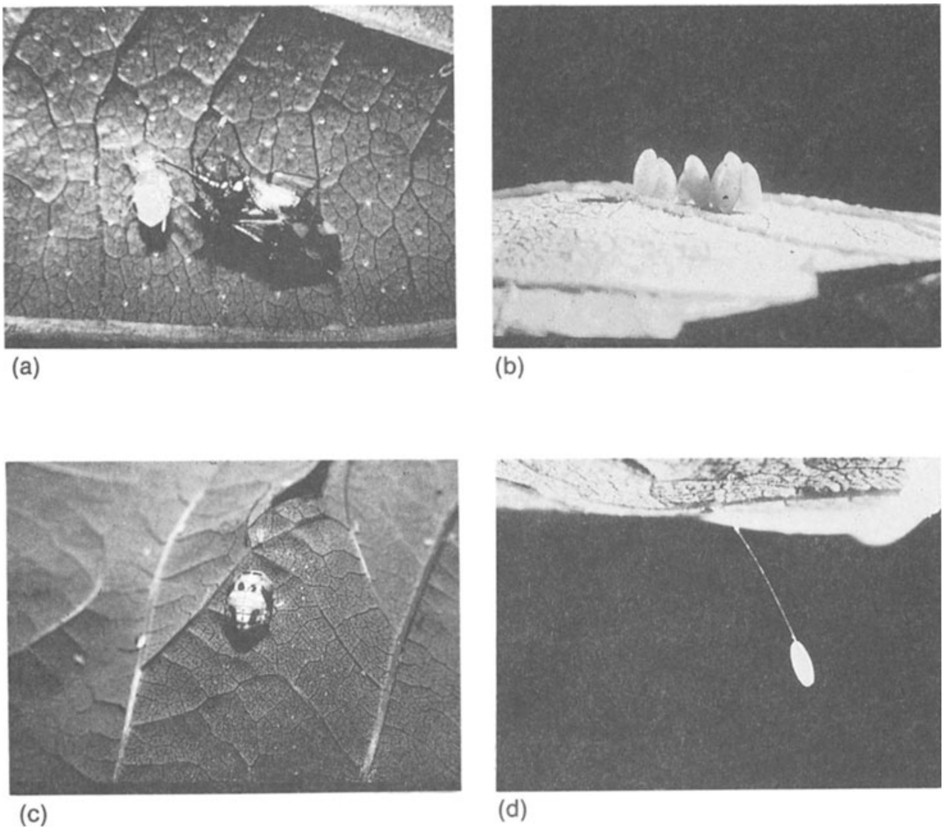
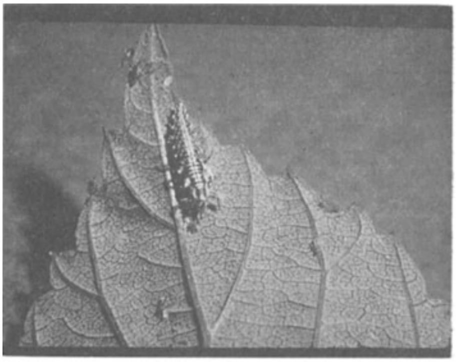


Figure 6.4 Predators of the damson-hop aphid: (a) anthocorid adult; (b) ladybird eggs; (c) ladybird pupa; (d) lacewing egg; (e) lacewing larva; (f) lacewing adult; (g) hover fly larva; (a and d IHR, Wye. b, c, e, f, g, Crown copyright).

6.2 SPIDER MITE: *Tetranychus urticae*

6.2.1 Description

This pest, formerly named *Tetranychus telarius* (L.) or *Epitetranychus althaeae* (var. Hanst), is commonly called the two-spotted mite or the red spider mite but the latter name is at times misleading since it is only the overwintering females that are a bright red colour. These shelter during the winter in the soil, under leaves, in cracks in hop poles or in the strands of the wirework (Darling, 1958). These adults leave their hiding places in the spring, climb the bines and feed on the lower surfaces of the leaves by sucking the sap from the epidermal and sub-epidermal cells. They lay small translucent eggs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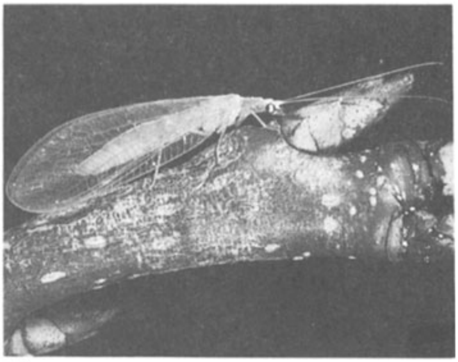
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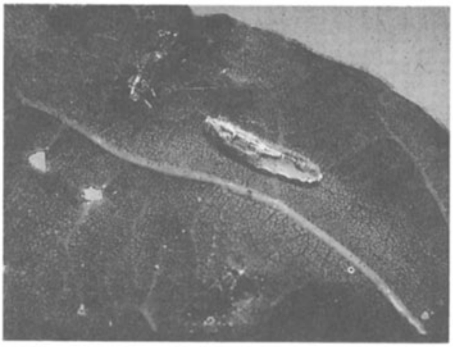
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and the mites that emerge are greenish-yellow with black markings and there are five to nine generations of these during the summer. They are small and, although just visible to the naked eye, a lens is very helpful in identifying them. The immature larval stages are six-legged while the adults are eight-legged.

Blattny and Osvald (1948) described them as one of the most important pests in Czechoslovakia and most serious in warm dry weather. Oviposition began when the mean temperature reached 12° C (54° F) and at that temperature the egg stage lasted for six days. At 18° C (64° F) the egg stage only lasted for three days. The mites stopped feeding when the relative humidity reached 80% and stopped reproducing when it reached 90%.

Cone *et al.* (1986) have reported from Washington State that overwintered females made a very rapid recovery once weather conditions were favourable and that they commenced egg laying within 24 hours of starting to feed. The first eggs to be laid had pigment similar to the female but many of these did not hatch. The subsequent eggs were normal (pearly-white) and hatched. On

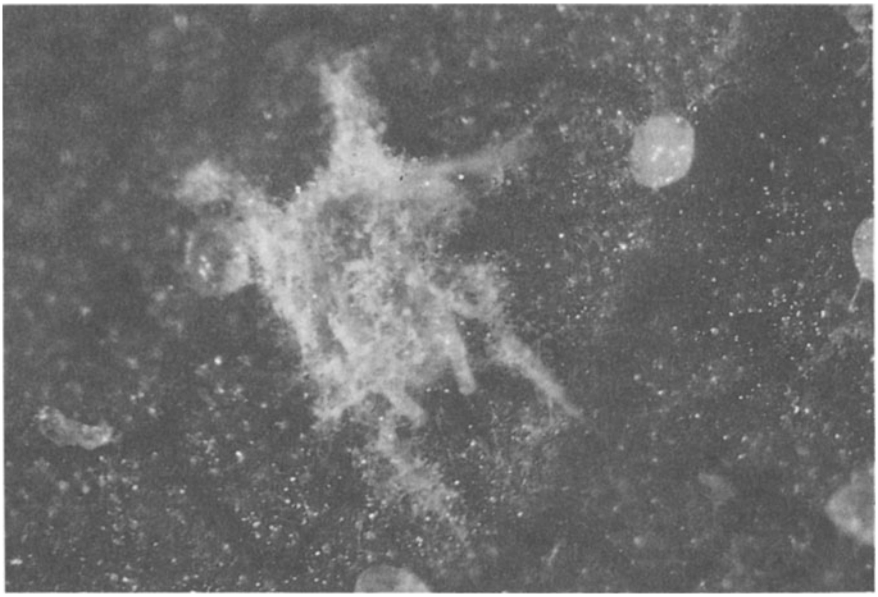


Figure 6.5 Damson-hop aphid infected by *Verticillium lecanii* (Crown copyright).

average, the females laid 20.8 eggs over a 20 day period. Of 2390 eggs laid in this study, 1036 hatched into females and 320 into males.

As the hop plants develop, the mites move up to feed on the younger leaves. Sites and Cone (1985) found that from May to early July the mites were mainly on the lower half of the plants but that by mid-August they were mainly on the upper half. The first sign of mite attack is a silvery speckling of the leaves and their presence is also indicated by the fine web which they spin as a protection. This can be shown up by sprinkling soil on the underside of the leaf where it is caught in the webbing. In small numbers the mites do not cause much damage but under favourable conditions they can multiply very rapidly and, if an infestation is allowed to develop, it will result in severe browning of the leaves and the cones. In severe cases the crop may be destroyed. In September the red hibernating females are produced, reproduction ceasing when daylight is less than fourteen hours (Moreton, 1964).

Unlike most pests and diseases of the hop, spider mites are not specific to that crop but have a wide host range outdoors and are also a serious pest of glasshouse crops. Their geographic distribution is not, therefore, restricted to areas where hops are native and they are to be found wherever hops are grown including countries in the southern hemisphere where they are the only major pest or disease of the crop. Since they flourish under hot dry conditions they are a serious problem in Australia and the Yakima Valley in the USA.

In cooler countries, they are usually only a problem in hot, dry summers and in Germany they are reported to be more of a problem on lighter soils (Kohlmann and Kastner, 1975). They are probably least important in England where conditions are not so frequently favourable for their development but even there they have become an increasingly serious problem as a result of the extensive use of mist propagation during which the cuttings spend some time in glasshouses where the mites flourish.

6.2.2 Chemical control

Before the introduction of the organo-phosphorous insecticides the spider mite could be a serious problem. Brown (1980) wrote that the reports on the Guinness hop farm at Bodiam made no mention of red spider from 1905, when the farm was established, until 1930 but that for some years after that it was a serious problem, especially in 1934. He comments that there was no effective insecticide and using water to drench the webs was reckoned to be the best that could be done. However, he also stated that flowers of sulphur were being used to control powdery mildew and this material was a reasonably effective miticide.

Dinocap, another fungicide used against powdery mildew, also gave some control of the mites and in many seasons these two products were probably sufficient to prevent the pest building up to the stage where specific measures became necessary. It was noted in one season at Wye that the only variety to be affected by spider mites was Wye Challenger which, because it was at that time resistant to powdery mildew, had received neither sulphur nor dinocap sprays.

The organo-phosphorous pesticides, when introduced, were as effective against the spider mites as they were against hop aphids and for some years the problem appeared to be solved. As with damson-hop aphids, however, resistance soon began to develop and alternative materials had to be sought. Control is a somewhat different problem with the mites because of the egg-laying stage between each generation. Some materials are toxic to the mites but not to the eggs and treatments need to be repeated to ensure that mites that subsequently emerge are sprayed before they have time to lay a further batch of eggs.

Several alternative products have been introduced as miticides but all seem to be subject to the risk of resistance developing while some have been found to be phytotoxic. Resistance does not develop everywhere at the same time. Muir and Cranham (1979) reported resistance to dicofol in England yet five years later Gesner (1984) found no evidence of resistance to this material in Czechoslovakia. In view of his results, Gesner said that the increasing damage being reported could not be attributed to resistance and in England dicofol is still proving of some use against the mites. The lack of agreement between laboratory tests for resistance and experience in the field may be due to variations within the population. One material for which there were no reports of resistance was cyhexatin but this was withdrawn from use in 1988 for health reasons.

6.2.3 Biological control

On fruit crops it has been possible to achieve considerable success in limiting the damage done by the fruit tree red spider with an integrated control programme based upon the activity of the predacious mite *Typhlodromus pyri*. One such programme relied upon using selective pesticides such as diflubenzuron or pirimicarb that are relatively harmless to any strains of this mite. An alternative approach was to introduce a strain of *T. pyri* from New Zealand that is resistant to organo-phosphorous insecticides and to use such materials in the control programme (Solomon and Cranham, 1980). Pesticide applications are reserved for occasions when the predacious mites have failed to keep the pests below a predetermined level.

T. pyri is however less likely to be effective against the two-spotted mite on hops because it dislikes the webbing which that mite produces. Some success in preliminary trials, however, has been achieved using the South American species *Phytoseiulus persimilis*.

In the USA the native species *Typhlodromus occidentalis* is an effective predator but it continues feeding on the two-spotted mite during the winter and reduces the population to a level where it will no longer support the predator. The surviving mites are then able to build up again. An alternative food source for the predator is being sought to bridge this gap so that it would be present in sufficient numbers to prevent renewed build-up of the mite (Cone, personal communication).

Blattny and Osvald (1948) reported that natural predators, of which *Stethorus punctillium* was the most important, destroyed large numbers of the mite at all stages and they commenced a programme of releasing them in areas where they were insufficiently numerous. In their book (1950) they state that the level of mite infestation depends, above all, on the numbers of natural predators that survived from the previous year and that is the reason why it is nearly impossible for it to be a problem in the same garden two years running.

There is little hope, however, of using *T. pyri* or other predators to control spider mites while aphids have to be controlled by chemicals, none of which are sufficiently selective to avoid destroying the predators. But if it is possible to develop an integrated control programme for the aphid, this is likely to help with the control of spider mites also since it is known that anthocorids, at least, will feed on mites as well as on aphids. The release of artificially-reared *Phytoseiulus persimilis* to control mites, combined with the release of lacewings for aphid control, was remarkably successful in a low trellis garden at Wye in 1990 – a difficult year for control of spider mites. On standard wirework they failed to control the mites on the upper parts of the bines.

In the southern hemisphere, where there is no problem with aphids, there should be far better prospects of success with biological control and recent work by the CSIRO, Canberra has shown promising results. With reduced

Figure 6.6 Predatory mite, *Typhlodromus occidentalis* (right) attacking red spider mite, *Tetranychus urticae* (left). (Division of Entomology, CSIRO, Canberra).

applications of miticides, several species of predatory mites have appeared at levels sufficient to give control (Figure 6.6). *Phytoseiulus persimilis* has also been introduced into hop gardens where it has established well and given good control although its ability to overwinter has not yet been established (personal communication).

There are some reports of differences in susceptibility of hop cultivars to the mite. Peters and Berry (1980a) found that in greenhouse experiments mite densities were greater on Comet and Fuggle than on L–8, L–1 or Cascade. There were no differences in oviposition, sex ratio or survival but highly significant differences in developmental rates. The pre-adult stages developed slower on L–16 and Talisman than on Cascade, Fuggle or Comet. In another paper (1980b) they report that oviposition increased on leaves with high density of hairs and there was a greater proportion of females on leaves with dense pubescence. The duration of development of pre-adult stages was longer when the hairs were dense.

6.3 NEMATODES

6.3.1 Dagger nematode: *Xiphinema diversicaudatum*

Although this eelworm species probably causes no direct damage to hop plants on which it feeds, it must be the next most serious pest of the crop, after aphids and spider mites, because it is the vector of Arabis Mosaic Virus (AMV) which can cause serious losses (section 8.4).

The role of X. *diversicaudatum* as a vector of AMV in other crops was first recognized by Harrison and Cadman (1959) and its occurrence in Britain was not recorded until 1959 when it was found in association with clover (Peacock, 1959) and also with strawberries infected with AMV (Jha and Posnette, 1959). Taylor and Brown (1976) later showed that it is widespread throughout England but it is most commonly found in soils with a high proportion of sand. They also comment that it is widespread in continental Europe although it appears to be restricted to the cool humid areas such as those along river banks, the Channel and Atlantic coasts. A survey in the Federal Republic of Germany found *X. diversicaudatum* only rarely in hop gardens and then only in one of the regions (McNamara and Flegg, 1984).

The identification of this nematode as the vector of AMV in hops, which causes nettlehead disease, was reported by Thresh *et al.* (1972) and Valdez *et al.* (1974). Subsequently there were various experiments to determine how to prevent it from spreading the disease. This work is described in section 8.4, but it is of interest to note here that a two-year fallow was found to eliminate the virus from infected land although it did not destroy the *X. diversicaudatum* population that was carrying it (Pitcher and McNamara, 1976). Taylor and Robertson (1970) demonstrated that this is because the virus particles are retained by the nematode on the cuticular lining of the gut. During the moult the cuticular lining is shed, together with the virus particles, and these are ingested into the intestine so that after moulting the nematodes are no longer infective.

6.3.2 Hop-root eelworm: *Heterodera humuli*

Percival (1895) attributed the cause of nettlehead to the eelworm *Heterodera schachtii* having found its cysts (Figure 6.7) on the roots of hops suffering from that disease but Duffield (1925) found no correlation between its presence and the incidence of nettlehead. Filipjev (1934) considered that the nematode found on hops differed morphologically from those found on other plants and renamed it as a separate species, *Heterodera humuli.*

It has been suggested in Germany that there may be an association between the presence of this eelworm in hop gardens and the incidence of verticillium wilt. This has been supported by von Mende and McNamara (1985) who found a strong indication of an interaction between *Heterodera* and *Verticillium* in that the bine length of Northdown plants was much reduced when both pathogens were present together; this did not occur in the wilt tolerant variety Wye Target. They had insufficient data to reach definite conclusions about other damage in the field but concluded that the nematode is a well-adapted

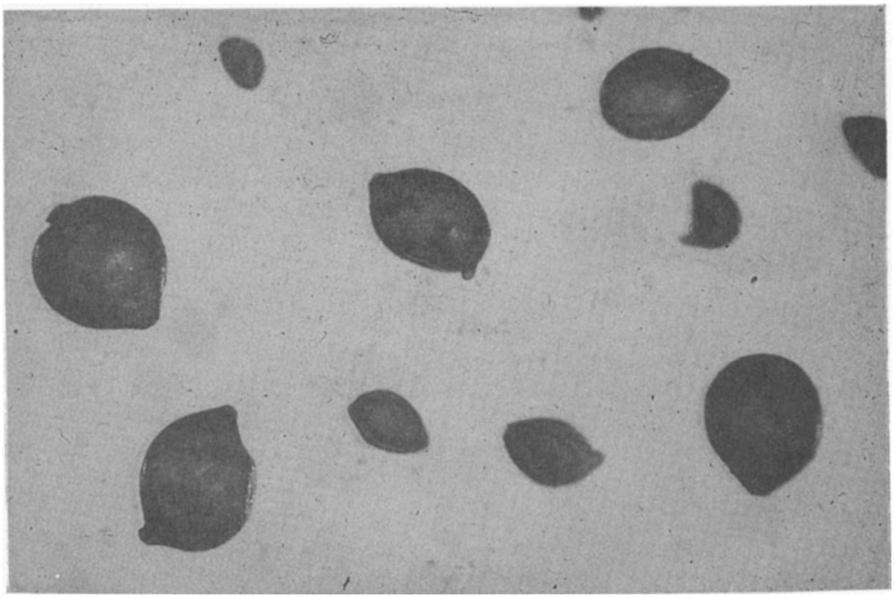


Figure 6.7 Cysts of hop-root eelworm *Heterodora humuli* extracted from hop garden soil (Crown copyright).

parasite that causes little or no growth reduction unless the root system is put under stress when it may become of major significance.

6.4 OTHER PESTS

There are several other pests that occasionally attack hops but they are generally not of great importance.

6.4.1 Clay-coloured weevils: *Otiorrhynchus singularis*

These wingless weevils (Figure 6.8), which are about 0.6 cm long, shelter under clods of earth during the day where they are difficult to see since their colour blends with the soil.They emerge at night to climb up the stems where they will gnaw at the bark or eat irregular holes in the leaves. If they eat enough of the bark they can cause the shoots to collapse. They are active in the spring until early summer when they lay eggs in the soil from which the legless larvae develop and feed on the roots before pupating.

Kohlmann and Kastner (1975) described the wingless weevil in Germany, the Liebstöckelrüssler (*O. ligustici*), as being 1.0–1.5 cm long and having a two-year life cycle. The larvae which emerge from the eggs pupate in the autumn

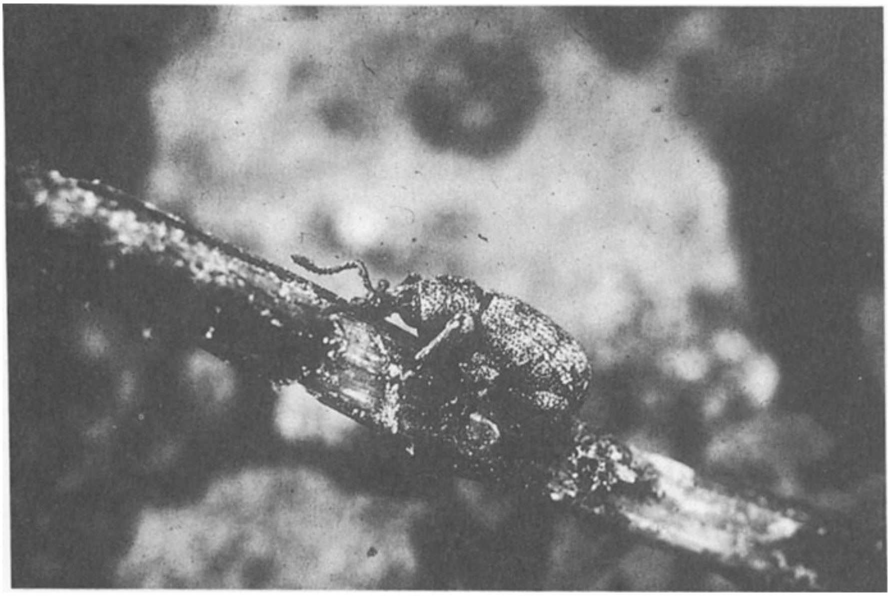


Figure 6.8 Clay-coloured weevil (*Otiorrhynchus singularis*) (Crown copyright).

and overwinter, and the young weevils which develop in the following July overwinter without leaving the soil but emerge as adults in the second spring to feed and lay eggs to complete the cycle. It is recommended that control measures, using organo-phosphorous or carbamate insecticides, should be undertaken when there are one or more weevils to three plants.

Mohl (1924) recorded that in the years 1880–2, in some regions of what is now Czechoslovakia, there were clusters of 5–25 beetles per plant and that they destroyed all the shoots that were produced between March and mid-May.

A recent report from Germany discusses the possibility of using parasitic nematodes to control this pest (Arndt, 1989).

6.4.2 Rosy rustic moth: *Hydroecia micacea*

These moths are on the wing from late July to early October with a peak in September. The eggs are laid in the autumn and hatch in the following spring. The caterpillars are pinkish with a dark central stripe with brown spots on each side, each with a bristle. French *et al.* (1973) described the results of a 6-year survey of this pest in Kent. In early to mid-May the larvae emerged from the soil (slightly later than reported in Germany) and bored into the stems, usually near soil level but sometimes up to a height of 30 cm (12 in), and tunnelled the pith. In June they emerged from the bine usually within 30 cm of soil level and then fed on the base of the bine or tunnelled into the crown or roots, pupating in July. Some larvae never fed on the bines but went immediately to feed on the crown and roots – usually when bine growth was weak or retarded.

The report says that the tunnelled bines did not wilt or show reduced vigour but that there was some leaf yellowing of the leaves in July or August. The tunnelled bines were more susceptible to infection with *Fusarium* canker and the larval exit holes sometimes caused the bines to split. More damage resulted from the subsequent feeding around the join between bine and rootstock which could cause the bine to collapse. In their survey they found fewer bines surviving on infested plots and, of those, from 8–12% were damaged. They obtained the best control using DDT which they applied twice, with a 10-day interval, commencing the first week in May and they recorded yield increases in both seasons of the trial. Damage was less if training was left until after mid-May.

Damage was said to be more severe in weedy gardens or next to the headlands where the moths were more likely to lay eggs. In recent years there have been few reports of damage and the pest may have diminished in importance since non-cultivation made conditions less suitable for it.

In Germany, where the insect is called the Kartoffelbohrer, it still appears to be of some importance and carbofuran is the recommended control treatment.

6.4.3 Flea beetle: *Psylliodes attenuata*

This was formerly a common pest in most hop gardens but is not as prevalent now. It is a small metallic-looking jumping beetle that feeds on young shoots in April and May, eating holes in the leaves. They lay their eggs in the soil from early April until early July. The larvae feed on the roots of the plants and then pupate. The beetles emerge in the following spring.

It is probably the introduction of more effective, systemic insecticides, coupled with the widespread adoption of non-cultivation in England, that has reduced the numbers of this insect in hop gardens.

6.4.4 Earwigs: *Forficula auricularia*

These are common and may, on occasions, cause noticeable damage by eating holes in the leaves but this is rarely sufficient to affect the crop. This damage may, however, be outweighed by the beneficial effect that they have as predators of the damson-hop aphid (Buxton and Madge, 1976; Campbell, 1978).

The eggs are laid in the soil during winter and again in May–June. During the day they shelter in cracks and crevices and emerge during the night to feed. Hop poles are a common place for them to shelter and plants next to poles are more likely to be visited by them.

6.4.5 Wireworm: *Agriotes* spp.

Young hops may sometimes be damaged by wireworm when they are planted in sites where the pest is to be found, most commonly land recently ploughed out of old grassland. They kill young shoots by biting into them below ground level in the spring. Where they are a problem the recommended control is currently by soil application of γ-HCH.

6.4.6 Slugs: *Agriolimax reticulatus* and *Arion hortensis*

These can cause so much loss of bine in certain seasons that control by poison bait such as methiocarb is necessary. They feed at night so may not be noticed but their slime trails are evidence of their activity.

CHAPTER 7

Fungal diseases

7.1 DOWNY MILDEW: *Pseudoperonospora humuli*

A recent comprehensive review of this disease is given by Royle and Kremheller (1981).

The spread of downy mildew in the 1920s throughout all the hop growing countries of the northern hemisphere and later into South America, as described in Chapter 5, must make this the most important disease overall affecting the crop even though other diseases may be locally more serious. Australia, New Zealand and South Africa have been able to exclude it by strict quarantine precautions.

The first appearance of the disease in the spring is when some of the many shoots that the plants produce develop into 'basal spikes' with a characteristic stunted form and pale downcurled leaves with a silvery upper surface (Figure 7.1). The undersides of these leaves turn black as dense masses of sporangia are formed on branched sporangiophores. Once a shoot has developed into a spike it does not grow any further and, if not removed or destroyed by chemical treatment, will quite soon die. These spikes are the primary source of infection each year and, as the sporangia spread the disease, other shoots may develop into secondary basal spikes. Lateral or terminal buds on the elongating bines may also develop into spikes. If this happens to the terminal bud there will be no further development of the main axis of that bine but, because apical dominance is lost, there is increased development of lateral shoots. If one of these laterals is trained in place of the main bine it may develop sufficiently well to give a satisfactory yield but otherwise there can be a serious loss of crop.

Leaves also become infected and once the diseased areas start sporulating they appear on the underside as black spots which are bounded by the veins of the leaf so that they have a characteristic angular shape (Figure 7.2).The black colour of these 'angular leaf spots' is due to the profuse development of sporangiophores. Infections of buds and leaves can occur at any time in the growing season, depending very largely upon weather conditions and the amount of inoculum being released.

Figure 7.1 Downy mildew 'spike' (right) and healthy shoot (left) (Crown copyright).

When the hops come into flower the developing burr and cones may also become infected. If the burr is attacked its development may be completely checked while diseased cones turn brown, especially the bracteoles, the bracts frequently being less severely discoloured (Figure 7.3).

Infection during the vegetative phase of growth does not often directly affect

Figure 7.2 Downy mildew: Angular leaf spot (Crown copyright).

the final yield. If so many shoots developed into spikes prior to training that there were insufficient healthy ones to train, this could affect the final yield although this is an unusual situation, especially on mature hills which have an abundant supply of shoots. When shoots that have already been trained are attacked the situation is more serious because at that stage there may be no replacements available. Terminal spikes will certainly check the vegetative development of the bines even if laterals are trained to take over the leading role and infection of lateral buds would result in the loss of lateral shoots that could have borne a crop of hops. Losses from such causes should, however, be minimal if normal control measures have been carried out.

Figure 7.3 Downy mildew infected cones (Crown copyright).

Infection during the vegetative growth is much more important as a source of inoculum that can infect the burr and cones when the greatest losses are likely to arise. The sudden flush of young tissue in the developing cones is very susceptible to infection and this is the time when the growth of the plant is at its most dense, making it difficult to achieve good spray cover with fungicides. There may be little reduction in yield if infection does not occur until after the cones are formed but the discoloration of the cones will usually lead to a serious reduction in the value of the hops.

