Department of Primary Industries

Hops
a guide for new growers

FIRST EDITION 2017

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Australian Government

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www.dpi.nsw.gov.au

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Published by NSW Department of Primary Industries, a part of NSW Department of Industry, Skills and Regional Development

First published March 2017

ISBN print: 978-1-76058-007-0
web: 978-1-76058-008-7

Job number 14293

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Acknowledgments

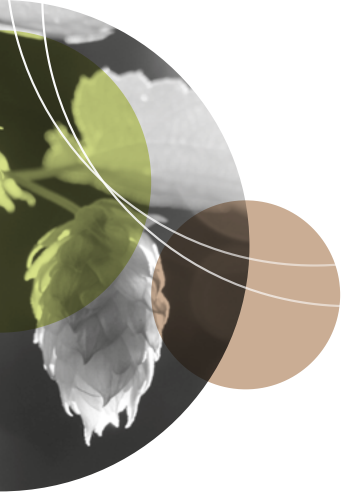
I acknowledge financial support provided by the Australian Government through the Murray Darling Basin Regional Economic Diversification Programme (MDBREDP). I thank the Batlow Fruit Co-operative Limited for inviting myself and the NSW Department of Primary Industries (NSW DPI) to join the investigation team for the 'Batlow Hops Diversification Project'.

Photography

Third party images used in this publication are acknowledged accordingly. All other images were taken by the author Mr Kevin Dodds (NSW DPI).

Funding

This handbook is a product of the 'Batlow Hops Diversification Project' which was funded by the Australian Government Department of Infrastructure and Regional Development, through the Murray Darling Basin Regional Economic Diversification Programme (MDBREDP).



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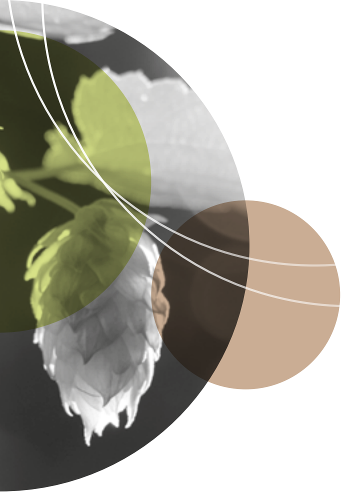


Preface

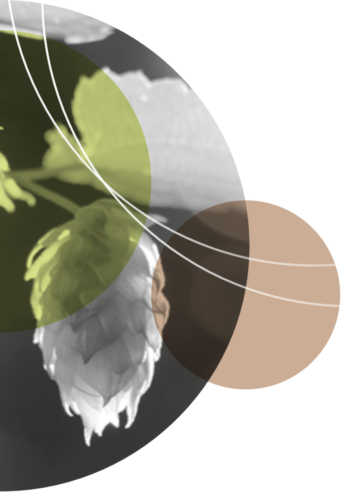
The Hops industry worldwide is experiencing a period of sustained expansion, largely as a result of strong growth in the craft brewing sector. Changes in consumer preference for fuller flavoured, aromatic beers, has seen a shift in focus from highly competitive alpha acid production toward the breeding and production of a wide variety of aroma hops.

Aroma hops are playing a key role in the development of new flavours and consumers are also driving demand for locally brewed beer using locally produced ingredients. As consumer demand and craft brewing continue to grow in the coming years, increased demand for locally produced aroma hops is expected to continue.

References on the production of hops in Australia are difficult to find. There are a number of excellent books and other international references already published on hops and their cultivation around the world. Hence, much of the information presented here is adapted from international sources and from observations made during study tours of the USA (August 2015) and New Zealand (February 2016) as part of this project.

Publications used in the development of this guide are listed in the reference section. The purpose of this guide is to provide potential hops growers in Southern New South Wales, with some entry level information to assist them to get started in this crop.

This is a first edition guide. As our knowledge and experience of hop cultivation in southern NSW develops, subsequent editions of the guide will provide growers with the most currently available information.



About hops

Origins and species

Hops are a member of the Cannabaceae family. The main commercial hop (*Humulus lupulus*) originates from the temperate regions of the Northern Hemisphere and is one of three species in the genus Humulus. The lesser known species *Humulus japonicas* and *H. yunnanensis* are not cultivated commercially, although the former is sometimes grown as a garden screening plant. Little is known about the species *H. yunnanesis* except that it grows at high elevation and the low latitude of 25°N in parts of China. This species could be of interest to plant breeders in the future for developing varieties that might grow productively over a wider range of latitudes.

The species *Humulus lupulus* encompasses five known varieties: 1. Neomexicanus, 2. Lupuloides and 3. Pubescens, which are all native to various parts of North America, and 4. *H. lupulus* var. *cordifolius* which originates from Eastern Asia.

The fifth variety, *H.lupulus* var. *lupulus,* originates from Europe and West Asia and represents most of the commercial hops grown worldwide. The cultivation of this variety is the main focus of this publication.

A very brief history of hop cultivation

Hop cultivation for use in brewing beer, originated in the Northern Hemisphere and is reported to go back to the mid 700s AD in the Hallertau region of Germany. In England, commercial scale production did not occur until the early 16th century. Although European hops were introduced into North America around 1629, they were not grown there on a commercial scale until the early 1800s (Neve 1991).

According to Pearce (1976), after several failed attempts to ship live plants to Australia from the UK soon after colonisation, the first successful plants were produced from seed in New South Wales in 1803. These early plants did not impress, probably because the open-pollinated seeds were highly variable in character and the growing locations' suitability, in terms of soil, water and climate, were questionable.

A former convict, James Squires, did manage to produce hops at Kissing Point on Sydney's Parramatta River in the early 1800s. Squires is said to have selected one or more successful hop plants from the imported seed progeny and vegetatively propagated from these to establish a successful five-acre hop yard (Pearce 1976). Squires was also credited with establishing Australia's first brewery on the same site in Sydney.

The year 1822 marks the earliest confirmed record of vegetative plant material being brought successfully to Australia from England. These plants were established in Tasmania by emigrant and experienced hop grower William Shoobridge. By the 1840s, the hop industry in Tasmania was well established around the Derwent River valley.

Botany

The hop plant consists of a crown of rhizomes below ground, annual climbing bines above ground, and flowers that are harvested as green cones.

The rhizome crown

The rhizome is the perennial storage organ of the plant. It feeds the growth of the productive canopy and ensures the plant's survival from one season to the next. Mature crowns typically have some very deep penetrating roots and a shallow feeder root system. Hop plants can remain productive for many years.

A rhizome is essentially an underground stem with buds and roots. As the hop crown matures and develops, some of the underground stems (rhizomes) can be harvested and used as a source of clonal propagation material (**see the section Hop varieties and propagation on page 11**).

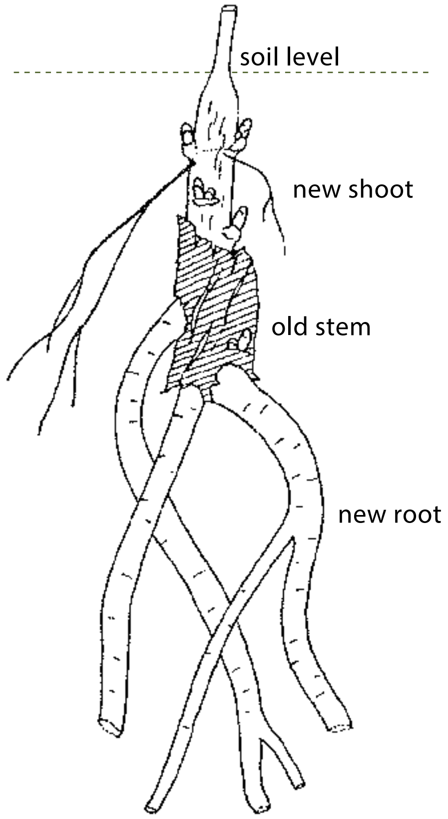


Figure 1. An example of a young hop rhizome. The hop plant survives over-winter as a dormant rhizome. Here is an example of a rhizome of a young hop plant (Williams, Roberts and Coley-Smith 1961).

The bines

The term bine is used instead of vine because, (unlike grapevines that use tendrils to climb) hop shoots have hooked hairs that enable the plant to attach itself to vertical supports. In spring, new shoots arise from dormant buds on the rhizomes just below the soil surface.

When viewed from above, bines grow in a clockwise direction around their chosen support. This is important when it comes to training the new season's growth, as each new bine should be wrapped in a clockwise direction onto the string. The climbing bines provide the canopy and photosynthetic capacity to support flowering.

Figure 2. When viewed from above, hop bines grow clockwise and need to be trained onto the strings in a clockwise direction in spring.

The flowers: male vs female

Hops are dioecious, that is male and female flowers are borne on separate plants. In commercial hop production, only unfertilised (seedless) female flower cones are desired as these produce the greatest lupulin (resin) yield. Male plants are used only when plant breeders wish to hybridise and develop new varieties.

Male plants are easily distinguished from the females; the former are routinely culled from the hop yard to ensure the harvested (female) cones are un-pollinated and seed free.

Figure 3. The flowers of the female plant (above) and male (below) are easily distinguished in the field.

The cone (strobile)

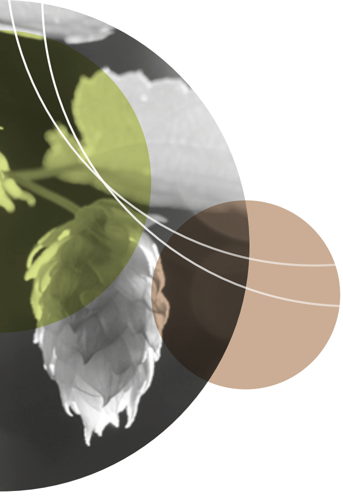
The hop cone is the mature female flower that is borne on current season lateral growth produced along the bines. The cone contains the lupulin glands that produce the alpha acids, beta acids and essential oils that brewers value for their bitterness and aromatic properties. Most of the lupulin is produced around the base of the bracteoles within the hop cone.

Figure 4. Cross-section of a mature female hop cone showing the yellow lupulin glands. Image of hop cone (Var. Krakanup) provided by C&B Butler – Hops West.

Photoperiodism – day length, vegetative growth and flower induction

Photoperiodism refers to a plant's propensity to grow and flower in response to day or night length. The hop is a photo-period-sensitive plant, which is most productive when day length ensures good vegetative growth and canopy development, then timely flower induction. Day length is a function of latitude, and for hops, the generally accepted latitude range for good commercial production is 35° to 55° north or south of the equator.

The further we move outside of this optimum range, the more likely that canopy growth and/or flowering will be reduced, making the crop less commercially viable. More information on latitude and hops production in NSW is provided in the **section Hop yard site selection on page 7**.



Hop yard site selection

Establishing a hop yard is a very significant capital investment. There's the cost of the land, planting stock, infrastructure (including posts, wires and irrigation) and of course, your time. It's well worth taking the time to select a site that will give you the best chances of making a successful return on your investment. Some major factors that determine a suitable location for the commercial production of hops include (in no particular order):

- latitude
- winter cold
- terrain
- soil type
- shelter from wind
- water availability.

Latitude

Latitude is important in hops production, because it determines seasonal day length which, in part, drives canopy growth patterns and timing of flowering induction. Most of the world's commercial hops are grown between latitudes 35° to 55° north. Hallertau in Germany and Yakima in the USA are the two largest regions for world hop production, located at 48°N and 46°N respectively.

Southern hemisphere production is centred around Nelson, New Zealand at 41.2°S; Myrtleford, Victoria at 36.5°S; the Derwent Valley, Tasmania at 42.7°S, and George, South Africa (SAF) at 33.9°S. There are reports of increasing production in parts of South America (Chile and Argentina), however, data on the current location and level of production is not readily available.

The industry at George, South Africa is located just outside the generally accepted optimum latitude range. Figure 1 shows the location of existing commercial scale hop farms in south-eastern Australia. In the early years at this location, commercially acceptable production was only possible by applying supplementary lighting, to top up marginal daylight levels. More recently, a hop breeding program in South Africa has selected a number of new varieties that are better adapted to this latitude, and commercial production is now possible without supplementary lighting.

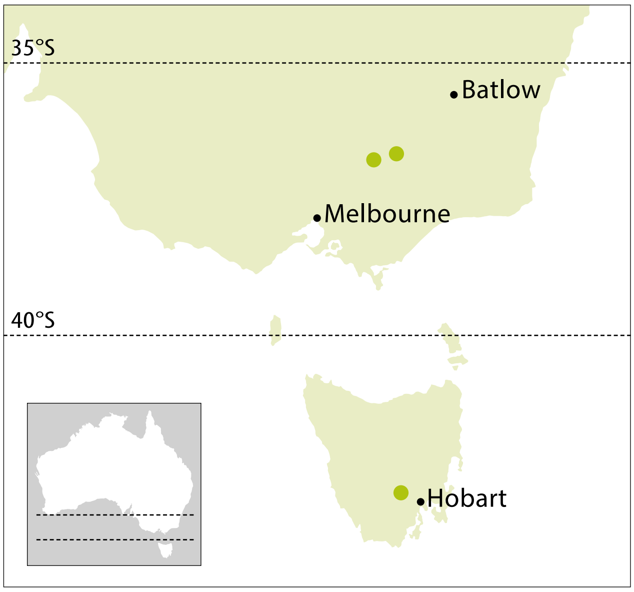


Figure 1. Existing centres of commercial hop production in south-eastern Australia (indicated by green circles).

