INFORMATION

Influence of plantation row spacing on quality and yield of hops

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ABSTRACT

In 2004–2006 an influence of various plantation row spacings on yield and quality of hops was observed in field trials. A hybrid variety Agnus was selected for this purpose. The common space between the rows remained (300 cm). The tested distances of individual hop plants within each row amounted to 114 and 133 cm. We compared the standard kind of four trained bines from each hill with a new one (five bines per hill). The yield of hops was the highest if row spacing 300 × 114 cm was used (2.80 tons of dry hops per hectare). If spacing 300 × 133 cm was tested, the yield amounted to 2.69 t/ha. The lowest yield of hops was obtained when the common row spacing 300 × 100 cm was used (2.58 t/ha). Yield increase in the plots with new spacing was at the limit of significance. Weather was the main factor influencing hop crop in 2006. Statistically significant differences in the yield of hop cones were proved in the year with very good growing conditions (2005) as well as in the year with relatively bad weather conditions (2006). If average conditions prevailed (2004) no significant differences between experimental and control plots were observed. Alpha acid contents were the highest (12.45%) in the perspective row spacing (300 × 114 cm); a slight decrease was found when the spacing of 300 × 133 cm was used (11.92%). In the case of the control variant with the common row spacing 300 × 100 cm, alpha acid contents amounted to 12.29%.

Keywords: hop; row spacing of plantation; yield and quality of hops; alpha acid contents

One of the most important agro-technical problems of hop cultivation is row spacing. There are two turning points in the history of hop garden establishment. The first one dates back to 1959, when Pokorný et al. (1959) compiled the principles of wide row spacing use. At that time the recommended row spacing of a new established hop garden was 260 × 110 cm. Since the middle of the 1970's new principles have been used. Beníček et al. (1976) recommended row spacing 300 × 100 cm. The density of plants inside a hop garden can be differentiated with varying number of bines trained per a wire according to specific growing conditions.

Nalivajko and Pročajev (1957) studied these problems in Russia; Borde (1961) dealt with them in Germany. By processing of accessible data on row spacing in the most important hop growing countries we obtained a review not only from Germany, USA and Russia, but also from France, Belgium, England, Spain, Bulgaria, and Poland.

In Germany the row spacing differs according to individual hop growing regions. In the most famous German region in Bavarian Hallertau, hop growers use 3.2 m between rows; in Elbe-Saale region (East Germany) the same spacing is used as in the Czech Republic (3.0 m); in Tettnang region near Bodensee the typical distance between rows is only 1.4–1.5 m if aroma varieties are grown, and 1.5–1.7 m if bitter varieties are cultivated, while each sixth row is used for irrigation (Anonym 2006c). At Flemish region in Belgium hop plants are grown in row spacing 3.0 × 1.2 m, as well as in Alsatian region in France (Anonym 2006e); in Spain they cultivate hop in a similar spacing (3.0 × 1.25–1.5 m) (Anonym 2006a).

In England the situation is rather different than in other European countries. It derives from quite a different type of their wireworks. Darby (2004) and Perry (2006) describe hop cultivation on low trellises that reach the height of 3.0 m at maximum. The rows of low trellis system are mutually independent, individually anchored, and they have a shape of oblong trellis. Hop gardens look as rows of low hedges, whose distance is 2.5 m.

In Poland and Bulgaria the most frequently used spacing is 280–300 × 100–120 cm according to a cultivated hop variety. Luo Xinchao (2005) does not mention any particular spacing used in China, we can however see from available pictures that hop cultivation on low trellises with the distance of 300 cm between rows prevails.

In the USA hop used to be traditionally grown in the spacing of 7 × 7 feet (ca 2 × 2 m). In the 1980's hop growers began to cultivate hops in spacing 3.5–14 feet (1 × 3 m); nevertheless, they returned to the original spacing (7 × 7 feet) in the 1990's due to the introduction of new irrigational systems (Anonym 2006b). For instance in Oregon a similar spacing is used (7.5 × 7.5 feet); however row spacing of 14 × 3.5 feet (420 × 105 cm) is used in this state as well (Anonym 2006d).