Even though diseased rootstocks usually produce sufficient healthy shoots to furnish all the strings, the subsequent growth may still be weaker than that from uninfected rootstocks. Williams *et al.* (1961) showed that during the winter the carbohydrate reserves declined much more rapidly in infected than in healthy rootstocks and this adversely affected their growth in the following season. Coley-Smith and Beard (1962) noted which hills of a number of Golding clones showed evidence of infection when they were dressed in the spring and at harvest recorded a reduction in yield of 27.7% compared with those with healthy rootstocks.

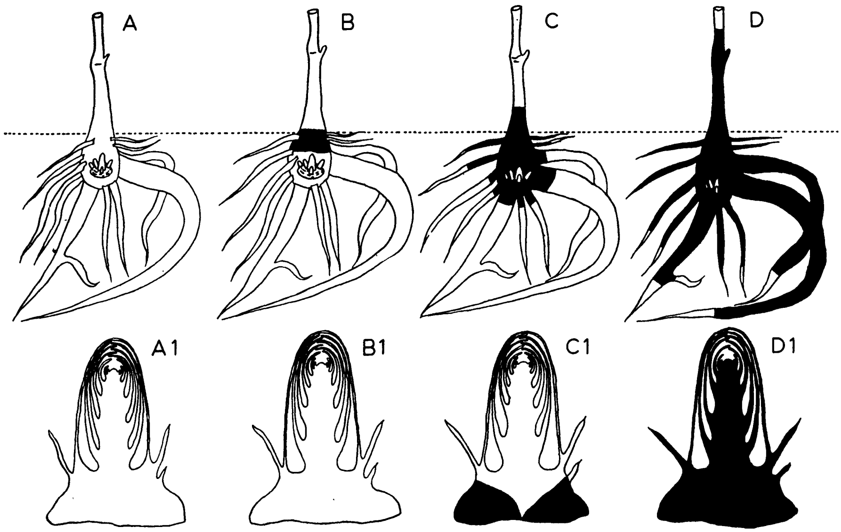


Figure 7.4 Growth of *Pseudoperonospora humuli* in artificially infected pot plants of Eastwell Golding. A-D diagrammatic representations of rootstocks, A1-D1 vertical sections through dormant buds. A and A1 one week after inoculation (September), B and B1 two weeks after inoculation (early October), C and C1 one month after inoculation (mid-October), D and D1 two months after inoculation (November). The diseased area is shown in black. The dotted line indicates the soil surface.

7.1.1 Overwintering

The fungus is an obligate parasite that is specific to hops. Ware (1926) showed that it overwinters as mycelium within the rootstock. Coley-Smith (1960) studied the way it progressed during the winter in plants that were inoculated in September by pouring a zoospore suspension onto the soil surface around the base of the bine. The fungus entered the stem at or near the soil surface and grew both upwards and downwards so that by October the rootstock was extensively colonized. No buds were infected by that time although hyphae were present in many of the cushions of tissue from which the buds arose. From November onwards, however, increasing numbers of buds had been invaded by hyphae passing through these cushions. Over 40% of all buds became infected and by March it was obvious that those invaded early in the winter were already dead (Figure 7.4).

Coley-Smith (1965) demonstrated that rootstocks could become infected by inoculating the bases of the bine at any time during the growing season or by inoculating the tips of bines that were 15 cm or less in length. If the bines were more than 17.5 cm long when the tips were inoculated the infection did not penetrate into the stock.

Skotland (1961), on the other hand, observed diseased crowns following the inoculation of the tips of shoots up to 90 cm (3 ft) tall although at least some of this could have been the result of secondary infection since this occurred in some of the uninoculated controls.

Skotland recorded a field plot of 368 plants and found that, in three consecutive seasons, 14%, 18% and 6% of them produced basal spikes but that only two plants produced them in all three seasons. All plants that produced basal spikes had infected rootstocks but not all infected stocks produced spikes.

When Coley-Smith (1964a) recorded field plots, he found infection persisting in rootstocks of Golding hops for four years and, unlike Skotland, he found that most of these plants produced basal spikes each year. It was on this evidence that he recommended the grubbing and replanting of diseased stocks as a means of reducing the level of infection (Coley-Smith, 1963).

Dormant buds that are heavily infected will normally die whereas those in which the fungus is only recently established can develop into shoots although many of these will turn into spikes after they have emerged. It appears that in some other cases infected shoots can grow away normally but that isolated pockets of mycelium may be carried upwards in the developing bines and then infect buds high up the bine to produce lateral or terminal spikes (Ware, 1926 and 1929).

Rootstock infection can have an important effect on yield by causing the death of the rootstock although cultivars vary in their susceptibility to such losses. Although in some cases a correlation has been found between numbers of basal spikes and the degree of rootstock infection within varieties, this is not true in all cases.The variety WGV is especially sensitive to rotting of the rootstock yet produces few basal spikes (Coley-Smith, 1964a). This is, presumably, because when the rootstocks become infected the disease spreads so rapidly that few buds survive to develop into spikes. On this basis an inverse relationship would be expected between rootstock susceptibility of a cultivar and the incidence of primary basal spikes.

Such an inverse relationship has been noted at Wye where Northern Brewer and Bullion were grown in an experimental garden in which no control of downy mildew was practised. Bullion produced few spikes but many hills died out while Northern Brewer produced very many spikes but no hills were lost.

There is some doubt as to whether the oospores, which are produced abundantly in diseased leaves, shoots and cones in the autumn, are a further means by which the fungus can overwinter. Early investigators, including Magie (1942), observed oospores germinating and quoted circumstantial evidence that they were the source of infection in the spring but more recent workers have been unable to substantiate these findings (Royle and Kremheller, 1981). There is no doubt that, even if oospores are capable occasionally of germinating, they are not an important source of infection.

7.1.2 Secondary infection

The primary spikes are normally too few to be a direct cause of loss but they are of the greatest importance as the source from which all secondary infection develops.

Secondary spread occurs by means of the sporangia produced on stems and the undersides of infected leaves. They are produced in a daily rhythm on the ends of each branch of the sporangiophores which emerge through the stomata of infected tissue. The sporangiophores were found by Yarwood (1937) to emerge by midnight and to produce small sporangia by 0300 h. By 0600 h the sporangia were full sized and release commenced by 0900 h. This rhythm was not disturbed, at least for 24 h, by submitting infected leaves to altered light routines.

Royle (1968) found that the production of sporangia occurred over a broad temperature range (approx. 8–25° C) but was absolutely dependent on high relative humidity, being most profuse between 96–100% and failing to occur below 90% RH. The release of the spores in static air conditions, however, increased with lowering humidity, being almost nil at 100% and greatest at 50% RH. The daily concentration of air-borne sporangia in an unsprayed hop garden was studied by means of a spore trap and the catches were more closely related to the amount of sporulating tissue than to any other factor.

Diurnally spore release also proceeds in a rhythmic fashion. On rainless days the maximum release of spores was at 10 am GMT but rain caused temporary increases in numbers as a result of the mechanical disturbance of the leaves.

The sporangia do not reinfect directly but under wet conditions each sporangium releases 4–8 zoospores which swim to the stomata, which only occur on the underside of hop leaves. After encysting, zoospores penetrate the stomata with a germ tube. It has been shown that within 2 min of being sprayed onto leaves that are in the light, zoospores commence settling selectively on the stomata which will be open, whereas on leaves in the dark, with closed stomata, the zoospores remain motile much longer and finally settle at random. The rapidity with which they locate open stomata is apparently due to a chemical attraction related to photosynthesis but they settle there, at least in part, as a physical response to the open stomata since they also settle on the open 'stomata' of perspex replicas made from leaves that were in the light but not on those made from leaves in the dark (Royle and Thomas, 1971a, b and 1973).

The zoospores are motile with two flagella and require surface moisture on the plant tissue in order to reach the stomata. The sporangia require wetness for a period of at least 1 h at 20–22° C to 10 h at 2° C before they release the zoospores, so there is generally sufficient surface moisture at that time for the zoospores' requirements.

A feature of this fungus recorded by Royle and Thomas (1973) is that the zoospores settle singly on the stomata whereas in the vine mildew, *Plasmopora viticola*, the zoospores settle on the stomata in groups of up to 30.

As sporangia age there is at first an increase, to a minimum of 3–4 h, in the period of wetness required before zoospores are released (Zattler, 1931; Magie, 1942) and with increasing age they quite rapidly become non-viable. Magie found that sporangia lived only a few hours when separated from the host plant and dried on glass slides in the laboratory. When sprayed onto leaves that were then exposed to sunlight on a greenhouse bench none were viable after 24 h. Sonoda and Ogawa (1972) also found that only 1% lived longer than 14 h under Californian conditions while, in Bavaria, Kremheller (1979) reported that 50% died within 1½ days although a few survived for 8 days.

Since infection takes place through stomata, and these are absent from juvenile bud leaves, the likely entry sites for shoot infection are the young bud stipules in which stomata are well developed. When looking for signs of secondary infection in the field the stipules should be carefully examined as they are frequently the first place at which it can be recognized.

After germ tubes have penetrated the stomata, an intercellular hyphal system develops which spreads quite widely between the cells of the plant. The cells are invaded by lobed haustoria which are a useful means of identifying the pathogen.

7.1.3 Hygiene

Since diseased rootstocks are the initial source of infection each season a programme of identifying and grubbing these as recommended by Coley-Smith (1963) can help to reduce the amount of primary infection in the garden. This can be done by marking hills that produce primary spikes in the spring so that they can be grubbed in the autumn. Alternatively the rootstocks can be inspected when being dressed in the winter and any that cut brown can then be grubbed.

Such grubbing is unlikely to be completely successful so even if it is carried out there would be some spikes developing in the spring. The next stage in field hygiene is carefully to inspect the young plants and remove, by cutting or pulling, any spikes that are seen. After the bines have been trained, and surplus shoots pulled out, the lower leaves should be stripped off by hand as soon as the bines are high enough. Initially they should be stripped to a height of about 0.6 m (2 ft) and then to twice that height or in particularly wet seasons, to as much as 1.5 m (5 ft) (Glasscock, 1956). This stripping of the base of the bine removes the leaves that are closest to the basal spikes and therefore the ones most likely to become infected. It is also helpful in promoting more movement of air through the garden, thereby reducing the period for which the foliage remains wet after rain.

The pulling of excess bines and the stripping of the lower leaves by hand has now been replaced, very largely, by the use of defoliating chemicals. This has the advantage that the chemicals will kill any spikes *in situ* whereas hand work carried the risk that it would, unintentionally, help to distribute the spores as diseased material was removed from the garden.

When severe outbreaks of the disease have occurred there have sometimes been rather desperate attempts to check further spread by removing infected leaves and side shoots by hand but it is doubtful if this was able significantly to affect the course of the disease once it was so well-established.

7.1.4 Chemical control

When hop downy mildew was first recorded in 1905 in Japan, the use of copper fungicides for the control of vine mildew was already well-established so spraying hops with Bordeaux mixture was immediately adopted as a control measure, combined with the removal by hand of infected shoots and leaves (Salmon and Wormald, 1923). Bordeaux and Burgundy mixtures continued to be used for very many years but, because they could cause a certain amount of damage to young leaves they were then replaced by less phytotoxic copper products such as copper oxychloride.

Copper fungicides were the only materials available until the 1950s when the organic dithiocarbamate compounds such as zineb were introduced. These were favoured because they did not harden the leaves so much and this became important with the introduction of machine picking since the harder, copper-sprayed leaves broke up more on the machine and so gave rise to more broken leaf in the final hop sample.

Typical spray programmes did not start until the bines reached the top wire although in wet seasons, which favoured the disease, it was suggested that they might start as early as April (Burgess, 1964). Some growers, however, believed that dusting the hills and young shoots very early in the season was beneficial and trials by Coley-Smith (1965) confirmed that this reduced secondary spread to leaves and shoots as well as reducing rootstock infection.

These fungicide treatments were only protective and did nothing to cure infection that had already occurred so it was essential to apply them in time to prevent further infection occurring.

A significant advance came with the discovery that spray applications of streptomycin were taken up systemically in the plant and so had some effect upon infections that were already established. Its use was first advocated by Horner and Maier (1957) who found that it could transform infected shoots into healthy ones. Coley-Smith (1966) found that two applications were necessary in most seasons and that its main effect was to reduce sporulation. There was always some unease about using this material for non-medical purposes. It was never approved in the Federal Republic of Germany and after being used for some 15 years it was withdrawn everywhere.

Even more effective systemic fungicides were introduced into trials in the late 1970s and two of these, metalaxyl (Ridomil) and fosetyl-aluminium (Aliette), were widely approved for use. Royle (1980) showed that metalaxyl residues could be detected in hop leaves for at least ten weeks after the application of a soil drench which gave complete control for four weeks and erratic control thereafter. When applied to the soil these systemic materials were capable of eliminating the fungus from rootstocks that were already infected.

Experience with pathogens of other crops showed that there was a risk of the hop pathogen developing resistance to metalaxyl and so its use as a soil drench was discontinued in the UK where it is now applied only as a foliar spray in mixture with copper oxychloride. It was hoped by this means that the risk of resistant strains becoming established would be reduced. In Germany and the USA, however, it has been used in granular formulations for soil application and unconfirmed reports from both these countries that resistant strains have developed suggest that the policy adopted by the UK distributors was justified.

Metalaxyl was so effective that it would even cure established infections and by removing sources of inoculum it could effectively eliminate the disease from a garden beyond the period when the concentration of the fungicide in the leaves was high enough to give direct control (Darby, 1984a). Writing at the time when metalaxyl had been in use commercially for only two years, Royle and Kremheller (1981) suggested that it might reduce the sources of downy mildew to such an extent that the disease would no longer pose a threat to the health of the crop. It has, however, never been used extensively enough by all the growers in a country to achieve that situation and it cannot be said whether it was even possible. In view of the rapidity with which the disease spread throughout Europe in the 1920s it is likely that there would always have been enough foci of infection on wild hops to re-establish the disease as soon as the spray programme was relaxed.

7.1.5 Epidemiology

When controlling downy mildew with protectant fungicides, the programme can be operated much more efficiently if it is known when infection is likely to occur. It has long been realized that the disease is worse in wet weather but further work was required to establish more precisely the factors that lead to the development of epidemics.

Magie (1942) examined the effect of temperature by inoculating leaves at 10, 13, 18 and 24°C and found that the shortest periods of wetness required for infection to occur at those temperatures were 6, 4, 2 and 1.5 h respectively. Royle (1970), working under controlled conditions in growth rooms, used the wider temperature range of 5–30°C and recorded minimum wetness requirements ranging from 1.5–24 h. These results agreed with those of Magie at 18 and 24°C but slightly shorter periods were recorded by Magie at 10 and 13°C.

In Royle's experiments, inoculated shoots needed to be exposed to wetness periods approximately twice as long as those required for leaf infection before they would eventually develop into spikes and no spikes developed from the treatments at the two extremes of the temperature range. He suggested that the reason for this longer period was that spikes only develop when the fungus reaches the growing point and to achieve this it must grow faster than the shoot. This may only happen when large numbers of fungal penetrations check shoot growth sufficiently for the growing point to be invaded.

Royle also examined the effect of temperature upon the incubation period (the time between inoculation and symptoms appearing) over the slightly narrower temperature range 7–28°C. The higher the temperature the shorter the incubation time which, for leaves, ranged from three to seven days. Again it took approximately twice as long as this for shoots to develop into spikes and none developed when incubated at the highest or lowest temperatures.

Skotland (1962) exposed plants that had been dusted with sporangia in a hop yard overnight and dews formed on each occasion. In four out of six trials some infection occurred but there was no correlation between infection and the temperature or the duration of the dew. Other workers who have similarly exposed plants have found that little infection occurred as a result of dew unless there were high levels of inoculum (Royle, 1973; Dolinar, 1976; Kremheller and Diercks, 1983). Three reasons suggested by Royle and Kremheller (1981) for this were: (a) dew starts to form in the dark when zoospores are not attracted to stomata; (b) rain is more favourable for infection than dew because inoculum that is splash-dispersed by rain augments that which is deposited dry after the daily release; and (c) the longevity of dry-deposited inoculum is reduced during the interval between release and wetting by dew, especially because dew is often associated with dry weather.

Pejml and Petrlik (1967) studied the incidence of the disease over many years and developed a points system based on weather parameters. A score of 0–500 meant conditions were unfavourable for infection, from 500–1000 infection could occur while over 1000 conditions were optimal. The number of sprays applied was adjusted on this basis.

Royle (1973) exposed healthy pot plants in an unsprayed hop garden for 48 h periods, incubated them for three days in a growth room and then for a further seven days in a glasshouse where infected leaves and shoots were recorded. Environmental conditions in the hop garden were recorded throughout the trial. A Hirst spore trap was used to record airborne inoculum which was computed hourly and a funnel trap recorded spores deposited by rain.

The level of infection was profoundly influenced by the amount of young, highly susceptible leaf and shoot available and allowance had to be made for the time lag between infection and the appearance of disease symptoms.

Periods when conditions of moisture and temperature were judged to be suitable for infection to occur were in good agreement with the subsequent disease recorded provided that wetness periods resulting from dew were excluded.

The infection records were related by inspection and by multiple regression analysis to the conditions when the plants were exposed. The spore catches in the funnel trap, which depended on rain, were closely related to infection while airborne counts showed only a weak correlation and only when all three years records were combined. There was no correlation with temperature. Variables such as temperature, vapour pressure deficit and airborne spores, which in their own were poorly correlated with infection, often significantly improved regression equations which were based on variables expressing wetness. The multiple regression equations that were developed accounted for 70–90% of the variation in infection and when used to predict infection periods there was good agreement between the predicted and observed results.

As a result two alternative formulae were developed for assessing when infection periods had occurred. If a spore trap was in operation to record airborne inoculum the formula was:

$$Y = 37 + 23\,\text{wet} + 66\,\text{rain} + 2\,\text{spores}$$

and if no spore count was available the alternative formula was:

$$Y = -63 + 22\,\text{RH} + 84\,\text{rain}$$

where

wet	=	hours of surface wetness in 48 h
rain	=	mm rain in 48 h
RH	=	hours of relative humidity above 80% in 48 h
spores	=	number of spores/m^3 air

When Y was greater than 500, infection periods were judged to have occurred. A warning system was initiated in England based on this work and, although operated for several years, did not get much support from growers and has now been abandoned in favour of routine treatments.

In the BRD on the other hand, a similar warning system is being operated very successfully (Kremheller, 1983; Kremheller and Diercks, 1983). The model used there is based upon the concentration of airborne spores, as recorded by spore traps set up in a number of hop gardens, and the duration of rain wetness. The threshold values set allow for burr and cones being more susceptible than leaves. In the period 1976–82 sprays could be timed more effectively and the quantities of fungicides used were reduced on average by 50%.

It is not clear why the German system has been much more successful than the one in England but a possible explanation is that hop farms in England are more scattered. With the highly concentrated hop cultivation in Germany, each recording station can effectively assess the conditions for the hop gardens in the neighbourhood. Royle and Shaw (1988) have also pointed out that a routine programme in England only involves 5–8 sprays whereas in Bavaria 15–18 applications are typical and a potential annual saving of DM11–15 m by use of the warning programme has been claimed (Kremheller, 1984).

7.1.6 Resistant cultivars

Soon after downy mildew had spread through the main hop growing areas varietal differences in susceptibility were noted. Salmon and Ware (1927) first considered that Fuggle was immune but later (1932) they reported that in the exceptionally wet season of 1931 it had become infected although not to the same extent as other cultivars. In the USA also, Fuggle was found to be one of the most resistant cultivars (Magie, 1942). In the Hallertau district of Germany it was noted that hops of the Saaz type (Saaz, Spalt, Tettnang and Schwetzinger) were less susceptible than the local cultivars but were not so well-adapted to the growing conditions there (Zattler, 1951).

Little effort was made to develop these differences in susceptibility except in Germany where a hop research institute was established at Hüll in 1926, largely in response to the problem of downy mildew, and a breeding programme commenced to develop acceptable cultivars with high levels of resistance to the disease. This work, which is described in Chapter 9, took many years to come to a successful result but it has finally led to very high levels of resistance being bred into new varieties in Germany and England. Since the resistance appears to be very stable, with little risk of breaking down because of more virulent strains of the fungus, it offers the possibility of a long-term solution to a very important disease.

In order to screen young seedlings for resistance it is necessary to have a plentiful supply of sporangia early in the season before field sources are available. Derbyshire and Dixon (1957) developed a successful method of growing hop plants throughout the winter in a heated glasshouse with artificial light to extend the daylength. Leaves detached from such plants are inoculated with mildew spores in the laboratory. The disease can be kept in an active state throughout the winter and then be bulked up in time for large-scale testing of seedlings when these are at the two to four leaf stage.

Griffin and Coley-Smith (1968) successfully cultured the fungus on hop callus cells on a solid medium. It produced intercellular hyphae and haustoria as well as sterile aerial hyphae and sporangiophores but this procedure has not been put to any practical use.

Figure 7.5 Powdery mildew 'blisters' on a resistant variety. Similar blisters occur in the early stages of infection of susceptible cultivars (IHR, Wye).

7.2 POWDERY MILDEW: *Sphaerotheca humuli*

There was a major review of this disease by Royle (1978).

Powdery mildew is the oldest of the fungal diseases of the hop and in Germany is called 'Echter Mehltau' (true mildew) to distinguish it from the much more recent downy mildew which is called 'Falscher Mehltau' (false mildew). In England it is commonly called 'mould'. Although it is so much older it is more restricted in range than downy mildew. It is a serious problem in England and Belgium but of less importance in the rest of Europe. In Germany it was a disease of little significance until Northern Brewer was planted extensively. This variety is particularly susceptible and the disease has increased as a consequence. There are recent reports that powdery mildew is proving a problem in Bulgaria.

It caused great damage in the USA when hops were grown on the east coast and was one of the problems that led to the American hop industry moving to the west coast where powdery mildew does not occur in commercial hop yards. When a collection of wild hops was grown in a glasshouse in Oregon, however, there was an outbreak of the mildew on them which had to be eradicated (Hampton, personal communication).

Quarantine restrictions have prevented this disease becoming established in South Africa or Australasia although on at least one occasion it is known to have occurred on imported material which had to be destroyed.

Figure 7.6 Powdery mildew sporulating on a susceptible cultivar (IHR, Wye).

The first sign of the infection on young leaves, especially on plants growing under glass, is the appearance of raised humps or blisters (Figure 7.5) on which the white sporulating mycelium (Figure 7.6) then appears (Salmon, 1917a). The blisters appear to result from hypertrophy of the cells around the infection site and as their expansion is restricted by the surrounding tissue they are forced to bulge outwards. These blisters are not as noticeable on the tougher leaves that are produced in the field or on leaves that are older when infection occurs. On plants in a glasshouse the sporulating pustules may be profuse on both the upper and lower surfaces of the leaf. On plants in the field they are mostly confined to the underside of the lower leaves, though their presence is indicated by pale spots on the upper surface. Higher up the bine they develop on both upper and lower surfaces. The poor development on the upper surface of the lower leaves is probably because these are more exposed to spray deposits (Royle and Liyanage, 1973).

The effect of the disease on the cones depends very much upon their stage of development when infected since further growth of infected tissue is almost completely inhibited. When the burr or very young cones are infected they remain as hard white knobs but later attacks may be localized and so cause a one-sided distortion of the cones (Figure 7.7). When hops are grown seedless they remain in the burr stage much longer than they do when pollinated and this is the stage at which infection can cause the greatest damage. However,

Figure 7.7 Cones infected with powdery mildew at various stages in their development, (Crown copyright).

growers in England are increasingly changing over to seedless production and there have been no strong indications so far that this has led to greater problems than those experienced by seeded producers.

In the early stages of infection the disease pustules appear white because of the prolific chains of asexual conidia that grow up from the surface mycelium. In the latter part of the season – from July onwards – there is usually a change to the development of cleistocarps. At this stage mycelium production is suppressed but the cleistocarps, which are dark coloured, can be recognized quite easily with the help of a hand lens. Cleistocarps may be produced on leaves but they are usually much more abundant on cones where chemical control at the end of the season is most difficult.

The cones on which cleistocarps are produced frequently develop a rusty-red colour and this stage of the disease is referred to as 'red mould' in contrast to the 'white mould' of the conidial stage. In some seasons growers have complained that their hops have ripened prematurely and it has been shown that this is often associated with the development of the cleistocarp stage on the cones although there may have previously been no obvious sign of white mould in the crop (Coley-Smith, 1964b). It should be noted, however, that the same conclusion was reached over 60 years earlier by Hammond (1900) who wrote:

> When I have asked further, What is Red Mould? I have never been able to get a direct specific answer, but have been persuaded to believe that it was a mysterious something, which, like charity, covered a multitude of sins.
>
> All this seemed so splendidly vague, that I resolved by the aid of the microscope to attempt the unravelling of the mystery, and I have succeeded so far that I am convinced absolutely that the author of all the mischief is none other than our old enemy the ordinary White Hop Mould.

This is not only an interesting example of how scientific discoveries tend to be forgotten and then rediscovered some 50–60 years later, but also of the more informal and more readable style of reporting that once existed.

Royle (1976) has demonstrated that the fungus is heterothallic and that cleistocarp production is preceded by fusion of the two mating types which exist. The different pathogenic strains, which have been identified from their reaction to resistance genes in host varieties, may each contain both mating types so fusion can be either between or within strains.

The white mould that develops on the leaves can usually be controlled sufficiently well for it not to affect the yield and it is infection of the cones that is the chief cause of loss. Cones infected at an early stage do not develop at all and those infected later will have their growth at least partly checked. This results in a reduction in yield but even more serious losses may result from loss of quality. Infected cones not only affect the appearance of the hop sample but they can also give it an unpleasant mushroom-like aroma. There have been many cases of a hop garden being so badly attacked that it has not been worthwhile to pick it. Salmon (1917b) described a severe outbreak in 1916 when 'some hundreds of acres had to be left unpicked' while many that were harvested were badly diseased and downvalued in consequence.

7.2.1 Overwintering

The commonest way for the fungus to overwinter is by means of the cleistocarps that are produced during the latter part of the growing season. When mature, the cleistocarps contain eight ascospores which are released in the spring to reinfect hop leaves. Liyanage and Royle (1976) showed that there are two peak periods for maturation, one in November and the other in March, but they were unable to induce any cleistocarps to dehisce and release the ascospores before April. This coincides with the time when hops are recommencing growth and when naturally dehisced cleistocarps could be found in the field.

The temperature at which the cleistocarp-infected material was kept during the winter months had little effect upon the proportion that finally discharged ascospores but there was an effect of temperature at the time of discharge.

When subjected to temperatures of 4, 8, 18 and 24°C (39, 46, 64 and 75°F) in April, more cleistocarps released ascospores at 18°C than at other temperatures. Even under the most favourable conditions, however, only a very small proportion (<2%) released spores. The germination of the ascospores was also best at 18°C when nearly 10% of the spores germinated while only 1–2% did so at the other temperatures. Ascospores were only released from the cleistocarps in the presence of moisture.

In the same paper, Liyanage and Royle reported the distribution, in the spring, of powdery mildew in a hop garden, part of which had been left unpicked the previous September because of a severe attack of the disease. Reinfection in the spring was almost entirely restricted to the unpicked portion of the garden which suggested that it was caused by ascospores released from infected cone debris in that area. They produced confirmatory evidence by spreading hop cones bearing many cleistocarps over healthy hop cuttings. Over 10% of the leaves that were examined on the young shoots were infected while no infection was found on the leaves of control plants, which had no infected cones spread over them.

During the last 20 or so years in England there have been reports of shoots emerging in the spring which were almost entirely covered by the white mildew, instead of showing the usual scattering of mildew pustules on the leaves. This phenomenon coincided with the adoption of non-cultivation techniques and Liyanage and Royle showed that this type of infection arose from buds that had overwintered with mycelium, sometimes accompanied by cleistocarps, between the bud scales.