Batlow, New South Wales (35.5°S) is a focus of this publication, as a potential new production area for hops in Australia. In terms of latitude and day length, Batlow compares favourably with the Ovens Valley at Myrtleford (Victoria) where commercial hop growing has been successful since the 1890s. Batlow is just one degree of latitude north of the ovens valley and has an annual daylight hours curve that almost mirrors the Victorian producing district (see Figure 2).

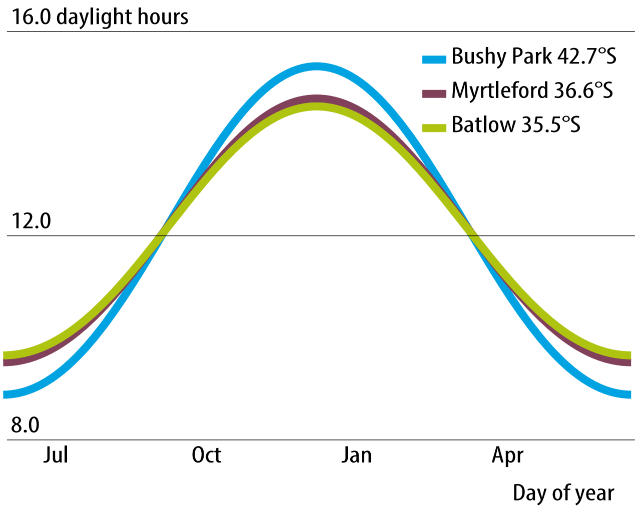


Figure 2. Chart of daylight hours at three locations in south-eastern Australia. Note the similarity in the curves for Myrtleford and Batlow, which are separated by 1° of latitude. (Source: **aa.usno.navy.mil/data/docs/Dur_OneYear.php**)

Winter cold

Adequate winter cold is another important factor in site selection for hops. According to Williams et al. (1961), dormancy in hops occurs in two stages, the onset of dormancy and break of dormancy. In response to shortening days in late summer and autumn, hop plants transition into a resting phase, which is characterised by the gradual death of shoots and fine roots and a transfer of food reserves into the storage roots. This is the onset of dormancy .

Without adequate chilling the break of dormancy can be insufficient, resulting in weak and erratic spring growth. Vigorous and synchronised spring growth is vital for good canopy development which, in-turn, will affect the uniformity of flowering, yield and cone maturity. The requirement for winter chill accumulation is widely accepted in industry, however, published data on threshold temperature and minimum chill requirements for the break of dormancy in hops is difficult to find. In the USA, hops extension sources suggest a threshold temperature of around 40–43 °F (4.4–6 °C) for a minimum cumulative period of 30–60 days.

It is worth noting that factors such as plant response to day length and winter chill requirement, are partly determined by genetics. This means that some hop varieties (genotypes) will grow and produce commercially where others might not, therefore, it is worthwhile trialling a selection of varieties on your site to find those that are best adapted to your latitude and seasonal conditions.

Terrain

The majority of world hops production occurs on flat to mildly undulating terrain. This is because level sites simplify establishing and managing the crop to reduce operational costs. There is also likely to be a higher degree of uniformity in soil type, depth and drainage on level sites compared with hilly terrain. In Yakima (USA) Figure 3, Nelson (NZ), Victoria and Tasmania, hops are grown primarily on alluvial river flats in sheltered valleys, while the Hallertau region of Southern Germany would be best described as gently undulating.

Figure 3. Typical hop yard site in the Yakima Valley, USA. Most hops in this area are planted on deep, well-drained sandy soils along the Columbia and Yakima rivers.

Soil

Hops will grow successfully on a range of soil types from light sandy soils to clay (Neve 1991). However, a light textured, deep soil, well supplied with moisture, but free of waterlogging is considered optimum. A naturally fertile soil would also be preferable, however, initial nutrient levels can be adjusted through pre-plant fertiliser treatments, and in the established hop yard, surface applications or fertigation are employed to manage long-term nutrition.

Soil pH is important, as it can significantly affect plant nutrient availability; if not in the desired range, it can lead to elemental deficiencies or toxicity. It is important to know the soil pH and adjust if necessary before planting. More information on amending pH and fertilising hops is provided in the **section Nutrition and fertilisers on page 30**.

Shelter from wind

Hops are sensitive to wind. Exposure to strong wind can cause leaf damage and some loss of cone-bearing laterals, both of which will affect bine health and yield (Figures 4 and 5). From flowering to maturity, exposure to hot winds can also negatively affect cone quality. The preference is for a site that is sheltered and relatively free of excessive wind. Hops are commonly grown in river valleys where the landscape provides the necessary protection from wind. Mountain ranges or hills situated between the production site and the prevailing weather can also provide protection. If your site is prone to some wind and is not naturally sheltered, consider using some type of natural or constructed wind-break. This can take the form of a tree shelterbelt or a post and mesh system (Figure 6).

Figure 4. Hops prefer a sheltered site, away from strong winds. Wind can cause cone-bearing laterals to be torn from the bine negatively affecting yield.

Figure 5. Hot winds can lead to scorching of the hop flowers and cones (Image: Shannon Hush).

Figure 6. An example of a post and mesh shelterbelt on a site that is otherwise exposed to wind.

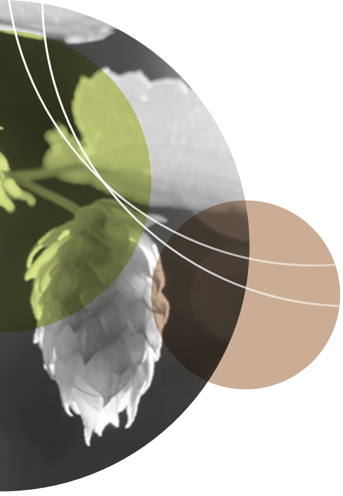
Water availability

Hops are a deep-rooted plant, however, the bulk of the feeder root system is located in the upper portion of the top soil. For optimum yield and cone quality, this feeder root system needs to be kept moist (but not saturated) during critical growth periods. In areas of moderate to low annual rainfall, spring/summer irrigations are essential to maintain adequate soil moisture.

In southern NSW, spring/summer rainfall is unpredictable and, as in many other perennial crops, supplementary water will be required in the hop yard. Access to a reliable and plentiful supply of water for irrigation is therefore a very important factor is selecting a site to grow your hops (Figure 7).

More information on irrigation set-up and application is provided in the sections **Hop yard design and establishment (page 16)** and **Hop yard management (page 23)**.

Figure 7. A reliable supply of water for irrigation is a vital factor in site selection.



Hop varieties and propagation

Hop varieties for brewing purposes are loosely grouped according to their alpha acid percentage (bitterness) and essential oil content (aroma). The terms used to identify the key varietal groups are **bitter**, **aroma** and **dual purpose**.

Bitter hops

It is the alpha acid contained in the lupulin of the hop cone that gives beer its bitterness. Varieties classified as bitter hops, typically have alpha acid levels of at least 8–10% of dry-weight. Some bitter hops are classified as **high alpha** hops, because they have alpha acid levels as high as 18%.

The varieties Columbus, Tomahawk® and Zeus, collectively referred to as CTZ, are three of the key bitter hops grown extensively in the USA. The variety Pride of Ringwood is Australia's most recognised bittering variety.

Aroma hops

A rapid and sustained growth in the craft beer brewing industry overseas and here in Australia is driving strong demand for hops with new and interesting flavours. **Aroma** hops usually have a lower alpha acid content compared with bitter varieties. The essential oil profiles of these varieties mean that the hop imparts more aromas and flavours to the beer. **Flavour** hops is a new term being used to describe certain varieties that are similar in many respects to aroma hops, but are known to deliver a particularly bold flavour.

Hop producing companies and government agencies around the world have identified the opportunity for new aroma and flavour hops to be developed through investment in plant breeding programs. Such programs have led to some very successful varieties protected by patent, trademark or plant variety rights (PVR).

The American variety Citra® and New Zealand variety Motueka® are examples of varieties privately bred and selected for their aroma properties. The Cascade variety is one of the world's most widely produced aroma hops, which resulted from a public breeding program run by the United States Department of Agriculture.

Dual purpose hops

As the name suggests, dual purpose hops have alpha acid and essential oil profiles that make them ideal for both bittering and aroma purposes. Some popular examples of dual purpose hops include Nelson Sauvin® (NZ), Centennial, Chinook and Simcoe® (all USA).

Popular varieties grown internationally

The International Hop Growers Convention (IHGC) maintains a comprehensive list of hop varieties grown worldwide. The IHGC is a member-based organisation with the primary goal of safeguarding the common interests of hop growers and hop merchants. Its activities are non-political and focus mostly on furthering the economic and technical aspects of hop production.

The complete 2016 IHGC Hop variety list includes details for 247 varieties grown by member organisations from 20 nations. The list is too large to reproduce here, however, it can be accessed via the IHGC web site (**www.hmelj-giz.si/ihgc**).

The peak body for hops production in the United States of America is USA Hops. This organisation prepares an annual statistical report that contains data on US domestic and international hops production. The 2016 USA Hops statistical report is a useful source of data on varieties produced in the USA. It is accessible via the USA Hops web site (**www.usahops.org**).

Table 1 lists the top 10 varieties currently planted in the USA. This list gives us insight to the range of key variety types grown by the largest producing nation. It is clear that, to meet the demand of the brewing industry and its consumers, a mix of bittering, aroma and dual purpose hops are grown.

Table 1. Top 10 varieties by acreage in the USA in 2016. Source: International Hop Growers' Convention (2016).

Variety or brand name	Type	Origin	Plant variety rights
Cascade	aroma	USA – public USDA	
Centennial	dual	USA – public WSU	
Citra®, HBC 394	aroma	USA private breeding program	US Patent
Simcoe®, YCR 14	dual	USA private breeding program	US Patent
Zeus	bitter	USA private breeding program	
Mosaic®, HBC 369	aroma	USA private breeding program	US Patent
Chinook	dual	USA – public WSU	
Summit™	bitter	USA private breeding program	US Patent, EU PVR
Nugget	bitter	USA – public USDA	
Willamette	aroma	USA – public USDA	

Varieties grown in Australia

There is no comprehensive list of all hop varieties available to grow in Australia. Only those that are grown on a commercial scale are identified in the IHGC world hop variety list (see Table 2).

Table 2. Varieties grown commercially in Australia in 2016 (Source: www.hmelj-giz.si/ihgc/obj.htm)

Variety or brand name	Type	Origin	Plant variety rights
Astra™	flavour	Australia θ	Ellerslie
Cascade	aroma	USA ω	
Centennial	dual	USA ε	
Cluster	dual	USA ω	
Ella	flavour	Australia θ	HPA*
Enigma	flavour	Australia θ	HPA
Galaxy	flavour	Australia θ	HPA
Helga	aroma	Australia θ	HPA
Melba™	flavour	Australia θ	Ellerslie
Pandora™	flavour	Australia θ	Ellerslie
Pride of Ringwood	bitter	Australia	
Spalter Select	aroma	Germany	
Summer	flavour	Australia θ	HPA
Super Pride	bitter	Australia θ	HPA
Topaz	flavour	Australia θ	HPA
Victoria Secret	flavour	Australia θ	HPA
Willamette	aroma	USA ω	

θ Private breeding program, proprietry variety, ω Public USDA, ε Public WSU, *HPA = Hop Products Australia Limited

There are currently two major hop producers in Australia with the total planted area estimated at around 600 hectares. Hop Products Australia Limited (HPA) produces hops in Tasmania's Derwent river valley and in the Ovens district near Myrtleford in north-eastern Victoria, while Ellerslie Hops has its hop yards at Myrrhee near King Valley in Victoria. Both HPA and Ellerslie Hops run private breeding/selection programs that have yielded some locally and internationally recognised and trademarked hop varieties. These companies closely control production of their varieties.

