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Specific Kieselguhr Increased Hop Yield Over Several Years

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Abstract

The yields of farm crops are strongly affected by rainfall. Cultivation methods that can alleviate rainfall shortage have been long awaited to ensure stable and sustainable crop production. Porous materials, such as kieselguhr and perlite, were applied during hop cultivation, and their contribution to yield and beer quality was analyzed. An increase of over 20% in yield was confirmed following the application of burnt coarse kieselguhr. This increase was sustained for at least 3 years from the time of burnt coarse kieselguhr application in the first year. Water content around the hop root was maintained at a high level after burnt coarse kieselguhr application. Therefore, it appeared that burnt coarse kieselguhr absorbs water in its porous space during rainfall and releases water to the plants thereafter, including during drought conditions. However, the quality of the hops was not changed following burnt coarse kieselguhr application. Burnt coarse kieselguhr application around the plant root is expected to alleviate the effect of climate change and contribute to the stable and sustainable production of various crops that need a constant water supply.

Keywords: deficit, diatom earth, diatomaceous earth, hop, kieselguhr, porous, shortage, water, yield

1. Introduction

Hop (*Humulus lupulus* L.) is a perennial dioecious climbing plant. Flowers (hop cones) that form on the female plants are ingredients used in beer production. In beer brewing, hops add a crispy bitterness without any lasting flavor, and produce a fresh hoppy aroma and fine foaming beer (Schönberger & Kostelecky, 2011; Steenackers, Cooman, & Vos, 2015). Its important position in beer brewing was established during the Medieval Ages in Europe, not only to enhance the flavor of the beer, but also for quality stabilization of the antibacterial activity of humulones. Compounds that affect flavor, such as humulones, which contribute to bitterness, and terpenes, which contribute to the hoppy aroma, are localized in the resin-like lupulin in the hop cone (Patzak, Krofta, Henychova, & Nesvadba, 2015; Wang et al., 2008). Moreover, xanthohumol, which contains a prenyl group and is a notable functional compound providing health benefits, is also localized in lupulin (Nagel et al., 2008). The bract of the hop contains a variety of phenols, which contribute to the fullness of the beer (Inui, Okumura, Matsui, Hosoya, & Kumazawa, 2017).

Hop is cultivated in cold districts, where the average temperature in mid-summer is under 25 °C. The major hop growing countries are the United States, Germany, Czech Republic, China, Australia, and New Zealand (Meier, 2017). Over 100 cultivars that have specific qualities are grown in the countries mentioned above (Kishimoto, Kobayashi, Yako, Iida, & Wanikawa, 2008; Kovacevic & Kac, 2002). Hop grows to a height of 7-9 m attached to a dedicated hop trellis (Matsui, Inui, Ishimaru, Hida, & Oka, 2012). Hop sprouts in early spring and grows to its maximum height in only 3 months; thereafter, it blooms, and harvesting is completed upon maturity, 1-2 months after blooming (Matsui, Inui, Oka, & Fukui, 2016). The time of harvest is judged based on the maturity condition of the flavor-related compounds for determining beer quality (Cocuzza, Lutz, & Muller-Auffermann, 2013; Kavalier, Ma, Figueroa, Kincaid, & Matthews, 2014; Keukeleire et al., 2003; Sharp, Townsend, Qian, & Shellhammer, 2014). These plants require considerably more water than other crops do, and the yield depends to a large extent on the amount of water received from rainfall or irrigation systems. Therefore, the yield of a hop garden that contains an irrigation system is stable. Most hop gardens in the United States install irrigation systems because rainfall is low during the hop cultivation period in the hop growing areas of the United States.