From the above-mentioned review we can summarize the following knowledge:

1. There are quite significant differences among row spacings not only in the individual countries but also within them. The width of the rows can vary from 210 to 420 cm and the distance between hills within a row can be 100–200 cm.
2. The trend to use wider rows and smaller distance of hop plants within a row is common in Europe.
3. In many hop regions in the world row spacing depends on different climate and soil conditions and the structure of cultivated hop varieties.

Until the middle of the 1990's only one hop variety (Žatec semi-early red-bine hop) was grown in the Czech Republic. Since 1994 the structure of hop varieties has been widen by hybrid bitter varieties (Bor, Premiant and Sládek); in 2001 another bitter variety was registered. These new varieties of hybrid origin differ from aromatic semi-early red-bine hop in many biological and growing characteristics. These differences can be resumed in the following way:

– later beginning of the vegetation and slower growth of shoots
– later and slower creation of inflorescence
– later but faster creation and maturity of hop cones
– vigorous habitus of hop plants
– better ability of training around a wire.

The objective of this work is to test and suggest suitable row spacings and optimal number of hop bines per a wire in order to reach permanent yield of 2–3 t/ha as well as high alpha acid contents.

MATERIAL AND METHODS

A new 2.5 ha hop garden was established in the research farm of the Hop Research Institute at Stekník in 2003 to test various spacings on it. A new hybrid hop variety Agnus was planted.

The experimental hop garden lies on the first terrace of the right bank of the Ohře river in the middle of a flat part of a valley delimitated by the slopes of other shelves from the north and east; from the south and west it is bordered by a slightly rolling country. The alluvial soil contains the mixture of humous sand and Blšanka stream clay sediments of perm origin. Soil profile is deep, arable land is loamy (I. category 30–40%) with a low content of sand (IV. category 2–3%). Arable soil is slightly humous, soil reaction acid – neutral (pH 6.2–7.0). The soil has good physical conditions, good inner drainage, and optimum natural stock of nutrients.

The universal distance between rows was kept at 300 cm. Within the individual experimental plots only the distance between hills in a row was changed. An unusual number of five bines from a hill were trained per two wires.

Table 1. The survey of individual experimental plots

Plot	Spacing (cm)	Area falling on one hill (m^2)	Number of hills/ha	Number of trained bines/hill	Number of bines/ha
Control	300 × 100	3.00	3333	4	13 332
No. 1	300 × 114	3.42	2924	5	14 620
No. 2	300 × 133	3.99	2506	5	12 530

Table 2. Yield of fresh hops per one bine

Plot	Spacing (cm)	Weight (kg)			Average	Index (%)
		2004	2005	2006		
Control	300 × 100	0.81	0.96	0.61	0.79	100
No. 1	300 × 114	0.76	0.98	0.67	0.80	101
No. 2	300 × 133	0.88	1.05	0.72	0.88	111

Experimental plots

Control plot: spacing 300 × 100 cm; two wires were hanged at each hill in a usual V system; two bines were trained at each wire.

Experimental plot No. 1: spacing 300 × 114 cm; two wires were hanged at each hill in a usual V system; five bines were trained from each hill (2 + 3).

Experimental plot No. 2: spacing 300 × 133 cm; two wires were hanged at each hill in a usual V system; five bines were trained from each hill (2 + 3).

Individual experimental plots (Table 1) were established; each plot included the space of ten poles and its area was 0.4 ha. Only the hop plants in inner (middle) rows were used for assessment. Pole rows were used as isolation rows. Agricultural technology was the same in all the plots. Irrigation was carried out according to actual needs.

RESULTS

Yield of hop cones was measured at all the individual plots in four replicates. In order to maintain the same experimental area in all three tested plots we determined the yield in the following way:

1. Control plot: four replicates comprised 32 hills
2. Experimental plot No. 1: 28 hills
3. Experimental plot No. 2: 24 hills

Total weight of hop cones was measured at each plot. The weight of fresh hops per one bine was calculated. Obtained results are reviewed in Table 2.