It is only buds at or above the soil surface that can become infected with the mildew and in cultivated gardens all of these are normally removed when the hills are dressed in the winter. Under non-cultivation this is not done and the buds at soil level are left undisturbed. It is from such buds that the infected shoots develop.

Non-cultivation also favours the disease because leaf and cone material that falls to the ground at the end of one season remains on the surface whereas in cultivated gardens a high proportion of it would be buried and unable therefore to release ascospores into the air where they could reinfect the plants. For these reasons, powdery mildew has presented English growers with increasingly severe problems since non-cultivation was widely adopted.

7.2.2 Secondary infection

Once primary infections have become established, the disease is spread by means of the conidia. Whereas the ascospores require water for germination, conidia can produce germ tubes which will develop on dry leaf surfaces in various atmospheric humidities.

The subsequent development of the germ tube, as described by Liyanage

(PhD thesis, 1973) and quoted by Royle (1978), depends upon the genotype of the hop plant on which it has landed. On susceptible hosts the first germ tube emerges from the conidium 6 h after inoculation, produces no obvious appressorium but penetrates the host through the cuticle and establishes an haustorium in an epidermal cell within 12–15 h. After 48 h the initial germ tube becomes a branching hypha and up to three more germ tubes develop. The colony begins to abstrict conidiophore initials after 96 h and the first conidia are apparent soon afterwards. Sporulation intensifies from 5–7 days after inoculation. Godwin *et al.,* (1987) give a similar account of the infection process.

Only the epidermal cells of the host are invaded. The haustoria have a central nucleate body with lobed outgrowths. Up to three haustoria per cell have been recorded but one is most common.

7.2.3 Hygiene

In the case of downy mildew there is a very discrete initial source of infection in the primary basal spikes so that removal of these is a feasible method of minimizing secondary spread. In the case of powdery mildew the same technique can be applied to the heavily infected shoots that develop from bud infection but most of the primary sources are the scattered pustules arising from ascospore infection and the removal of these by hand is not practicable.

Stripping the lowest leaves from the bine, as for downy mildew, will remove some of the primary sources and also those leaves most liable to secondary infection. The use of chemicals to replace hand stripping is probably beneficial, as with downy mildew, since it destroys the spores *in situ* and avoids the risk of further spread as the diseased material is removed from the garden.

A return to cultivation after a period of non-cultivation should help to reduce the level of infection but the advantages of the non-cultivation technique are sufficient to outweigh, for most growers, the value of this as a hygiene method.

Perhaps the most important precaution that should be taken is to ensure that the minimum of diseased debris, especially infected cones, is left in the garden at the end of the season since this provides the starting point for the disease the next season. The greatest danger arises when a crop is so badly diseased that the grower decides not to harvest it. One virtue of machine picking is that only the lowest part of the bine, most of which has been stripped of any leaves, is left in the hop garden, and so most diseased material is removed. When a badly diseased crop is not harvested, therefore, every effort should be made to cut the bines down and burn them as quickly as possible. The longer they are left the greater the risk of the cones shattering and spreading diseased material.

7.2.4 Chemical control

The earliest chemical used to control powdery mildew was sulphur and it is still used to some extent today, either as powder or as a spray. Dinocap became available later and for many years control was based on these two materials. Newer products, some with limited systemic activity, include pyrazophos (Afugan) which was tested by Royle and Liyanage (1973) and found to be much more effective than dinocap and, even though it caused some phytotoxicity, the yield was better.

More recently approved chemicals in England include bupirimate (Nimrod), triadimefon (Bayleton), triforine (Saprol) and penconazole (Topas). Of these triforine was shown to be the most effective (Royle, 1976) and this has been the general experience of growers. It can however cause a reduction in yield and it is recommended that its use should be limited to four applications during the season. When a crop is threatened with severe damage it is better to risk some phytotoxicity if the disease can be checked by further use of this material. One disadvantage of the newer chemicals is that they do not have the same acaricidal effect as sulphur and dinocap.

Although copper fungicides do not directly affect powdery mildew it has been noted that they do contribute towards its control (Royle and Griffin, 1968). This is almost certainly an indirect effect due to hardening of the leaves which are consequently less susceptible to infection.

Since the mycelium of this fungus grows entirely on the plant surface it should, on the leaves, be an easier target for chemical control than downy mildew which proliferates within the plant tissues. In practice, however, it can be an extremely difficult disease to control and this is probably because it is tolerant of a wide range of environmental conditions.

7.2.5 Epidemiology

Whereas epidemiological studies on downy mildew were very successful in relating the development of infection to climatic conditions, similar studies with powdery mildew have proved much more unsatisfactory. One major reason for this difference is probably that powdery mildew is not dependent upon free water for secondary infection to occur. Prolonged spells of dry weather can reduce downy mildew infection in a garden to such a low level that there is a considerable delay before it builds up again with the return of wet conditions but mould infections are not so susceptible to adverse weather.

Powdery mildew conidia are able to germinate under dry conditions and in general these mildews are reputed to be inhibited by water. Royle (1978) found, however, that high levels of infection could be obtained in hops by spraying leaves with aqueous suspensions of conidia.

Although secondary infection can therefore occur on either wet or dry leaves it appears that the fungus is susceptible to very high temperatures and low atmospheric humidity. The summer of 1976 was one of the driest on record and Royle (1977) concluded that this was the reason why infection in that year was extremely low. It has frequently been noted at Wye that although mildew will spread on plants in the greenhouse with great speed during the early part of the season, it practically dies out in the height of the summer. It is probably such hot dry conditions that account for its absence from American hop yards.

The main conclusion from Royle's investigations was that the amount of the disease increased most rapidly and inoculum production, as recorded in spore traps, was greatest when there were flushes of growth of highly susceptible, young material. There were three main danger periods during the season: before training, when lateral shoots appeared and when burr was produced (Royle, 1979).

This gives some guidance to growers for the timing of their chemical control programme. An early application should be made regardless of whether or not the disease has been observed since it will not only help to eradicate any primary infection that has been overlooked but will also protect the plants during the first of the risk periods. The timing of further sprays may be judged by the development of the disease, although many growers rely on a routine application every 10–14 days, but in any event they should include an application at each of the other risk periods.

7.2.6 Resistant cultivars

In England powdery mildew is proving very difficult to control by chemical means thus there has been much interest in the development of resistant cultivars. The first to be widely grown was Wye Challenger which also had a very high level of resistance to downy mildew. It was first distributed to growers in the spring of 1972 but in 1974 the first record of the resistance breaking down was reported. The way in which the outbreaks of the disease were distributed suggested the possibility that the pathogenic race of the fungus was already established, possibly on wild hops.

Wye Target was released to growers in 1973 and it has since been so widely planted that it now occupies 30% of the English hop area. It has a different resistance mechanism to Wye Challenger and so far this resistance has proved stable under field conditions except for three reports of infected plants in 1979. Only one of these locations was notified in time for it to be investigated and there only one plant was found to be infected. The fungus from that plant was inoculated onto other plants of Wye Target under laboratory conditions and confirmed as weakly pathogenic (Neve and Lewis, 1980). On none of the sites did the disease recur. Isolates which sporulate on Wye Target have also been recovered from screening programmes under glass (Godwin *et al.,* 1987) but these do not appear to be viable under field conditions.

The resistance of Wye Challenger is characterized, on plants grown under glass, by the development of blisters very similar to the early stages of infection in susceptible plants. There is then only very sparse development of mycelium which soon dies. The blistering is rarely seen on plants growing in the field but since most of the testing for resistance is carried out under glass it is the diagnostic feature of the genotype and is referred to as the 'blister reaction'. It is almost certainly the type of resistance described by Salmon (1919) as 'semi-immunity'. The segregation of this character in seedling families indicates that it is controlled by a dominant major gene.

When Wye Target is inoculated there are either no visible symptoms or tiny necrotic flecks which suggest a hypersensitive reaction. The segregation of this type of resistance also indicates control by a dominant major gene. Other resistance genes have also been identified, and the original designations suggested for those controlling the blister reaction of Wye Challenger and the immune reaction of Wye Target were B and I_2 (Liyanage *et al.,* 1973). Four different resistance genes have now been identified by the reactions between hop genotypes and fungal isolates and the designations were amended to R_B, R_1, R_2 and R_3 by Liyanage (1973). He designated the corresponding virulence genes of the pathogen V_B, V_1, V_2 and V_3.

Strains of the fungus have arisen that are pathogenic under field conditions to all commercial varieties except Wye Target but other, non-commercial, immune host genotypes have been identified. These come from various sources including Russia and the USA and some, at least, are probably unrelated to the source of the Wye Target resistance. It is not known whether these carry the same resistance gene since there are no fungal isolates that will distinguish between them.

Godwin *et al.* (1987) reported no consistent differences in the frequency of conidial germination on susceptible Northern Brewer and resistant Wye Target but germ tube and hyphal lengths were much less on Wye Target. Nor was there a significant difference in the frequency of haustorium initiation but on the resistant plants fungal growth was usually restricted soon afterwards. On Wye Target, the penetrated epidermal cells showed a hypersensitive reaction with granulation of the contents and death of the haustorial initials.

There have been three instances when sectorial chimaeras have been discovered on hop seedlings in which one sector has been susceptible to the disease and the other immune (Figure 7.8) (Neve, unpublished; Darby and Gunn, 1987). In at least one instance the mutation must have been from a susceptible to an immune genotype but again it is not known whether the resistant gene is one already in the gene bank.

The varieties which were resistant when originally selected have frequently proved to be highly susceptible when strains have appeared that could overcome their major gene resistance. Wye Challenger was in commercial production before a pathogenic strain appeared but other seedlings which also

Figure 7.8 Chimaerical hop plant with sectors resistant or susceptible to powdery mildew (IHR, Wye).

carried the blister gene were at an advanced stage of selection. One of these was subsequently released under the name Yeoman and this has proved to be particularly susceptible. This stimulated renewed interest in the development of breeding lines with high levels of polygenic resistance. On its own such resistance would yield varieties on which the control of mould by chemicals would be relatively easy. Combined with major gene resistance it would reduce the likelihood of races pathogenic to the major gene developing and even if this did happen the polygenic resistance would still be operative (Neve and Darby, 1982).

The initial screening at Wye of seedling populations for their reaction to powdery mildew infection is carried out in the glasshouse when the plants are still quite small and large numbers can be tested quickly. Darby *et al.* (1989) compared the reaction of seedlings in such a screen with their subsequent performance in the field where a natural epidemic was encouraged. They found a significant positive association between the level of disease on male seedlings in the glasshouse and on their leaves in the field. There was no corresponding agreement in female plants for leaf infection in the field but a weak association with cone infection. They suggested that the difference between male and female plants was due to the plant producing flushes of young, susceptible leaves at different times during the growing season.

Although the correlation between glasshouse screening and field performance was not strong, they found that the initial screen was more efficient at identifying the highly susceptible seedlings and that by discarding these they could achieve worthwhile benefits to the selection process.

The continued breeding of resistant cultivars is being given a very high priority in England as described in more detail in Chapter 9 but in other countries the disease is not of sufficient importance to require similar activities.

7.3 VERTICILLIUM WILT: *Verticillium albo-atrum*

7.3.1 Description

The first record of this disease was in England in 1924 at Penshurst, Kent on the cultivars Fuggle and Tolhurst (Harris, 1927). No further cases were recorded until 1930 when more severe outbreaks began to appear and by 1937 about 12 had been identified. It continued to spread rapidly both on farms and between farms. Keyworth (1942) described how, on one farm, it was first recorded in 1934 with a group of 20 wilted plants in one field. By 1938 there were 2000 diseased plants in that field and a year later 26 out of 31 fields on the farm were affected.

The leaves of affected plants develop yellow patches followed by irregular black necrotic areas between the main veins giving a characteristic black and yellow pattern described as 'tiger striping' (Figure 7.9). It is a dry wilt and the affected leaves drop off very easily. This is used as a help towards diagnosis but the most reliable symptom is on the lower part of an infected bine, the woody core of which turns a coffee-brown colour. In some cases the lower 1.2–1.5 m (4–5 ft) of the bines become swollen but, unlike plants affected by Fusarium canker, they do not develop a restricted 'neck' at the base.

Keyworth (1942) noted that there appeared to be two different types of outbreaks which he described as 'fluctuating' and 'progressive'. In fluctuating cases thickening of the bines was more common, the browning of the wood was often limited to the centre and plants which had shown wilt symptoms commonly recovered. The severity of fluctuating outbreaks would vary from season to season but there was little increase in the number of plants showing symptoms in succeeding years.

In progressive outbreaks the symptoms appeared earlier in the season (sometimes as early as May), diseased plants usually died and the infection spread rapidly through the garden. It was noted that in gardens that were cultivated in both directions there was a general spread in all directions but in gardens that could only be cultivated one way the spread was very much restricted to that direction.

It was originally thought that the differences in severity of the disease were the result of different soil conditions, especially soil water (Harris, 1936).

Figure 7.9 Male plant infected with verticillium wilt showing typical 'tiger striping' of the leaves (Crown copyright).

Keyworth was unable to confirm this in the fields that he examined and made many isolations of the pathogen from outbreaks of all types.

A study of such isolates by Isaac and Keyworth (1948) established that the difference between fluctuating and progressive outbreaks was due to differences in the virulence of the pathogen which appeared to exist in two distinct forms. The terms 'fluctuating' and 'progressive' which were used to differentiate between the strains of the fungus really describe symptoms and these depend not only on the virulence of the pathogen but also upon the susceptibility of the host. For this reason the strains would be better identified as 'mild' or 'severe' but the original designations have been incorporated into legislation in *The Progressive Wilt of Hops Order* introduced in 1947, which made it compulsory to notify outbreaks of progressive wilt while fluctuating wilt was not notifiable.

The purpose of this legislation was to prevent the spread of the progressive form of the disease to areas other than the Weald where it was firmly established. When outbreaks were notified in other areas steps were taken to eradicate them and this approach was very successful for many years, even in East Kent which was so close to the Weald that isolated outbreaks occurred quite frequently. Within the Weald itself the disease was so firmly established by the time its true cause was identified that any attempt at eradication was impractical.

The legal distinction between the two forms of the pathogen made it necessary to be able to distinguish between them. Talboys and Wilson (1954) described a method for doing this by inoculating susceptible plants growing in concrete troughs in the open and this method was adopted for the official tests on one of the Ministry of Agriculture experimental stations. The facilities there became inadequate to cope with the numbers that required testing and a new system was developed in which plants grown in growth chambers were used for the test.

The results of the outdoor test could be seriously affected by weather conditions and Clarkson and Heale (1985a) found that tests over more than one season would be necessary to reliably distinguish fluctuating and progressive isolates. The outdoor tests had the further disadvantage that no results were available until at least 12 months after the outbreak was notified. During that time the uncertainty could lead to further spread of the disease since control measures could not be enforced until the fungus had been proved to be a progressive strain.

Growth rooms were not affected by weather conditions and more than one series of tests could be carried out during the year so that the earliest results were obtained quicker than with the outdoor test. This was, however, only a partial improvement since even the earliest results were not available for some months while the latest were as long delayed as with the outdoor test. A great deal of research has therefore been devoted to attempts to find a rapid method of characterizing the two forms of the pathogen.

Sewell and Wilson (1980) describe how the 'progressive' strain spread rapidly through Kent destroying all the commercial varieties. By 1965 the disease was largely controlled by the use of resistant varieties, accompanied by restricted nitrogen fertilizers, non-cultivation and high standards of hygiene. But between 1968 and 1971 severe wilt developed in previously resistant cultivars and pathogenicity testing confirmed that this was due to two 'super-virulent' strains, V2 and V3.

In a later paper, Sewell and Wilson (1984) reported that the levels of resistance of the test varieties retained the same relative ranking to the 'super-virulent' V2 and V3 strains as they did to other isolates and that there was no evidence of specificity. The new strains were initially isolated from nine farms all in the same area and they concluded that they had spread from a single focus as did the original progressive (V1) strain.

Although the progressive strains of wilt spread very fast through the Weald of Kent, it was possible for very many years to eliminate the outbreaks that occurred in other districts. The situation in the West Midlands was made more confusing by the fairly widespread incidence of mild, fluctuating outbreaks. In the end, however, a new outbreak of a severe strain could not be contained and it spread rapidly to many farms in the area. In east Kent, where fluctuating wilt was rare, there have been frequent outbreaks of the severe strains but most farms have been able to contain these.

Isolates of the fungus can be grouped by comparing their effects, in tank tests, on the varieties Bramling Cross and Wye Target. V1 is of low virulence on both, V2 causes severe wilt on Bramling Cross but not on Wye Target while V3 is virulent on both although less so on Wye Target. Wye Challenger, which had been judged to be fully susceptible when released, is moderately resistant to V1 (Sewell *et al.,* 1979).

There have been various attempts to develop a faster and more reliable method of distinguishing between the fluctuating and progressive strains of the fungus. Webb *et al.* (1972) used gel electrophoresis to determine total protein and specific enzyme patterns of different isolates but found no association with their virulence. Mohan and Ride (1984) studied the morphological and biochemical characteristics of three serotypes of the fungus but also failed to establish such a correlation. Nor did the assay of polygalacturanase by workers at East Malling using electrophoresis, in collaboration with the Ministry of Agriculture laboratory at Harpenden, consistently correlate with the virulence of the isolates.

Hignett *et al.* (1983) grew a number of mild and virulent isolates on medium augmented with hop cell wall as the sole carbon source on which enzyme and pH changes were monitored. By statistically combining four characters 90% of the isolates could be correctly classified. The use of the ELISA technique to distinguish between isolates serologically has also proved unreliable. The results supported previous data indicating that there is no absolute discontinuity between the progressive and fluctuating types (Swinburne *et al.,* 1985).

The most recent attempt to develop a rapid test to distinguish between mild and severe strains is adapting the technique of 'genetic finger-printing' to this purpose (Heale, personal communication).

It is becoming increasingly clear, as a result of these various procedures, that there is now a continuum of strains ranging in pathogenicity from very mild to very severe with no clear-cut division into two distinct classes.

The increased range of pathogenicity now encountered may be the result of genetic recombination between strains. Hastie (1962) first demonstrated that *Verticillium albo-atrum* from hops could undergo such recombination. Clarkson and Heale (1985b) studied heterokaryon compatability between isolates and concluded that there was greater genetic homology between fluctuating isolates than between progressive strains and that V2 and V3 isolates showed the greatest divergence from other isolates.

Because the distinction between fluctuating and progressive strains has apparently been eroded, Talboys (1985) proposed that the time had come for all cases of wilt to be treated in the same way. He suggested that the risk of even more virulent strains arising is not necessarily greatest amongst the present range of 'super-virulents' but might equally arise from the mild types. He suggested that the West Midland outbreak might have originated in this way and not from the movement of an existing strain from Kent.

Observations in the field have indicated that, although the level of infection in Fuggle hops is not affected by temperature or rainfall, disease expression in other cultivars is greatest in years when soil temperatures in the spring are low (Talboys and Wilson, 1970). This was confirmed by inoculating hop plants that were growing in temperature-controlled tanks (Sewell *et al.,* 1978).

Although English hop growing suffered the first, and the most virulent outbreaks of wilt, it has since become a problem elsewhere. In the Federal Republic of Germany the first report of wilt was by Zattler (1960b) who stated that there had been 55–60 ha affected in 1956 which had increased to 120 ha by 1959. Of the traditional varieties being grown, Spalter was the least and Hallertauer the most susceptible, Hersbrucker and Rottenburger being intermediate. The examination of a number of isolates indicated that these were all of equal virulence (Zattler and Chrometzka, 1960) and there has since then been no indication of increasing virulence similar to that in England. The disease has, however, spread very widely through the Hallertau district, the main hop growing area, and has led to a drastic reduction of the local Hallertauer variety.

The English cultivar Northern Brewer is highly susceptible to progressive wilt in England but highly resistant in Germany suggesting that the strain there is equivalent to a severe fluctuating type in England to which the cultivar has also shown resistance.

In the DDR the disease was first recorded in 1966 on an 11 ha holding in which there were three main foci of infection. There have also been reports of the disease in Poland, Belgium, Yugoslavia and France.

In New Zealand, Christie (1956) isolated the fungus from hops of the Californian variety that were planted to follow a potato crop. He compared his isolate with a fluctuating strain obtained from England and found his to be more pathogenic to Californian and less pathogenic to Fuggle than the English isolate. In the USA, Zehsazian (1968) found that the strain isolated from hops in Oregon was not a virulent pathogen to that crop, being better adapted to other species. In none of these countries does the disease appear to be as serious a problem as it is in England or Germany.

7.3.2 Hygiene

Keyworth (1942) demonstrated that diseased bine or leaves and the soil from around diseased plants were all potential sources of infection and he described many of the farming operations, such as cultivations and movement of plant material, that could spread the disease. Sewell *et al.* (1962) studied the effect of composting on the infectivity of the waste material from a picking machine by collecting it in an enclosure that was formed by brick walls on two sides and straw bales on the other two. They tested waste material from different positions in the heap 21 weeks after harvest and found 99% of the samples to be non-infective, the exception coming from the outside of the heap. On most farms the waste is left in an unenclosed heap so there is likely to be a greater volume of material that has not reached a sufficiently high temperature for the fungus to be destroyed.

Because there is no chemical control available and because the disease can very easily be carried in mud or plant remains, scrupulous attention to hygiene has been the only available method of minimizing its spread. Where the disease is endemic there has been little incentive for farmers to undertake tedious and time-consuming control measures, but in the wilt-free areas growers have gone to great lengths to prevent the disease appearing on their farms and this has been reinforced by government action.

The legislation for the control of wilt restricts the movement of plants, used hop poles, etc., from areas where wilt is endemic to eradication areas. Every care should be taken to ensure that vehicles are not driven from infected areas onto land in clean districts. Visitors to uninfected farms should be made to wear clean footwear before entering any hop gardens.

On a farm where only some areas are affected separate implements should, if possible, be kept for the diseased and healthy gardens. Otherwise each round of operations should start in the clean areas and on leaving the infected areas the tractor and implements should be carefully washed down.

Diseased hills should be carefully cut down and all the bines and as much of the leaf material as possible bagged up before removing it for burning. Infected bines may not always have developed wilt symptoms by the time they are harvested so all the waste collected at the picking machine should be regarded as highly dangerous. It should not be allowed to blow around nor be returned to hop gardens though after composting it could be used in orchards or arable land.

7.3.3 Cultural methods

Sewell and Wilson (1974) found that, compared with normal tillage, non-cultivation reduced wilt by some 28% on sites where the incidence was high. They attributed the reduction to the lack of root damage and the action of the simazine herbicide treatment which eliminated weed hosts of the fungus and inhibited surface rooting by the hops. On sites where the initial wilt incidence was low, however, it increased slightly under non-cultivation and they suggested that this was due to differential effects on soil nitrogen.

Since cultivations also spread infected material, non-cultivation was very widely adopted in England as a means of reducing the incidence of wilt. The firmer soil surface and better dräinage under this system also made it far easier to clean tractors and sprayers which might otherwise spread diseased material from infected gardens.

The importance of the level of nitrogen treatments to the incidence of wilt was demonstrated by Sewell and Wilson (1967) who compared rates of 235, 157 and 78 kg/ha (210, 140 and 70 lb/acre). The 157 and 78 kg/ha treatments reduced the incidence of wilt by 25% and 60% respectively compared with the heaviest application.

There have been many similar observations on the influence of nitrogen levels. In Germany, for example, Kamm (1970) reported that wilt was increased by high rates of nitrogen fertilizers but was suppressed by rich humus. This conflicts with observations in England where some severe infections of resistant varieties have followed heavy applications of farmyard manure. In France Marocke *et al.* (1977) found that wilt was most severe when nitrogen was applied as calcium nitrate and less if ammonium sulphate was used. The level of infection was least when urea was used and, in one instance, it even gave an apparent cure.

On farms where wilt is established there is little more that the grower can do by cultural management to minimize the disease. On farms where efforts are being made to eradicate it the management of infected areas, after the diseased plants and those close to them have been grubbed, is most important.

Trials conducted by Sewell and Wilson (1966) showed that the most effective way of eliminating the pathogen from infected soil was to eliminate all the broad-leaved plants that could act as hosts. When tomatoes were planted in test sites after a four year bare fallow there was a very low level of infection while on plots that had been under grass for the same period there was none. When hops were used to detect residual infection this was found to be very low after two years and nil after three to five years under a weed-free grass sward.

In eradication areas, plant health regulations in England required, for many years, that infected areas should be grassed down, fenced and left in that state indefinitely. More recently, growers have been allowed to bring such areas back into production after a suitable period under grass. It is most important for grassing down to be effective that the sward be kept free of broad-leaved weeds, if necessary by the use of selective herbicides.

7.3.4 Chemical control

Keyworth (1942) applied a range of soil disinfectants to infected soil which was then left for two to three weeks before planting Fuggle hops to test for residual infection. None of the treatments were completely effective though 2% formalin at 36 l/m^2 (8 gal/yd^2) gave the best result. Formalin has proved very effective in the treatment of 'apple replant disease' and this success may be related to the rapid recolonization of the soil by *Trichoderma* spp. (Freeman, 1980) which can be antagonistic to some pathogens. It has been suggested that formalin treatment might be worth looking at again in the light of the apple experience.

Sewell *et al.* (1971) detected benomyl at very low levels in xylem sap of pot plants to which it had been applied, but not in mature field-grown plants. The treatment controlled wilt in the pot plants but not in the field. Other fungicides that have been assessed for their effectiveness against wilt have included metalaxyl, fosetyl-aluminium, thiabendazole and some experimental materials. Although some treatments have reduced wilt infection when applied to pot plants they have been ineffective in the field and some have, in addition, proved phytotoxic (Chambers *et al.,* 1982, 1983).

A major problem with such treatments is that the hop is so deep rooted that it is difficult to incorporate the fungicide to sufficient depth to reach all the infected layer. A systemic fungicide that was effective against the pathogen and would translocate downwards into the root system might give control but most systemic materials only move upwards with the sap flow.

Because high soil nitrogen levels favour wilt development trials have been carried out with nitrification-inhibiting compounds. No difference was noted with ammonium nitrate but when urea was used as the source of nitrogen there was a reduction in infection in the presence of the inhibitor (Chambers, 1987).

7.3.5 Biological control

Wilderspin *et al.* (1983) initiated a programme to investigate three possible approaches to biological control of wilt. One was to elicit resistance of hops by treating the roots with heat-killed conidia or with culture filtrates. Another was to increase the antagonism of other organisms by organic soil amendments while the third was an investigation of the 'wilt-suppressive' effect observed in some gardens. In their next report (1984) it was said that the addition of 1% chitin to hop garden soil reduced the population of *Verticillium* propagules by 10% after 48 days and that hops and antirrhinums grown in amended soil showed 5–8% infection compared with 40% in the controls. Similar results were obtained with a crude preparation of *Laminaria* seaweed.

Their next report (1985), on the other hand, stated that adding *Laminaria* stimulated the germination of dark resting mycelium and sporulation so that there were more propagules than in unamended soil although it remained to be seen whether the rapid germination would lead to reduced viability after 12 months or more. Chitin, at 1% addition, was less stimulatory and inhibition of germination occurred after two months while three months after a 5% addition no propagules were detectable. The addition of chitin, *Laminaria* or yeast waste as soil amendments three months prior to planting in *Verticillium* infected soil reduced the number of wilted plants to about 20% of the controls.

7.3.6 Resistant cultivars

Once wilt has become established on a farm there is no control method that makes it possible to grow susceptible cultivars economically and hop cultivation has only been able to continue in such areas as the Weald of Kent or the Hallertau district of Bavaria by planting resistant varieties, the development of which is described in Chapter 9.

Keyworth (1953) demonstrated by grafting experiments that resistance to wilt was located in the root and not the bine and this was supported by the results of stem inoculation. When a small volume of spore suspension was injected into bines of the susceptible cultivar, Fuggle, they developed mild symptoms, but when a large volume was injected the symptoms were severe and the bines died above the injection point. The reaction of the grafted bines presumably reflected the quantity of inoculum that was able to reach the bines through the root system of the susceptible or resistant varieties on which they were growing.