The Saaz variety, which is cultivated in the Saaz region of the Czech Republic, is famous for its pleasant hoppy aroma and mild bitterness, and it is referred to as a "Fine aroma hop" in breweries worldwide. In the past 11 years, yields in 4 years (2006, 2007, 2012, and 2015) were lower than the standard yield, and requisitions during these 4 years for this hop variety from breweries could not be satisfied. Neither the growers nor their cultivation methods differed across years in the districts cultivating the Saaz variety (approximately 4,000 ha); therefore, it was speculated that the climate conditions affect yield instability. According to the growers, the lower the rainfall is, the lower the yield. Long-term climate modelling analysis of the Saaz region has shown that rainfall will decrease gradually in the future (Hanel et al., 2018; Mozny et al., 2009), and hop yield is related to rainfall during the cultivation period (Mozny et al., 2009). Irrigation systems are installed in only 30% of the hop gardens because of the lack of a water source in the Saaz hop growing districts. It is thus possible that periods of lower yields might occur more often in the future. Importantly, effective methods to mitigate the effects of rainfall shortage must be developed in the Saaz hop growing regions.

In other crops, such as corn and strawberry, it has been determined that adding kieselguhr to the soil increases yield and improves quality (Escobar, Espejo, & Rodríguez, 2014). The mechanism underlying this effect might be that kieselguhr holds water and nutrients in its porous space and constantly releases them. This mechanism might be effective for the stabilization of hop yield during periods of rainfall shortage. In the present study, we placed different porous materials around hop roots to identify measures to obtain stable yields during periods of rainfall shortage. Kieselguhr and perlite were the porous materials tested. Kieselguhr is the fossil of diatoms (*Bacillariophyceae*). Diatoms absorb silica during their lifetime; after their death, all the components, except silica, are removed over millions of years of fossilization. Kieselguhr is mainly used for filtering liquids such as beer, juice, and oil. In addition, it is used as a component of materials for the construction of the walls of houses because it absorbs moisture under high humidity conditions. Perlite is produced from volcanic ash at high temperature and high pressure and also has a porous structure. Although these porous materials have been used previously for soil improvement (Aksakal, Angin, & Oztas, 2012) in other crops, they have not been used for hops to date. Kieselguhr is classified into burnt and unburnt types, and its particle size is variable. The water absorption ability of kieselguhr might be affected by these factors (Nascimento et al., 2018). The type of kieselguhr most suitable for providing water to crops has not yet been determined. In the present study, we assessed two categorizations of kieselguhr—burnt *vs.* unburnt and fine *vs.* coarse for their suitability for the stabilization of hop yield over a period of 3 years beginning 2015.

2. Method

2.1 Average Yield of Saaz Cultivar and Climate Data in Saaz-cultivating Districts

The average yield of hop (dried hop cone) of the Saaz cultivar grown in the Saaz region, Czech Republic, originated from Bohemia Hop Co. Ltd. (Zatec, Czech Republic). Temperature and precipitation data were obtained from the climate observation systems administrated by the Hop Research Institute Co. Ltd. (Zatec, Czech Republic).

2.2 Porous Materials

Three types of kieselguhr and one type of perlite were used in the present study (Table 1). All the materials were obtained from the Showa Chemical Industry Co. Ltd. (Tokyo, Japan).

Table 1. Porous materials used in hop gardens since 2015

Porous material	Product name	Category in kieselguhr insdustry	Type	Abbreviated name in this study	Particle diameter (μm)	Density (kg/L)
Kieselguhr 1	#300	Powdery calcined kieselguhr	Burnt fine	KBF	13 (Ave.)	0.394
Kieselguhr 2	RC417	Granular calcined kieselguhr	Burnt coarse	KBC	400-1700	0.388
Kieselguhr 3	KF-N	Granular natural kieselguhr	Dried coarse	KDC	500-2000	0.438
Perlite	M-1	-	-	P	850 (Ave.)	0.177

2.3 Hop Garden

The hop garden used for the tests is located in the Steknik village, 5 km east of Zatec city. Its acreage is 2 ha. The planting density was 3 333 plants/ha.