There are more varieties in Australia than those listed by the IHGC in Table 2. However, there is presently no system in place to certify the origin or identification of these varieties, nor is there any requirement for hop planting material suppliers to certify their plants' health status. Open source varieties listed by various (small scale) suppliers for sale in Australia include, but are not necessarily limited to, the following:

- Challenger
- Chinook
- Cluster
- East Kent Golding
- Fuggle
- Golden Cluster
- Goldings
- Hallertau
- Hersbrucker
- Kracanup
- Mount Hood
- Nugget
- Perle
- Precoce d'Bourgogne
- Pride of Ringwood
- Red Earth
- Saaz
- Target
- Tasmanian Cascade
- Tettnanger
- Vienna Gold
- Willamette
- Wuerttemberger

On the world stage, some of these varieties are considered old and no longer widely produced, having been superseded by new varieties with characteristics preferred by brewers.

Which variety to plant?

Market demand and cultivar performance on your site will drive variety selection. Hops have a very specific end use in brewing and alternative uses are minor, therefore, brewer demand for your hops is essential. Take the time to speak to brewers in your local area and beyond to ascertain which varieties and hop characteristics they are looking for.

Hop varieties can be highly variable in growth and productivity at different sites and our knowledge of varietal performance in southern New South Wales is currently limited to a small trial planting on one site at Batlow (established 2013). We recommend that new growers evaluate varieties on their own site before undertaking any large-scale investment.

Plant virus status

Hops are susceptible to a number of plant viruses and viroids including *Hop stunt viroid*, *Hop latent viroid* and the more common *Apple mosaic virus*, some of which are present in Australia (Crowle 2010; Crowle et al. 2003; Pethybridge 2000). These viruses can significantly affect plant growth and yield.

In the USA, growers source certified virus-free hop planting material through programs such as the National Clean Plant Network at Washington State University, Prosser. No such public programs for hops currently exist in Australia and the virus status of open-source hop planting material in this country is largely unknown. Until a certified virus-free plant supply is established, propagation should only be made from parent plants known to have good growth, yield and to be free of virus symptoms. Buyers should discuss plant health status with their nursery supplier and, if possible, inspect the source plants in the field.

The NSW DPI plant health diagnostic service (PHDS) offers a virus testing service for hops. For more information contact Customer Service on 1800 675 623.

Exotic pests and diseases

In Australia, we are fortunate to be free of some of the world's major hop pests and diseases including hop downy mildew and hop powdery mildew (Figure 1). These pests and diseases cost overseas producers millions of dollars annually in crop loss and crop protection expenses.

The Australian Government Department of Agriculture and Water Resources (**goo.gl/jqbxr6**) regulates and manages plant material importation into Australia. Protocols exist for legal importation and quarantine processing of dormant rhizomes, dormant cuttings, seed and tissue-cultured hops. In 2010, the department completed a policy review on importing Humulus genus propagative material into Australia: the Review of policy: importation of hop (Humulus species) propagative material into Australia (**goo.gl/LHP8e7**).

It is vital for the industry's future in Australia that exotic pests and diseases are prevented from entering the country. The Australian Government Biosecurity Import Conditions website (**goo.gl/bHiR5c**) is a good place to start if you wish to import hop plant material.

Figure 1. It is vital that exotic plant diseases such as Hop Powdery Mildew are prevented from entering Australia. Pictured is foliage with disease symptoms (above) and damage to hop cones (below) caused by Hop Powdery Mildew *Podosphaera macularis* (Images: David Gent, USDA Agricultural Research Service, **Bugwood.org**).

Bringing hop plants into NSW from other states

Moving certain plant material from other states and territories into NSW is subject to state biosecurity regulations. Similar regulations apply to movement from NSW to other jurisdictions. Depending on the source and nature of the hop plant material, certification and pre-treatment might be required. Importers and their interstate suppliers need to be aware of, and abide by, any relevant regulations. Visit the **Biosecurity NSW** website or call 1800 084 881 for advice on bringing hop plant material into NSW.

Propagation

With the exception of the large commercial growers mentioned earlier, propagating hops in Australia appears to be largely uncoordinated. Finding a supply of clean, good quality plant material in commercial quantity is a significant challenge for the new grower. Once you identify the right variety for your market and growing location, on-farm propagation is one practical way to upscale your production, particularly in the absence of an alternative cost-effective supply.

Hops do not produce true to type from seed so this method is only used in plant breeding where the genetic variability is valued. Vegetative propagation is essential to ensure that the resulting plants are clones of the chosen parent. New plants are produced mostly by dormant rhizomes collected from the mature crown in the cooler months (Figure 2) or green cuttings from current seasons growth in spring/summer (Figure 3 and 4).

Figure 2. Dormant rhizome cuttings enable the grower, in cooler months, to propagate from established crowns of high performing mother plants (Image: Haydn Smith).

Figure 3. Green stem cuttings taken in spring and early summer can be an effective method of propagating large numbers of new plants during the growing season.

Rhizomes are underground shoots that can be pruned from the crown, cut into sections and planted directly in the hop yard, or potted and grown-on in the glasshouse. Rhizome cuttings like the one shown in Figure 2 are ideally 110–160 mm long with a diameter of 15–20 mm and a minimum of 2 nodes (Rybáček 1991). Propagation by rhizomes is somewhat limited by the amount of suitable source material available to the grower or nurseryman.

Softwood propagation by green cutting is an effective method to rapidly multiply hop plants (Figure 3):

1. Take single-bud cuttings in spring and summer once the new season's growth has developed sufficiently to have viable axillary buds at each of the leaf nodes.
2. Set the cuttings into trays or tubes with a suitable propagation media and hold in a glasshouse under mist until they develop roots.
3. Transfer rooted cuttings into pots to be grown on in the nursery.
4. Plant rhizome cuttings or new plants in the following spring, once the risk of severe frost has passed.

Figure 4. Early season green cuttings can be set in trays in a propagation house under mist then transferred to individual pots to be grown-on.

Hop varieties and propagation

Hop yard design and establishment

Key decisions and activities in establishing a new hop yard, apart from site and varieties (already covered), are the:

» trellis system

» planting density (row and plant spacing)

» site preparation

» irrigation system

» planting

» early management.

Trellis and planting density

The most common training system used for hop production worldwide is the V-trellis (Figures 1 and 2). Other systems, such as the low trellis (Figure 3), have been trialed, but are not widely adopted due to lower yields per planted acre or hectare. Trellis and growing systems vary in top height, row spacing, plant spacing, number of strings and bine spacing according to the location, variety and intended method of harvest.

Variety vigour and growing conditions determine how high your hops will grow and accordingly, dictate what the top height of your trellis needs to be. Hop plants need sufficient trellis height to allow the bines to complete their annual extension growth and terminate without growing too far beyond the top wire. Local knowledge/experience will be required to determine the optimum height for your trellis. Early indications for the Batlow district of NSW for the Cascade and Chinkook varieties on a V-trellis with two strings per plant, are that a trellis height of approximately 5 m might be appropriate. However, more local experience is required to confirm this with certainty.

Figure 1. In New Zealand, V-trellis row spacing is generally narrower than in the USA and the top wire height is reduced to around 5 m.

Top height around the world typically varies between 4 m and 6 m for V-trellis, or 3 to 4 m for a low trellis. The length of cone-bearing laterals also differs by variety and this, in part, determines the suitable spacing between plants and bines.

In Washington State (USA), commercial growers mostly use a V-trellis (Figure 2) with a top height of around 6 m and a row spacing of 3.5–4.0 m, while in New Zealand the V-trellis (Figure 1) top height is around 5 m and row spacing is around 2.5 m.

The V-trellis is also common in existing Australian commercial hop yards with the top height and row spacing similar to that of New Zealand. Some commercial hop yards in Australia utilise a single string rectangular planting system thought to be established on a 2 m row × 1.8 m plant spacing. Like all trellis systems, this approach needs local validation before establishing large scale plantings of this design.

Figure 2. A 6 m V-trellis in full canopy just before harvest (Yakima, USA). The cross wires that connect the rows strengthen the trellis and support foliage wires along the row.

Figure 3. An example of a 3 m low trellis (hedgerow) under trial in the USA.

Optimum plant spacing along the row depends on the number of training strings used for each crown and the variety's lateral growth length. There is no hard rule to determine plant spacing in the row; local experience will play a significant part in this decision. Plant spacing in V-trellis blocks in the major hop-producing countries ranges from about 0.8 m to 1.5 m. The aim is to grow a canopy that maximises the available space while allowing some light penetration around the bines. Table 1 shows typical row and plant spacing for various countries, regions and trellis systems.

A V-trellis incorporates support poles along the planted row. These poles also align across the rows. Cables are attached to the tops of the poles and run along and across the hop yard. All cables are tensioned and anchored at the row ends and sides of the hop yard. For each planted row, two foliage wires are attached to the row end cables, with one placed on each side of the planted row. Hop bines are grown onto strings that are attached to the foliage wires and anchored in the planted row forming the V canopy. Figures 4 and 5 show the typical layout of a commercial-scale V-trellis.

Table 1. Typical row and plant spacing in various hop-producing regions of the world (Oldham 2016; Kořen 2007; Rybáček 1991).

Country	Region	Dominant growing system*	Typical spacing between rows (m)	Typical plant spacing along the row (m)
Germany	Hallertau	V-trellis	3.2	1.3–1.7
USA	Washington State	V-trellis	4.0	0.9
Czech Republic	Saaz, Trschitz and Auscha	V-trellis	3.0	1.0
United Kingdom	West Midlands and south-east	Low 2D trellis	2.5	0.6–0.9
New Zealand	Nelson	V-trellis	2.5	1.2

Note: The openness of the V-trellis systems varies considerably from country to country with differences in row spacing. V-trellis canopies in Washington State, USA are much wider than those in Germany or New Zealand.

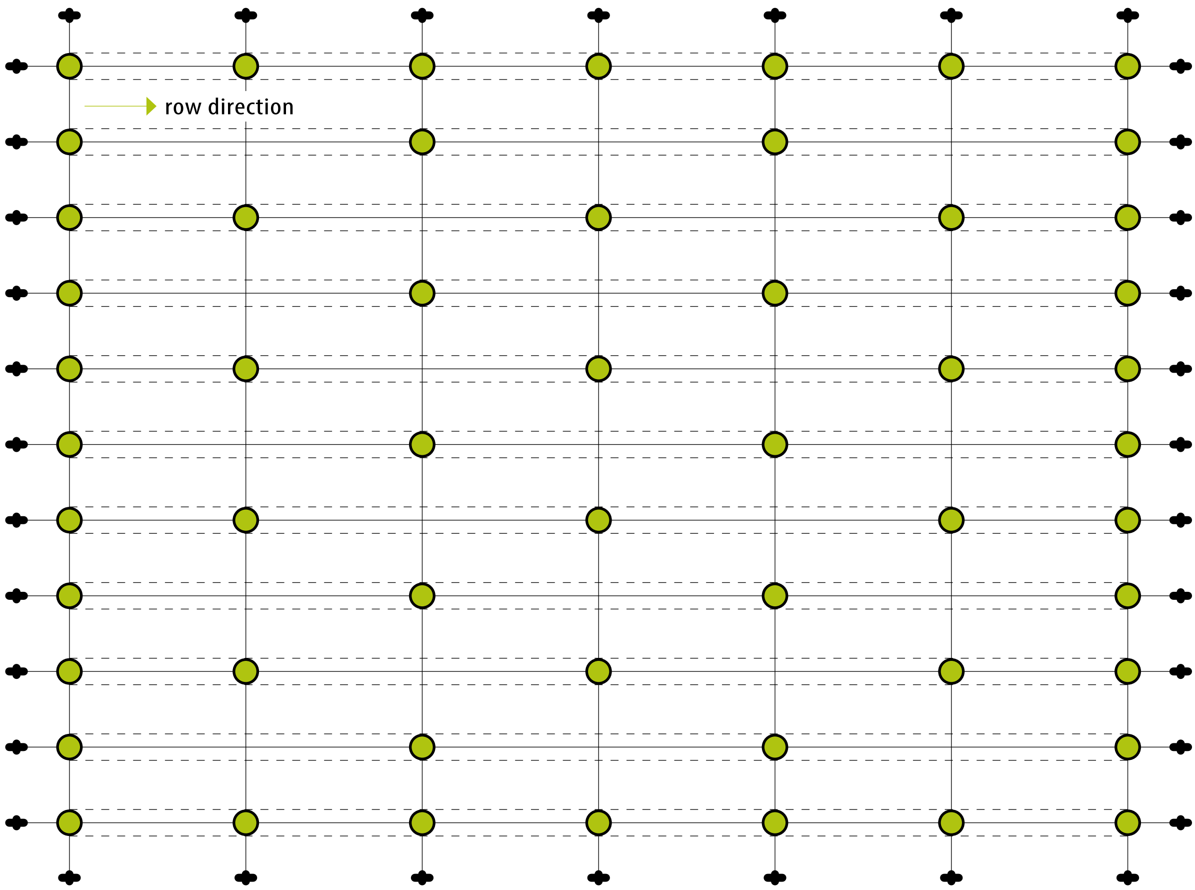


Figure 4. A possible hop yard design plan showing distribution of posts, cables, wires, stays and anchors.

posts ground anchors - - - wire — cable

Figure 5. Image of a newly established 6 m V-trellised hop yard showing pole distribution, cabling, foliage wires and end assemblies (Yakima, USA).