Talboys (1958a) found that the initial reaction of the hop to infection is a lignification of epidermal and cortical cells in contact with the fungus. Where a hypha penetrates a cell wall, lignin-like deposits build up on the inside of the wall, extending the distance that the hypha has to penetrate. These deposits form peg-like lignitubers through which the hyphae sometimes emerge but, more frequently, are complete occluded. This mechanism is most pronounced in sensitive hosts invaded by a mild pathogen and does not appear to be an effective defence mechanism against more virulent strains. The more effective defence mechanism is located in the endodermis, the cells of which, in resistant cultivars, are strongly suberized. Rudolph (1968) reported that varietal resistance to wilt is related to the distance between the root tip and the first lateral root because the xylem above the lateral root is protected by the endodermal suberin layer.

If the fungus penetrates to the vascular system this stimulates the production of tyloses in the xylem vessels which help to limit the development of the infection. Leaf necrosis is due to fungal toxins and not to tyloses restricting sap flow (Talboys, 1958b).

No hop genotypes have been discovered that are immune to wilt and even highly resistant cultivars can become infected, often without showing any symptoms. For this reason it was part of the eradication policy in England to ban the planting of resistant cultivars in wilt-free areas for fear that they might become infected and provide an unidentified focus of infection for other hops in the neighbourhood.

This policy underwent some modification when a few growers were unable to eradicate the disease from their holdings so that, in spite of grubbing and grassing down each outbreak that occurred, further infections continued to develop. Such gardens continued to represent a risk to neighbouring farms because fresh diseased material was produced each year and it also became uneconomic for them to continue in that way. These farms were, therefore, licensed to plant resistant varieties and it was thought that by reducing the amount of infected material that would result from this the risk to other farms might also be reduced.

This judgement was supported by observations on the levels of wilt in Wye Target, the most resistant cultivar so far developed in England (Chambers, 1985). It was found that in gardens of this variety that initially had high levels of wilt symptoms, there was a rapid and continuous decline in the succeeding years that could not be attributed to the effects of temperature or nitrogen levels. It was suggested that this indicated that with a cultivar of such high resistance, the amount of inoculum returned to the soil from new infections was less than the amount destroyed by the activity of soil organisms.

This report was accompanied by a warning that planting highly resistant hops in soils with a high level of infection creates strong selection pressure for the development of yet more virulent strains of the fungus. It was recommended that such varieties should only be planted into 'clean' land or heavily infected land that is first 'cleaned up' by at least two years under grass.

7.3.4 *Verticillium dahliae*

Although this is a common pathogen of other crops such as potatoes, tomatoes or strawberries it rarely attacks hops. It is more likely to do so in warmer conditions where it is much more widespread and it is occasionally reported on hops from the USA and also from New Zealand.

It can occur elsewhere and since the symptoms are similar to those of *V. albo-atrum* it can be a cause of alarm where steps need to be taken to eradicate that disease. For this reason it is advisable not to plant hops immediately following crops such as potatoes and strawberries which are liable to provide sources of infection.

A particular problem occurred in the USA where soil had been treated with the insecticide heptachlor in past years when other crops were grown. Skotland and Romanko (1987) record that in hop fields in which there were heptachlor residues of 0.02 and 0.03 ppm, nearly 100% of the hop plants became infected with *V. dahliae* whether the cultivar was normally susceptible or resistant to the pathogen. In Idaho, the insecticide is used as an aid in the routine testing of selections for resistance to *Verticillium* by growing them in a field that had been treated with it.

7.4 OTHER FUNGAL DISEASES

7.4.1 Fusarium canker: *Fusarium sambucinum*

The commonest form of damage from this disease is found at the base of the bine which is girdled so that only the innermost core is left attached. This constriction causes the bine to wilt and the reason for this is readily identified by the way the narrow neck can be broken by quite a gentle pull.

The fungus usually invades through a damaged point and this may be where the bine joins the rootstock. If there is much movement of the bine at this point a crack can develop providing a point of entry. In gardens that are cultivated there is usually some mounding of soil about the base of the bine which is supported so that cracking is less likely to occur than on non-cultivated hops which lack this support. The mounded-up earth may also cover any cankered area that has developed and roots will then grow from above the canker which will help to keep the bine from wilting.

The bine above the canker will usually become thickened because the downward flow of carbohydrates to the rootstock is interrupted. Although Verticillium wilt can also cause the bine to fatten, the two diseases can quite easily be distinguished. With canker the wilted leaves become flaccid whereas on *Verticillium*-infected bines they are stiffer and drop off easily while the pulling-off of the bine at the base is typical of canker.

Normally no special control measures are required other than good hygiene, any diseased material being cut off and removed. In the early 1970s there was a major replanting programme in England during the course of which there were a number of complaints about rotting of setts between their delivery to the farm in the autumn and planting in the spring. The setts arrived looking healthy and were bedded in until required but when lifted for planting many were found to be rotten. *Fusarium sambucinum* was identified as the cause of the problem but investigations by Royle and Liyanage (1976) could find no evidence of the plants on the propagators' holdings being infected. Their experiments were rather inconclusive because the problem only occurred sporadically but it did appear that the setts were particularly vulnerable if they were allowed to dry out. On the basis of information on hop canker from Germany and of the disease on other crops, they suggested that dips or drenches with fentin acetate and maneb or benomyl might be useful.

A few years later a problem arose on the cultivar Yeoman, when hill deaths became frequent after the setts had been planted, most deaths occurring during the next winter. This cultivar also developed a lot of bine canker and it is suspected that *F. sambucinum* was involved in both these problems.

Trials were carried out to attempt chemical control of the problem and there were encouraging results from basal sprays with a formulation of thiabendazole (Darby, 1984a).

7.4.2 Black root rot: *Phytophthora citricola*

A black root rot of hops caused by *Phytophthora citricola* has been a serious problem in New Zealand for many years although the development of resistant cultivars has reduced its significance there (section 9.2). In Australia the same pathogen was reputed to be the cause of a black root rot which became much less common following the establishment of Pride of Ringwood as the principal cultivar. In a recent study, Skotland (personal communication) consistently isolated *Pythium intermedium* from rotted crowns of Pride of Ringwood whose storage roots had typical 'black rot' symptoms. He did not isolate *Phytophthora citricola* and it is possible that, in the past, this was erroneously assumed to be the causal organism in Australia because it had been identified as such in New Zealand. *P. citricola* has, however, been identified as the cause of black root rot in South Africa, where it has been a serious problem, and in England, where it is only rarely serious (Royle, 1966).

It is a soil-borne fungus that invades the rootstock at or near the crown. The water-conducting vessels of the rootstock become blocked with fungal hyphae and tyloses and the infected area becomes watersoaked and blackened and initially is clearly delimited from neighbouring healthy tissue. The first sign of infection of the rootstock appears late in the season when the bines suddenly wilt in a soft, flagging or drooping manner. This type of wilt can be confused with canker but bines infected with black root rot do not pull-off like cankered bines.

The disease is too infrequent in Europe for any chemical control measures to have been adopted. In New Zealand and South Africa there were trials with soil disinfecting agents but the development of resistant cultivars has largely solved the problem.

7.4.3 Grey mould: *Botrytis cinerea*

This is a disease of hop cones that is reported to have become increasingly serious in Japan since 1952 (Sakai, 1976) but elsewhere it is only a problem if conditions are very favourable to its development. Although reports of it in Germany go back to 1953 it was not of importance until around 1970 when it forced some growers in the Hallertau district to harvest their hops early before the disease caused too much damage. It was originally thought that the disease only developed after the cones had suffered from insect damage but in more recent outbreaks insects have not been involved (Kohlmann and Kastner, 1975).

It is favoured by wet conditions during cone development and appears as a grey, fuzzy mould, starting at the tip of the cone where moisture persists for the longest period of time, and causing the cones to turn brown. The bracteoles are more susceptible to damage than the bracts and so the cones often have a striped appearance.

Only in Germany are any fungicide treatments officially approved for the disease on hops, the materials recommended there being dichlofluanid, procymidon and vinclozolin.

7.4.4 *Alternaria alternata*

This fungus is not normally recognized as a pathogen of hops so there is no common name to describe it. In September 1982 there was a widespread discoloration of hop cones in England which was at first attributed to late infection by powdery mildew. Since cultivars resistant to the mildew were also attacked, this diagnosis was unlikely and, on examination of affected cones, *A. alternata* was the only pathogen to be consistently recovered. Inoculation of healthy cones with the fungal isolates produced similar symptoms and it was found that infection was favoured by high humidity and by injury to the cones such as would be caused by high winds. As with *Botrytis,* it was the bracteoles which were most prone to infection and so the cones developed a similar striped appearance (Darby, 1988). In the case of *A. alternata* infection, however, there was none of the grey mould typical of *Botrytis.*

7.4.5 Black mould: *Cladosporium*

This is another relatively unimportant disease first described by Salmon and Ware (1936). It also causes a brown discoloration of the cones but in this case it is the bracts that are discoloured and the bracteoles that remain green so the striped effect is the reverse of that seen on hops infected with *Botrytis* or *Alternaria.*

7.4.6 Armillaria root rot: *Armillaria mellea*

Hops are only liable to be attacked by this fungus when there is a source of infected wood nearby since it is primarily a disease that affects trees. The fungus grows out of tree roots with long round rhizomorphic strands, from which it gets its name of the 'bootlace fungus', and these spread through the soil below the surface.

Salmon and Ware (1937) described an outbreak in which the infection came from an oak stump some 7 m from the nearest hop hill to be infected.

Hedgerows can be another source of infection while one instance was noted at Wye where a wooden stump used to mark an experimental plot was the cause. The problem is an infrequent one but hops planted on old orchards are a special risk since this is one of the rare occasions when they will be planted after trees.

CHAPTER 8

Virus diseases

Because commercial hop gardens are invariably planted with vegetatively propagated material the stocks are liable to accumulate virus infections. The traditional hop varieties have been in cultivation for a very long time, possibly for as long as 200–300 years. In England the Fuggle variety, which is a comparative newcomer, has been grown for over 100 years. In view of their long history it is surprising that virus problems have not been more severe.

The first account of a virus disease in hops is probably the description by Percival in 1895 of what he called the eelworm disease of hops although the plants were also described as 'nettle-headed' or 'skinkly'. The problem is now called nettlehead and is known to be a virus disease. Since it was not until 1898 that the first virus (tobacco mosaic virus) was isolated it is not surprising that Percival failed to identify the true cause of the problem. It was not until 1966 that Bock was able to identify arabis mosaic virus in hops and suggest that it was implicated in the disease.

The identification of the viruses infecting hops has been one of the most difficult problems facing hop research workers and only recently has a fairly complete picture of the situation emerged. The work has been greatly facilitated by the development of the enzyme-linked immunosorbent assay (ELISA) method of determining the presence of viruses in plants which was very rapidly adopted for use with hops (Thresh *et al.*, 1977; Barbara *et al.*, 1978).

Just as important for the control of the diseases, once they had been identified, has been the elimination of the viruses from infected plants by heat therapy and meristem-tip culture (Vine and Jones, 1969; Schmidt *et al.*, 1973; Adams, 1975). The use of these two techniques combined with the Ministry of Agriculture A plus certification scheme for hop propagators has transformed the health of the English hop crop and similar measures have been adopted elsewhere.

When the very tip of an apical shoot is dissected out and grown on under sterile conditions, plants often can be regenerated that are virus-free. Virus multiplication is inhibited by maintaining plants at a high temperature and a combination of heat treatment and meristem-tip culture has made it possible to obtain virus-free clones of all the important cultivars.

The ELISA technique uses an antiserum for the particular virus under investigation and a quick and reliable colour reaction determines within two days whether or not the virus is present in the sample. The method is much quicker and more reliable than the older method of inoculating indicator plants of other species that are virus sensitive and many more samples can be tested.

8.1 HOP MOSAIC VIRUS (HMV)

Hop varieties are either sensitive to this virus or else, when infected, the plants show no symptoms but carry the virus and can be foci for further spread. Whether infected or not such varieties are referred to as 'carriers'. The typical symptoms on sensitive hops first appear as pale vein-banding of the leaves (Figure 8.1) which then become mottled and strongly down-curled. The down-curling is normally a good diagnostic feature to distinguish HMV from nettlehead in which the leaves curl upwards, but the Australian cultivar, J78, is an exception. It very rapidly became infected with HMV when grown at Wye although, because the leaves curled upwards, nettlehead was first suspected.

Diseased hills can survive for several years during which time they are stunted with short internodes and the bines fall away from the strings. Production from such plants is minimal and they should be grubbed as soon as possible to prevent them acting as sources of infection.

Adams and Barbara (1980) purified the virus and found it to be a member of the carlavirus group with filamentous particles *c.* 14 × 650 nm composed of *c.* 6% single-stranded RNA of mol. wt *c.* 3.0×10^6 and a single protein species of mol. wt *c.* 34 000. It is a distinct member of the group though distantly related to hop latent virus and others.

Although the damson-hop aphid (*Phorodon humuli*) was thought to be the most likely vector of the virus, Massee (1943) failed to demonstrate transmission while Paine and Legg (1953) obtained transmission with the spring alatae but failed to do so with apterae. Bock (1967) recorded the spread into 650 seedlings from a mosaic-sensitive cross that were exposed in batches of 50 for 24 h periods during the spring migration of *P. humuli* with yellow traps distributed amongst the seedlings. Only 22 of the seedlings developed mosaic but from correlations with the aphid species caught in the traps Bock considered that *Macrosiphum gei* was the probable vector. Adams and Barbara (1980) showed that the apterae of the hop aphid can transmit the virus, as can those of *Myzus persicae* and *Macrosiphum euphorbiae*. It seems therefore that HMV is similar to other carlaviruses in having low vector specificity, being transmissible by numerous aphid species.

Transmission can only occur when the aphids move from one hop plant to another and apterae seldom do this. Even though the alates of *P. humuli* are

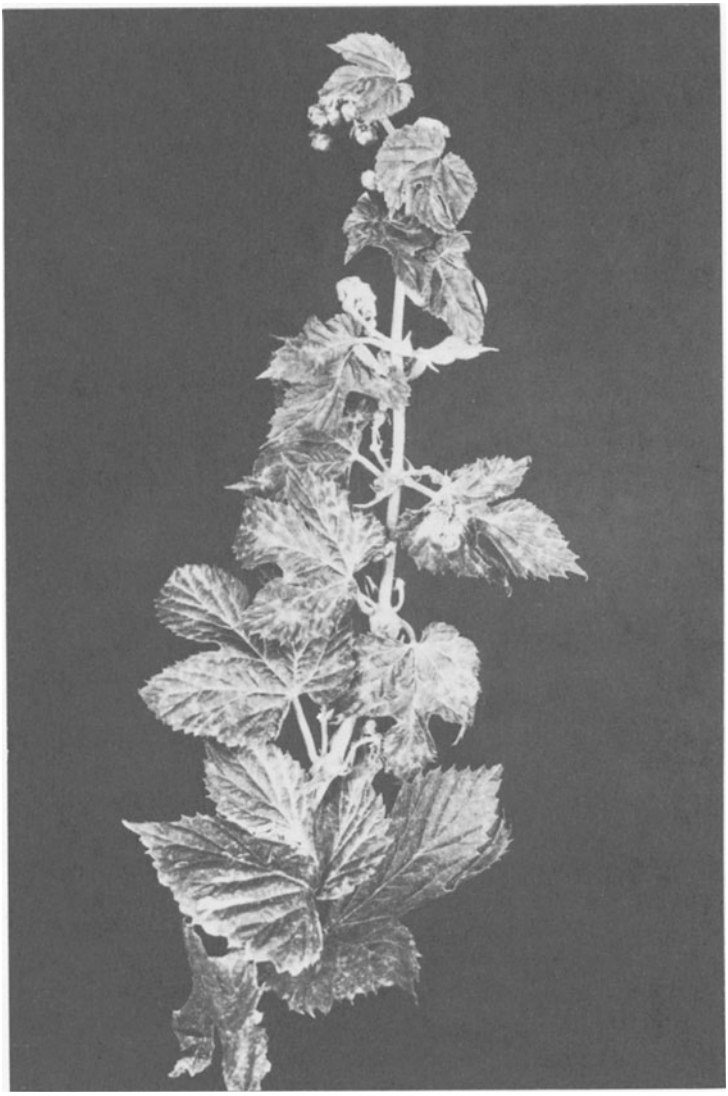


Figure 8.1 Hop mosaic (Crown copyright).

evidently inefficient vectors they are very numerous and it is possible that they are the cause of most of the spread although other species which rarely settle after alighting on hop plants might be important. Once hop aphids have alighted on a hop plant they are more likely to move if they find the host unsatisfactory. They may then fly to another plant but such flights are short so the isolation required to prevent spread between susceptible and carrier varieties is only about 100 m (Thresh and Adams, 1983). It is much more important to ensure that none of the plants in a garden of a sensitive cultivar are carriers. Problems were sometimes experienced because males that were infected carriers were planted amongst sensitive Golding hops, leading to a conspicuous patch of diseased plants around the male (Keyworth, 1947).

Field trials of mosaic-free and infected material of carrier varieties have been carried out at Wye College and Rosemaund Experimental Husbandry Farm in Hereford and no consistent effects on yield or α-acid found (Thresh and Adams, 1983) although in one of the trials with Wye Saxon there was some evidence of a fall in production in the year in which infection was detectable followed by a recovery in subsequent years (Neve and Lewis, 1979). In Australia, preliminary results indicate there may be severe yield reduction in Pride of Ringwood infected with HMV (Lewis, 1988).

The striking feature of two of these trials was the difference between the two cultivars, Wye Saxon and Wye Northdown, in the rate at which reinfection occurred. In the Saxon trial about half the meristem plants were infected between planting in 1975 and harvest in 1976 and by 1978 most were infected and the trial had to be abandoned (Neve and Lewis, 1977, 1979). The Wye Northdown was planted in 1980 and seven plants were found to be infected by 1981 but there was only one additional case in 1982 and none in 1983 (Neve and Darby, 1983, 1984a). It is suggested that the differences reflect aphid preference for the two cultivars, with Wye Northdown being so acceptable that aphids remain on the plant on which they first alight.

Hop mosaic was first described by Salmon in 1923 but examination of his field records indicates that for some years he had mistakenly diagnosed the problem as nettlehead and cases of mosaic infection in his breeding material at Wye can be traced back as far as 1906.

Mackenzie *et al.* (1929) described how a grower in Kent obtained cuttings of the Hallertauer variety from Germany between 1904 and 1908. These were planted with the English variety Cobbs on either side and, although the Hallertauer hops remained healthy, the Cobbs adjoining them suffered from mosaic disease. Similar events followed the distribution from Wye of two seedling varieties to farms where they were planted amongst Golding hops. An extensive series of intervarietal grafts was carried out to determine which varieties were sensitive to the virus and which were carriers or potential carriers. All the clones of the true Goldings were sensitive as was the 'Golding Variety' Tutsham. Although the disease had not been reported from Germany they found that some hops of German origin, though not exactly identified, were sensitive, as were hops obtained from France labelled 'Alsace' and 'Spalt'. The identity of these two sorts must be suspect since there is no evidence that genuine stocks of these varieties are sensitive.

Since sensitive cultivars formed a large part of the English hop area at the time of these reports and the disease had not previously been reported, it must be concluded that it was introduced early this century. Apart from the importation of Hallertauer hops mentioned above, Mackenzie *et al.* (1929) stated that a garden of German varieties existed at Wye College before 1900 and that other hop growers had also introduced them. They found that most introduced hops were either carriers or potential carriers but were unable to say whether the carriers were infected when introduced or had become infected subsequently. All the female hops from the USA were carriers although the Red Vine obtained from Canada (but which had originated from New York) sometimes showed atypical virus symptoms that they termed 'masked mosaic'. On the other hand all the male hops they obtained from the USA were extremely sensitive so that there was great difficulty in maintaining the stocks at Wye.

An atypically mild strain of hop mosaic was described by Legg (1959a) in which symptoms, consisting of a light green or yellow mottle, did not appear on young leaves until they were fully expanded. The bines continued to climb but vigour was impaired. Flowers were produced normally but the cones were small and loosely formed. Infection with the mild form provided cross-protection against infection with the severe strain.

Hop mosaic has, until recently, attracted little attention outside England, but the spread of verticillium wilt in Germany has led to the replanting of large areas of the Hallertauer Mittelfrüh variety with Hersbrücker Spät hops. This has been accompanied by reports of mosaic infection in the Hersbrücker variety. Kremheller *et al.* (1989) recorded the incidence of HMV in plants that were virus-free when planted 3–5 years earlier and expressed surprise that only 1.3% had become infected but they gave no indication of the proximity of sources of infection. They found no effect of infection upon yield or α-acid contents.

They contrasted the situation in 1956, when Zattler found mosaic symptoms in 3% of plants of Hersbrücker Spät in the Hersbruck region but none in Hallertauer Mittelfrüh, with what had happened in the 1970s when such symptoms began to appear in the Hallertau region in Northern Brewer, Brewer's Gold and Hüller Bitterer. Subsequently the symptoms were observed in Perle and Orion. All the plants with these symptoms that were tested were found to be infected with HMV, but other infected plants were symptomless. Tests showed that the symptoms were not associated with infection with Hop Stunt Viroid (see section 8.7.1) and they were unable to establish the cause.

In Australia, Munro (1987) carried out a survey on the main cultivar, Pride of Ringwood and found levels of infection ranging from 1–68%. Since the damson-hop aphid is not present in Australia there must be some other vector operating there since Pride of Ringwood was bred in Australia and there is no evidence that the virus is seed transmitted.

8.1.1 Control

Where mosaic-sensitive varieties of hops are grown it is important to ensure that the planting material comes from a mosaic-free stock and that there are no admixtures of plants of a carrier variety. When replanting a garden that previously grew a carrier variety, great care must be taken that none of those plants survive to act as sources of infection. The garden should be isolated from others containing carrier varieties but the distance between them need not be very great – it would appear that 100 m is probably sufficient to avoid infection being transmitted from one to the other. Any male plants to be included in the garden should come from a known mosaic-sensitive source.

If any plants do become infected they are easily recognized and should be grubbed as soon as possible but their position should be noted. If there are rogue carrier plants in the garden they will tend to infect the plants in their immediate neighbourhood and a record of where infection has occurred can help to identify the source.

Since there is no clear evidence of any reduction in yield in carrier varieties infected with the virus there is no justification in going to the expense that would be involved in raising mosaic-free stocks and ensuring that they could be multiplied without becoming reinfected. It is accepted in the UK, therefore, that material of carrier varieties within the A plus certification scheme are infected with mosaic.

8.2 HOP LATENT VIRUS (HLV)

Adams and Barbara (1982) found that virtually all commercial varieties in England are uniformly infected with this carlavirus, the only exceptions being some of the meristem clones most recently released to propagators. The filamentous virus particles of this virus (Figure 8.2) were *c.* 14 × 675 nm composed of *c.* 6% single-stranded RNA of mol. wt *c.* 2.9×10^6 and a single protein species of mol. wt *c.* 33 000.

The virus is transmitted by the damson hop aphid and is widespread in Europe, the USA and Australia but there is no evidence that it has any effect upon the productivity of infected hops and no control measures are advocated.

Munro (1987) also checked for this in Pride of Ringwood and recorded levels ranging from 1–58%.

8.3 AMERICAN HOP LATENT VIRUS (AHLV)

This is the third of the carlaviruses known to infect hop plants. First reported by Probasco and Skotland (1978) in North America, it was subsequently found at Wye College in some recent introductions from the USA although it was not

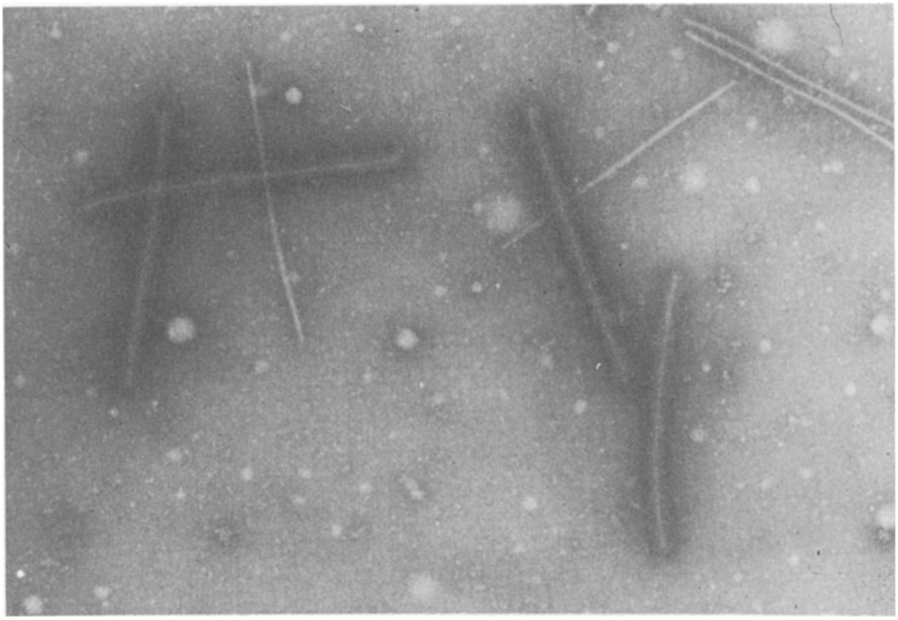


Figure 8.2 Virus particles of hop mosaic and hop latent viruses distinguished by 'decoration' with hop mosaic antiserum (IHR, East Malling).

present in any of the older introductions from there. Eppler and Sander (1980) carried out a survey of hops in the BRD following the report of AHLV having been found in England but only found it in a hop clone introduced from the USA and growing in an isolated breeding garden. A check on the neighbouring seedlings did not disclose any indication of the virus having spread. It has also been found in New Zealand where 9–10% of the plants tested were infected (Hay, F. S., unpublished).

The infected material at Wye had been planted out in an experimental garden but it was grubbed as soon as the infection was identified and, although this virus is also transmitted by the damson hop aphid, checks of neighbouring plants failed to detect any evidence that it had spread from the original source. While very little is known, at this stage, about the effects of the virus on infected plants, it is obviously desirable that every effort should be made to prevent it from becoming established outside the USA.

Virus preparations contained filamentous particles *c.* 15 × 680 nm composed of *c.* 6% single-stranded RNA of mol. wt 3.0×10^6 and a single protein species of mol. wt *c.* 33 000.

8.4 ARABIS MOSAIC VIRUS (AMV)

Nettlehead disease has been a major problem for hop growers for a very long time. Percival (1895) attributed the cause to the nematode *Heterodora schachtii* but Duffield (1925) eliminated nematodes as the cause by demonstrating that they occurred as frequently in the soil surrounding healthy plants as those that were diseased. It was not until much later that Bock (1966) suggested that arabis mosaic virus (AMV) was the cause. He identified 30 nm polyhedral virus particles found in hops as AMV and roughly spherical particles of *c.* 25 nm diameter as necrotic ringspot virus (NRSV). He found that AMV was always present in nettlehead-diseased plants but not all plants with AMV showed the disease symptoms. A rod-shaped virus that he also detected was not associated with the disease. He suggested that nettlehead was the result of dual infection with AMV and NRSV and mentioned that the nematode *Xiphinema diversicaudatum* was present in low numbers in most gardens but extremely numerous in three gardens where nettlehead was prevalent.

Schmidt *et al.* (1972) similarly identified AMV and apple mosaic, which is a form of NRSV, in hops suffering from nettlehead and concluded that the disease was caused by the combination of those two viruses.

Subsequent work confirmed the role of AMV in nettlehead but not Bock's suggestion that NRSV was also involved although it became evident that there must be a second element to the disease since all nettlehead plants were infected with AMV but not all AMV-infected plants developed nettlehead. Clark and Flegg (1979) found that a satellite consisting of a low molecular weight species of nucleic acid (SNA) was consistently associated with AMV in nettlehead plants. Subsequent reports (Clark and Davies, 1980, 1981; Davies and Clark, 1982, 1983) described a second species (SNA-2) and continued to find a good correlation between plants with nettlehead or stunting and the presence of SNA in the AMV preparations.