2.4 Porous Material Application

Porous material application was undertaken at the end of April, immediately after pruning in spring. A total of 20 L of soil around the hop roots was dug out. Subsequently, a mixture of the designated amount of kieselguhr or Perlite and soil were placed back around the hop roots (Figure 1). In the control, 20 L of soil around the hop roots was removed and 20 L of soil was added back. A list of the tests performed is provided in Table 2.

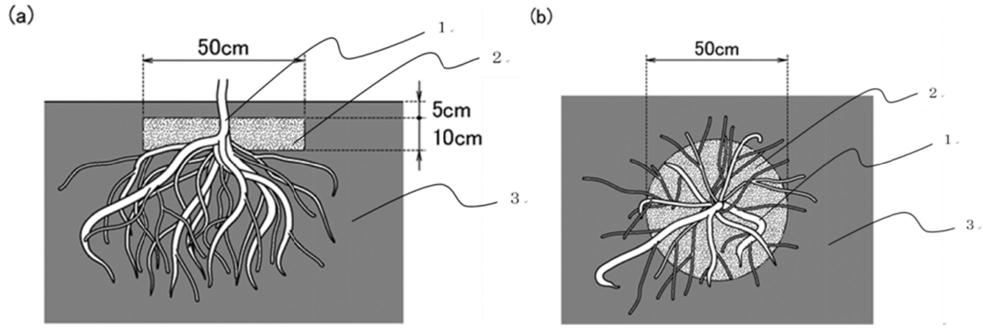

Figure 1. Application of porous materials. (a) Horizontal view and (b) vertical view. (1) Hop plant, (2) mixture of the designated amount of porous material and soil, and (3) soil

Table 2. List of tests performed from 2015 to 2017. Abbreviations (KBF, KBC, P, and KDC) are from Table 1

Test No.	Porous material	Kieselguhr application	
		Amount (L/plant)	Year
1	- (Control)	0	2015
2	KBF	20	2015
3	KBC	20	2015
4	P	20	2015
5	- (Control)	0	2017
6	KDC	20	2017
7	KBC	14	2017
8	KBC	8	2017
9	KBC	2	2017

2.5 Temperature and Water Content in the Soil

Sensors (5TE, Decagon Co. Ltd., Pullman, WA, USA) for measuring the temperature and water content in the soil were placed around the hop roots at a depth of 20 cm from the ground surface. Two hop plants were randomly selected from each test treatment to measure temperature and soil water content. Loggers (Em50 5ch, Decagon Co. Ltd.) were also used to record the data.

2.6 Hop Yield Calculation

A picking machine was used to collect all raw hop cones from each bine and the weight of the raw hop cones was measured before kilning from each bine.

2.7 Hop Samples

After harvest, the hop samples in one test were divided into three samples from eight randomly selected bines. They were kilned at 55 °C for approximately 8 h until their moisture content reached 10±1%. Dried hop samples were packed immediately using nitrogen purge and stored below freezing point until subsequent use in chemical analyses.

2.8 Chemical Analyses of Hop Samples

Chemical analyses of hop samples were performed at the Hop Research Institute Co. Ltd. in Saaz, Czech Republic. Humulones were measured using the European Brewery Convention 7.7 liquid chromatography (high-performance liquid chromatography) method with a Nucleosil RP C18 column (Macherey-Nagel, Düren, Germany, 5 µm, 250 × 4 mm) and a Shimadzu LC 20 A chromatograph (Shimadzu, Japan) with diode array detectors.

Hop essential oils were obtained by steam distillation and the terpene content of the distilled oil was determined using gas chromatography (GC) on a DB 5 capillary column (Chromservis, Czech Republic, 30 m × 0.25 mm × 0.25 µm film thickness) using a Varian 3400 gas chromatograph together with a Finnigan ITD 800 mass detector. Qualitative criteria were based on a comparison of the GC retention indices and mass spectra with those of pure compounds. A semi-quantitative evaluation of the composition of hop oils was performed based on the peak area of individual components and was expressed in relation to the total integrated area of all substances detected.