To the novice hop grower, a commercial scale V-trellised hop yard like the one shown in Figure 5, can appear over-engineered. However, the poles, cabling and anchors are all essential design features that ensure the structure is capable of supporting the significant weight of the canopy and crop, especially during wind or storm conditions.

During the planning phase, new hop growers should visit existing hop plantings in their area to gain a practical understanding of the components and trellis layout. There are also numerous sources on the internet with instructions for designing and constructing hop-yard trellises.

Soil preparation

A soil test should be the first step in preparating your site. A full soil test including pH, organic carbon and elemental analysis will provide vital information for making any necessary adjustments during cultivation. Hops are deep rooted, so it's worth taking separate top-soil (0–15 cm) and sub-soil (15–90 cm) samples for testing. The topsoil sample will give a good indication of general soil fertility; the subsoil sample will help identify potential problems such as acidity and possible toxicities.

Southern NSW soils can often be acidic and naturally low in phosphorus. These problems are best corrected before planting when you have the opportunity to incorporate amendments such as lime and superphosphate. Pre-planting is also a good time to add and incorporate organic matter if necessary. More information on amending pH is provided in the **section Hop yard management on page 23**.

Hops prefer a loose, well-drained soil. Cultivation before planting will ensure that the young hop plants enjoy the best possible soil structure for good growth and establishment. Deep cultivation, or ripping, is recommended on soils with a sub-soil clay layer or hard pan, as this will aid drainage and root penetration. Mounding the planted row can also help enhance drainage if deemed necessary on your site. This practice is common on flat alluvial soil sites around the world.

Irrigation systems

In southern NSW, irrigation will be essential. The two most common irrigation systems currently in use in commercial hop yards are drip and overhead sprinklers. Each type has its advantages and disadvantages and the choice will depend on your intended ground-based hop yard management.

Overhead sprinklers mounted on the trellis posts (Figure 6) are common in New Zealand where hop growers like to graze their sheep among the bines. Setting the irrigation above the crop removes the risk of livestock causing damage to pipes and emitters. This approach also keeps the planted row clear of irrigation pipes, simplifying routine management activities such as spring trimming.

Figure 6. Overhead sprinklers (above) and ground drip irrigation systems (below) have their own unique advantages and disadvantages.

Drip irrigation systems are more water efficient than overhead systems and allow targeted application of soluble or liquid fertilisers by fertigation. Using drip irrigation in preference to overhead irrigation is becoming more common in, for example, the USA, where diseases such as hop downy mildew and hop powdery mildew are present. Australia does not have these pathogens, but the efficiency and fertigation advantages of drip irrigation mean it is likely to be adopted in NSW hops in preference to overhead systems.

Regardless of which irrigation system you choose, it must be installed and ready to use from the day of planting.

Planting

In spring, plant hops as rhizome cuttings, or rooted cuttings from the previous spring/summer. For rhizome cuttings, it is usual to place more than one cutting in each planting hole to maximise strike rate, early production and minimise unproductive gaps in the hop yard.

Rhizome cuttings may be planted vertically or horizontally ensuring that any existing buds are facing upward. Manual planting is labour-intensive, but practical when working between the established trellis posts. Make a planting furrow by inserting a shovel into the cultivated strip or mound and rocking the shovel back and forth. Insert the cuttings into the furrow and replace the surrounding soil, covering the top of the cuttings with approximately 50 mm of soil. Firm the soil over the cuttings using your foot.

Plant dormant potted cuttings at about the same time as rhizome cuttings. If you are planting actively growing potted cuttings, take care to avoid spring frosts.

Early management

Encouraging healthy growth is the priority in the first season after planting. Soil moisture management, nutrition, pest/weed management and bine training all contribute to successfully establishing the hop yard.

Monitor soil moisture at least daily, and be sure your irrigation system is ready to run from day one after planting. It is best to water frequently with shorter durations, keeping soil moist but not saturated.

Pre-plant soil test results will help guide your initial fertiliser needs. nitrogen (N) is a key nutrient for strong vegetative growth. Sources in the USA recommend first year additions totalling 85 kg of actual N per hectare (Gingrich et al. 2000). If fertigation is an option, split the total nitrogen input across a number of irrigation cycles over the spring and early summer.

If soil phosphorus (P) was amended during soil preparation, it should not need to be added after planting in the first season of growth. Consider the status and need for additions of other key growth-limiting nutrients including potassium, zinc and boron.

Weed management reduces competition for soil moisture and available nutrients. For small hop yards, manually removing weeds (chipping) could be an option. Consider mulching the young hop plants, which will not only suppress weed growth, but will also help retain soil moisture and build soil organic carbon.

Chemical weed control is the most cost-effective means of managing weeds. However, there are presently very few herbicides registered or permitted for use on NSW hops.

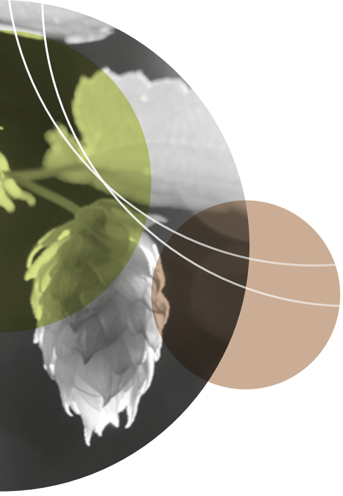
Simazine is a pre-emergent herbicide with label registration for hops in New South Wales. Apply simazine (according to label instructions) soon after planting to reduce new weed emergence.

Other herbicides with registration in NSW are broad spectrum and must not come in contact with actively-growing hop plants. For this reason, approach their use with extreme caution.

More information on crop protection products registered in NSW can be found in the **section Hop yard management on page 23**.

Newly planted hops will take 2–3 seasons to produce a full commercial canopy. In the first season, train the strongest hop bines to a single string only (Figure 7). Train bines by wrapping them onto the string in a clockwise direction once they reach 60–90 cm in length. Retain weaker side-shoots in order to maximise the photosynthetic canopy of the new plants.

Figure 7. In the first season or two, a single string per plant will be sufficient to support and encourage the new growth.



Hop yard management

Growth stages and activities calendar

Knowing a crop's annual growth cycle helps us to understand the timing of key seasonal management activities. The hop plant is annual above ground and perennial below. In autumn and winter, current season bines die back to soil level, while the crown remains viable and will re-shoot in spring.

According to the German BBCH scale published in Meier (2001), the annual growth of the hop has nine stages. The following list and primary growth stage diagram (Figure 1) have been adapted for this publication, from the BBCH scale. Note: The primary growth stage numbering and stage order have been altered from the original to reflect our current understanding of the hop growth cycle.

1. sprouting
2. leaf development
3. elongation of bines
4. formation of side shoots
5. flower emergence
6. flowering
7. development of cones
8. maturity of cones
9. senescence (start of dormancy).

The full BBCH scale for hop (not reproduced here) includes sub-stages that allow growers and researchers to more accurately identify the crop's phenological growth stage. We recommend that readers obtain a copy of the full BBCH scale for hops and consider using it in your management and record keeping. This will ensure consistency of crop records from one season to the next according to crop growth stage.

Note: The BBCH growth stages 2 and 3 (formation of side shoots and elongation of bines) have been switched in our diagram. This is because side shoots or laterals generally grow after the elongation of bines, when the shoots reach the top wires and apical dominance is reduced.

By graphically relating key hop production activities to time of year and the plant's primary growth stages, we can view a full year of activities on the hop farm in one look-up table (Table 1). Because it is possible to store whole dry hops and packaged processed hops for extended periods, activities such as storage, pelletising, packaging and marketing can span the full year. Other activities such as spring trimming and training of bines have very specific timings in the annual production cycle as identified in Table 1.

In the hop yard, the period from late dormancy (August–September) to spring (mid-October) is a time of preparation and renewal. The mid-season period from October to January focuses on maintaining optimal bine growth to support flowering and cone production. The latter part of the season from the end of harvest (mid-March) to full dormancy (July) is the least busy time in the hop yard, with activities primarily focused on maintenance, propagation and some ongoing weed management.

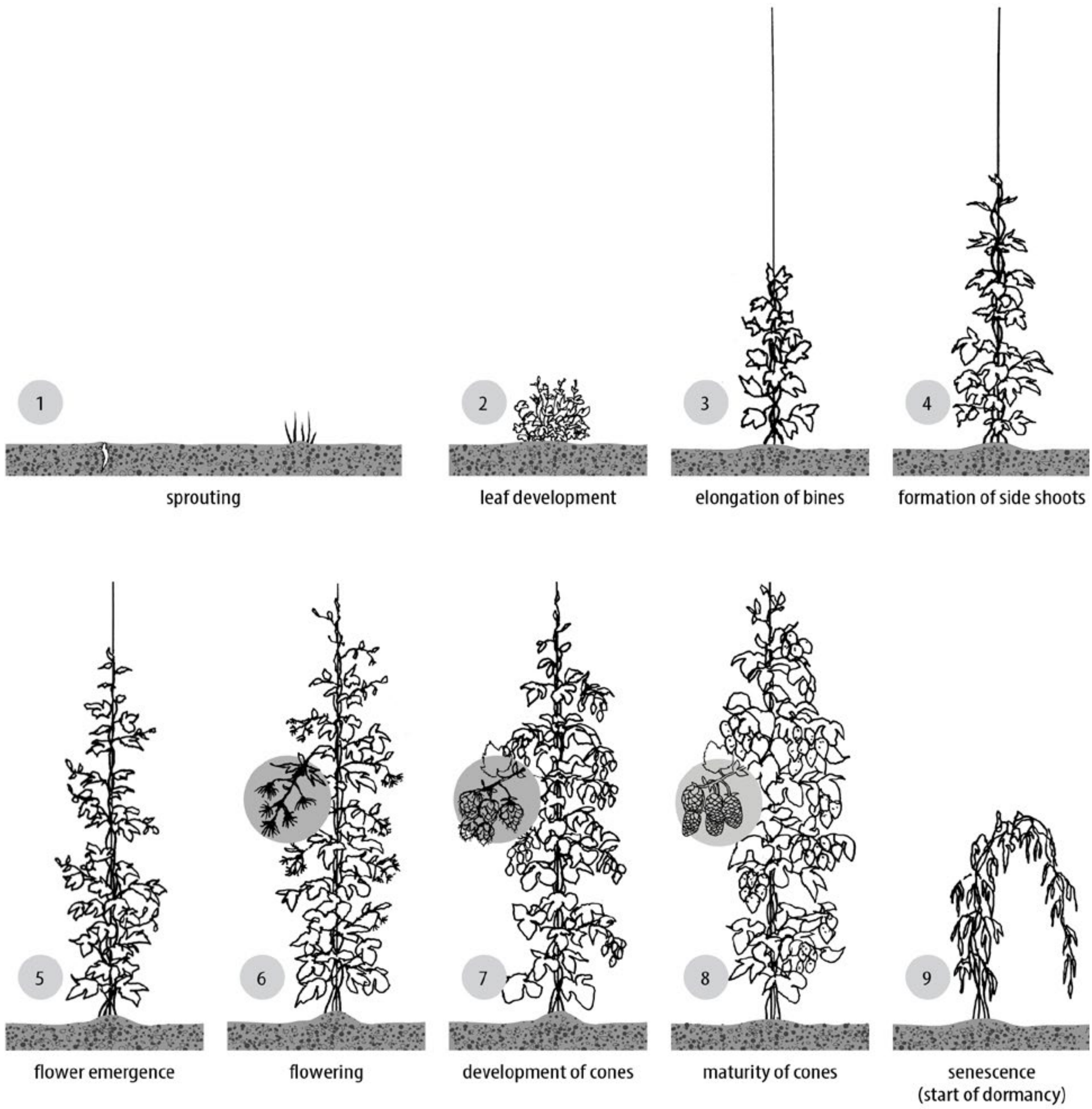


Figure 1. Primary growth stages of the hop adapted from the BBCH system.

Managing spring growth

In spring, the first shoots to emerge from the hop crown, tend to produce uneven growth which, if trained onto the strings, will result in an inconsistent canopy. **Spring trimming** of the first flush of growth will encourage a second flush of stronger more uniform shoots.

Worldwide, spring trimming is achieved either manually (with a slasher) or with a desiccant herbicide such as paraquat+diquat. There is, at present, no herbicide registered in NSW for this purpose, so manual trimming is currently the only option in this state.

Stringing the hop yard occurs in spring before there is significant new season's growth, or immediately after the first flush is trimmed. In the establishment period (seasons 1–3), the grower must decide how many strings to deploy per crown in order to optimise the use of available canopy space. In new production areas such as Batlow, NSW this decision will become easier as growers build on their local knowledge.