Nettlehead usually spreads slowly but tends to be particularly serious alongside hedgerows, where hedges have been grubbed and after orchard crops or permanent pasture (Keyworth and Davies, 1946; Keyworth and Hitchcock, 1948). These observations suggested that it is soil-borne, but it was many years before the vector was identified as the dagger nematode *Xiphinema diversicaudatum* (Valdez *et al.*, 1974).

An unusually rapid spread of the disease was recorded on a farm in Worcestershire where hops were planted in the winter of 1968–9 with locally produced setts on a site that was formerly an old pasture. Nematodes were widely distributed and AMV was probably introduced in the planting material. Infection increased from 2.9% of the plants in 1970 to 43.6% by 1977, the newly infected plants usually being adjacent to those that had earlier shown symptoms (Adams *et al.*, 1978). By 1984 over 70% of the plants were showing symptoms (Thresh and Adams, 1985).

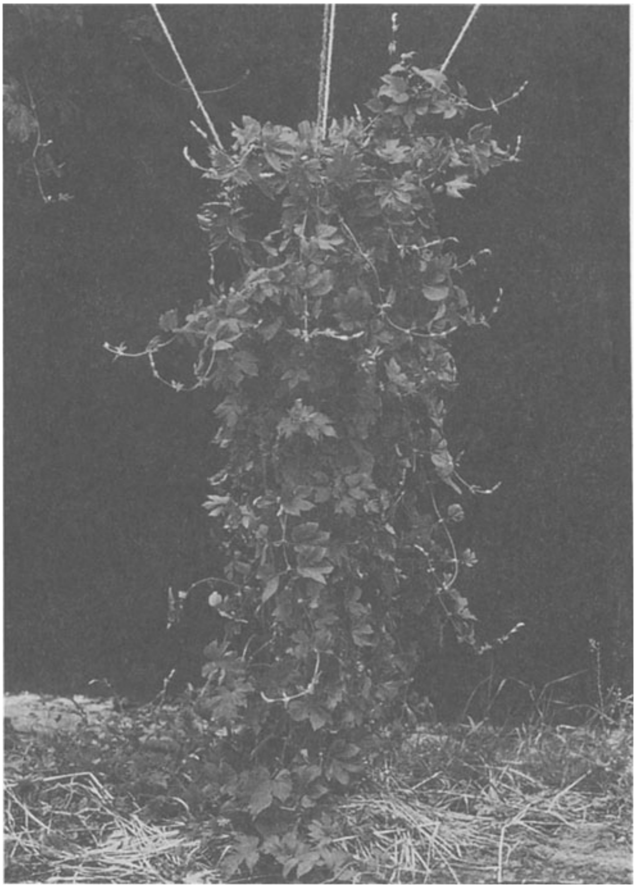


Figure 8.3 Nettlehead (IHR, East Malling).

Thresh *et al.* (1972) described three distinct diseases, nettlehead, split leaf blotch and bare-bine that could result from infection with AMV. Subsequently Adams *et al.* (1987) identified AMV as the cause of hop chlorotic disease also.

8.4.1 Nettlehead

This is the most serious of the three diseases associated with AMV and apparently results from infection with the virus in association with SNA. Infected plants have weak bines which climb badly, the tops falling away from the strings. The internodes are shortened, the leaves are small with margins up-curled, in contrast to mosaic in which they are normally down-curled. The cones are small and distorted and the crop is reduced by as much as 75% (Legg, 1959b) (Figure 8.3).

Symptoms do not usually appear until the year after the hill becomes infected and although the symptoms from then on are variable, diminishing in hot weather, there is a progressive weakening of the plant although they do not normally die. The centre of the stock tends to become rotten and new buds are confined to a rim of living tissue.

A severe outbreak of nettlehead was reported in 1983 on the variety Yeoman which had been planted following Bramling Cross, a hop which has long been known to have considerable tolerance of infection compared with others such as Fuggle and W.G.V. The Yeoman plants were severely stunted with very conspicuous nettlehead symptoms whereas previously there had been no obvious problem at the site with the Bramling Cross (Thresh, 1984).

8.4.2 Split leaf blotch

This disease was given its very descriptive name by Salmon and Ware (1934) on account of the translucent, yellow, oily blotches which develop on some leaves of infected plants. As the leaves expand the blotches frequently split (Figure 8.4). Fuggle is the only variety to suffer from this disease to any noticeable extent and this may be because infection accentuates the tendency of even uninfected plants to show some slight blotching. Legg (1959b) recorded reductions of yield of infected plants of about 50% and Thresh *et al.* (1972) suggested that in Fuggle it might cause greater losses than nettlehead because, although less severe, it was much more common.

8.4.3 Bare bine or spidery hop

The majority of plants infected with AMV show bare bine symptoms in the spring even though they may subsequently recover and appear to be healthy. Affected plants are weak when growth commences in the spring and have a spidery, bare appearance compared with normal hills (Figure 8.5). Few shoots develop and these have a characteristic curvature, dark colour and small, retarded leaves. The difference disappears within a few days and is no longer recognizable after the hills have been trained and the excess shoots removed (Thresh *et al.*, 1972).

The condition was not recognized until recently because the symptoms are very transient and they were only noticed after serological tests had made it possible to compare the growth of large numbers of plants known to be infected or free from AMV. With experience, however, the symptoms can be recognized without too much difficulty.

The only evidence about the effect of this type of infection on yield is from a trial on the variety Bullion in which plants showing bare bine symptoms, and subsequently confirmed as being infected with AMV, yielded some 25% less and had α-acid contents about 8% lower than uninfected plants so that their

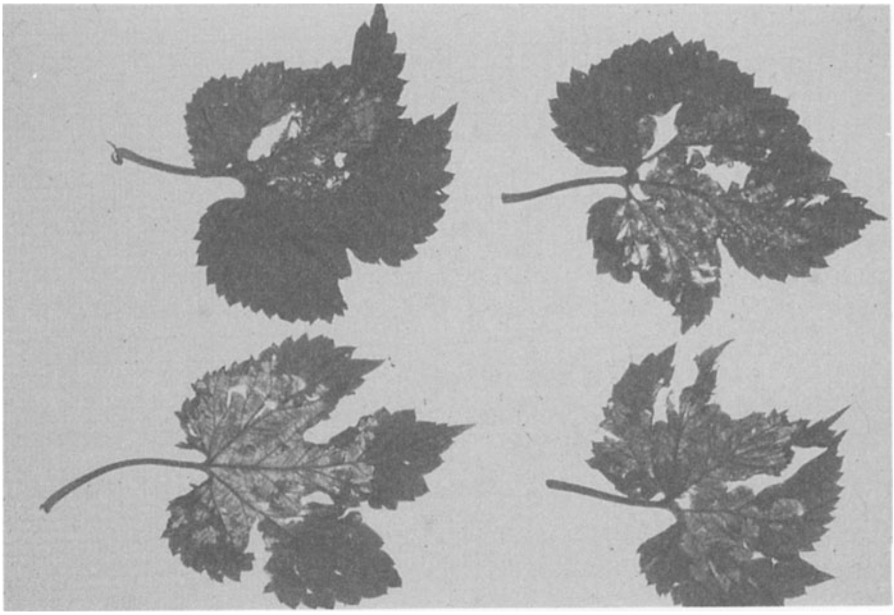


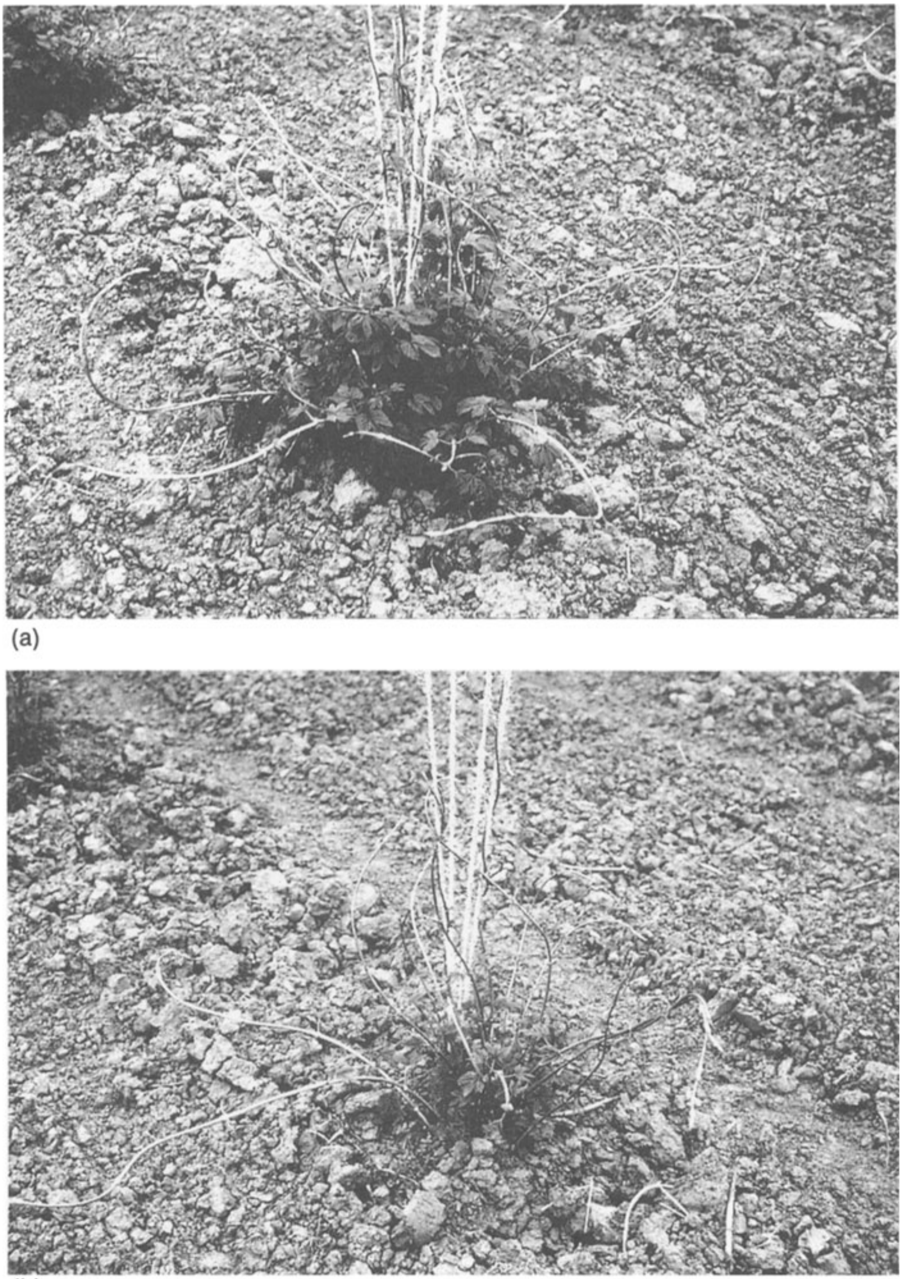
Figure 8.4 Split leaf blotch in cv Fuggle (IHR, East Malling).

total α-acid production was reduced by 30% (Thompson and Neve, 1971). Although bare bine causes far less damage than nettlehead to affected plants, it is much more prevalent so that its overall effect may be at least as serious.

8.4.4 Hop chlorotic disease

This disease was described in detail by Salmon and Ware (1930) but has rarely been reported since. Leaves produced early in the season are severely distorted and chlorotic, often with a characteristic parrot-beak shape (Figure 8.6). Growth is reduced but the lateral shoots and upper parts of the main bine are usually symptomless. The disease is transmitted by grafting, by sap inoculation and to seedlings of infected plants. It has also been reported from Germany, Russia and Poland (Schmidt and Klinkowski, 1965; Eppler and Sander, 1981).

Adams *et al.* (1987) investigated an outbreak in Kent and found that it was caused by a distinct isolate of AMV. Although indistinguishable from other hop isolates serologically or by inoculation to other herbaceous species, it produced distinctive chlorotic symptoms in hop plants inoculated with purified virus. The basis of the difference in pathogenicity was not established. Because the symptoms and effects on growth are much more severe than the bare bine condition, plants infected with this strain of the virus are unlikely to be used for propagation and this probably accounts for its comparative rarity.



(b)

Figure 8.5 Early season growth of: (a) healthy plant; and (b) one showing bare bine symptoms (IHR, East Malling).

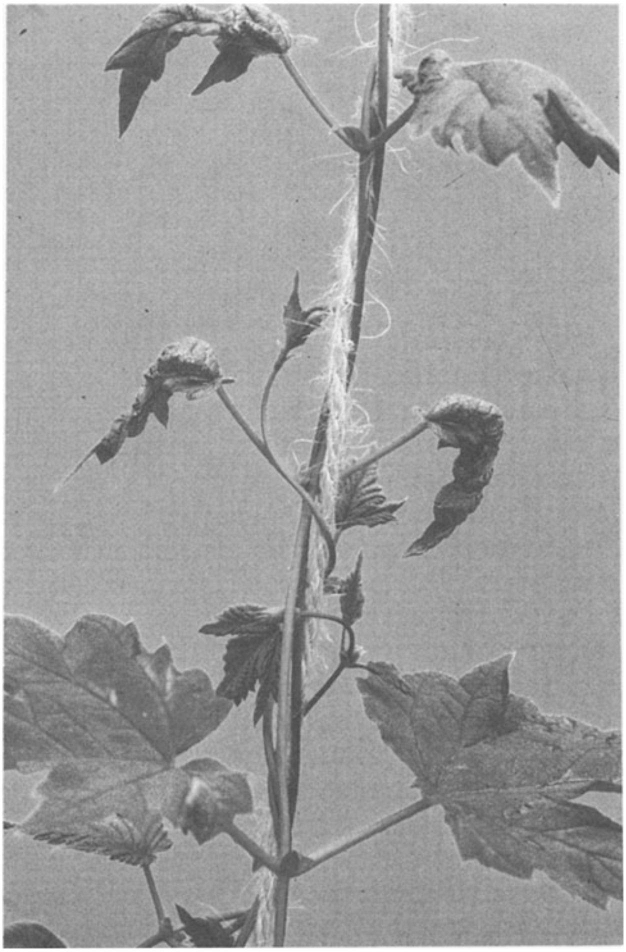


Figure 8.6 Hop chlorotic disease (IHR, East Malling).

8.4.5 Control

Percival (1895) advised growers to avoid planting cuttings from infected localities. This advice had little effect and nettlehead became so widespread that, according to Keyworth (1945), it was difficult to find any gardens that were free from it. In spite of the policy of grubbing infected plants, growers found it necessary to abandon hop growing completely in some gardens (Ogilvie, 1939).

A certification scheme was introduced in 1943, for which gardens were checked primarily for freedom from verticillium wilt so that they could be used as sources of propagating material but HMV and nettlehead were included in the inspection. Nettlehead was so widespread that it was not possible to set a nil standard but only 'a limit of very low percentage of virus infection' (Keyworth, 1945). Since then, however, the A plus certification scheme has been upgraded to the stage where AMV-free clones of all cultivars are available.

Arabis mosaic virus will only spread within a garden if *Xiphinema* eelworms are present and there are diseased plants to act as sources of infection. The first precaution, therefore, must be to plant only AMV-free material and when *Xiphinema* are not present this is the only precaution that needs to be taken. Where the eelworm is present it is equally important to ensure that there are no plants surviving from a previous crop in which the disease was present. This means that grubbing of the previous crop must be carried out with extreme care, or that there is a sufficient interval between grubbing and replanting for any ground-keepers to be seen and removed.

Although *Xiphinema* are widespread throughout England they are more common on lighter soils and in perennial crops (Taylor and Brown, 1976). The likelihood of them being present in a hop garden depends upon the previous cropping of the land and on the soil type and there is a good chance of a garden being uninfested. Where they are present they will carry the virus over when a garden is replanted unless special precautions are taken.

Experiments at Rosemaund Experimental Husbandry Farm and elsewhere (Pitcher and McNamara, 1976; Adams *et al.*, 1979) showed that fumigation with D-D, Di-Trapex, dazomet or quintozene gave good control of the nematodes in infested soils but even the most effective material, D-D, did not reduce their numbers sufficiently to stop re-infection of hops with AMV (McNamara and Pitcher, 1974). This was found to be unimportant when cultural treatments ensured that the nematodes had lost their infectivity. This could be achieved by fallowing the land for two years during which time the nematodes would moult and shed the cuticle lining of the oesophagus where the virus particles are retained (Taylor and Robertson, 1970). The results of fallowing were improved if it was combined with an initial fumigation and this resulted in no reinfection of hop plants following a fallow of only 19 months. Fallow periods of 19 or 20 months could be achieved by grubbing the previous crop immediately after harvest and replanting in the months of May or June using setts that had been held in a cold store. In this way only one full cropping season was lost (Adams *et al.*, 1979).

In hop gardens where there are no *Xiphinema* there is no need to carry out these procedures and virus-free material can safely be planted immediately following hops that were even heavily infected. Unfortunately, soil tests can only examine such a small sample, relative to the volume of soil occupied by the roots of a hop plant, that a negative result does not necessarily mean that the garden is free of the nematode.

8.5 PRUNUS NECROTIC RINGSPOT VIRUS (NRSV)

This virus was first detected in hops in the 1960s and it has since been shown that it was present throughout all the main commercial varieties in England at that time and no uninfected stocks were discovered. Hops in Germany are not, at the present time, so totally infected since Eppler and Sander (1981) found it in only 57% of 2112 plants examined although it was found in 91% of the gardens surveyed. The level of infection varied significantly between certain varieties and this may be because, as in England, recent plantings have been with NRSV-free material.

Using the ELISA technique, two serotypes of the virus have been detected in hops. One is similar to apple mosaic virus (ApMV) and is referred to as such by some workers while others designate it the 'A' type of NRSV. The other appears to be a strain intermediate between 'A' type and the 'C' type from cherry or plum and this has been designated 'I' type (Adams *et al.*, 1978). The authentic 'C' type has not been found in hops although references to 'C' strains occur in the literature.

Under English conditions NRSV is normally symptomless in hops but in 1976, following a prolonged period of unusually hot dry weather, a conspicuous line pattern appeared in the leaves of several varieties in late July to early August when temperatures were lower (Figure 8.7). A resurgence of NRSV was detected in some plants and the incidence of the symptoms appeared to be correlated with infection with that virus (Adams *et al.*, 1977).

In other countries NRSV is reported as causing ringspot-type symptoms on hops. In the DDR, Schmidt (1967) reported that a disease described as hop necrotic crinkle mosaic was caused by a serotype of NRSV. In Czechoslovakia, Albrechtova *et al.* (1979) detected ApMV in plants with ring and band patterns on the leaves and similar symptoms are reported from Germany. Smith and Skotland (1986) in the USA described two serotypes of NRSV, both of which gave line pattern and ringspot. The symptoms were most prevalent in the summer when cool periods followed warm periods, and in the fall when temperatures were decreasing. Sano *et al.* (1985) isolated ApMV which, when reinoculated produced chlorotic spots, ringspots and a band pattern accompanied by leaf necrosis, symptoms that are prevalent in the field in Japan.

By 1969 a meristem clone of Northern Brewer and a clone of the new variety Wye Northdown were available in England that were free of NRSV and a trial was planted at Wye to compare these with clones infected with the virus. Trials were also started with other varieties as suitable clones became available. These trials showed that although the infection usually remains symptomless it does have a significant effect upon crop production. The virus-free clones outperformed the infected clones consistently as shown in Table 8.1.

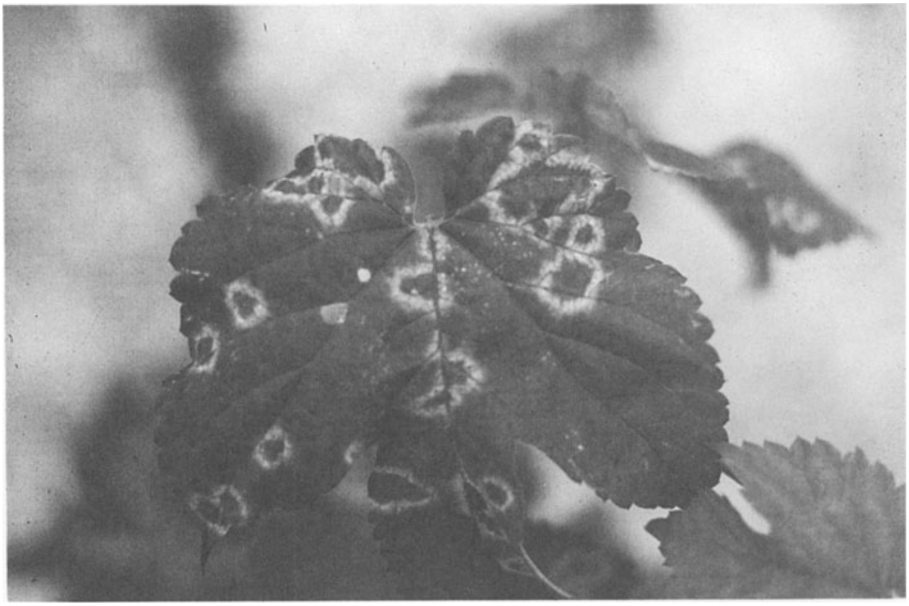


Figure 8.7 Line pattern (IHR, East Malling).

TABLE 8.1 *Increased production from NRSV-free clones.*

	Yield (% change)	α-acid content (% change)	α-acid, yield per unit area (% change)
Northern Brewer	+ 3	+16	+21
Wye Northdown	+16	+11	+27
Wye Target	+10	+ 4	+14
Wye Challenger	+21	+10	+33
Bullion	+18	+ 6	+26

Kremheller *et al.* (1989) found that yield and α-acid contents were not affected when plants were infected with HMV alone but that infection with HMV and ApMV reduced yield by 4–38% and α-acid content by 18–26%.

The studies on NRSV in England coincided with a period of extremely rapid replanting of new varieties and, because it was possible to release these largely free of NRSV, this contributed a great deal to the increased production of α-acid that resulted, estimated at the time as being worth an additional £1 million a year in a crop worth some £16 million.

The rate of reinfection of NRSV-free plants has been recorded and usually the only plants to acquire the virus are those growing adjacent to others already infected. The vector, if any, has not been identified and spread might possibly be purely mechanical by stem or root contact.

8.5.1 Control

Because the spread of NRSV is so restricted and there is no evidence of it surviving in the soil or in a soil-inhabiting vector, it is one of the easiest disease problems to control. All that is required is that the hop garden should be free from any infected hop plants left after grubbing a previous crop and that the new plant should be free of the virus. In these circumstances the benefits of planting healthy material, which does not involve much additional cost, will continue for a very long time.

8.6 OTHER VIRUSES

The discovery of AHLV in hops introduced to Europe in breeding material from the USA indicates the care that must be taken to ensure that other diseases do not become established as a result of such introductions. It is not yet clear what effect AHLV may have on production but the evidence from NRSV shows that absence of any symptoms does not necessarily mean that it is not damaging.

Quarantine precautions are not difficult to operate against diseases that are known to exist in other countries since methods of identifying them will be available. The problem is discovering the presence of diseases, particularly virus diseases, that have not previously been identified. AHLV could very easily have become established in Europe if it had not been identified in America shortly before it was exported.

Another recent example of a virus being introduced was the discovery of a virus in seed of *Humulus japonicus* imported from China. Little is known about this virus (that has been code-named humulus japonicus virus) except that it is an ilarvirus and distantly related to NRSV. Since some other members of that group are pollen-borne or mite-transmitted, there could be a danger of it spreading into cultivated hops (Adams and Barbara, 1988; Adams *et al.*, 1989).

There are various reports of other viruses being found in hops including alfalfa mosaic virus (Novak and Lanzova, 1976; Yu and Liu, 1987), tomato bushy stunt virus (Novak and Lanzova, 1976) and tobacco necrosis virus (Albrechtova *et al.*, 1979). While none of these may be of any significance, they do indicate how easily new virus problems could be spread around the hop growing countries of the world if the greatest care is not taken to check the health status of imported plants.

8.7 VIROIDS

Viroids are similar to viruses in some ways but consist of only a small piece of RNA and have no protein coat and so cannot be detected serologically.

8.7.1 Hop stunt viroid (HSVd)

A stunt disease of hops has been reported in which the growth rate of all parts of an infected plant is retarded and the wax deposits of the leaf cuticle are modified. It has been shown to be caused by a viroid which has been named hop stunt viroid (HSVd). Yield is reduced from ½ - ⅓ of healthy plants and the lupulin glands are severely shrivelled (Momma and Takahashi, 1984).

Vectors are not known for viroids and transmission appears to be purely mechanical. Takahashi and Yaguchi (1985) have described chemical and heat treatments that will successfully decontaminate tools. HSVd has only been recorded in Japan and in the Japanese variety Kirin 2 grown in South Korea. It has been very largely eradicated by the rogueing of infected plants and by avoiding transmission on contaminated tools. Although it has such a limited distribution in hops it is much more widely distributed in grapes and Japanese workers have suggested that it originally infected hops from grapes (Barbara *et al.*, 1988).

8.7.2. Hop latent viroid (HLVd)

A second viroid was identified by Puchta *et al.* (1988) and found to be widespread in German hops and in many English varieties, although some of the English hops tested had been grown in Germany for several years. It appeared to be common in hops from other countries also. Although these workers found the viroid in a number of stunted plants, these were also infected with other viruses and they were unable to link symptoms with the presence of the viroid and they therefore named it hop latent viroid (HLVd).

Subsequent work by Barbara *et al.* (1990a) in England showed an interesting distribution of the viroid. All cultivars susceptible to verticillium wilt (except for one old variety grown on only one farm) were infected to some extent, the most heavily infected being Omega, the cultivar most recently released to growers. No infection was found in commercial samples of the three most widely grown wilt tolerant cultivars, although some of the less important wilt tolerants yielded some infected samples.

Four plants of each cultivar are maintained in an insect-proof glasshouse at Wye to provide the nucleus for commercial propagation stocks and the virus status of these is regularly checked. When tested for HLVd infection, however, it was found that in many cases all four plants were infected and, with one exception, the remainder had some infected plants. The exception was the

Australian variety J78 which was free of the viroid. These workers thought that the difference in levels of infection between wilt-susceptible and wilt-tolerant hops was more likely to be a chance effect following the recent introduction of HLVd into the nuclear stocks, rather than a direct relationship with levels of susceptibility to wilt.

Further work (Barbara *et al.* 1990b) indicated that this viroid could be a far more serious problem than had at first been thought. During sampling of the heavily infected cultivar Omega, it was noted that some plants were greener and more vigorous than surrounding plants and subsequent testing showed that these were not infected while the less vigorous ones were. In the cultivar Wye Northdown, however, no visual symptoms were seen that would distinguish infected plants.

Yields from infected Omega plants were about 35% less than from uninfected ones and this was due to lower cone weight rather than fewer cone numbers. Alpha-acid contents were significantly lower in infected plants but β-acids, total hop oils and myrcene were higher. These results suggested that presence of the viroid accelerated the maturation of the hop cones. In Wye Northdown the differences between healthy and infected plants were not so great but the results indicated an overall reduction in α-acid production of 15–20% compared with a 50% reduction in Omega.

Further work is required to confirm these initial results and to determine differences in susceptibility of the various cultivars, but it has already been suggested that the spread of this viroid through commercial hop gardens may be partly responsible for the disappointing yields that have been a feature of the late 1980s.

These results indicate the importance of establishing HLVd-free nuclear stock plants to replace those presently being used and in the UK such plants of most commercial varieties have already been identified. It will, however, take much longer before infected stocks in commercial gardens can be replaced by healthy ones.

CHAPTER 9

Varieties and breeding

9.1 HISTORICAL INTRODUCTION

The origins of hop growing and the sources of the original plants must be a matter for conjecture but presumably hop cones were first harvested from wild plants and some of the same plants would have been collected when they were first taken into cultivation.

The original gardens would have contained a mixture of several different genotypes from which, with experience, the better plants would be selected. The first selection would have been on the basis of how successfully the plants grew and yielded, the best being used as a source of cuttings to either plant new areas or to replace the inferior plants in an existing garden.

This process of selection would lead to the plants within a hop garden becoming more uniform, and once this happened, brewers would be able to notice the relative merits of hops from different sources. This could then lead to the second stage of selection based upon the suitability of different types for brewing. A grower whose hops were in demand would be able to sell cuttings of his plants to growers who had more difficulty in selling the cones of their less popular sorts.