It is obvious from the results that the weight of fresh hops from one bine increases with greater spacing of the hills within a row; it shows that the greater spacing is used the larger area per one hill is, and the better light conditions are in the hop garden. Considerable differences in the weight of fresh hops within the individual years were caused by specific weather conditions. They influenced the growth of hop plants. Average monthly temperatures and precipitations during the vegetation period are shown in Tables 3 and 4.

As regards average temperatures, we could observe an obvious warming up in the last two years compared to the long-term mean value; it was very striking in the year 2006. Abnormal temperatures influenced negatively alpha acid contents.

We noticed that regular precipitations within the vegetation period are more important than their total sum.

Table 3. Average monthly temperatures (°C) in the vegetation period and their comparison with long-term (30 years) mean values

Month	2004		2005		2006	
	average temperature	deviation	average temperature	deviation	average temperature	deviation
April	9.8	+1.3	10.2	+1.7	8.9	+0.4
May	12.4	–1.0	14.4	+1.0	13.7	+0.3
June	16.6	–0.1	17.5	+0.8	18.2	+1.5
July	18.4	+0.4	19.0	+1.0	22.8	+4.8
August	19.0	+1.6	16.8	–0.6	16.7	–0.7

Table 4. Monthly sums of precipitations (mm) in the vegetation period and their comparison with long-term (30 years) mean values

Month	2004		2005		2006	
	precipitations	deviation	precipitations	deviation	precipitations	deviation
April	10.2	–21.8	22.9	–9.1	48.8	+16.8
May	71.6	+17.6	92.6	+38.6	39	–15.0
June	73.6	+17.6	43.6	–12.4	72.4	+16,4
July	30.6	–29.6	94.4	+35.4	59.5	+0.5
August	64.4	+2.4	28.8	–33.2	76	+14.0
Σ	250.4	–13.8	282.3	+19.3	295.7	+32.7

Table 5. Influence of spacing on yield of hop cones in Agnus variety

Replicate	Yield (t/ha)		
	control	plot No. 1	plot No. 2
2004			
1	2.60	2.89	2.56
2	2.37	2.69	2.56
3	2.70	2.63	2.46
4	2.80	2.60	3.16
Average	2.62	2.70	2.69
SD	0.16	0.11	0.28
CV (% rel.)	6.1	4.2	10.3
2005			
1	3.16	3.45	3.24
2	2.97	3.58	3.33
3	3.22	3.37	3.13
4	3.18	3.57	3.08
Average	3.13	3.49	3.19
SD	0.11	0.10	0.12
CV (% rel.)	3.6	2.9	3.6
2006			
1	2.2	2.3	2.5
2	2.1	2.4	2.2
3	1.8	2.3	2.1
4	1.8	2.5	2.1
Average	1.98	2.37	2.20
SD	0.21	0.11	0.18
CV (% rel.)	10.8	4.7	8.1
Average (2004–2006)	2.58	2.85	2.69

Influence of spacing on yield of hop cones

Calculation of yield of dry hops per hectare was carried out from the average weight of fresh hops per one bine, a theoretical number of bines per hectare and the actual percentage of bines that reached the ceiling of wirework. The coefficient of 4.1:1.0 was used for this purpose. The results are shown in Table 5.

The statistical evaluation of the influence of hop plantation on yield was carried out using the one-parameter analysis of dispersion. The results show that differences in yield were statistically significant in 2005, when weather conditions were suitable for the growth of hop plants, and in 2006, when the weather was unfavourable (Table 6).

In both years the statistical significance in yield was found between the control plot and experimental plot No. 1 (spacing 300 × 114 cm). Statistical significance between the control plot and experimental plot No. 2 (spacing 300 × 133 cm) was proved only in 2006. Statistical significance between experimental plots No. 1 and No. 2 was observed only in 2005.

Average results are reviewed in Table 7.