Once fully established (season 4 onward), the number of strings per crown will be the same from one season to the next. Mature hop yards in Washington State, USA typically carry three to four strings per crown, whilst two strings per crown seems more common in New Zealand and Australia.

Tractor drawn platforms (Figure 2) are essential for larger hop yards as they increase labour efficiency during stringing.

Table 1: Approximate timing of key hop management activities South Eastern Australia

Approximate time of year – southern NSW*

Month	Aug				Sep				Oct				Nov			
Week																
BBCH growth stage (approx.)	Dormancy							Sprouting		Leaf development		Elongation of bines			Formation of side shoots	
Management activities																
Irrigation maintenance																
Propagation	RC	RC	RC	RC	RC	RC						GC	GC	GC	GC	
Trellis maintenance																
Soil sampling																
Plant tissue sampling																
Weed control	PE	KD	KD	KD											M	M
Trim first shoots																
Irrigation																
Fertilising			S	S					F	F	F	F	F	F	F	F
Stringing																
Training bines																
Pest/Disease monitoring + Control																
Preparation for harvest																
Harvesting																
Processing/Cleaning/Drying/Baling																
Cool storage																
Pelletising/Packaging																
Marketing/Sales																
Hop Yard end of season clean-up																
Season review and forward plan																

Month	Dec				Jan				Feb				Mar			
Week																
BBCH growth stage (approx.)		Flowers		Flowering			Development of cones			Maturity of cones					Senescence	
Management activities																
Irrigation maintenance																
Propagation																
Trellis maintenance																
Soil sampling																
Plant tissue sampling																
Weed control	M	M	M	M												
Trim first shoots																
Irrigation																
Fertilising	F	F	F	F	F											
Stringing																
Training bines																
Pest/Disease monitoring + Control																
Preparation for harvest																
Harvesting																
Processing/Cleaning/Drying/Baling																
Cool storage																
Pelletising/Packaging																
Marketing/Sales																
Hop Yard end of season clean-up																
Season review and forward plan																

Month	Apr				May				Jun				Jul			
Week																
BBCH growth stage (approx.)							Dormancy									
Management activities																
Irrigation maintenance																
Propagation															RC	RC
Trellis maintenance																
Soil sampling																
Plant tissue sampling																
Weed control							KD	KD	KD	KD	KD	KD	KD	PE	PE	PE
Trim first shoots																
Irrigation																
Fertilising																
Stringing																
Training bines																
Pest/Disease monitoring + Control																
Preparation for harvest																
Harvesting																
Processing/Cleaning/Drying/Baling																
Cool storage																
Pelletising/Packaging																
Marketing/Sales																
Hop Yard end of season clean-up																
Season review and forward plan																

* Growth stage timing based on current knowledge of Cascade and Chinook varieties at Batlow, NSW. Other varieties may be earlier or later in their development.
RC=Rhizome cuttings, GC=Green cuttings, PE=Pre-emergent, KD=Knockdown, M=Manual Weeding including cultivation, F=Fertigation, S=Surface applied

Figure 2. Hop growers in the USA use tractor-drawn platforms to reduce labour costs during stringing.

The type of string used is important and finding the right product is not always easy. During a recent study tour of the hops industry in New Zealand, growers reported difficulty sourcing a suitable natural fibre string and were instead, using a plastic product, which posed some problems due to its persistence in the hop yard and interference with machinery.

Coir rope, made from the husks of coconuts, is the traditional string product favoured by hop growers in the major production regions of the world. Coir is strong, durable (yet biodegradable) and provides a good climbing surface for the hop bines (Eyck & Gehring 2015). Rot-proofed sisal string is more commonly available in Australia than coir and is a viable alternative (Figure 3).

Figure 3. Natural fibre strings are preferred, however, they must be durable enough to take the weight of the full canopy and cones. Multi-strand coir or sisal twine are suitable options.

Tie hop strings to the top wire and anchor them in the planted row next to the crown. In the USA, growers use a product called the W clip (Figure 4), which anchors the hops string inside the mound using a special applicator. This method keeps the mound area clear of any wire that could interfere with mechanical slashing. In New Zealand, where spring trimming is done chemically, growers use wire 'Pigtail' pins inserted near the crown as string anchors (Figure 5).

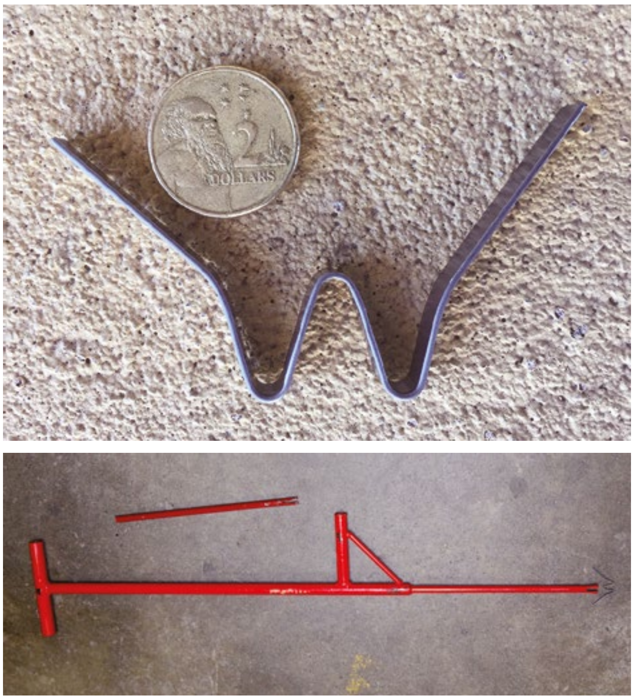


Figure 4. W clip and applicator used commonly in the USA to anchor hop strings. This method is preferred in hop yards that use mechanised slashing for the spring trim because it leaves nothing in the row that can interfere with equipment.

Figure 5. Pigtail pins are suitable for anchoring strings in situations where spring trimming is done by hand or spraying.

Bine training begins once the second flush of new growth reaches about 60 cm long. When a majority of crowns have developed shoots of a suitable length, workers go through the hop yard training two or three of the strongest shoots onto each string, wrapping them in a clockwise direction. If the new season growth is not uniform, multiple passes might be required to complete the training. Once trained, bines will usually grow along the string unaided for the rest of the elongation period (Figure 6).

Figure 6. Stringing and bine training are two of the most labour intensive operations carried out in spring.

Pest, disease and weed management

Pest and disease pressure in Australian hop yards is very low, compared with countries such as the USA. Most of the world's damaging hop pests, diseases and viruses do not currently exist here. There are no significant or widespread leaf pathogens currently affecting hops in Australia. Accordingly, there are also no fungicides registered or permitted for use on hops anywhere in Australia.

In 2010, the Australian Government conducted a review of policy regarding importing hop propagative material. Table 2, extracted from the review document, lists the key quarantine pests for hops grown in Australia. New and existing hop growers should familiarise themselves as much as possible with these quarantine pests, be vigilant and report any suspected incursions to the Exotic Plant Pest Hotline, 1800 084 881.

EXOTIC PLANT PEST HOTLINE
1800 084 881

It is vital that anyone wishing to import hop propagative material (including soil-free dormant rhizomes, cuttings, tissue cultures or seed), visits the Australian Government Biosecurity Import Conditions website (**goo.gl/cvQD2w**).

Table 2. Quarantine pests for *Humulus* propagative material (extracted from: **www.agriculture.gov.au/biosecurity/risk-analysis/plant/hops/final_hops_review**)

ARTHROPODS
Coleoptera
Prionus californicus (Motschulsky): California prionus
Lepidoptera
Grapholita delineana Walker: Hemp borer
Hydraecia micacea Esper: Rosy rustic moth
Hydraecia immanis Guenée: Hop vine borer
Ostrinia nubilalis (Hübner): European corn borer
PATHOGENS
Fungi
Podosphaera macularis (Wallr.) U. Braun & S. Takam: Hop powdery mildew
Pseudoperonospora humuli (Miyabe & Takah.) G.W. Wilson: Hop downy mildew
Verticillium albo-atrum Reinke & Berthold (hop strain): Hop wilt
Verticillium dahliae Kleb: (hop strain)
Phytoplasmas
Candidatus Phytoplasma asteris: Hop shoot proliferation disease
Viroids
Apple fruit crinkle apscaviroid (AFCVd) (hop strain): Apple fruit crinkle disease
Hop stunt hostuviroid (HpSVd) (hop strain): Hop stunt disease
Viruses
Alfalfa mosaic virus (AMV) (hop strain): Alfalfa mosaic
American hop latent virus (AHLV): Hop latent disease
Arabis mosaic virus (ArMV) (hop strain): Hop bare-bine
Cherry leaf roll virus (CLRV): Cherry leaf roll virus
Humulus japonicus latent virus (HJLV): Humulus japonicus latent disease
Petunia asteroid mosaic virus (PetAMV): Petunia steroid mosaic disease
Strawberry latent ringspot virus (SLRSV): Strawberry latent ringspot virus
Tobacco necrosis virus (hop isolate): Tobacco necrosis disease
Nematodes
Ditylenchus destructor Thorne: Potato tuber nematode
Heterodera humuli Filipjev: Hop cyst nematode

Spraying to control diseases and pests is a regular management activity in USA hop yards. Larger producers have fleets of air-blast sprayers ready to apply fungicides and insecticides throughout the growing season (Figure 7). Crop protection expenses and crop losses from damage caused by pathogens such as hop powdery mildew cost northern hemisphere producers millions of dollars every year.

Figure 7. Typical air-blast sprayers used in the USA to apply fungicide and insecticides. Canopy sprayers are not common in Australian and New Zealand hop yards due to minimal pests and diseases.

Two-spotted mite (Figure 8) (TSM) and various caterpillars (including light brown apple moth and Heliothis) are the most likely pests to occur on hops grown in NSW and other parts of Australia. There are currently no chemicals registered or permitted in NSW to control these pests.

In the case of TSM, biological control is sometimes possible with resident populations of predatory mites and other beneficial insects. The predatory mite *Phytoseuilis persimilis* (Figure 9) is available for purchase and release against TSM. Consult your bio-control supplier for more advice on using *P. persimilis* in hops. Growers should monitor their hop yards weekly during the growing season to determine if, and when, to intervene to control two-spotted mite. There is currently only one miticide active ingredient registered for use in hop yards in NSW – Abamectin.

TSM feed mostly on the underside of the hop leaf, causing a visible bronzing on the upper surface (Figure 10).

Figure 8. Two-spotted mite adults.

Figure 9. *Phytoseiulis persimilis* predators feeding on TSM adults.

Figure 10. Leaf symptoms of two-spotted mite infestation (Image: David Gent, USDA Agricultural Research Service, **Bugwood.org**).

Light brown apple moth (LBAM) is a native leaf-roller caterpillar that occasionally feeds on hop leaves. Damage from LBAM is usually sporadic and might not be worth attempting to control. There are currently no registered spray options for the control of LBAM in NSW hops.

Figure 11. Light brown apple moth caterpillars.

Figure 12. A webbed LBAM pupae.

Weeds compete with hop plants for water and nutrients and, if left uncontrolled, affect growth and yield.

Weed management in dormant–early spring is aimed at establishing and maintaining a weed-free strip along the planted row. Mulching after planting is also an option to retain moisture and suppress weed growth, thereby giving the young plants the best conditions for establishment.

Weed matting and natural mulches represent a viable option in small hop yards or those operating under organic certification. In some parts of the world, hop growers also use cultivation to manage weeds (Figure 13).

Figure 13. Cultivation discs in the USA for trimming unwanted hop runners and controlling weeds during the growing season.

Chemical weed management is a cost-effective alternative to physical methods, however, options in NSW are very limited. Table 3 lists the herbicide active ingredients currently registered for use in New South Wales hops yards, of which there are only three.

Table 3. Herbicide active ingredients currently registered for use in NSW hops and their modes of action (Source: Australian Pesticides and Veterinary Medicines Authority, November 2016).

Active: product type
Simazine: pre-emergent
Glyphosate (various formulations): knockdown
Carfentrazone-ethyl: knockdown enhancer

Simazine pre-emergent herbicide is applied to bare soil to prevent weed seed germination. The most appropriate timing for this product is during the late dormant period. Take care when applying simazine to ensure it does not contact or leach down to affect hop buds and shoots. Label recommendations for simazine state that hop plants must be covered by at least 50 mm of soil at the time of application.

Figure 14. Example of herbicide injury on young hop shoots. Always follow label instructions closely when applying herbicides near hops, particularly when actively growing.