2.9 Water Absorption Capacity

Water absorption capacity (WAC) is defined as the volume of water that can be absorbed per liter of porous material. A sample of 50 mL of each porous material was placed in a separate plastic bag (Seisannipponsya Co. Ltd., Tokyo, Japan). Subsequently, 1-5 mL of water was added until the porous material was saturated with water. Water saturation was judged from the confirmation of non-absorbed water on the plastic bag surface. WAC was calculated from these data.

2.10 Statistical Analysis

Statistical tests were conducted using the JMP 12.01 software program (SAS Institute Inc., Cary, NC, USA). Statistical differences between means were determined by two-way analyses of variance, considering two significance levels: $P < 0.05$ and $P < 0.01$.

3. Results and Discussion

The yield of the Saaz cultivar from 2009 to 2017 varied from -27% to +27% of the standard yield (Figure 2). Growers and their cultivation methods did not differ across years over the entire Saaz region (approximately 4,000 ha). Therefore, the climatic conditions might have caused this large variation in yield. Analysis of hop yield and climatic conditions (daily average temperature and rainfall) was performed. Although the positive correlation between yield and rainfall during the cultivation period from April to August has been confirmed previously based on a long-term study conducted over 50 years (Mozny et al., 2009), this trend was not confirmed during the short-term period of 9 years in the present study (data not shown). However, the positive correlation between yield and rainfall from 10 July to 10 August (2009 to 2017) was confirmed during this short period (Figure 3). This period generally corresponds to the hop blooming period of the Saaz cultivar in the Saaz district. If the rainfall during this period decreases, the number of flower settings might decrease. It thus seems apparent that low rainfall during this period might result in low yield. If enough water could be preserved in the soil until the blooming stage, stable yield could be realized even under conditions of rainfall shortage. In the present study, the application of porous materials around hop roots was assessed to determine its efficacy for this purpose. Porous materials might absorb water from rainfall in their porous spaces and emit water during drought periods. This hypothetical mechanism might contribute to achieving stable hop yield.

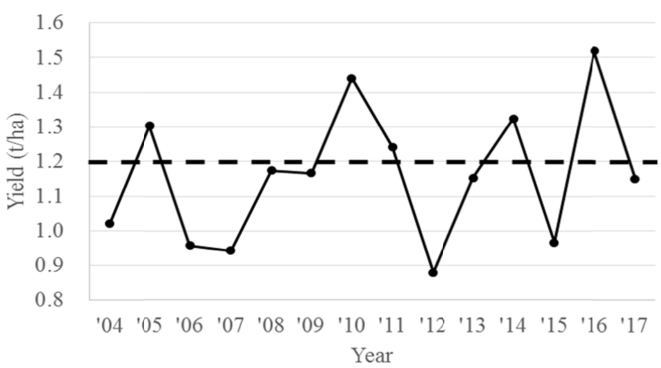

Figure 2. Trend of average yield of Saaz cultivar in the Saaz region. Data was provided from Bohemia Hop Co. Ltd. The dotted line shows the standard yield of the Saaz cultivar (1.2 ton/ha)

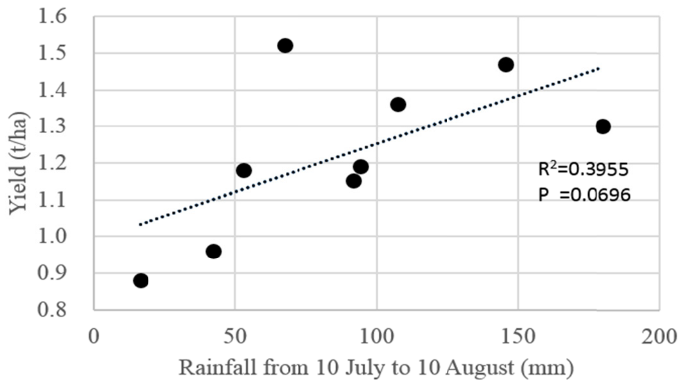

Figure 3. Relationship between hop yield and rainfall from 10 July to 10 August (2009 to 2017). Yield data was obtained from the Bohemia Hop Co. Ltd. Rainfall data in Zatec city was provided by the Hop Research Institute Co. Ltd