There is an interesting comment on varieties in England by Mills (1763) who wrote:

> The several kinds and goodness of hops may likewise be known by the colour of the vines, binds, or stalks. The whitish binds produce the white hop, both the long and the oval: the grey or greenish binds commonly yield the large square hop: and the red binds bear the brown hop, which is the least esteemed.
> The planter of hops ought to be extremely careful in the choice of his plants, or sets, particularly in regard to the kind of the hop: for it is a great trouble and loss to him when his garden proves to be a mixture of several sorts of hops, ripening at different times. He who plants the three sorts of hops before mentioned, viz. the early, the long white, and the square hop, in three distinct parts of his ground, will have the conveniency of picking them successively as they become ripe.

In the days when transport was difficult over any long distance, hops would have been mostly used close to the area where they were grown and so each locality would tend to make its own selections, though these would become more widely distributed as transport improved. In England, Percival (1901) described 20 different varieties, although these did not include some of the attractively named sorts, such as Golden Tips or Farnham Bell, referred to by earlier writers. In Germany, Wagner (1905) also listed 20 different varieties, 8 of which were early maturing, 5 mid-early and 7 late, while Braungart (1901) referred to '. . .the 60 European hop varieties at Weihenstephan'.

From these many different types, one or two became dominant in each area, a trend that was probably encouraged by the development of the railways and the consequent extension of national and international trade since it would be far easier for merchants to deal in a few standard types. This standardization resulted in the practice of continental hops being sold by the district of origin rather than by variety and Thompson (1972) states that the majority of the 'district' hops in Germany, and the hops grown in most east European countries, were of the Saazer or Hallertauer type. In Yugoslavia, however, the variety grown in Slovenia, although known there as the Savinja Golding, is the same as the English Fuggle. It is recorded that hops were introduced into Yugoslavia from England and it seems likely that the Fuggle variety was supplied under the misnomer of 'Fuggles Golding' – a practice at one time resorted to since Goldings were of superior quality to Fuggles.

These English varieties illustrate the common practice of naming varieties after the growers (Mr Fuggle and Mr Golding) who developed them. Thompson referred to the same practice on the Continent where the Semsch hop, selected by a grower of that name from the Altsaazer hop, was long regarded as the best type of Saaz hop although marketed without references to the grower's name.

The origins of most of the old varieties are obscure but several of them are almost certainly clonal selections that differ from one another in only one or two characters. The English Golding hops are a good example of this since there are many different types which are scarcely distinguishable, except for differences in the time of ripening, and it is only the most recently selected clones whose history is recorded. One distinct variety with a recorded history is the Fuggle which is reputed to have been selected as a seedling in 1861, the plant finally being introduced into commerce about 1875 (Parker, 1934).

There is little evidence that the old European cultivars are an improvement on the hops that were growing in the wild; they would appear to be merely selections of the best of the existing material that could be found. In the USA, however, the situation is different. The traditional hops there, the Clusters, do appear to be hybrids between European cultivated hops and the wild hops of America. Brooks and Horner (1961) suggest that the Late Cluster originated as a seedling of English Cluster during the early settlement of the eastern seaboard, where hops were introduced by the Massachusetts Company in 1629, and was then taken to the west coast by early settlers. The Early Cluster probably originated from the Late Cluster in Oregon about 1908 as a bud-sport.

The earliest efforts at improving hops by hybridizing and selecting the resulting seedlings appear to have been commenced in Germany by Stambach in 1894 and Remy in 1898 followed in the USA in 1904 by Fairchild (Smith, 1937). These early efforts were soon abandoned and of far greater significance was the initiation of a breeding programme at Wye College in England, also in 1904, by Howard (1905) who reported that 'During the past year, various English and German female plants have been crossed with widely different males, and twenty-three sets of seed have been obtained for growth next spring'. The collection of the plants used as parents in this programme had been made during the preceding 10 years, the College having been opened in 1894.

When Howard left Wye his work on hop breeding was taken up by Salmon who joined the College in 1906. At that time Salmon was aged 35 and an expert plant pathologist, having published an outstanding work on the powdery mildews, *A Monograph of the Erysiphaceae*. Burgess and Glasscock (1960), in their obituary to Salmon, point out that hop powdery mildew received special mention in this work and suggest that it may have been his interest in the disease that led him to make hops the main object of future research. Although Salmon officially retired in 1937 this made no difference to his enthusiasm for hop breeding which continued to occupy him until very shortly before his death in 1959. His successors at Wye have continued to build on his pioneering efforts.

Salmon's work will be referred to frequently in the sections that follow and there can be little doubt that he has had more influence on the nature of the crop than anyone else who has worked on it.

Fairchild's initial work in the USA was followed by a new programme, commenced by Stockberger in 1908, which was pursued energetically until 1916 when it was abandoned as a consequence of the 1914–18 war and the introduction of prohibition. Hop research was resumed in the USA in 1931 in Oregon where most of the American hops were then grown (Haunold, 1981).

Another breeding programme that started very early was one at the Carlsberg Breweries in Denmark, initiated by Schmidt (1915a) and later conducted by Winge (Winge, 1963). Their approach was very similar to that of Salmon and they might well have had a similar influence on the crop if hop production in their country had not been of so little importance that it was abandoned after the 1914–18 war. A breeding programme was also carried on at Svalof in Sweden but this too was abandoned because the crop was not grown commercially there. One of the Svalof varieties has, however, been used in the Wye programme because of its exceptional earliness which is the result of selection under very long-day conditions.

Research on hops in Czechoslovakia was commenced at agricultural schools in 1894, the same year as at Wye College in England, and a Hop Research Institute was established in 1925 (Fric, 1985). The approach to varietal improvement there has been to concentrate, until quite recently, on clonal selection, rather than hybridization, in order to retain the particular quality characteristics of the Saazer hop.

The spread of downy mildew throughout Europe was one of the principal reasons for the founding in Germany, in 1926, of the Hans-Pfülf-Institut for Hop Research at Hüll where a programme was immediately commenced to develop varieties resistant to that disease (Zattler, 1951). Downy mildew also provided the stimulus for the recommencement of breeding work in the USA, in 1930, by the Department of Agriculture in co-operation with Oregon Agricultural Experiment Station (Smith, 1937).

More recently, breeding work has been carried out in both the Slovenian and Backa regions of Yugoslavia, in the DDR, Poland, Russia, South Africa, Australia, New Zealand and Mexico.

The traditional cultivars were originally judged by brewers mainly on their aroma and appearance, with relatively little importance being attached to their bittering power, or 'preservative value', although the superiority of American hops in this respect was recognized by some brewers who imported considerable quantities. Salmon (1917c) and Schmidt (1915b) both emphasized that aroma depended upon the genetic nature of the variety and not the country in which it was grown. Both of them paid particular attention to the resin content of the seedlings that they raised but it was Salmon's work which bore fruit and led, eventually, to a whole class of 'bitter' cultivars as distinct from the old 'aroma' hops.

9.2 AROMA HOPS

One of the major concerns of brewers is that the character of their beers should remain constant and, for that reason, they are generally reluctant to change the hops that they use unless there is some special reason for doing so. It is, therefore, almost a contradiction in terms to suggest improving the aroma of a variety since that involves change. The improvement of such hops has consequently been aimed at introducing superior agronomic characters while retaining an aroma as close as possible to the original.

Aroma is not only a very complex genetic character but its organoleptic assessment is subjective and dependent upon the preferences of individual buyers. Hop plants are, genetically, extremely heterozygous so that there is great variability within any seedling family. The chances of a hybrid having the same aroma characteristics as its female parent are extremely low and selections raised from seed have, in general, only been accepted as replacements for traditional aroma types when the production of the latter has been threatened in some way.

The outstanding example of this is the devastation of Fuggles in England by verticillium wilt. This disease can only be controlled by growing resistant cultivars and the first ones to be discovered were very different in aroma from Fuggles but had to be grown for want of anything better. They were Keyworth's Midseason and Keyworth's Early and were second and third generation, open-pollinated seedlings, respectively, of a wild American female hop var. *neo-mexicanus* (Salmon, 1949).

Bramling-Cross, which followed (Salmon, 1951), came from a cross between Bramling (one of the true Golding hops) and a first generation male from a wild Canadian hop from Manitoba. It was quite well-accepted by brewers and was widely grown for a time but its popularity subsequently declined. These varieties had been raised before wilt became a problem and were discovered purely as a result of Keyworth screening a wide range of Salmon's breeding material. The most successful of all the wilt-resistant aroma hops in England has been WGV, a hybrid raised by a private grower in 1911 and discovered on his farm after it had been bought by the Whitbread brewery. The records detailing the parentage of this cultivar have, unfortunately, been lost.

Once such sources of resistance had been discovered, a breeding programme was initiated by Keyworth in 1944 aimed specifically at developing a wilt-resistant replacement for the Fuggle. This resulted in the release, in 1958, of three selections named Density and Defender (seedlings of Keyworth's Midseason) and Janus (from WGV) (Wilson, 1959). Of these only Janus was planted to any extent and that quickly declined. Another programme, commenced jointly by Wye and East Malling in 1950, led to the selection of Progress and Alliance, both of which were seedlings of WGV but by different wilt-resistant males (Farrar *et al.,* 1966; Wilson *et al.,* 1967). They were judged to be acceptable replacements for Fuggle in extensive brewing trials but they only achieved limited success when grown commercially. This was partly because they were released at the time when brewers suddenly started to demand many more bitter hops and fewer of the aroma types that they had previously required.

Although work in England has concentrated on hybridization, there has also been some clonal selection of established cultivars. From amongst a range of Fuggle material grown at East Malling Research Station, Beard selected three clones that were planted in a trial in 1931 and, of these, Fuggle N was selected as a superior clone (Beard, 1943b). A further selection of 78 Fuggle clones was commenced in 1943 but only two of these were found to match the performance of Fuggle N (Thompson and Farrar, 1965). Although not in itself superior to Fuggle N, one of these, Fuggle 37, was selected for distribution when virus-tested stocks became available so that the different designation would serve to distinguish between the old virus-infected and the new virus-tested material.

In 1943 a trial was planted to compare seven different Golding clones between which Beard (1952) found big differences in the incidence of downy mildew. In the meantime, a much larger trial had been planted at Wye in 1949 to compare 118 Golding clones, selected from a number of growers' farms. These were reduced to 23 which were replanted in a replicated trial in 1957 and, from these, four clones with a range of maturation dates were finally selected on the basis of cropping, market valuation, resin content and susceptibility to downy mildew (Beard and Thompson, 1961).

The breeding programme at Hüll was aimed at developing downy mildew resistant cultivars that were to be of comparable quality to the traditional varieties. It required many years of patient work, finding sources of limited resistance amongst cultivars and wild hops and crossing and back-crossing these to build up the resistance to an effective level (Zattler, 1951). It was almost 40 years before the first varieties, Hüller Anfang and Hüller Start (1962) and Hüller Fortschritt (1966), were released for commercial production but these had relatively low yields which, combined with the spread of wilt, to which they were susceptible, meant that they did not succeed (Maier and Narziss, 1979). Some non-commercial selections that were highly resistant to downy mildew were made available to English research workers and have played an important part in the breeding programme at Wye.

Just as Fuggle was the cultivar to be most seriously affected by wilt in England, so it was Hallertauer Mittelfrüh, the principal German cultivar, that was devastated there. The breeding programme was re-orientated in the early 1960s to deal with this problem and the first selection with resistance to both downy mildew and verticillium wilt was Hüller Bitterer (now known simply as Hüller) which is a spontaneous triploid. By 1974 it occupied one-fifth of the aroma hop area in the Hallertau district, although an alternative traditional cultivar, Hersbrucker Spät, that is reasonably resistant to wilt, was even more widely planted. Both these cultivars suffered from the disadvantage of unsatisfactory yield, and also susceptibility to viruses, so the release of a superior new variety, Perle, in 1978 proved very valuable. Not only is it reported to have aroma characteristics as good as those of Hallertauer Mittelfrüh, but it also yields well and has a higher α-acid content (Maier and Narziss, 1979).

The revival of hop research in the USA in 1931 was stimulated by the spread of downy mildew although the disease was, for many years, controlled in Oregon by growing the English cultivars Fuggle, Bullion and Brewer's Gold which were more resistant than the American Clusters. The cultivation of Clusters moved to the drier states of Washington and Idaho where the disease was much less of a problem. That left Fuggle as the only aroma hop in Oregon where it was found to be uneconomic to grow it seedless. The first cultivar to be released as an aroma hop from the Oregon breeding programme was Cascade (Brooks *et al.,* 1972) which had much of Fuggle in its parentage and was quite widely grown for some years but has since declined (Romanko, 1986).

A colchicine-induced tetraploid form of Fuggle was later introduced into the USA breeding programme and two triploid seedlings, Willamette and Columbia, were released as replacements for Fuggle itself (Haunold *et al.,* 1976a, b, 1977). The nearly sterile nature of the triploids meant that good yields of seedless cones were readily achieved. Willamette is very widely grown in Oregon but Columbia is of little importance.

There is a considerable demand from some American brewers for a supply of European hops, especially Hallertauer Mittelfrüh, and as supplies of it became limited, because of losses from wilt in Germany, there was increased interest in attempts to grow it in the USA. The European varieties are, however, not well adapted to growing conditions there and, as an alternative, triploid seedlings have been bred from a tetraploid form of Hallertauer (Haunold and Nickerson, 1987) and one of them released under the name Mt Hood.

In Czechoslovakia, the Saazer hops are renowned for their good aroma but they give low yields and research has been concentrated on improving the type by clonal selection. It is feared that attempts to increase yield by hybridization would result in a loss of the aroma that is characteristic of the traditional sort.

Improvement has been achieved by clonal selection from within the old land cultivars. Such selections have been made on populations from different regions and the relationships between them are not clear. Three Osvald clones (31, 72 and 114) were selected from the original Zatec (= Saazer) variety and released in 1952. Zlatan came from the same source and was released in 1976. Other varieties have been developed by mass selection within land cultivars. Aromat was selected from hops growing at the village of Lhota while the variety Sirem came from a village of that name (Fric, 1985). Vent and Beranek (1970a, b) state that Aromat is outstanding for aroma and spiciness while both cultivars outyield the Osvald clones with which they were compared. All these selections are marketed as Zatec (Saazer) hops and it is claimed that they are extremely uniform although there do seem to be noticeable differences in form between some of the clones.

Such clonal selection is still an important part of the Czech programme. Between 1971–80 over 700 selections from commercial cultivars have been evaluated, of which 125 were further tested in 1982–7. Of the 8 clones finally selected, 4 have been recommended for state trials (Rigr and Beranek, 1988).

In Russia also, the emphasis appears to have been on clonal selection from the standard variety Serebrianka. Haunold (1981) listed a number of clonal selections and suggested that the emphasis on ‘medium early’ and ‘red’ in the Russian varietal names indicated a relationship to the Czechoslovakian Saazer variety. Some hybridization has also been carried out, however, since the selections 38/19 and Zitomir 8 have been described as hybrids that are earlier and more productive than clone 18.

The standard hop variety in Japan, Shinshuwase, is reputed to be a hybrid between Saaz and White Vine but Ono (1959) queried this because, from the morphological point of view, he thought it resembled the American hop more than the European one. Kirin II is a clonal selection from Shinshuwase, while Mori *et al.* (1969) reported the selection of a mutant form, named Golden Star, that was higher yielding, was easier to pick and more resistant to downy mildew.

There is, in reality, no very clear distinction between aroma hops and bitter hops since there appears to be no evidence that good aroma characteristics cannot be combined with high α-acid contents. The American Clusters occupy an intermediate position since they were, for many years, the most widely grown variety in the USA and accepted as the standard kettle hop against which others would be judged. Their α-acid content of around 7% was higher than that of the standard European hops, which was generally around 5%, and their α-acids are very stable in storage. It was for these reasons that they were bought in considerable quantities by English brewers.

The Early Clusters are thought to be a clonal selection from the Late Cluster and, apart from the difference in maturation dates, they are very similar. Because these were the most widely grown hops in the USA, and because it was realized that the productivity of individual plants was very variable, a clonal selection programme was initiated in 1957. Forty-one selections were tested for virus infections by grafting to susceptible hop cultivars but only hop mosaic was identified. Yields and α-acid contents were recorded in 1962–4 and four clones selected to give a range of harvest dates. By 1972 these four clones constituted 80% of the Washington hop acreage (Skotland, 1973).

Another hop that is classed with the Clusters in the USA, but should perhaps be included with the bitter hops, is Talisman which was raised from open pollination of Late Clusters by Romanko in Idaho (Romanko, 1964b) and released in 1965. It has a higher α-acid content than Clusters (about 8–9%) and gives high yields but it has now been largely superseded.

9.3 BITTER HOPS

In a paper given to a meeting of the Institute of Brewing in London, Salmon (1917c) described the main objective of his breeding programme as combining the high resin content of American hops with the European-type aroma. At that time he had achieved some success by crossing American Clusters with European males and European cultivars with American males but his real break-through came almost immediately after he gave the paper with the introduction from Canada of a wild hop from Manitoba. This plant, which he designated BB1, was planted in 1917, and open pollinated seed was collected from it in 1918, after which it died. From the seedlings raised in 1919 he selected the varieties Brewer's Gold (Salmon, 1934) and Bullion (Salmon, 1938). These set new standards by combining high resin contents and excellent yields although their aromas had definite traces of the 'blackcurrant' character that is a feature of wild American hops. Their α-acid contents are greatly influenced by environmental conditions but with values around 7% in Europe and 9% in the USA they were above anything else available at that time.

Salmon later crossed a male seedling of Brewer's Gold with Canterbury Golding and obtained Northern Brewer (Salmon, 1944) which had a much better aroma than the other two selections but was not so high yielding. Its α-acids were frequently higher than those of his other two cultivars and were more consistent.

Bullion and, to a lesser extent, Brewer's Gold were widely planted in Oregon in the 1950s and in the Yakima valley in the late 1970s, Bullion being preferred because it was earlier maturing (Romanko, 1986). Apart from their high productivity, they were popular with growers because they were, under those conditions, resistant to crown infection by downy mildew.

In Germany, Brewer's Gold was preferred to Bullion but Northern Brewer was of even greater importance because it was found to be resistant to the strain of verticillium wilt that was destroying the hops in the Hallertau district.

The planting of high α-acid cultivars was also stimulated by the development of hop processing, especially in Germany, and by 1978 they accounted for 47% of the German hop area. Brewer's Gold and Northern Brewer have also been widely planted in Belgium and they are the main cultivars in Spain where they are called Hybrid 3 and Hybrid 7. They are also the principal varieties in Bulgaria while Northern Brewer is grown extensively in the DDR where a clonal selection from it, named Braustern, with higher yield and α-acid content, has been described by Dolzmann and Wilding (1985).

It is ironic that these cultivars bred by Salmon should have been grown so widely in other countries yet never achieved similar importance in England where they had been developed. Bullion and Brewer's Gold were only acceptable to a limited number of UK brewers because of their American-type aroma and expansion of the Northern Brewer acreage was resisted by growers because the hop was very susceptible to powdery mildew. It is a further irony that Salmon became interested in hops through working on their diseases, and gave the first reports of resistance to powdery mildew, yet his successful cultivars should have been very susceptible to either downy or powdery mildew.

Before they were superseded by newer selections, Salmon's cultivars accounted for about one-third of the world hop acreage but their importance did not stop there since nearly all the new high α-acid cultivars have been bred from his varieties. In most countries, the objectives of recent breeding programmes have been to raise the α-acid contents still higher while, at the same time, improving the aroma so that it came closer to that of the traditional types. These common objectives have been combined with more local requirements such as resistance to diseases or seedlessness.

The first of the new generation cultivars to be developed was Pride of Ringwood, bred by Nash in Australia. He collected open-pollinated seed of

Salmon's variety, Pride of Kent, at Wye and raised the seedlings in Australia. Pride of Ringwood was a seedling of one of these plants that was also open pollinated and not, as usually reported, crossed with a Tasmanian male plant (Nash, personal communication). Released in 1958 it came to dominate the Australian hop industry, reaching over 90% of the acreage.

In England the increased demand for high α-acid hops that developed in 1966 had been anticipated and a revised breeding programme commenced in 1961. The main objectives were to improve the aroma and resistance to the mildew diseases and so eliminate the objections that brewers and growers had to the existing bitter varieties. Northern Brewer was chosen as the female parent because it had a better aroma than Bullion or Brewer's Gold and was less susceptible to downy mildew. Additional resistance to downy mildew was introduced by the use of male plants that had been bred from the female genotypes generously made available from Hüll.

Wye Northdown was selected from the first generation seedlings from this cross. One of its sisters was crossed with a male which was resistant to downy mildew but also had the 'blister' (R_B) type of resistance to powdery mildew (section 7.2.6) and this cross yielded Wye Challenger. Another sister of Wye Northdown was crossed with a male seedling of Eastwell Golding that was resistant to verticillium wilt and immune to powdery mildew (R_2) and Wye Target was selected from this family (Neve, 1972).

Wye Northdown, which was released to growers in 1971, had α-acid contents higher than Northern Brewer although subsequent work showed that this advantage was due to its freedom from prunus necrotic ringspot virus. It had fairly good resistance to downy mildew and was not quite as susceptible to powdery mildew as Northern Brewer. Wye Challenger, released in 1972, was highly resistant to downy mildew and, initially, completely field resistant to powdery mildew (R_B) although this only persisted for a few years until a more virulent strain of the fungus became widespread. Its α-acids were generally lower than those of Wye Northdown but it was higher yielding. Both cultivars were very popular with some brewers and they were widely planted, although only in wilt-free areas since both of them were susceptible to that disease. Because of pressing demands from growers in the wilt areas for a high α-acid hop, Wye Target was released in 1972 on extremely limited evidence and, in spite of some cultural disadvantages such as very poor climbing ability, it has become the most widely grown cultivar in England.

The main advantages of Wye Target are a very high level of resistance to *Verticillium*, immunity to powdery mildew (R_2) and a high α-acid content of about 11%, but it is very susceptible to downy mildew. It is unusually infertile for a diploid hop and, even when heavily pollinated, its seed content rarely exceeds 7%. It is therefore quite easy to achieve seed contents below the European limit of 2% for seedless hops without having to eliminate male plants from the entire neighbourhood of the garden.

Because Wye Target is late maturing, growers required an earlier variety to spread the picking season and Yeoman was selected as a hop that would meet this need (Neve and Darby, 1984b). Although it has shown satisfactory resistance to verticillium wilt, has α-acid contents similar to those of Wye Target and excellent storage stability, many growers have had difficulty in growing it. It is susceptible to canker (*Fusarium sambucinum*) which appears to be the cause of some heavy losses from hill death during the winter, and it is also very susceptible to powdery mildew (*Sphaerotheca humuli*). When first selected, Yeoman was resistant to powdery mildew because it carried the 'blister' gene but when this resistance was overcome by a pathogenic strain of the fungus it became apparent that the hop lacked an effective alternative resistance mechanism.

At about the same time as these cultivars were being released in England, a series of high α-acid cultivars were put into production in Yugoslavia. In Slovenia there were four 'A' varieties of which Atlas, Apolon and Ahil were seedlings of Brewer's Gold while Aurora was a seedling of Northern Brewer. Aurora and Apolon were the most resistant to downy mildew but Aurora was the most susceptible to verticillium wilt. All four varieties are sold under the general description of 'Super Styrians' but Aurora and Atlas are the most widely grown. The trade name relates solely to the area in which they are grown and does not imply any genetic relationship to 'Styrian Goldings'.

In the Backa region of Yugoslavia, three cultivars, Neoplanta, Vojvodina and Dunav with high α-acid contents were selected from seedlings of Northern Brewer and put into production (Mijavec and Spevak, 1973).

A second, 'B', series of new selections was released in Slovenia in 1980 with the names Blisk, Bobek and Buket. Bobek and Buket are both seedlings of Northern Brewer while Blisk is a triploid seedling of a tetraploid form of Atlas. Buket has an α-acid content of about 10%, with Blisk about 8% and Bobek about 6.5%. Although they have good characteristics they do not appear to have been widely planted and this is probably because they are not competitive as producers of α-acids and are not as yet in demand as aroma hops.

Northern Brewer has been the starting point for breeding programmes at Hüll, on account of its high α-acids and its resistance to the German strain of *Verticillium*. Although the emphasis was originally on developing aroma varieties, more recently bitter hops have become a breeding objective and the first of these, Orion, is reported to have α-acid contents of about 10% (20% higher than Northern Brewer), to be resistant to wilt and downy mildew and high yielding (Gmelch, 1985).

In the USA there has been some very successful breeding of high alpha varieties. The first, but least successful, was Comet (Zimmermann *et al.,* 1975) from a cross between a seedling of Salmon's variety Sunshine and a wild male from Utah. It had α-acid contents of 8–11% but also a pungent 'Wild American' aroma and is no longer grown (Romanko, 1986).

Much more successful were Galena and Eroica both of which were raised by Romanko in Idaho from open pollination of Brewer's Gold. Galena (Romanko *et al.,* 1979) is early maturing with α-acids from 12–13% and good storage stability. It is unusually sensitive to day length and yields are reduced if it is trained too early. Eroica (Romanko *et al.,* 1982) is later maturing with α-acids from 11–12% and inferior storage stability. It is more resistant to downy mildew than Galena but is not so popular with growers and is less widely planted (Probasco, 1985).

These were followed in 1982 by Nugget, raised by Haunold in Oregon with Brewer's Gold in the pedigree of both male and female parents so that 5/8 of its genetic composition came from that variety (Haunold *et al.,* 1984). It is useful because it matures after Galena and before Eroica and has the added advantages of good yield, high α-acids (12–13.5%), good storage stability and fairly good resistance to downy mildew.

Two further varieties, Olympic and Chinook, were released soon afterwards, both bred by Zimmermann at Prosser in Washington. Olympic was released in 1983 with 3/4 of its parentage derived from Brewer's Gold and it is similar in yield, maturity and α-acid content to Nugget (Kenny and Zimmermann, 1984). Probasco (1985) suggests that, because it is inferior to Nugget in storage stability and is more susceptible to downy mildew and insect attack, it offers no advantage over that variety. Chinook, which was released in 1985, only has 1/4 of its parentage from Brewer's Gold but another 1/4 from a wild hop from Utah (Kenny and Zimmermann, 1986). Although, according to Romanko (1986), it has a pronounced 'Wild American' aroma it appears to have been found more acceptable to growers than Olympic.

It should be noted that the α-acid values quoted for the American cultivars are from spectrophotometric analysis which generally gives higher readings than the lead conductance method used in Europe (Chapter 2).

In Japan there is only a limited effort put into hop breeding but there Salmon's variety Northern Brewer was used also, in a cross with one of his male selections (OB79), to produce the variety Toyomidori (Mori, 1981).

The above account shows very clearly the extent to which the development of high α-acid varieties has been based upon Salmon's original efforts. His success must be attributed in the first place to the fact that he set himself the very precise objective of increasing the resin content of hops. Any successful breeding programme depends upon clearly defined objectives, since attempts to achieve too many improvements in the same programme can cause excessive delays. Salmon's lack of success with disease resistance has already been mentioned but if he had added this as an objective he might have been far less successful. He also showed great initiative in going back to wild plants as a source of new genetic material, long before this became one of the standard methods in plant breeding.

The very painstaking work at Hüll, which led to the development of plants that are so highly resistant to downy mildew, must be given similar acknowledgement. Salmon was able to see the benefits of his work quite quickly; the workers at Hüll had to persevere for many years before they reaped their reward and again it was the clearly defined objective of the programme which was essential to ultimate success. The breeding programmes at Wye and Hüll have each benefited from the work of the other. Downy mildew resistant genotypes from Hüll made it possible to introduce such resistance into the Wye programme very rapidly, whereas the breeding for verticillium wilt resistance and high α-acids at Hüll has been based on Salmon's cultivar Northern Brewer.