Certain knockdown herbicides containing the active ingredient glyphosate, are registered for use in hops during the dormant season when there is little risk of spray drift causing damage. Carfentrazone-ethyl (Spotlight Plus®) is registered in NSW for application with knockdown herbicides to improve broadleaf weed management and increase the speed at which these weeds show symptoms of control. If used incorrectly, herbicides can cause serious damage to hop plants (Figure 14). Use herbicides only for the registered purpose and as directed on the product label.

Irrigation

Irrigation is essential in most hop growing regions of the world to support good growth and productivity. This will certainly be the case in southern NSW. Watering frequency and run-time depends on factors including system design, soil type and seasonal conditions. Monitor soil moisture to a depth of at least 60 cm and irrigate as required from sprouting stage through to harvest. Regardless of the system being used (drip or overhead), the aim is to maintain a good soil moisture level throughout the growth cycle, without over irrigating (waterlogging) and leaching the soil of nutrients.

Irrigation maintenance is done pre-season and involves pump servicing, flushing irrigation lines and checking emitters for blockages. This is also a good time to check the operation of your fertigation system. The NSW Department of Primary Industries (DPI) Primefact No. 1358 *Maintaining a drip irrigation system for perennial horticulture* provides useful guidelines on this subject (Giddings et al. 2016).

Nutrition and fertilisers

Fertiliser application key times are late-dormancy for solid products and mid spring to pre-harvest for liquid or soluble fertilisers applied through the irrigation system (fertigation). The NSW DPI Primefact *Fertigation: delivering fertiliser in the irrigation water* by Treeby, Falivene and Skewes (2011) is a great introductory reference on setting up and using a horticultural fertigation system. Figures 15, 16 and 17 illustrate some of the simple and more complex options.

Figure 15. Fertigation can be as simple as an inline Dosatron® unit.

Figure16. A basic fertigation injection system.

Figure 17. A more complicated system capable of delivering multiple fertiliser products at the same time.

IMPORTANT: Nutrient application guidelines are yet to be developed for hop production in southern NSW. For now, recommendations published in countries such as the USA are our best available reference. These need to be paired with knowledge of your site, including local soil and tissue test results to help guide your fertiliser decision-making.

Estimating crop and plant nutrient removal can help determine replacement fertiliser needs. Mature hops produce much more canopy and crop compared with young plantings and therefore, they remove more nutrients from the soil. Estimate nutrient removal by using dry matter percentages and knowledge of the biomass produced by the crop in total kilograms per hectare. Browne (year unknown) presented dry matter (DM) percentages for hops grown in Michigan State, USA as 3.0% of DM for nitrogen, 2.0% potassium and 0.50% phosphorus. Other factors that affect replacement nutrient requirements include, soil organic matter levels, organic soil amendments and returning spent bines to the hop yard as compost. These factors result in a return of, or addition of, nutrients to the soil and effectively discount the final nutrient replacement required.

Soil and tissue tests help to inform your crop nutrition decisions. **Soil testing** every two years in late winter to early spring is sufficient to identify changes in soil nutrient balance over time in established blocks. Pre-plant soil tests will help to identify any major issues relating to factors such as soil pH and phosphorus, which are best corrected before planting. According to Darby (2011), the optimum soil pH range for hops is 6.0–6.5 as measured in calcium chloride ($CaCl_2$).

If the pH is below 6.0 (in $CaCl_2$) and adjustment is required, incorporating a fine agricultural lime (calcium carbonate) will do the job, unless magnesium is also required, in which case dolomitic lime (calcium magnesium carbonate) would be the product of choice. If the pH is above 6.5, do not apply lime or dolomite.

Plant tissue samples should be collected when bines reach approximately half canopy height. Reuter and Robinson (1997) published tissue analysis standards for hops based on the youngest mature leaf. In some hop producing regions of the world, petioles (leaf stems) are sampled instead of leaves, although it is hard to find published nutrient standards for this method.

Nitrogen (N)

Good soil nitrogen (N) is vital for strong canopy growth in hops; inputs of this nutrient are required annually. Nitrogen deficiency will be expressed as pale or yellowing foliage and reduced growth rate. The best timing for nitrogen input is during the rapid vegetative growth stage (bine elongation and lateral formation) around October to early December in southern NSW. Avoid applying nitrogen after flowering starts as this can result in unwanted vegetative growth during the cone development phase.

Typical in-season application of N for first year hops in the USA is around 85 kg of actual nitrogen per hectare split over a number of applications (Darby 2013). Mature hops on soils with moderate organic matter (OM) levels (2–5%) in the USA typically receive 120–170 kg/ha of actual N as supplementary fertiliser. Suggested N application rates are adjusted accordingly for soils with lower or higher OM levels, with annual N inputs as high as 230 kg on low OM soils.

Soil acidification occurs naturally, but most nitrogen fertilisers accelerate acid produced in the soil. Nitrate fertilisers, while expensive, can have the opposite effect and increase pH to a depth of 60 cm. Careful fertiliser management, liming and increased organic matter content in the soil will help to slow the acidification process.

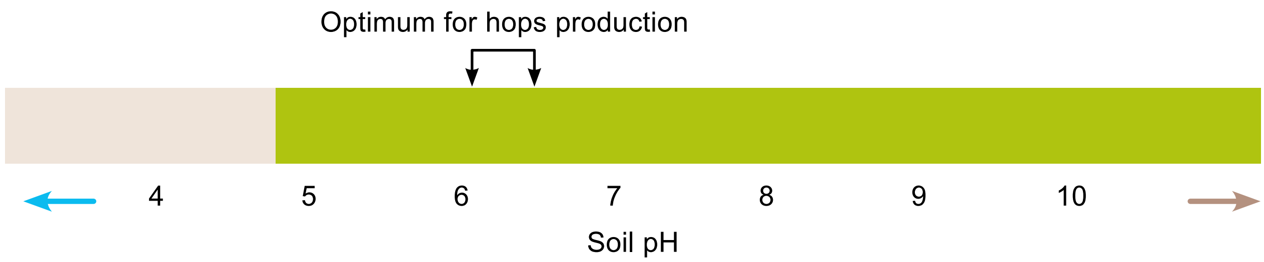


Figure 18. Optimum soil pH range for hops as measured in calcium chloride ($CaCl_2$).

Potassium (K)

Potassium is important for healthy leaf development, bine growth, plant–water balance and cone development, and in most situations will require annual inputs. Potassium deficiency in hops is usually characterised by marginal leaf scorch and poor growth. According to Gingrich, Hart and Christensen (2000), seasonal uptake of potassium in hops is around 90–170 kg/ha with one quarter of this stored in the hop cones and the other three-quarters in bines and leaves. If the spent vegetative plant material is returned to the hop yard as mulch after picking, then a majority of the K is also returned. In the USA, typical potassium inputs for a site with moderate soil K are around 90–115 kg/ha.

Phosphorus (P)

Of the key macro nutrients (N, P, K and S), phosphorus (P) is the least demanded by hops. Based on a whole crop P dry matter percentage of 0.5%, and a total dry matter production (cones and canopy) of say 4,000 kg/ha, phosphorus removal would be approximately 20 kg/ha. Adjust the actual rate of phosphorus fertiliser according to the P status of the soil. Issues relating to low soil P are best dealt with before site establishment, because phosphorus is not highly mobile and can be difficult to amend to depth after establishment.

Trace elements

Key trace elements for hops that are likely to be deficient in southern NSW, include magnesium (Mg), zinc (Zn) and boron (B).

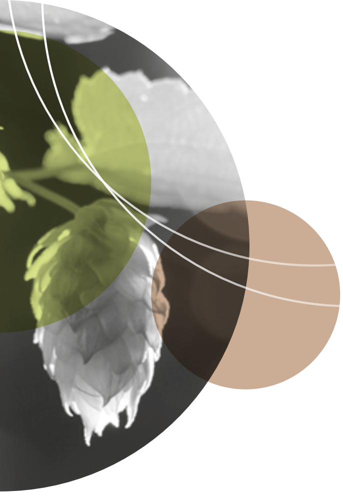
Magnesium deficiency can occur due to low soil Mg, an imbalance in the calcium:magnesium ratio of the soil or excessive potassium fertilisation. Liming with calcium carbonate on low Mg soils can induce a magnesium deficiency due to its impact on the ratio of calcium to magnesium in the soil. The generally accepted optimum Ca:Mg ratio is around 2.5–5:1.

The main symptom of Mg deficiency is interveinal leaf chlorosis (yellowing) where the veins themselves remain green. Dolomitic lime and magnesium sulfate are the two most common amendments for low soil Mg. Dolomite is applied pre-planting, while magnesium sulfate can be applied in-season to top up plant available Mg.

Zinc deficiency is characterised by small, chlorotic, upwardly-cupped leaves, and weak lateral and bine growth. Zinc sulfate is commonly used to correct zinc deficiency and can be applied as a foliar spray or through irrigation.

Low soil boron levels produce plant deficiency symptoms including delayed shoot development, crinkling and distorted foliage (Neve 1991). Soil analysis results will help determine if supplementary boron is required. Boron deficiency is easily corrected with soil-applied soluble boron fertiliser. When needed, a typical application rate of actual boron applied in the USA is around 1–2 kg/ha.

Take care not to over-fertilise with boron as this element can quickly become toxic.



Harvesting, processing and marketing

Pre-harvest maintenance and harvest planning

Preparation for harvest includes testing, maintaining and repairing all harvesting and processing equipment. Equipment maintenance usually takes place in the week or two leading up to cone maturity, and helps to avoid unwanted delays during harvest from mechanical failures. According to Rybáček (1991), the hop drying process dictates the timing and speed of harvest and post-dry processing operations. Harvest is scheduled so that hops are stripped, cleaned, dried, baled and/or pelletised in a continuous process without the need to stockpile green hops, which is undesirable for quality reasons.

Are my hops ready to pick?

Brewers value your hops for the bittering and preservative potential of their alpha (α) and beta (β) acids, and for their essential oils, which drive aroma and flavour in beer. According to Lizotte (2015), the essential oil content of hops continues to increase beyond traditional harvest dates; beers made with a single hop variety harvested at different times will have different flavour and aroma characteristics. Correctly timing harvest will optimise these characteristics in the final hop product and, ultimately, the beer.

The two most common methods used for determining hop cone maturity on the farm are:

1. look, feel and smell (sensory)
2. dry matter percentage (measured).

Experienced growers can become quite proficient at estimating hop maturity using sensory keys. As hop cones mature, they typically go through a subtle colour change from green to yellowish. They become papery to the touch and the yellow colour of the lupulin glands intensifies.

Monitoring for changes in aroma also helps to identify the best time to harvest. This is done by rubbing several hop cones between the palms of the hands and sniffing the crushed hops. Calderwood (2015) describes immature hops as having a 'green' grass or hay-like smell, whilst over-mature cones can smell like onion, sulfur or garlic. Because they are qualitative, sensory methods such as those outlined, require a high degree of experience and skilled interpretation.

As hop cones grow and mature, the percentage of dry matter to green weight increases by around 1% every 4–7 days depending on variety. Dry matter percentage testing is quantitative (measurable) and related to known standards. The most common dry matter harvest target referenced in the literature is around 23%, although this can range between 20% and 23% depending on variety (Madden and Darby 2012).

Dry matter tests are easy to do and performed using some basic equipment such as a dryer/dehydrator or microwave and an accurate set of scales. The following is a simple six-step procedure for doing your own dry matter tests on hops (Madden and Darby 2012).

1. Collect a random sample that represents the block and variety. As an example, this could be all the hops from 10 laterals selected from a number of bines across the target area. Make sure the height on the bine and the location in the hop yard represents the majority. Avoid sampling when the bines are wet or during a rain event.
2. Pick the cones into a container, mix the sample and take a sub-sample of 100–150 cones.
3. Using a set of scales capable of measuring to at least one decimal place, weigh an empty container large enough to hold your sub-sample. Record the weight of the empty container.
4. Place your 100–150 cone sub-sample in the container and re-weigh. Record the total weight and subtract the weight of the container. This is your 'green cone weight'.
5. Using a food dehydrator, microwave oven or a Koster Moisture Tester (used in testing forage moisture) dry the green cones until they reach 0% moisture. If using a food dehydrator, this can be left overnight. If you use a Koster Moisture Tester or microwave for drying, you will need to constantly monitor moisture loss throughout the drying period by re-weighing the sample. Once the sample reaches a constant weight, all the moisture has been removed and you are ready to calculate the dry matter percentage. Record the final weight of the sample and subtract the weight of the container. This is your 'dry cone weight'.

6. Use the following formula to calculate the dry matter percentage of your sample using the green and dry weights collected.

Hop% dry matter
= 100 × (dry cone weight ÷ green cone weight)

Example
= 100 × (25 g ÷ 110 g)

= 100 × (0.227 g) = 22.7%

Using a combination of dry matter testing and sensory evaluation will give you the best chance of identifying the right time to harvest.