Three types of porous material, kieselguhr burnt fine (KBF), kieselguhr burnt coarse (KBC), and perlite (P), shown in Table 1, were applied to the hop roots as shown in Table 2 and Figure 1. A total of 24 plants were used for each test and the amount of porous material applied per plant was 20 L. Fine and coarse kieselguhr were tested because kieselguhr particle size might affect the amount of water absorption and soil aggregate structure formation. The yield from plants treated with KBC was 29%-44% higher than that of the control, and this effect continued for at least three consecutive years (Figure 4). Following KBF application, yield increased only during the second year. The yield did not increase significantly following P application over the 3 years.

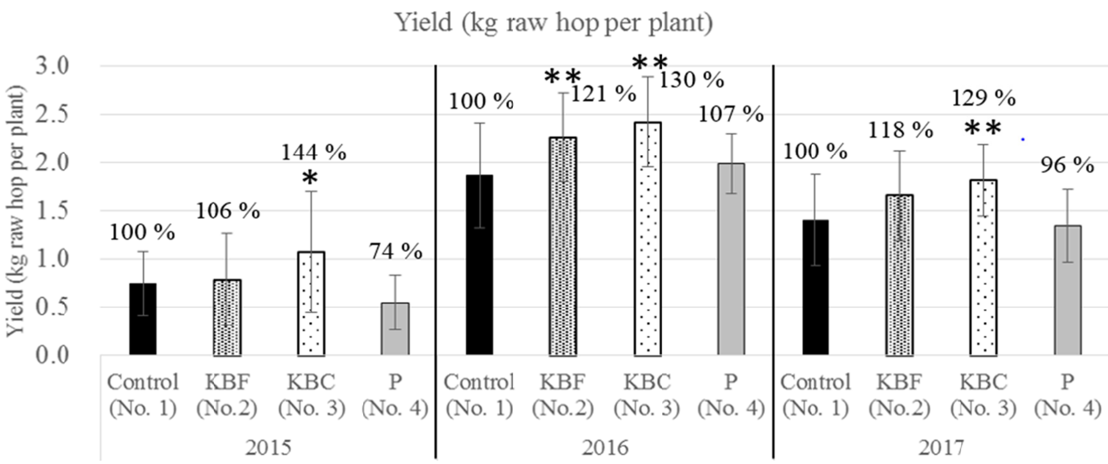

Figure 4. Average raw hop yield per plant. Calculations were based on data from 24 plants. Asterisks indicate significant differences from the yield in the control during the same year; *: $P < 0.05$ and **: $P < 0.01$. Porous material was applied only in 2015

The difference in soil temperature between the control and the treatments was not significant (data not shown). Soil water content around the hop roots after KBC was applied to the plants was always higher than that of the control in 2017 (Figure 5). This tendency was also confirmed in 2015 and 2016 (data not shown). However, no stable increases in soil water content in the KBF and P treatments were observed compared to that of the control (data not shown). The soil water content suggested that water retained by KBC near the hop roots might increase the yield. Yields in 2015 were, in general, lower than those in 2016 and 2017. The amount of rainfall in 2015 was the lowest (see Figure 2 and 3) of the 3 years, and this might have caused the low yield in 2015. The yield increase ratio owing to KBC application in 2015 was 44%, which was higher than that in 2016 (30%) and 2017 (29%). The increase in yield owing to KBC application might be larger under conditions of low rainfall. This implies that KBC might contribute to hop yield stabilization.