A breeding programme that was virtually independent of any other was that of Roborgh in New Zealand. Californian Clusters became the standard cultivar there because they were better adapted to the daylength at that latitude than European hops, but they suffered considerable loss every year from *Phytophthora* root rot. By crossing the Californian hop with English males that were resistant, Roborgh produced a number of resistant varieties, the outstanding member of which was Smoothcone which also had a somewhat higher α-acid content than Californian. His major achievement came when he bred three triploid hops which have much higher yields and α-acid contents than the diploids from which they were developed. The most successful are Green Bullet and Roborgh Superalpha, both of which were seedlings of a tetraploid form of Smoothcone. Less successful is Stickelbract, bred from tetraploid First Choice which is itself less successful than Smoothcone (Frost, 1980).

9.4 VARIETAL ACREAGES

The increasing demand from brewers for high α-acid hops and the need for growers to plant cultivars that are resistant to verticillium wilt have led to major changes in the varieties being grown. Whereas in 1958 production was almost entirely of traditional varieties, by 1981 new varieties occupied 56% of the hop area in BRD, 38% in the USA, 81% in the UK over 37% in Yugoslavia, 99% in Australia, 70% in DDR, 55% in Hungary, 74% in France, 77% in Belgium and 100% in New Zealand.

The changes from aroma to bitter types and wilt susceptible to resistant in England and BRD are illustrated in Figures 9.1 and 9.2. Verticillium wilt has not been a factor in the USA but there was a major switch to high α-acid hops there too. In England from 1972–81 the total area under hops declined by 15%, the proportion of high α-acid cultivars increased from 17–62% and the overall α-acid content of the crop increased from about 5.5% to nearly 8%. Production of α-acid increased from about 550–750 tonnes in spite of the reduced area.

High α-acid hops have been so widely planted that there is, at present, a surplus of them and the current trend is for a move back to aroma hops, especially in the USA and BRD.

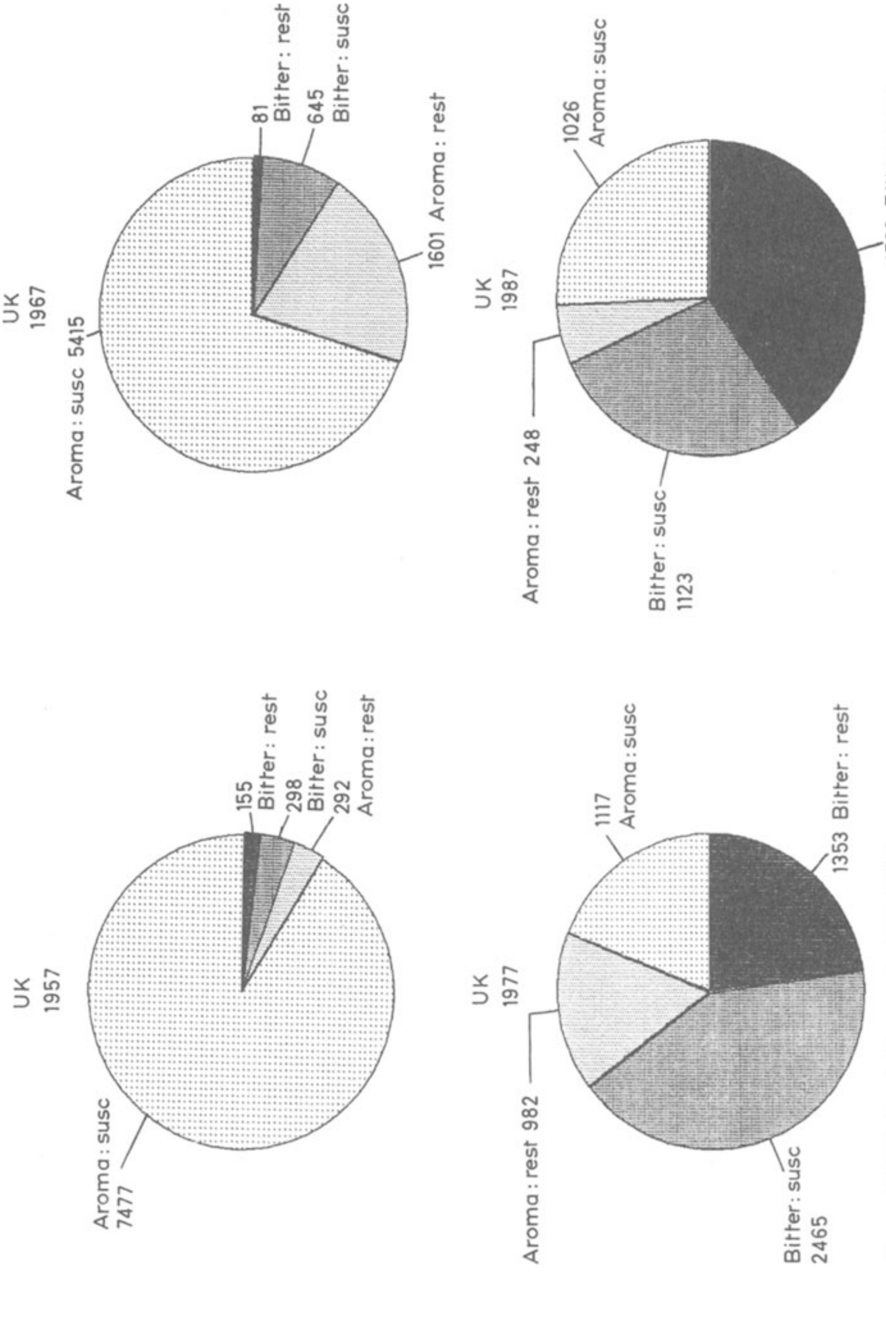


Figure 9.1 Varietal changes in UK, 1957–87.

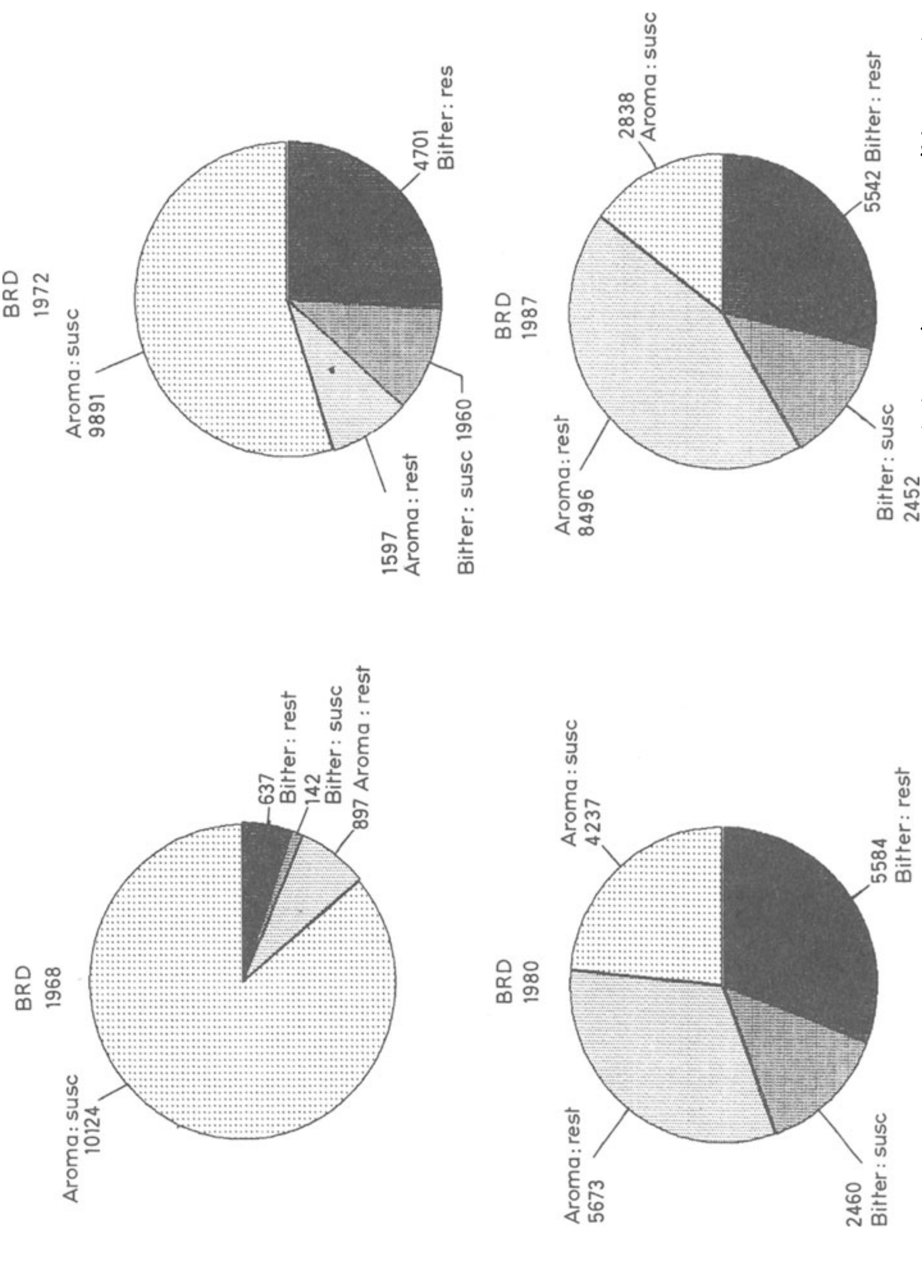


Figure 9.2 Varietal changes in BRD, 1968–87. Hectares of high bitter/aroma varieties, resistant or susceptible to verticillium.

9.5 FUTURE DEVELOPMENTS

Since it normally takes a minimum of about 10 years from the time a hop breeder makes a cross to having a new selection ready for release, it is essential to anticipate what will be required in the future. Some of these needs are already apparent.

9.5.1 Pesticide residues

Increasing concern about the effect of pesticide residues on health and the environment is already having serious effects upon the international hop trade because some countries have set limits on the residues that are accepted. These are based upon the needs of their own hop producers and do not provide for growers elsewhere having different problems that require different pesticides. There is little doubt that restrictions on pesticide usage will become more stringent and alternative methods of control will be required. The most effective of these is to breed resistance to the pest or disease into the hop plant itself and considerable progress has already been achieved with this. Complete field immunity to powdery mildew has survived in Wye Target for some 15 years and other sources of resistance are available. Very high levels of resistance to downy mildew have been incorporated into several cultivars and can probably be developed still further.

Aphids and spider mites are less easily dealt with in this way but considerable effort is being devoted to finding sources of resistance to the attacks of these two pests. Any success in significantly reducing pesticide usage will, however, probably depend upon augmenting such resistance with biological control by predators.

9.5.2 Dwarf hops

The first published reference to dwarf hops was by Neve (1979) who reported finding a dwarf at Wye in 1977. However, it has recently been pointed out to him that Salmon made the following note about one of his seedlings in 1911. 'V. vig growth, laterals of medium length, v. closely placed, hops densely clustered, v. fruitful, of no direct promise'. This would appear to be a description of a dwarf-type hop and suggests that Salmon may have envisaged the possibility of making use of this character. The breeding and selection of dwarfs is being actively pursued at Wye together with the appropriate cultural and harvesting techniques. Gunn and Darby (1987) have described the benefits that can be expected from this development as being cheaper supporting systems, reduced stringing costs, easier pest and disease control and, most significantly, much lower harvesting costs.

Much remains to be done before dwarfs can be shown to be a viable commercial crop but, if successful, there is no reason why dwarf varieties cannot be developed to meet all needs. Because the criteria for bitter hops are less stringent than those for aroma hops it is likely that the first commercial dwarf varieties would be of the bitter type.

9.6 INHERITANCE OF IMPORTANT CHARACTERS

Dark (1951) pointed out that there was no precise information on the inheritance of any characters in the hop and the situation today, although better, is still very unsatisfactory. It is important for the breeder to have some idea about the heritability of the characters that he is trying to improve. Some of the variation between individual plants is due to the genotype they have inherited from their two parents, some is due to other causes such as the environment in which they are growing. Selection of individuals for characters that are highly heritable can be expected to result in worthwhile genetic improvement, whereas the same amount of effort put into selection of characters with low heritability will be far less rewarding. Several attempts have been made to assess the heritability of some of the most important characters, particularly resin contents and yield.

9.6.1 Resin contents

Schmidt (1915a) measured the lupulin content of the progeny of several families and found that the progeny of high-lupulin females had means lower than the parent while low-lupulin females gave progeny with a mean exceeding that of the parent but in all cases some seedlings had lupulin contents exceeding those of the parents. Schmidt considered it: '. . .hopeless to attempt, on the basis of these experiments, any determination of what has, genetically speaking, taken place in the course of these crossings'. Lewis (1980) was able to calculate from Schmidt's data that the heritability in that population was approximately 0.66.

Farrar *et al.* (1956) crossed a high and a low α-resin containing female, which had similar β-resin contents, with two male parents and concluded from the analyses of the progeny that α- and β-resin contents were inherited independently while the total resin content was merely the sum of the two quantities, implying that limiting reactions occurred after the synthetic pathways of the α- and β-resins diverged. Neve (1958b) crossed a tetraploid with six different males and found significant differences between the mean α-resin contents of the progenies. There was no segregation into separate classes within the progenies, indicating that control was polygenic, and in most families there was no correlation between α- and β-resin contents.

Keller and Likens (1955) estimated the heritability for a number of characters, including resin contents, in early and intermediate maturity groups of selected clones. They calculated heritability values for total soft resin, α-acid and β-fraction of 0.87–0.96 for plants grown in replicated plots and estimated the potential gain from selecting the top 5% of the population to be as high as 50% for α-acids.

Brooks and Likens (1962) measured the α- and β-acids in the flowers of male hops and determined the heritability of resin content, gland number and gland size. There was a significant correlation between α- and β-acids but they considered that the lack of a perfect correlation indicated limiting reactions after their synthetic pathways diverged.

Tetraploid plants with XXXY sex chromosomes are monoecious, making it possible to compare the resin contents of male flowers and female cones on the same plant. Hartley and Neve (1965) found that the mean value for α-acids in the cones was 13.0 times that for male flowers but that there was a significant correlation between the two sets of values. The β-resin content of cones was only 5.9 times that of male flowers so the α-acid:β-resin ratio was higher in the cones. Similar results were obtained when comparing male and female seedlings of two normal, dioecious diploid plants from two families. In a further study on dioecious families they found no correlation between the α-acid content of the flowers of male parents and the cones of their female progeny (Hartley and Neve, 1968) although the males were clearly exercising some genetic control. They suggested that the breeding value of a male was indicated better by the α-acid content of its female parent than by analysis of its own flowers.

Whereas the resin contents in the above investigations were determined as a percentage of the whole cones or male flowers, Likens *et al.* (1978) additionally measured the α- and β-acid contents of isolated lupulin glands of 112 female and 74 male siblings. They found that lupulin from the females had an average ($\alpha + \beta$) content of 73.3% and from the males 72.5%. Although there was no significant correlation between the α and β-acid contents of the cones of these plants, the α-acid and β-acid contents of the lupulin were negatively correlated. This was interpreted as indicating a biochemical and genetic relationship between the two and that the α:β ratio was inherited as such. However, because the α- and β-acid values were recorded as a percentage of the weight of lupulin and their combined value was regularly about 73% of the total, such a negative correlation is mathematically inevitable and, in the opinion of the present writer, adds nothing to the attempt to determine whether or not α-acids and β-acids compete for a common precursor.

Lewis (1980) distinguished between broad sense heritability, which gives no indication of the genetic causes, and narrow sense heritability which partitions them into additive genetic effects versus the rest. Narrow sense heritability has been described as the fraction of the phenotypic differences between parents that the breeder can reasonably expect to recover in the progeny. The quality traits Lewis studied included the lead conductance value (LCV), spectrophotometric determination of α-acid, β-acid, $\alpha+\beta$-acids and $\alpha:\beta$ ratio. All were highly heritable in the broad sense but, in the narrow sense, LCV, α-acid and $\alpha+\beta$-acids were more highly heritable than either β-acid or α/β ratio. The results for storage stability of the resins were inconclusive but it appeared that, although fairly highly heritable in the broad sense, the genetic variability was partly non-additive and there were consistent indications of a substantial maternal effect.

9.6.2 Yield

Keller and Likens (1955) found yield to be highly heritable with heritability values from replicated plots ranging from 0.67–0.92 and the expected gains from selecting the top 5% of the population to vary between 15 and 55%. Lewis (1980) on the other hand found that although flowering date, ripening date, bine internode length and mean cone weight were highly heritable, cone number and yield were so much affected by the height of the shoots that were trained that this masked the genetic variation. He was, however, recording individual seedling plants whereas Keller and Likens worked with 5-hill plots of each clonally propagated variety and this would reduce the non-genetic variation.

9.6.3 Resistance to verticillium wilt

The source of resistance to wilt is not clear. All the genotypes from within Salmon's material that were found to be resistant to wilt had North American hops at some point in their pedigree, suggesting that resistance might have come from that source. Since most of his selections were of such hybrid origin, however, this is not very strong evidence. Dark (1952) pointed out that one of the American parents, a New Mexican hop, was itself susceptible and suggested that the European and American stocks contained complementary genes which, when brought together, developed resistance. Some support for this theory was obtained by Neve (unpublished) who crossed an American female and European male, both susceptible to wilt, and found some resistance amongst the progeny.

On the other hand, neither the cultivar WGV nor a male (No. 15) amongst the Wye breeding material are thought to have any American ancestry yet both are wilt resistant. Moreover, other wild American introductions have been found to be resistant (Neve, 1964b; Darby, personal communication) suggesting that complementary gene action is not essential for resistance genes in either American or European populations to express themselves.

No major genes for resistance have been identified and, as there appears to be a continuous range of reactions from very susceptible to very resistant, it would appear that control is polygenic.

There is some evidence that resistance is linked with undesirable agronomic characters. Neve (unpublished) found an association between resistance and low yield in one family while Darby (personal communication) has found a similar association with low α-acid levels.

9.6.4 Resistance to downy mildew

As with wilt resistance, there is no evidence for major gene action in host reaction to downy mildew and it is assumed that control is polygenic. There appear to be some differences between the disease in the USA, where the main problem is rootstock infection, and in Europe where it is leaves and cones that are most seriously affected. It is not clear whether this reflects differences in the pathogen or the environmental conditions.

9.6.5 Resistance to powdery mildew

Salmon (1917b) first reported resistance to this disease in nine plants raised from seeds of wild Italian hops as well as in an ornamental 'golden hop'. These plants were immune when grown in the glasshouse and subjected to very heavy levels of inoculum, but some infection developed on some of the Italian plants at the very end of the season when they were grown in the field. In another report Salmon (1919) described a 'semi-immune' response to infection which appears to be identical with the 'blister' reaction described by Liyanage *et al.* (1973).

Salmon (1920) raised open-pollinated seedlings from the 'golden hop' and one of the immune Italian plants. One group of seedlings from the golden hop segregated for leaf colour 170 yellow : 178 green while another group, when subjected to heavy doses of inoculum, segregated 72 immune : 33 susceptible. Amongst the suceptible seedlings there was wide variation in the level of infection. There did not appear to be any linkage between leaf colour and susceptibility. The progeny of the Italian female segregated 24 immune : 9 susceptible.

Since most of the male plants in the breeding garden would have been susceptible to the disease, it is unlikely that the large excess of immune over susceptible would be due to the male parents. It is more likely that both the female parents were heterozygous for two dominant genes, either of which could confer immunity. In this paper Salmon also described a third source of immunity in a plant supplied to him from the USA as the cultivar 'Golden Cluster' but which turned out to be a male, the true origin of which was never established.

More recent investigations (Liyanage, 1973; Liyanage *et al.,* 1973) have established that there are at least three dominant major genes that confer immunity to some strains of the pathogen as well as the 'blister' gene (section 7.4.6). There is also a wide range of reactions amongst susceptible plants indicating polygenic control. Recent work indicates that the immune reactions of the major genes are also modified by this polygenic background.

9.6.6 Reaction to viruses

Only in the case of hop mosaic virus is there any evidence of genetic variability in host reaction to infection although cultivars may vary in the frequency with which they become infected with other viruses. Plants infected with hop mosaic are either susceptible or symptomless carriers. Susceptibility appears to be due to a single major gene for which the English Goldings are heterozygous. Good 1 : 1 or 3 : 1 genetic ratios have been obtained in several crosses but there have also been some unexplained cases where such ratios have not been found.

9.7 POLYPLOIDY

Ono (1959) referred to an earlier Japanese paper of his (Ono, 1948) which appears to be the first report of the induction of polyploidy as a breeding technique in hops. He stated that some economically promising triploid seedlings had been obtained but this work appears to have been terminated before any new cultivars were developed.

Dark (1953) considered Ono's work to be of limited value because it involved the treatment of seedlings with colchicine and he initiated a programme based on the treatment of young vegetative buds on shoots of standard cultivars. He suggested that triploids would have three valuable properties: they would be stimulated by pollination yet remain largely seedless, they would be more vigorous than their parents and, because they would receive two chromosome sets from the tetraploid female parent but only one set from the diploid male, they would closely resemble the original diploid female variety.

Dark's work was continued at Wye for several years and tetraploid forms of Fuggle, Goldings, Saazer and Hallertauer Mittelfrüh were produced and used as parents in the breeding programme. The low seed content of pollinated triploids was confirmed but it was only rarely below the 2% level necessary to qualify as seedless by European standards. The greater genetic contribution from the tetraploid female parents proved to be a disadvantage when trying to introduce resistance to verticillium wilt from the male parents (Neve and Farrar, 1961). Although several thousand triploid seedlings have been raised and tested at Wye, only two ever reached the stage of farm trials and neither of these proved satisfactory.

Elsewhere the breeding of triploids has been much more successful. In New Zealand, Roborgh bred three high yielding, high α-acid varieties named Harley's Fulbright, Green Bullet and Stickelbract which now occupy most of the hop acreage. It was found that successful triploids were invariably later maturing than their female diploid parent (Frost, 1980).

Haunold (1971) described the objectives of a polyploid breeding programme in the USA and listed the frequencies of triploid and aneuploid seedlings in the progeny of tetraploid parents. From the tetraploid Fuggle induced for this programme, the triploid variety Willamette was raised (Haunold *et al.,* 1976a) and more recently tetraploid Hallertauer has yielded seedlings that have a European-type aroma (Haunold and Nickerson, 1987).

In England many triploids have been too late maturing and this is one reason why none have proved commercially successful. The main reason for their lack of success, however, is that they represent a dead-end in the breeding programme. Not only do they produce little seed but the few seedlings that can be raised from them have very variable chromosome numbers and are rarely of any practical value. In order to combine adequate levels of wilt resistance with the other characteristics required in a commercial variety, several generations of breeding have been required and triploids can only be of use in the last stage of such a programme.

Neve and Farrar (1961) suggested the possibility of using tetraploid plants with XXXY sex chromosomes, which are monoecious, as male parents after selecting them on the basis of their female cones. This has not been pursued because it would involve too much time, breeding suitable monoecious plants, before they could be used as parents in the second stage of such a programme. Haunold *et al.* (1979) have described triploid male plants that can be used as pollinators to stimulate yield of fertile diploids while retaining the seedless nature of the cones (section 3.8).

9.8 MUTATIONS

Spontaneous mutations modifying two different characters have been recorded. One is a mutation from green to yellow leaf which was first observed at Wye in Brewer's Gold but has occurred in other varieties since then. Also at Wye, on three separate occasions when screening young seedlings for their reaction to powdery mildew infection, a plant has been noted with a leaf, or leaves, divided into susceptible and resistant sectors. On at least one of these occasions the mutation was from susceptible to resistant.

Both these mutant forms were immediately recognizable and, by taking cuttings from the mutant sector, plants were produced that were entirely of the mutant type. There would, however, be no possibility of recovering a mutant sector that was not immediately recognizable. Many mutations are recessive and, if it is a character not present in the population, the mutant cells will be heterozygous for it and the new form will not be expressed. Even dominant mutations may not be immediately recognizable. Changes in the chemistry or content of oils or resins, for example, could only be detected by analysis and there would be nothing to indicate from which part of the plant samples should be collected to demonstrate the change. Since most of the characters required by the hop breeder are available in existing genotypes, combining these with other commercial qualities is more likely to be achieved by hybridization than by mutagenesis.

The artificial induction of mutations is not, therefore, a very promising technique but various workers have attempted it. A report from Czechoslovakia (Beranek and Srp, 1976) gives details of radiation dose rates and claims that seed obtained from irradiated plants yielded seedlings with improved properties. Since these were of necessity hybrid plants, such improvement could have been due to normal genetic segregation and not the result of any mutation.

More reliable methods of producing and selecting mutations would be of great interest to hop breeders because, unlike hybrids, they offer a means of introducing a new character, such as disease resistance or different maturation periods, into the original cultivar without affecting other important features such as its aroma. There is, therefore, much interest in the use of *in vitro* culture techniques aimed at developing somaclonal mutant forms. Mutagenic agents applied to whole plants or seeds are only likely to give rise to mutant sectors in the treated plant whereas somaclonal variants regenerated from cell culture or from callus are much more likely to be non-sectorial.

Tissue culture has been used by Heale and co-workers at King's College, London, in attempts to select novel sources of resistance to *Verticillium albo-atrum*. They screened regenerating green callus of Wye Challenger in liquid medium against crude culture filtrate of the pathogen for a 4 week period, with fresh culture filtrate added at weekly intervals. Some green, viable areas of callus survived from which shoots were excized. Regenerated plants were screened for resistance against live inoculum in the glasshouse and four clones showed reduced symptom expression. When subsequently tested under field conditions at East Malling, however, they were found to be susceptible (Heale *et al.,* 1988).

Tissue culture would be most usefully applied in cases, like this one, where screening for the desired character can be carried out in culture, but such situations would seem to be rare. The demand for improved cultivars that retain the brewing characteristics of established types is such that a start has been made at Wye to apply the technique on a large scale as an alternative to hybridization as a means of creating variability in the population.

9.9 WILD HOPS AND GENE POOLS

Wild hops have already proved a source of valuable characters for the plant breeder. High α-acid and resistance to *Verticillium albo-atrum* have both been introduced from wild American plants and resistance to downy mildew has been derived mainly from wild sources. The current search for plants resistant to aphid attack may also benefit from some of the wild hops maintained in breeders' collections.

Wagner (1975) made an extensive collection of wild hops from the different regions of Yugoslavia and some of these were found to have good agronomic characters. The main value of such material, however, would be when breeders required a source of some new character that was lacking in the currently grown cultivars. This could be resistance to some new pest or disease or it might be that brewing chemists wanted hops with different oils or resin characteristics. The wider the range of material available for screening, the greater the chances of finding a hop with the required character.

The importance of maintaining as broad-based a collection of hop genotypes has been recognized, and Wagner (1978, 1980, 1984, 1986), on behalf of the Scientific Commission of the International Hop Growers' Convention, has assembled lists of the various collections maintained by each member country and it is considered most important that such collections should not only be maintained but, whenever possible, extended.

9.10 CHARACTERISTICS OF PRINCIPAL CULTIVARS

The characteristics of any cultivar vary considerably from season to season and from location to location. Table 9.1 is an attempt to detail the more important features of each of the varieties listed, but it should be emphasized that the information does not come from hops grown under uniform conditions or assessed by identical methods.