Harvesting

Harvest is the most intense period of activity in both the hop yard and processing shed. Hand-picking was standard practice before hop harvesting machines were invented. However, labour costs today mean that manual harvesting is uneconomical for anyone wanting to sell their hops for profit.

Mature cones must be harvested, cleaned and dried in the shortest time possible to ensure optimum quality and storability. Depending on the range of varieties planted, a typical hop harvest period can be around one month. In southern NSW we expect hop maturity will occur during the months of February and March.

Around the world, there are two basic approaches to commercially harvesting hops.

1. **In-field picking** using a purpose-built harvester that travels along the rows and removes the cones from the bines in-situ (Figures 1 and 2). In a low-trellis hop yard, the harvester straddles a single row of hops and strips the cones, leaving the trellised bines in place. In both low-trellised and v-trellised hops, stripped cones go into a mobile storage bin for transfer to the shed for cleaning. Spent bines are returned to the ground as mulched clippings either during or following the harvest. This approach to harvest is fairly common in Washington State, USA. There are labour savings associated with this method of harvest. Downsides include the capital costs of having sufficient machines to manage the harvest window and concerns about soil compaction with heavy machinery operating in the hop yard.

Figure 1. Front view of an in-field hop picking machine used in large scale v-trellised hop yards in the USA.

Figure 2. A typical large-scale in-field harvest set-up includes harvester, storage bin and tractor.

2. **In-shed picking** involves harvesting and transferring whole bines and stripping the cones in the shed using a stationary picking machine. Bines are cut from the top wire and at the base, either manually or using a combine style head and cutter (Figure 3). In some medium scale hop yards (i.e. Nelson, New Zealand and Australia), bines are removed from the top wire using a tractor-mounted bine puller (Figures 4 and 5). The bines are loaded into trucks or storage bins and transferred to the shed. Once at the shed, the bines are attached to a conveyor chain which pulls them (one at a time) through the picking machine to remove the cones. The spent bines are shredded and, in most cases, would be mulched and returned to the hop yard.

Figure 3. Combine style top-cutters detach the whole bines from the wire and drop them into a truck for transport to the shed for in-shed picking.

Figure 4. Bine pullers are used as an alternative to top cutters in medium sized hop yards like those found in New Zealand and Australia.

Figure 5. Bine pullers work along a single row of bines at a time dragging them off the top wire and into a harvest bin for transfer to the shed for machine picking.

The picking fingers inside the harvesting head that remove the cones have remained relatively unchanged since their development in the early 1900s. Each picking head consists of wire picking fingers arranged in rows and joined by drive chains at either end to form a circulating belt (Figure 6). In most designs, two belts are mounted facing toward each other leaving a space through which the hop bine passes, allowing the picking fingers to strip the cones.

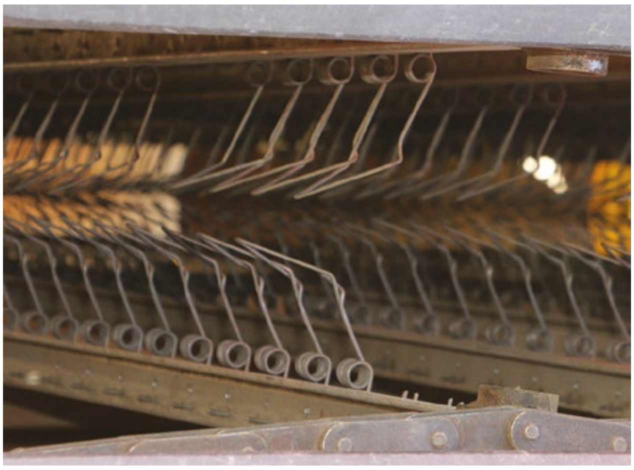


Figure 6. Rows of chain-driven spring-loaded wire picking fingers in the hop picking machine that pluck the cones form the hop bines.

Worldwide growth in demand for craft beer has led to an associated growth in the number of small- to medium-sized hop yards. One of the biggest challenges for new hop growers, is finding picking and processing equipment that is affordable and scaled appropriately for their operation. Subsequently, a number of designers and manufacturers have developed smaller-scale equipment to meet this market. These include machines such as the HopsHarvester™ (Figure 7) made in the USA and a build-it-yourself design developed by the University of Vermont (Darby and Madden 2012).

Figure 7. The USA made HopsHarvester™ has been developed to cater for small to medium scale hop yards.

Picking machine productivity is measured in processing speed (bines/hour) and picking efficiency (percentage recovery). Consider both factors carefully when deciding on the appropriate machine for your hop enterprise.

Shed-based picking and cleaning

In-shed picking machines vary in size and processing capacity. Their purpose is to strip the cones from the bines and remove unwanted leaf and stem material from the final product. They usually consist of a bine conveyor, picking head, secondary picker, vertical air-assisted screen (trommel) and dribble belts. Wolf (Germany), Dauenhauer (USA) and Bruff (UK) brand pickers are three of the most commonly used picking and cleaning machines for shed-based operations. The Wolf (Figure 8) and Dauenhauer machines are still in production, while the Bruff picker (Figure 9) is not. The manufacturers of Wolf pickers acquire and recondition used picking machines and distribute these worldwide to meet demand from the growing number of producers.

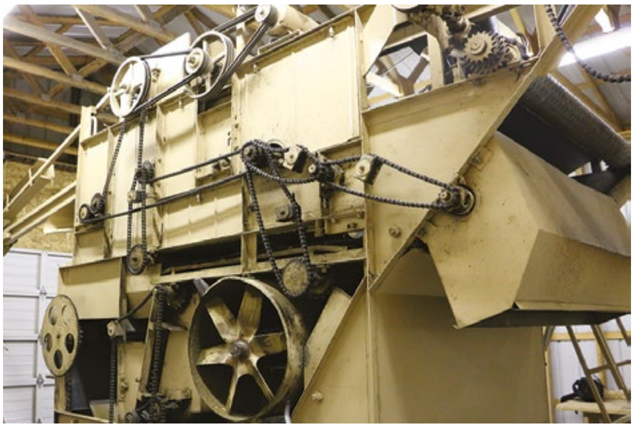


Figure 8. A Wolf picker with a capacity of 80–120 bines per hour; suitable for small- to medium-sized hop enterprises.

Figure 9. This Bruff picker/cleaner in New Zealand, picks and processes around 12 ha of hops each season. In the centre of this view are the angled dribble belts that separate cones from leaf and stem material.

Drying, conditioning and baling

For optimum storability and quality, freshly harvested hops with a field moisture content of around 80% are dried down to 8–12% moisture. Above this target moisture content, hops are prone to breakdown, and below this level they become brittle and suffer from increased oxidation (Madden and Darby 2012).

Hops are dried in purpose-built kiln rooms. Figure 10 shows the top level of a multi-layer kiln in New Zealand. Large fans (Figure 11) force clean heated air into a chamber below the drying beds. Energy sources for heating in most modern kilns are fossil fuels such as coal or gas. Clean air is achieved using a boiler and heat transfer system to ensure the hops are not tainted by smoke or exhaust fumes. The heated air passes through the hop beds taking moisture out through the roof of the kiln. When the bottom layer reaches the correct moisture content, it is removed from the kiln. The louvered floor of the next layer is opened allowing the hops to drop to the bottom and so-on for the remaining layers. The top layer becomes available and a new batch of green hops is brought in. The multi-layered kiln allows for a continuous drying process.

Figure 10. The top floor of a multi-level hop kiln in New Zealand. Heated air is pumped through the louvered floors at the correct temperature and velocity to dry the hops down to approximately 8–12% moisture content.

Figure 11. Large fans force clean heated air into a chamber below the kiln. The chamber design ensures even air distribution and drying.

Large scale modern kilns in the USA, are typically single layered and use gas-fired boilers.

Correct drying is a science in itself, involving factors such as time, temperature, air speed, and drying bed depth. Consider all these factors when designing your drying facility. Neve (1991) provides a useful review of drying studies and commercial practices around the world. Typical air temperatures used for drying hops range from around 55°C to 65°C. Studies have shown that drying at temperatures above this range can lead to a significant loss of alpha acid content. The aim of any kiln is to deliver the correct temperature and air flow to ensure hops are dried efficiently and uniformly. Removing moisture from hops quickly and at relatively low heat will minimise the risk of oxidation and associated alpha acid and essential oil losses. A typical drying duration for a batch of hops in the USA is around 8–10 hours.

Monitor reference samples closely throughout the drying period in order to determine when the correct moisture content is reached. Use the following formula to calculate a target dry weight for a sample of known green weight.

Target dry weight =
(Harvest % dry matter × green sample weight)
÷ target dry matter %

For example, the target dry weight for a 100 g of green sample harvested at 23% dry matter, and a target dry matter of 90% (i.e. 10% moisture) would be calculated as follows:

Target dry weight =
(23% harvest dry matter × 100 g green sample weight)
÷ 90% dry matter

= (23 × 100) ÷ 90 = 25.5 g

In this example, drying is complete when your reference sample reaches 25.5 g. Using this method, the reference sample needs to be contained in a mesh bag throughout the drying process; the weight of the bag needs to be taken into account during your calculations.

When the dried hops emerge from the kiln, there remains significant variation in moisture content throughout the batch. Hops that were on the bottom of the bed tend to be drier than those on top. To overcome this variation and achieve a uniform moisture content, dried hops are conditioned before baling. Freshly dried hops are piled on cooling floors and allowed to sit for a period, allowing the remaining moisture to redistribute (Figure 12).

Figure 12. Before baling, freshly dried hops are held on cooling floors for a conditioning period to ensure a uniform moisture content.

After conditioning, dried hops are transferred to a hydraulic press and compacted into bales very similar to those used for wool. Small windows cut into the side of the bale allow for quality control sampling and moisture content testing using a probe (Figure 13).

Figure 13. A typical New Zealand hop bale packed using a modified wool press.

Storage

Properly dried hops can be cold stored for long periods, allowing processing and marketing to occur year round. Hops do not store well at room temperature. Recommended storage conditions for dried baled hops (GCCA 2008) are as follows:

Temperature: −4.44 °C to −2.22 °C

Relative humidity: 70% to 85%

Storage period: 12 months.

Storage stability varies by variety and is measured by the loss of alpha acids over time at a given temperature. Many hop variety lists include a storage index or rating to give the end user some idea of the storage potential for each variety.

The relative humidity (RH%) of the cold store is important, because if it's too low, hops will lose moisture and weight and if it's too high, the hops will absorb moisture and the risk of breakdown is increased.

Pelletising

Vacuum sealed, pelletised hops (Figure 14) are popular with brewers as they tend to have a longer storage/shelf life, take up less storage space and are easier to handle in the brewing process. For this reason, many hop growers invest in a pelletising machine (Figures 15 and 16) and vacuum packing equipment to meet market demand for this type of product.

Hop growers or processing companies produce pellets in two formats, T90 and T45. The former, (T90) pellets are made by milling the whole dried hop cones and placing all of the milled powder into a pellet-forming machine where it is forced through a die to produce the typical pellet shape. The 90 in T90 refers to the approximate yield in pellets from processing 100 kg of dried hops (i.e. 100 kg hops = 90 kg pellets). Similarly, T45 pellets result in 45 kg of product per 100 kg of hops. The T45 process results in a more concentrated product with a higher lupulin:weight ratio, meaning less product is required in the brew compared with T90 pellets.

Figure 14. Pelletised hops are vacuum sealed to minimise the risk of oxidation. Nitrogen flushing can be added to this process to ensure unwanted oxygen is removed from the package. The same packaging method can be used for marketing small quantities of whole, dried hop cones.

Figure 15. A typical T90 ring pelletising machine.

Figure 16. The internal die of a ring pelletiser.

Marketing your hops

Cooperative storage, processing and marketing is worth considering, particularly where several growers are producing hops in the one region. Pooling product can deliver benefits, including efficiencies of scale, branding and the opportunity to invest in research and development.

Nelson-based cooperative, NZ Hops Ltd, is a successful example of this processing and marketing model. One important key to the recent success of Hops NZ is its investment in a private breeding program in collaboration with the New Zealand Government. This program has led to the development and selection of a significant number of new hop varieties trademarked and managed by Hops NZ. The success of these varieties on the New Zealand domestic market and internationally is key to the success of the cooperative. Well-known varieties bred and owned by NZ Hops Ltd include Nelson Sauvin, Motueka, Riwaka and the Pacific series of varieties.

If you do not have a license to grow and sell trademarked varieties, then you will most likely be growing open source varieties and competing with everyone else who has these varieties. The alpha acid market in the USA is a good example of growers competing on price for commonly grown varieties. Smaller growers with unlicensed varieties such as Cascade should establish close relationships with local brewers and seek out opportunities to market their hops with a focus on provenance or terroir. Understand your market and develop a product range (i.e. green hops, whole dried hops, pellets) in a range of pack sizes to meet demand.