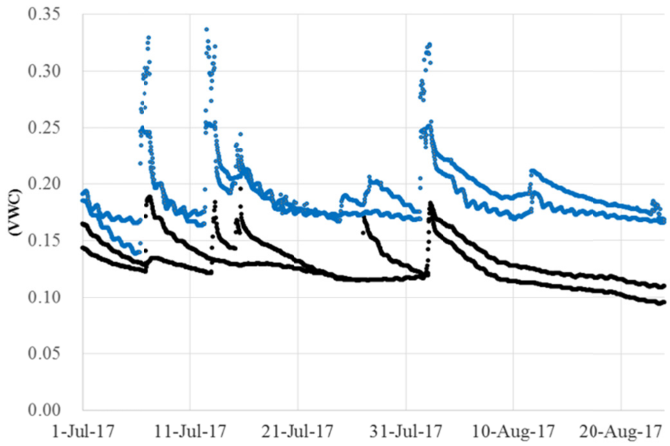

Figure 5. Soil water content from July to August 2017 from test No. 1 (Control, black dots) and test No. 3 (KBC, blue dots). Measurement sensors were set for two randomly selected plants in each test. The measurements were taken once per hour

The amount of essential oils was measured, and humulone and linalool content was analyzed as an indicator of beer quality. No significant differences between treatments were confirmed between hops harvested in the same year (data not shown). Figure 6 shows the comparison between the control and KBC application that yields were higher than control (Figure 4). The blooming period, leaf mineral content in July, and the indicator of chlorophyll content (SPAD value) were also determined, and no significant differences were confirmed between KBC and control hop plants (data not shown). In addition, no difference in hop cone size was confirmed. Therefore, KBC might not affect the physiological state and secondary metabolism of hop plants. This suggests that there are no significant differences in hop quality between treatments. KBC supplied water continuously to the roots of hop plants, and this might have increased the number of hop flowers (cones), leading to an increase in yield.

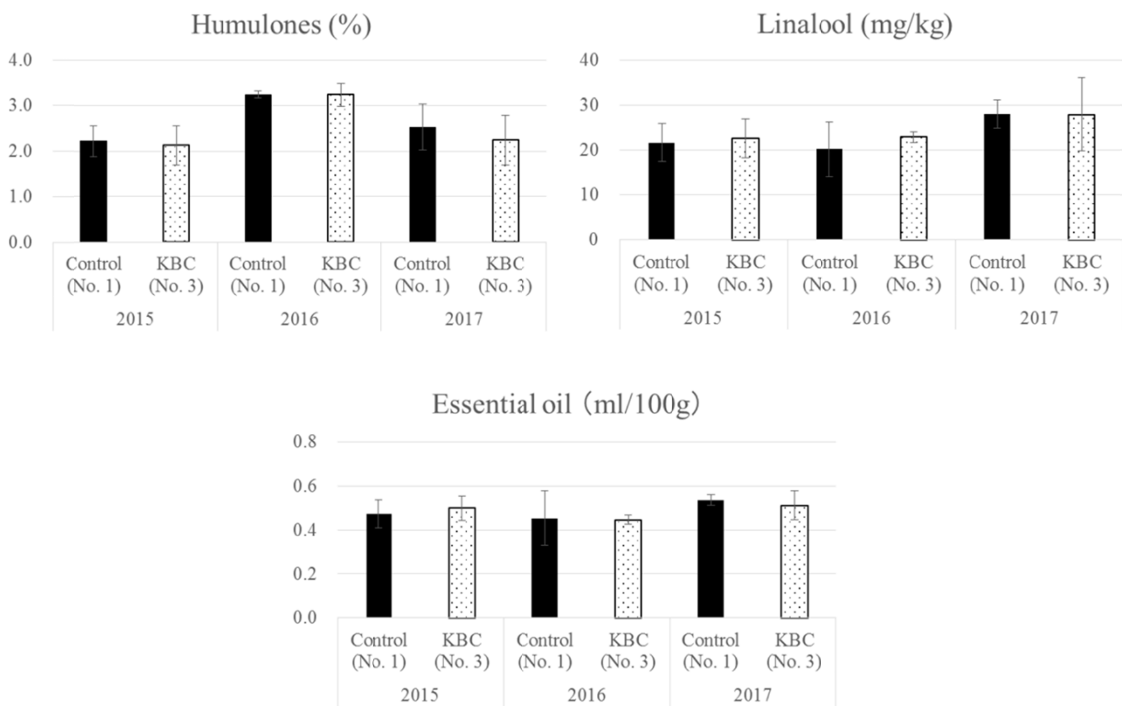

Figure 6. Hop qualities harvested from test No. 1 (Control, black columns) and test No. 3 (KBC, dotted columns)