TABLE 9.1 Principal features of hop cultivars

Variety by country of origin	alpha-acid content %	α-acid/β-acid ratio	Co-humulone%	Oil content, ml/100g	Humulone/caryophyllene ratio	Proanthocyanidin content %	Proanthocyanidin/α-acid ratio	Storage stability	Time of ripening	Aroma	Yield	Susceptability or resistance to diseases: Peronospora (downy mildew)	Sphaerotheca (powdery mildew)	Verticillium (England)	Verticillium (Germany)	Verticillium (USA)
ENGLAND																
Goldings	4.5–6.0	2.3	22	1.0	3.5	–	–	good	mid-late	good	good	susc	susc	susc	–	–
Fuggle	4.5–5.5	1.8	26	1.4	3.3	2.0	0.63	good	mid-early	good	mod	mod	susc	susc	–	–
Northern Brewer	6.5–10.0	2.0	23	2.0	2.8	3.2	0.35	good	mid	mod	mod	susc	v.susc	susc	rest	–
Bullion	6.0–9.0	1.9	36	3.2	1.5	–	–	poor	late	poor	v.good	susc	susc	susc	–	–
Brewers Gold	5.5–8.5	1.9	38	1.5	2.3	2.7	0.48	poor	late	poor	v.good	susc	susc	susc	mod	–
Wye Northdown	7.5–10.0	1.6	30	2.7	2.7	2.6	0.30	good	mid	good	mod	mod	susc	susc	–	–
Wye Challenger	6.5–8.5	2.0	21	1.7	3.1	2.4	0.30	good	late	good	good	rest	susc	susc	–	–
Omega	9.0–11.5	3.0	27	1.3	3.7	–	–	good	late	good	good	rest	susc	susc	–	–
Progress	5.0–7.5	2.8	27	1.0	3.3	–	–	mod	mid	mod	mod	susc	susc	rest	–	–
WGV	5.5–7.0	2.8	27	1.1	3.5	–	–	good	mid	good	good	susc	susc	rest	–	–
Bramling Cross	5.0–7.0	2.2	27	1.0	2.2	–	–	mod	early	mod	mod	susc	susc	rest	–	–
Wye Target	9.5–13.0	2.2	35	1.4	2.4	–	–	poor	late	mod	mod	susc	rest	rest	–	–
Yeoman	10.0–12.0	2.0	25	1.1	3.5	–	–	v. good	early	good	poor	mod	v.susc	rest	–	–

TABLE 9.1 Principal features of hop cultivars

Variety by country of origin	alpha-acid content %	α-acid/β-acid ratio	Co-humulone%	Oil content, ml/100g	Humulone/caryophyllene ratio	Proanthocyanidin content %	Proanthocyanidin/α-acid ratio	Storage stability	Time of ripening	Aroma	Yield	Susceptability or resistance to diseases: Peronospora (downy mildew)	Sphaerotheca (powdery mildew)	Verticillium (England)	Verticillium (Germany)	Verticillium (USA)
GERMANY																
Hallertauer	3.5–5.5	1.0	21	1.0	3.7	3.7	0.89	good	early–mid	good	mod	susc	susc	susc	susc	–
Tettnanger	3.5–5.5	1.0	25	0.8	3.6	–	–	good	early	v.good	mod	susc	susc	susc	susc	–
Spalter	4.0–5.5	1.1	24	0.7	3.3	–	–	good	early–mid	v.good	mod	susc	susc	susc	mod	–
Hersbrucker	3.5–6.0	0.9	25	1.2	2.5	1.6	0.33	good	late	good	good	susc	susc	susc	rest	–
Hüller Bitterer	4.5–7.0	1.2	30	1.2	1.9	–	–	mod	mid	mod	mod	rest	susc	susc	rest	–
Perle	6.0–8.5	1.6	29	1.0	3.3	–	–	v. good	mid	good	good	rest	susc	susc	rest	–
Orion	7.0–10.0	2.0	30	1.4	2.6	–	–	good	late	mod	good	rest	susc	–	rest	–
BELGIUM																
Record	5.5–8.5	1.0	30	1.8	2.5	–	–	mod	late	mod	mod	susc	susc	susc	susc	–
FRANCE																
Strisselspalt	3.0–5.0	1.0	24	0.7	2.4	–	–	good	mid	good	mod	susc	susc	susc	–	–

CZECHOSLOVAKIA																
Saazer	3.0–4.5	0.9	26	0.4	3.5	3.5	1.46	good	early	v.good	poor	susc	susc	susc	susc	–
POLAND																
Lublin	3.5–4.5	1.3	27	1.0	3.7	–	–	good	early	good	mod	–	–	–	–	–
Lubelska (Pulawy)	4.5–6.0	1.4	–	–	–	–	–	good	early-mid	good	mod	–	–	–	–	–
YUGOSLAVIA																
Savinja Golding	4.5–6.0	2.0	28	0.8	3.1	–	–	good	early–mid	good	mod	mod	susc	susc	susc	–
Ahil ('Super Styrians')	8.0–10.0	2.2	27	1.0	2.4	–	–	mod	late	good	good	susc	susc	susc	–	–
Apolon ('Super Styrians')	8.0–10.0	2.2	27	1.0	2.5	–	–	mod	mid–late	good	good	susc	susc	susc	–	–
Atlas ('Super Styrians')	8.0–10.0	2.2	31	0.8	2.3	–	–	poor	late	good	good	susc	susc	susc	–	–
Aurora ('Super Styrians')	8.5–10.5	2.1	25	1.0	2.9	–	–	good	early–mid	good	good	susc	susc	susc	–	–
Backa	3.0–6.0	0.7	20	0.6	3.2	–	–	mod	mid–late	good	good	susc	susc	susc	–	–
Dunav	7.0–10.0	1.3	30	0.7	3.4	–	–	good	early–mid	mod	good	susc	susc	susc	–	–
Neoplanta	6.0–7.5	1.5	36	1.5	2.4	–	–	mod	early–mid	mod	good	susc	susc	susc	–	–
Vojvodina	7.5–10.5	1.6	33	1.0	2.9	–	–	good	early–mid	mod	good	susc	susc	susc	–	–
USSR																
Zitomir	3.0–4.0	–	–	–	–	–	–	–	early–mid	good	poor	susc	susc	susc	–	–
Serebrianka	2.4	–	–	–	–	–	–	–	mid–late	good	poor	susc	susc	susc	–	–

TABLE 9.1 Principal features of hop cultivars

Variety by country of origin	alpha-acid content %	α-acid/β-acid ratio	Co-humulone%	Oil content, ml/100g	Humulone/caryophyllene ratio	Proanthocyanidin content %	Proanthocyanidin/α-acid ratio	Storage stability	Time of ripening	Aroma	Yield	Susceptability or resistance to diseases: Peronospora (downy mildew)	Sphaerotheca (powdery mildew)	Verticillium (England)	Verticillium (Germany)	Verticillium (USA)
USA																
Clusters	4.5–5.5	1.4	39	0.6	1.8	4.0	0.67	v. good	early–late	mod	good	susc	susc	susc	–	–
Talisman	7.5–10.0	1.8	52	0.7	1.2	–	–	mod	late	mod	mod	mod*	susc	–	–	–
Eroica	11.0–13.0	1.4	40	1.0	0.1	–	–	poor	late	mod	good	mod	susc	–	–	–
Cascade	4.5–7.0	1.0	37	1.2	2.7	1.6	0.31	poor	mid	mod	mod	rest*	susc	mod	–	rest
Willamette	5.0–7.0	1.6	33	1.2	2.9	4.2	0.81	good	early–mid	good	mod	mod	susc	–	–	susc
Nugget	12.0–14.0	3.3	27	2.0	2.2	–	–	good	mid	good	good	mod	rest	–	–	–
Olympic	11.5–13.5	2.7	31	1.7	1.4	–	–	mod	mid	mod	good	susc	susc	–	–	–
Chinook	12.0–14.0	3.9	32	2.0	2.2	–	–	good	mid–late	mod	good	mod	susc	–	–	–
Mount Hood	5.0–8.0	1.1	23	1.1	2.5	–	–	mod	mid	good	mod	–	–	–	–	–
Aquila	5.0–8.0	1.1	47	1.4	0.1	–	–	mod–poor	mid	mod	good	–	–	–	–	–
Banner	8.0–12.0	1.5	33	2.2	2.4	–	–	mod–poor	mid	mod	good	–	–	–	–	–

AUSTRALIA																
Pride of Ringwood	9.0–11.0	1.7	33	2.0	0.1	–	–	poor	mid–late	mod	good	susc	susc	susc	–	–
NEW ZEALAND																
Green Bullet	12.5–13.5	1.8	42	0.8	3.2	–	–	–	late	–	good	–	–	–	–	–
Sticklebract	13.5–14.5	1.7	38	1.0	1.8	–	–	–	mid	–	good	–	–	–	–	–
Super Alpha	12.5–13.5	1.5	38	1.5	3.2	–	–	–	early–mid	–	good	–	–	–	–	–
Pacific Gem	14.0–16.0	1.8	41	1.5	3.2	–	–	–	early–mid	–	good	–	–	–	–	–
CHINA																
641	5.5–8.0	–	–	–	–	–	–	mod	–	mod	–	–	–	–	–	–

* Resistance to rootstock infection

This information should be treated as an approximate indication of varietal characters since it is drawn from a number of different sources involving different environmental conditions and experimental techniques.
Resistance to powdery mildew may only be effective against some strains of the fungus.

CHAPTER 10

The hop trade

The hop growers' problems do not end with harvesting and drying the crop since they still have to worry about selling it at a price that will give them a reasonable return. Unlike many crops the consumption of hops does not increase if the price is reduced since the brewers' requirements are determined solely by the quantity of beer that they sell. If a cheap supply of hops is available they may buy more than their immediate requirements in order to put them into storage for future use but that only depresses the market the following year.

On the other hand, it is essential for the brewer that he has sufficient hops to produce all the beer that he can sell so that, if hops are in short supply, he is willing to pay high prices to ensure that his needs are met.

The introduction of cold storage has prolonged the useful life of whole hops, enabling brewers to hold reserves that reduce their dependency on any particular year's production. This flexibility has been increased still further by processing hops into powders or extracts which can be stored for long periods with very little deterioration. Even so the market is still subject to marked fluctuations as the supply situation changes and it has frequently been the case that growers have achieved a better return in years when yields have been bad because the high price has more than compensated for the small crop.

It is not clear how hops were marketed in the earliest days although there are references to merchants being involved from an early period and any trade with brewers living remote from the growing areas must have been handled by middlemen. There are records to show that large quantities of hops were imported into England, for example, before they were cultivated there, while the discovery of what was apparently a cargo of hops in the Graveney boat (section 2.1), carbon-dated to about 950 AD, indicates that trading must have started at a very early date. Parker (1934) quoted an act of 1603 entitled 'An Acte for avoyding of deceit in selling, buying or spending corrupt and unwholesome Hoppes', the preamble of which commences: 'For so much as of late great fraudes of deceits are generally practised and used by Forreiners Merchants Strangers and others in forreine parts beyond the Seas in the false packing of all forreine Hoppes brought into this Realme of England. . .' This act clearly shows that merchants were very much involved, at least in foreign trade.

For the English home trade, many hops were sold at fairs that were held in various parts of the country. Stourbridge, in Cambridgeshire, is mentioned as the principal outlet in the 17th and 18th centuries and Defoe (1724) said that prodigious quantities of hops were sold there and that the prices obtained set the standard for the rest of the country. Stourbridge was later overtaken as the main fair by Weyhill in Hampshire while, although there were small fairs and markets in Kent and Sussex, most of the crop from the south-eastern counties was sold in London.

Parker (1934) recorded that there was a market in Little East Cheap on the north side of the Thames from the year 1681 but at some stage it moved just south of the river to the Borough of Southwark (Figure 10.1). There were rules governing the sale of hops, one being that they should be brought to market before being sold and in 1800 a Mr Waddington was fined £500 and imprisoned for a month for forestalling the hop market (Clinch, 1919). The Borough gradually became the main centre of the trade with most of the merchants and factors established there although '. . .the hops from Hereford and Worcester were principally sold at the County Towns' (Lance, 1838).

In an Act of 1710 a duty of 3 pence per pound was imposed on imported hops and in 1734 a duty of 1 penny per pound was levied on hops grown in England and this tax continued until 1862. The requirement that hops should not be sold before being brought to market was presumably to ensure that they did not escape being recorded for the purpose of this tax.

Hop production was subject to close control to ensure that the tax was collected and some of the requirements (and penalties) were as follows. Hop grounds and places for curing and keeping the hops had to be entered in the books of the excise (40 shillings per acre); defrauding the revenue by using twice or oftener the same bag, with the officer's mark upon it (£40); the removal of hops before they had been bagged and weighed (£50); concealment of hops (£20 and the concealed hops) and privately conveying away hops with intent to defraud (5 shillings per pound) (Lance, 1838).

Although England has, at times, had a sizeable export trade in hops it has never played an important part in the world's hop market which, according to Gross (1900):

> . . .is controlled by Germany, Austria and the United States, and is largely in the hands of merchants who serve as go-betweens for the grower on the one side and the consumer (brewer) on the other, the latter generally preferring – whether as a matter of convenience, credit, or for other reasons – to deal with agents rather than direct with the growers.
>
> The largest hop market in the world is that of Nürnberg, where a large proportion of the total crop finds its way every year, and where there is a large colony of hop merchants, agents and dealers. Many of these have their own warehouses and conditioning houses, and there are also warehouses for provisional storage in the town.

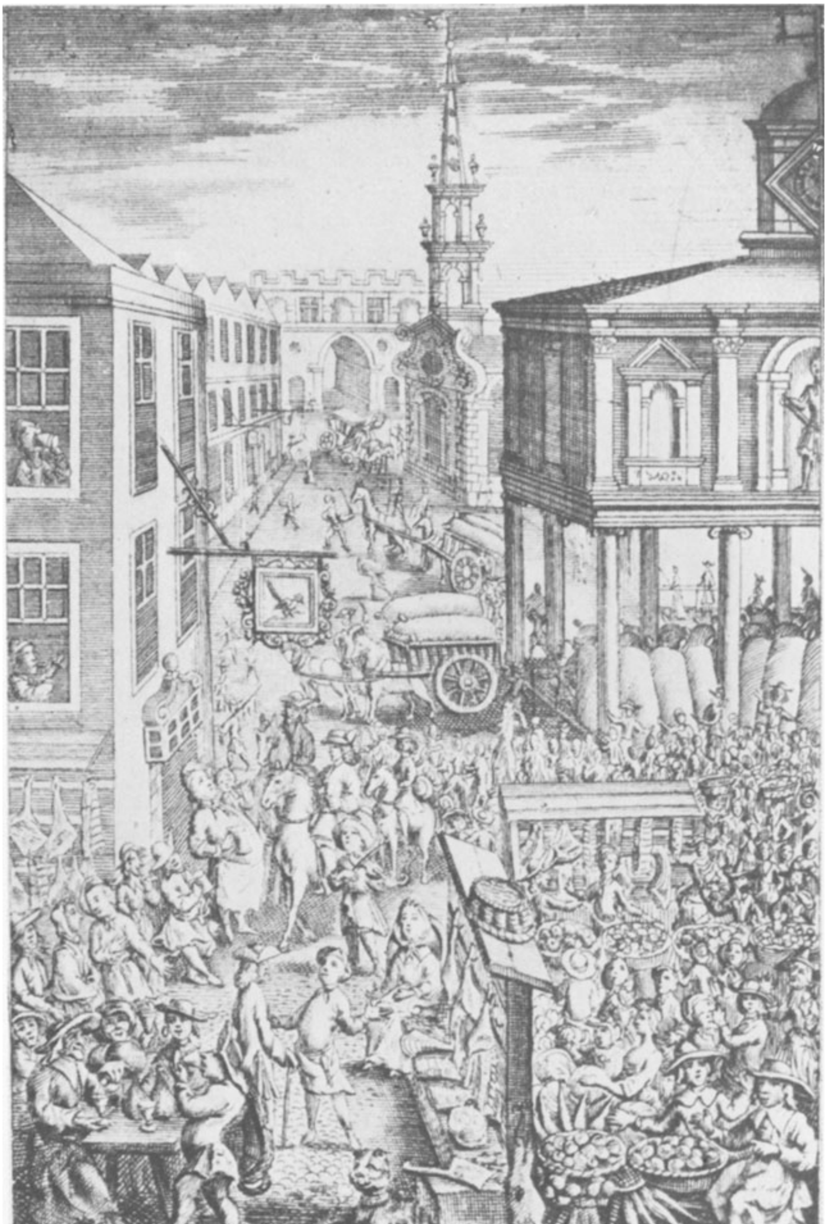


Figure 10.1 The hop market in the Borough (London). (From an engraving of 1729.)

Conditioning establishments are really necessary at Nürnberg, it being the custom among a large section of Bavarian growers to leave to the merchant the task of getting the hops ready for sale; consequently, it frequently happens that the former are careless over the drying of their produce. Moreover, in many cases the hops are bought by the merchants as soon as picked, and are sent into the town for further treatment.

The part played in Germany by Nürnberg is performed in Austria by the town of Saaz, which is the centre of the hop trade in the latter country. Of course the volume of business done is smaller than in Nürnberg, since the supply is a local one; nevertheless a large trade is carried on, chiefly in the finer qualities.

Other large hop markets are held in London, New York and Warsaw; and there are smaller business centres in all producing districts.

The town of Saaz referred to is now the town of Zatec in Czechoslovakia. According to Günzel (1904) there are, unfortunately, no records for the town from the 10th and succeeding centuries because the town hall was the victim of fires in 1767 and 1788. He stated, however, that there is no doubt that hop growing was introduced to Saaz from Germany and especially from Bavaria where hops had been grown at Freising since the 9th century. Similarly, hop merchants moved into Saaz from Germany and there is documentary evidence that they were established there by 1774.

In Nürnberg the hop trade can be traced back to 1400, at which time it was a town monopoly and brewers purchased hops from the town administration. Hops became economically important when hop cultivation was increased in the beginning of the 18th century (Anon, 1969b).

The German merchants have continued to dominate international trade and Raiser (1987) accounted for this as follows:

By tradition Germany has a high consumption of beer and an important brewing industry which has been the backbone of German hops. As beer became gradually popular worldwide, breweries were built in almost every country. This trend has not yet come to an end. Germany through not having been able to take advantage of this development to expand its brewing industry beyond its own borders like other countries, such as the Netherlands, nevertheless was having considerable benefit from it by becoming a leading exporter of brewing technology and know-how. A majority of breweries in the world are brewing a German type of lager beer, a great many of them are using German equipment and are employing German technicians or have their own people trained in Germany. It is only natural that they are looking into Germany also for their raw materials and particularly into hops, which are supposed to be of the greatest importance as to the type and quality of beer. Thus German hops were able to build up a world-wide image for quality, the industry had a sound base for expansion and a strong international dealership could evolve. Efficient and large-scale processing facilities were established to satisfy the needs both of the homemarket and abroad for a reduced volume and the preservation of brewing value even under strenuous conditions.

A standard arrangement grew up in England whereby the growers' interests were managed by factors and the brewers' by merchants, each of them operating on a commission basis. In Germany, on the other hand, there was only one middleman, the merchant who acted as go-between for the grower on the one side and the brewer on the other. Brewers generally preferred to deal with agents rather than direct with the growers, either as a matter of convenience or because the merchant allowed them credit (Gross, 1900). However, Gross also deplored the number of intermediaries between the grower and brewer – the local dealers, the buyers and their agents, the merchants, the consignment house for export trade and the commission agents – and also the way that dealers resorted to talk of overproduction when buying and of shortages when selling in order to increase their profits. The English grower may, therefore, have been well-served by his factor who would have been far better informed than most growers about the state of the market.

In Germany growers started forming themselves into associations to strengthen their position, the first being formed at Förrenbach in the Hersbruck district by a clergyman named Kelber. These associations supervised the quality of the hops to be marketed and fixed the price and, in order to help them compete with the dealers, the Bavarian Government assisted them with subsidies and interest-free loans. Today, each hop growing region has its own organization under the umbrella of the 'Verband deutscher Hopfenpflanzer e.V.' (Kohlmann and Kastner, 1975).

Such associations can do little to overcome the fluctuations in price that result from the unpredictability of hop yields from season to season. In England there was close control of production during the 1914–18 war by the Hop Control. When this ended, a duty of £4 per cwt was imposed to protect the industry but in spite of this there were serious difficulties with marketing in the subsequent years. From 1925–8 there was an effort to regulate sales by means of a voluntary co-operative, English Hop Growers Ltd, whose members represented nearly 90% of the hop acreage. Its efforts to control prices were hampered by a large surplus left over from 1924 and large crops in 1925 and 1926. Its members agreed to reduce their acreage but non-members undermined this action by increasing theirs and the organization collapsed.

The introduction of the Agricultural Marketing Act in 1931 gave legal support to co-operative action and the hop industry was the first to take advantage of this legislation. A Hops Marketing Scheme came into operation in 1932 under which all producers were obliged to sell through the Hops Marketing Board while the Board was obliged to accept any English hops consigned to them in fulfilment of a grower's contract. Growers were given a basic quota, based on their previous production, which was varied each year in accordance with brewers' requirements. The costs of production were determined by means of a survey each year and the price based on this. This meant that prices in the UK bore no relationship to prices in the rest of the world and the system could only operate because there were restrictions on the importation of hops from other countries.

This scheme was successful in ensuring that brewers and growers were protected from violent fluctuations in price and it was possible for them to budget forward with some confidence. On the other hand it severely restricted the ability of English merchants to deal in foreign markets because they could never quote a price until some months after the crop was harvested, when all the calculations of costings and weights had been finalized.

The entry of the UK into the EEC opened the market to all hops from within the Community and it was no longer realistic to impose an embargo on any imported supplies so the industry was forced into an internationally competitive situation. Nevertheless, the Board continued to function for some years with all growers remaining members, even after EEC regulations required it to become a voluntary organization, and it changed its name to English Hops Ltd. Many UK brewers continued to purchase hops from it at prices fixed on a similar basis to the old arrangement but, eventually, conflicts of interest led to some break-up of the organization and growers have now formed themselves into several different producer groups although English Hops Ltd is still the largest. The development of these co-operative grower organizations reduced the role of the factors in the marketing of the hops although they continued to serve the growers by representing their interests when hop samples were being valued.

In the USA there has been a somewhat similar sequence of events. In 1937 their Agricultural Marketing Agreement Act was amended to include hops and a Marketing Agreement and Order operated, effectively controlling prices, from the 1938 crop. After 1942 there was no surplus to be controlled and the Agreement and Order were terminated in 1945. The return of a surplus in 1948 however, led to their renewal in 1949 (Productivity Team Report, 1951) only to be terminated again in 1952. Once again the market, and American hop acreages, fluctuated widely and a further renewal of the Order was made in 1966 only to be again terminated in 1986. The difference between the UK and USA situations was that changes in the USA were at the wish of growers whereas in the UK the ending of the Board was the result of political changes and was very unpopular with most of its members.

The marketing schemes in the UK and USA were effective because they had legal backing, whereas voluntary co-operative schemes failed because of the activities of non-members within the country. Similar problems faced these marketing schemes on the international scale because of the activities of other countries where growers were quick to take advantage of their freedom from any restrictions. On each occasion that production in the USA was controlled, there was a very satisfactory increase in the price paid to American growers but this made hops from other sources more competitive and they captured some of the American growers' markets. The Americans would doubtless have lost even more sales were it not that many brewers are reluctant to switch their sources of supply, partly because they do not want to change the type of hop that they use but also because they like to feel that supporting their usual sources helps to guarantee their future supplies. Nevertheless, without international agreements, it is doubtful whether efforts to control production in any one country can be a permanent solution to the growers' problems.

In Europe, the EEC has adopted various devices to support hop production in the member countries. Income support has been given to try and ensure that growers' income does not fall below a reasonable level but the scheme has not been very satisfactory. If growers in one country could show that a particular variety warranted support, the same support had to be given to all growers of that variety, even if it had given better returns elsewhere. Without any legal means of controlling acreage, the Community has provided financial incentives to growers for grubbing their hops in times of surplus but has not been able to prevent them being replanted as soon as there were signs of the market recovering.

In the communist hop growing countries the marketing arrangements are unified under government control but whatever the internal arrangements, all producers have to compete in a free market where international trade is concerned. To succeed in this it is important that buyers are confident that the hops will be of the type specified in the contract and of acceptable quality.

In 1884 the town of Saaz established a Hop-Marking Institute (Signirhalle) which checked that the hops submitted by the producers were '. . .fine red hops, grown in the district and in an unspoiled condition'. After weighing, the bags were numbered and sealed. Similar arrangements for certifying and sealing were commenced in Germany at about the same time (Gross, 1900) and these continue to this day.

Within the EEC it is now required that all hops harvested there (except those grown and used by a brewer or those put up in small packages for sale to private individuals for their own use) are certified in accordance with Council regulations. These require that, with each consignment, the grower must provide his name and address, the year of harvest, the variety, the registered number of the holding where they were produced and the number of packages in the consignment. The hops must be supplied in closed bags or bales and be marked as appropriate: 'prepared hops' or 'unprepared hops' and 'seeded' or 'seedless'. In England, the drying and packaging is always completed on the farm so all hops sent from there are 'prepared hops'. On the continent most hop preparation is finished at the merchant's warehouse so they are supplied as 'unprepared'.

The consignment must be sampled and the samples examined to ensure that they meet the following requirements:

1. *Moisture Content;* the moisture content should not exceed 12% but if it lies between 12–14% the hops may be certified and labelled as 'unprepared hops'.
2. *Leaf and Stem;* (defined as leaf fragments and pieces of stem, leaf strigs and cone strigs 2.5 cm or more long).

Maximum allowed (by weight) 6%

3. *Hop Waste;* (defined as small particles of the hop plant resulting from machine harvesting, varying in colour between dark green and black, which generally do not come from the cone)
   Maximum allowed 3%
4. *Seed Content;* Seedless hops must not contain more than 2% by weight. Hops with more than 2% müst be certified and labelled as seeded.

Hops which do not meet these requirements may not be sold but they may be returned to the grower for additional drying and cleaning and resubmitted for certification.

In the USA, hops are also subject to inspection but there are not such rigid limits to what may be sold. Instead there is a system whereby the contract price for the hops is adjusted with premiums for low seed or leaf and stem contents. Seedless hops are defined as those with less than 3% seed by weight, those between 3–6% are 'semi seedless' and over 6% are classed as seeded. Only when the leaf and stem content exceeds 15% are the hops unmerchantable.

The EEC regulations do not permit the blending of hops (other than for the preparation of powders or extracts) unless they are from the same harvest, from the same production area and are of the same variety; then the blending must be carried out under the supervision of a certifying officer. For the manufacture of powders and extracts different varieties from different production areas within the Community may be blended provided the details are recorded on the certificate.

These restrictions on blending are especially important for the aroma hops since brewers buying these are generally paying a considerably higher price to obtain a particular type of hop. Those buying bitter hops are usually much less concerned about their source and many contracts are simply defined in terms of a weight of α-acid at a price per kg, usually with a minimum α-acid content stipulated. Powders and extracts generally have to be supplied at a specified α-acid content and in order to achieve this blending is essential.

As a result of the increased demand for high α-acid hops in the 1960s the cultivars then available were planted more widely, replacing aroma sorts, while the newer, higher α-acid selections that became available were rapidly taken up by growers in many countries. This change of varieties, combined with the adoption of brewing techniques which utilize α-acids more efficiently, went too far and there is at present a surplus of bitter hops, the market for which is very depressed, while there is a more active demand for aroma types.

Not only is the basic price of the aroma hops higher but their lower α-acid content means that two to three times the quantity is required to produce the same level of bitterness in the beer. Although the most conservative brewers will doubtless continue to insist on using them, the switch towards high α-acid cultivars seems certain to continue, especially as breeding continues to improve their aroma. Most bitter hops will be used in a processed form and, in order to achieve a predetermined level of α-acids in the products, the manufacturers will need to buy hops wherever they can obtain those that will blend to give the required level.

The brewing trade has already gone through a period of mergers and take-overs that have concentrated much of the industry in the hands of relatively few companies and there is little doubt that the process will continue still further. This is leading to a corresponding concentration of hop buying into fewer hands which will have a dominant effect upon the market, laying down the criteria for their large-scale purchases. Growers will have no choice but to try and meet these requirements and the surviving small brewers may have little influence and will have to accept the same standards.

The large number of hop varieties being grown at the end of the 19th century was quickly reduced to five or six dominant types during the first half of this century. Intensive breeding activity to meet the changing needs of brewers and growers has led to renewed variability in the hops that are available and it is certainly desirable that this should continue. Too much uniformity exposes the industry to the very real threat of another new disease problem creating havoc in the way that downy mildew in the 1920s and, to a lesser extent, verticillium wilt in the 1960s have already done. It is to be hoped that the major hop buyers will be willing to purchase a mixture of alternative varieties from different countries so that as much diversity as possible can be maintained within the crop as a safeguard against any future disruption of supply.

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Index