Table 6. Statistical significance of spacing influence on yield of hops (Agnus)

	Plot	No. 1	No. 2
2004	control	–	–
	No. 1		–
2005	control	*	–
	No. 1		*
2006	control	*	*
	No. 1		–

Table 7. Influence of spacing on yield of hop cones (Agnus)

Plot	Spacing (cm)	Yield of dry hops in t/ha			Average	Index (%)
		2004	2005	2006		
Control	300 × 100	2.62	3.13	1.98	2.58	100
No.1	300 × 114	2.70	3.49	2.37	2.85	110
No. 2	300 × 133	2.69	3.19	2.20	2.69	104

Influence of spacing on hop quality

During the harvest samples for chemical analysis were taken from each plot. Alpha acid contents were determined with the help of gas chromatography by the EBC 7.7. method. Results are shown in Table 8.

Table 8. Influence of spacing on hop quality (Agnus)

Replicate	Alpha-bitter acid contents (% of weight in dry matter)		
	control	plot No. 1	plot No. 2
2004			
1	13.99	14.28	12.97
2	15.52	13.35	13.93
3	14.69	14.14	12.66
4	12.52	12.69	12.80
Average	14.18	13.62	13.09
SD	1.10	0.64	0.50
CV (% rel.)	7.8	4.7	3.8
2005			
1	11.58	11.93	10.82
2	11.60	10.88	10.94
3	11.17	12.02	10.85
4	11.21	12.45	10.68
Average	11.39	11.82	10.82
SD	0.23	0.67	0.11
CV (% rel.)	2.0	5.6	1.0
2006			
1	10.9	12.7	11.8
2	12.3	12.2	11.9
3	11.0	11.5	12.7
4	11.0	11.3	11.0
Average	11,29	11.91	11.86
SD	0.70	0.67	0.67
CV (% rel.)	6.2	5.6	5.7
Average (2004–2006)	12.29	12.45	11.92

Important differences were found between the experiment years in alpha acid contents; they must have been influenced by different weather conditions during the vegetation periods of individual years. On the other hand, there were no significant differences in resins among the individual experimental plots within a year. Statistical evaluation was done using an analysis of dispersion. Statistically significant differences were found only in 2005 between experimental plots No. 1 and No. 2 (Table 9).

Average values of alpha acid contents within the experimental period are shown in Table 10.

DISCUSSION

A narrow relation between the yield of hops and a number of hop plants reaching the ceiling of the wirework has been confirmed in field trials. There are various possibilities of spacings as well as numbers of trained bines per hectare, as it is obvious from the introduction of this paper. To increase the number of bines per hectare three bines per wire are often recommended; in this way higher yield of hops may be reached.

If we use wider spacing within a row, habitus of hop plants is usually more vigorous and laterals

Table 9. Statistical significance of spacing influence on alpha-bitter acid contents (Agnus)

	Plot	No. 1	No. 2
2004	control	–	–
	No. 1		–
2005	control	–	–
	No. 1		*
2006	control	–	–
	No. 1		–

Table 10. Influence of spacing on alpha acid contents (Agnus)