Analytical profiling of hops

Kerry Pinchbeck, AWRI

Growing hops in Australia is becoming more common – with this comes a greater need for formally analysing hops samples in the laboratory. Analytically profiling hops material gives important information about aroma and bitterness potential, and overall quality. Brewers are most interested in the α and β hop acids, total essential oils and the hop oil profile.

The α and β acids are the primary precursors that contribute to bitter attributes in beer. Values obtained from this analysis are used to formulate beer recipes to gain the desired bitterness levels, and are also a key indicator of hops quality.

The essential oils in hops are important contributors to beer flavour and aroma. The total essential oil measure is the percentage of oil contained within the hops (based on mass) and gives an indication of the overall aroma potential of the hops.

The hop oil profile is an extension of this analysis in the sense that it details the concentrations of specific flavour and aroma compounds within the hops oil. This provides information about the aroma profile the hops will give. This combination of analysis is useful in creating a hop profile, allowing easier comparison between varieties and giving an indication of the properties that can influence beer flavour and aroma.

AWRI Commercial Services offers hops analysis as well as many other services for the beer industry. For more information on any hops- or beer-related analysis, please contact the team on 08 8313 6600 or **commercialservices@awri.com.au**.

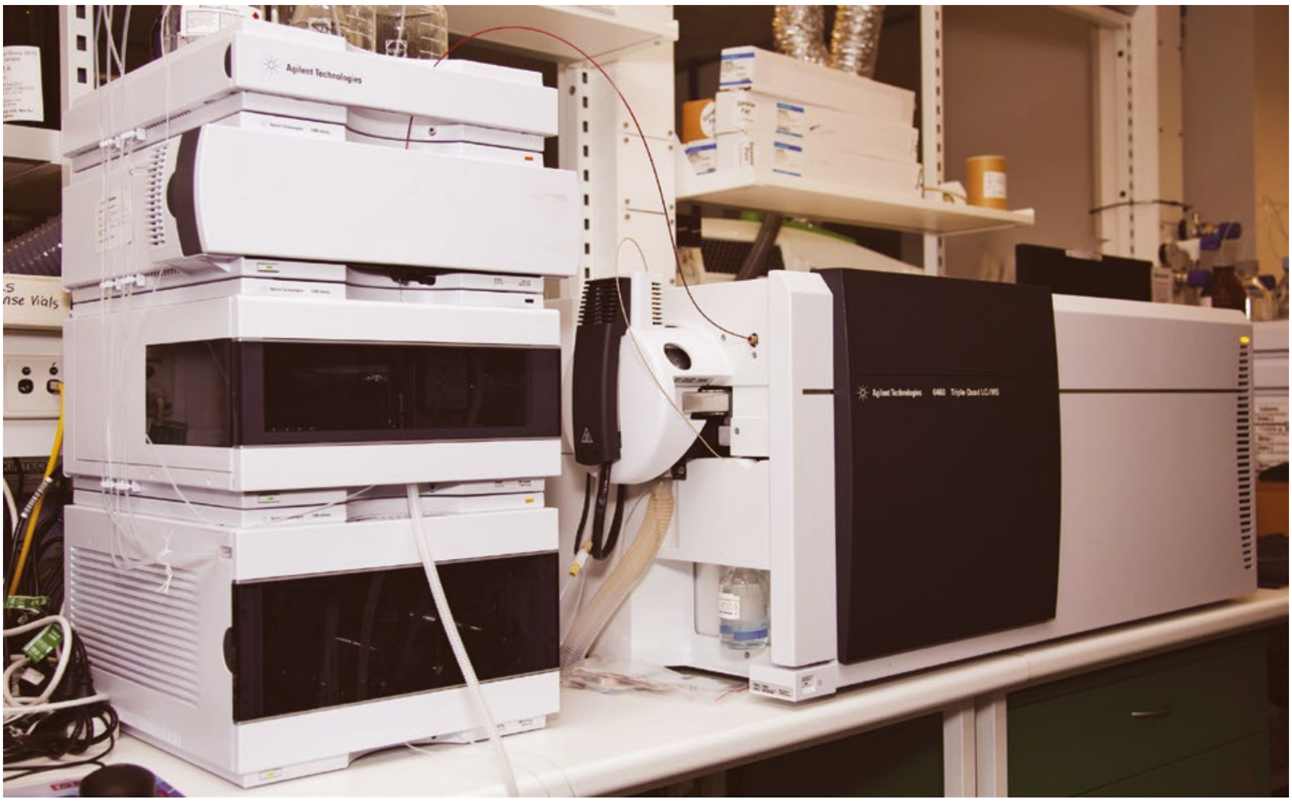
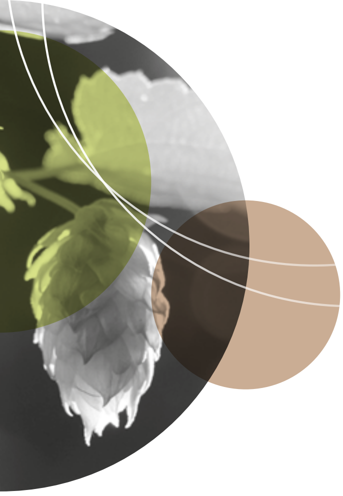


Figure 17. High Performance Liquid Chromatography (HPLC) equipment used for the measurement of alpha and beta hops acids



Hop growing resources

Books

Hops by RA Neve

Hop production by V Rybáček

The hop growers handbook by LT Eyck and D Gehring

Hop variety handbook by D Woodske

For the love of hops by S Hieronymus

The hop industry in Australia by HR Pearce

Websites

Hop Growers of America
www.usahops.org

International Hop Growers Convention
www.hmelj-giz.si/ihgc

Michigan State University Extension – Hops
msue.anr.msu.edu/topic/info/hops

University of Vermont Extension – Hops
www.uvm.edu/extension/cropsoil/hops

North Carolina State University – Hops Project
www.ces.ncsu.edu/fletcher/programs/nchops

Hops Clean Plant Network
nationalcleanplantnetwork.org/HOPS_CPN

Australian Government – Biosecurity Import Conditions
bicon.agriculture.gov.au/BiconWeb4.0

Yakima Chief – Hop Union
ychhops.com

New Zealand Hops
www.nzhops.co.nz

South African Breweries (SAB)
www.sab.co.za/the-sab-story/proudly-south-african-hop-varieties

Australian hops websites

Hop Products Australia
www.hops.com.au

Ellerslie Hops
www.ellersliehop.com.au

Bintani Australia
bintani.com.au

Whitehouse Nurseries
whitehousenursery.com.au/hops

Hopco Pty Ltd
hopco.com.au

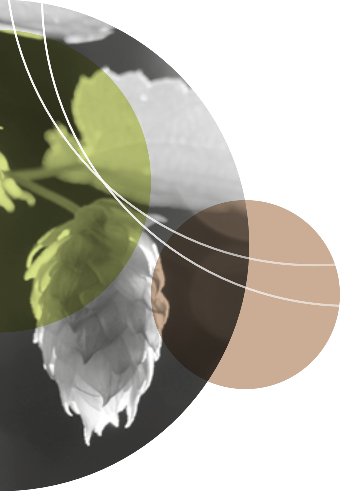
Social networking

Australian Independent Commercial Hop Growers Forum
www.facebook.com/groups/AustralianIndependentHopGrowersForum

HopsWest
www.facebook.com/groups/963794440342334

Hop Growers Forum (Nationwide) USA
www.facebook.com/groups/387211704650588

Aussie Hop Head Chat
www.facebook.com/groups/1219747821411139



References

Browne D (year unknown.) *Fertilizers and nutrient management for hops*. **msue.anr.msu.edu/uploads/236/71505/Hop_fertilizer_and_nutrient_requirements.pdf** Michigan State University Extension, Michigan, USA. Downloaded 16 February 2017.

Calderwood L & Post J (2015). Hop harvest timing in the Northeast. University of Vermont Extension Northwest Crops and Soils Program and USD, Vermont, USA. **www.uvm.edu/extension/cropsoil/wp-content/uploads/Hop-Harvest-Determination-factsheet.pdf**. Downloaded 20 February 2017.

Crowle DR (2010). Molecular variation of viruses infecting hops in Australia and associated studies, (PhD thesis). University of Tasmania, Hobart, Australia.

Crowle DR, Pethybridge SJ, Leggett GW, Sherriff LJ & Wilson CR (2003). Diversity of the coat protein-coding region among Ilavirus isolates infecting hop in Australia. Plant Pathology, 52:5, 533–672. The British Society for Plant Pathology.

Darby H (2011). Fertility guidelines for hops in the Northeast. **www.uvm.edu/extension/cropsoil/hops** University of Vermont Extension, Vermont , USA . Downloaded 16 February 2017.

Darby H (2013). *Nitrogen management in hops*. **www.uvm.edu/extension/cropsoil/hops** University of Vermont Extension, Vermont , USA. Downloaded 16 February 2017.

Darby H & Madden R (2012). *The UVM mobile hop harvester*. **www.uvm.edu/extension/cropsoil/wp-content/uploads/The-UVM-Hop-Harvester-Project-Report-Drawings.pdf** University of Vermont, USA. Downloaded 22 February 2017.

Eyck LT & Gehring D (2015). *The hop grower's handbook: The essential guide for sustainable, small-scale production for home and market*. Chelsea Green Publishing, White River Junction, Vermont, USA.

GCCA (2008). WFLO Commodity storage manual: Hops. World Food Logistics Organisation **www.gcca.org/wp-content/uploads/2012/09/Hops.pdf** Downloaded 23rd February 2017.

Gent DH, Sirrine JR & Darby HM (2015). Nutrient management and imbalances, pp. 98–100. *Field guide for integrated pest management in hops*. 3rd ed. Hop Industry Plant Protection Committee, Pullman, WA: U.S.

Giddings J, Conash P, Henry P & Hoogers R (2016). *Maintaining a drip irrigation system for perennial horticulture*. NSW Department of Primary Industries, Primefact 1358 First edition. Orange, New South Wales, Australia.

Gingrich C, Hart J & Christensen N (2000). *Fertilizer Guide – Hops*. Oregon State University Extension Service, Corvallis, Oregon, USA

Hop Growers of America (2017). 2016 Statistical report. Moxee, Washington, USA, **www.usahops.org/img/blog_pdf/76.pdf**. Downloaded 2 February 2017.

International Hop Growers' Convention (2016). IHGC hop variety list, **www.hmelj-giz.si/ihgc/doc/2016%20NOV%20-%20IHGC%20hop%20variety%20list.pdf**. Downloaded 2 February 2017.

Kořen J (2007). Influence of plantation row spacing on quality and yield of hops. *Plant, Soil and Environment*, 53, 276–282. Czech Academy of Agricultural Sciences, Czech Republic.

Lizotte E (2015). The art and science of hop harvest. **msue.anr.msu.edu/news/harvest_time_approaching_for_hop_growers_1** Michigan State University Extension, Michigan USA. Downloaded 21 February 2017.

Madden R & Darby H (2012). *Hops harvest moisture determination*. **www.uvm.edu/extension/cropsoil/wp-content/uploads/Hop_harvest_fact_sheet.pdf** University of Vermont Extension Northwest Crops and Soils Program and USD, Vermont, USA. Downloaded 20 February 2017.

Meier U (2001). *Growth stages on mono and dicotyledonous plants – BBCH Monograph*. Federal Biological Research Centre for Agriculture and Forestry. Bonn, Germany.

Neve RA (1991). *Hops*. Chapman and Hall, UK.

Oldham C (2016). Pers. comm, Study tour of New Zealand hops industry – February 2016, New Hoplands, Tapawera, New Zealand.

Pearce HR (1976). *The hop industry in Australia*. Melbourne University Press, Australia.

Pethybridge SJ (2000). *Epidemiology of viruses infecting hop (Humulus lupulus L.) in Australia*, Volume 2. University of Tasmania, Hobart, Australia.

Reuter DJ & Robinson JB (1997). *Plant analysis an interpretation manual*, Second edition. CSIRO Publishing, Collingwood, Victoria, Australia.

Rybáček V (1991). *Hop production*. Developments in Crop Science 16. Elsevier Science, Amsterdam, The Netherlands.

Treeby M, Falivene S & Skewes M (2011). *Fertigation: delivering fertiliser in the irrigation water*. **www.dpi.nsw.gov.au/__data/assets/pdf_file/0006/378564/Fertigation-delivering-fertiliser.pdf**. Primefact 1089, NSW Department of Primary Industries, News South Wales, Australia. Downloaded 17 February 2017.

Unknown (1958). New South Wales could produce hops. *The Agricultural Gazette*, February.

Williams IH, Roberts JB & Coley-Smith JR (1961). *Studies of the dormant phase of the hop (Humulus lupulus L.) Annual report for 1960*. Department of Hop Research, Wye College England pp. 48–58.

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