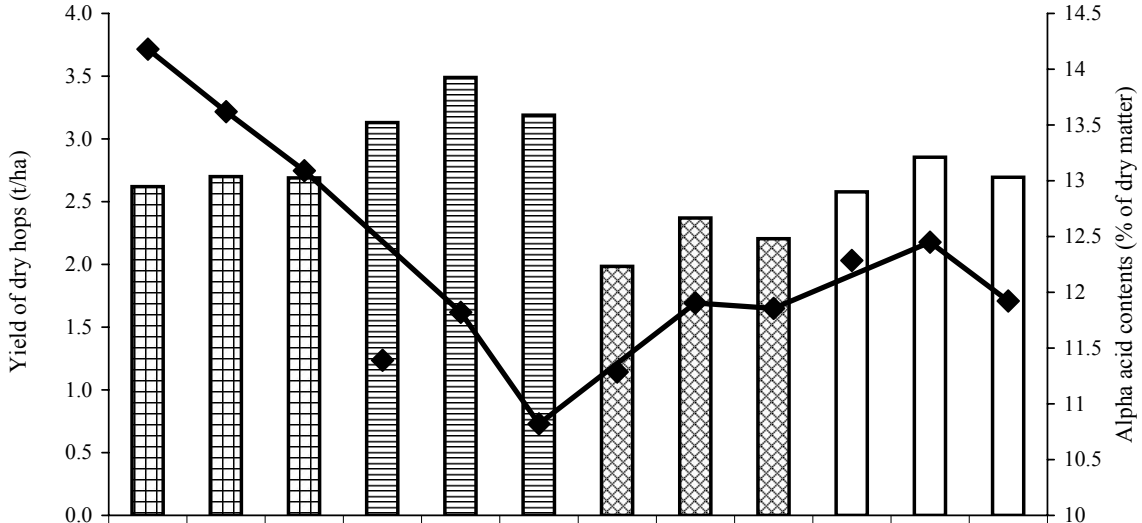
Plot	Spacing (cm)	Alpha bitter acids in % of dry matter			Average	Index (%)
		2004	2005	2006		
Control	300 × 100	14.18	11.39	11.29	12.29	100
No. 1	300 × 114	13.62	11.82	11.91	12.45	101
No. 2	300 × 133	13.09	10.82	11.86	11.92	97

are longer (at first if three bines are trained per a wire) due to better light conditions and a larger nutritive area per one hill. Fructiferous laterals grow from lower parts of hop plants as well, and spreading of hop cones within a hop plant is more equal; the experience from the 1960's has been confirmed in this way. Sachl (1961) says that wider spacing with longer distance of hills in a row positively influences microclimate in hop gardens. The growth of hop plants is better and their production is higher. It is necessary to have a hop garden without missing hop crowns and to have the needed number of bines in order to reach higher yield of hop cones.

If we compare the calculated yield of dry hops per hectare, we can conclude that the highest yield was reached if spacing 300 × 114 cm was used; the increase was by 10% higher in comparison with the control plot. Differences in the yield between the control plot with traditional spacing and the experimental spacing 300 × 133 cm are not so significant. Nevertheless, there was slightly higher yield in the experimental plot if hop hills with longer distance within a row were used; the increase of the crop was by 4.0% higher. Hence, a hypothesis that hybrid varieties with more vigorous habitus can be cultivated in newly tested spacing with longer distance of hop hills in a row has been confirmed. If we take into consideration the yield of hops we can recommend the spacing 300 × 114 cm (No. 1).

The advantage of new spacings with longer distance of hop hills within a row can also be expressed in the saving of planted rootstocks (409 rootstocks for the spacing 300 × 114 cm, and even 827 rootstocks in the case of spacing 300 × 133 cm). Guide wire is saved by 13 and 25%, respectively. Another savings consist in higher capacity during pulling down hop bines in the course of harvest and later during hanging bines in the harvest machine.

There is no significant difference in alpha acid contents among the individual plots. A slight in-



	Control	No. 1	No. 2	Control	No. 1	No. 2	Control	No. 1	No. 2	Control	No. 1	No. 2
	2004			2005			2006			Average		
Yield of dry hops	2.62	2.7	2.69	3.13	3.49	3.19	1.98	2.37	2.20	2.58	2.85	2.69
Alpha acids	14.18	13.62	13.09	11.39	11.82	10.82	11.29	11.91	11.86	12.29	12.45	11.92

Figure 1. Influence of plantation spacing on alpha acid contents (Agnus 2004–2006)

crease of alpha acid level (by 4.0%) was found in the case of the plot No. 1, whereas a slight decrease was observed in the plot No. 2 (3.0%). This tendency may be caused, among others, by different microclimate. Lower fluctuations in temperature due to higher density of hop bines within a hop garden are typical for the traditional spacing 300 × 100 cm. It may influence alpha acid contents in hop cones as well.

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