Another coarse kieselguhr, kieselguhr dried coarse (KDC) was studied in 2017 (Tables 1 and 2) because the effect of coarse kieselguhr (KBC) was confirmed in 2015 and 2016. However, no difference in yield (Figure 7) or quality (data not shown) was observed from those of the control.

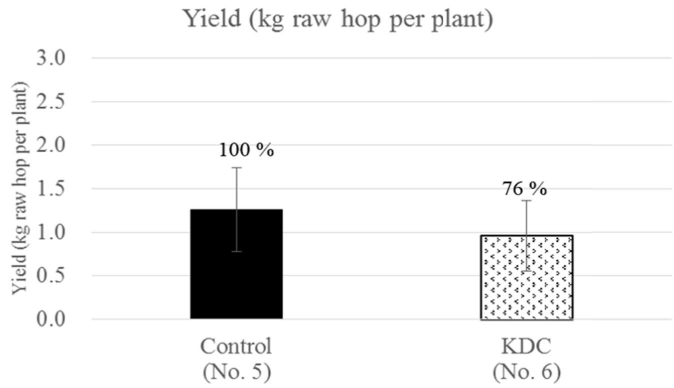

Figure 7. Average raw hop yield of one plant in 2017. Calculation was based on eight plants. Significant difference was not confirmed between the control and KDC application treatment. KDC was applied in 2017

WAC was measured in the four porous materials (Figure 8). The WAC of KBC was the highest among these materials (580 mL L^{-1} KBC). This high WAC might increase the soil water content and lead to a higher hop yield. Although the WAC of KBF was high (520 mL L^{-1} KBF), it did not increase soil water content (data not shown) and hop yield (Figure 4). KBF with saturated water lacked sufficient air space (Figure 9). Therefore, air supply to hop roots and the water supply efficiency of KBF might be low. Although two different particle sizes of kieselguhr were used in the present study (Table 1), the range of particle sizes suitable for increasing hop yield remains unclear. This needs to be determined in future research. The WAC of KDC and P were lower than that of KBC. These reflect the soil water content (data not shown) and hop yield (Figure 4). KBC was prepared by burning at 600 °C for more than 30 min, which removed the organic substances present in the porous spaces. Nonetheless, some organic substances might have remained in the porous spaces of the KDC, which were smaller than those in the KBC. In addition, organic substances in porous spaces might inhibit the absorption and release of water from the porous spaces.

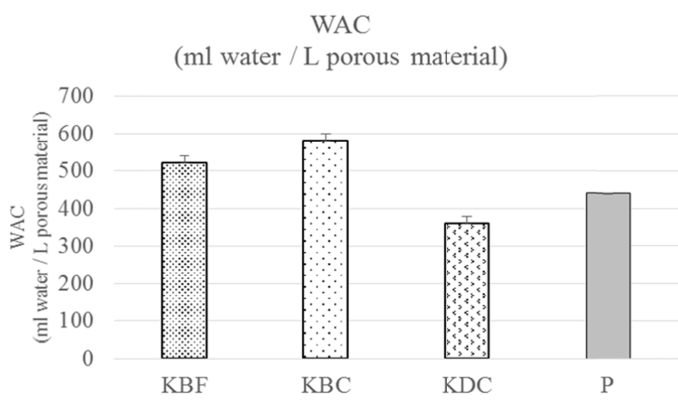

Figure 8. Water absorption capacity of each porous material. Significant differences (P < 0.01) were confirmed in all the combinations

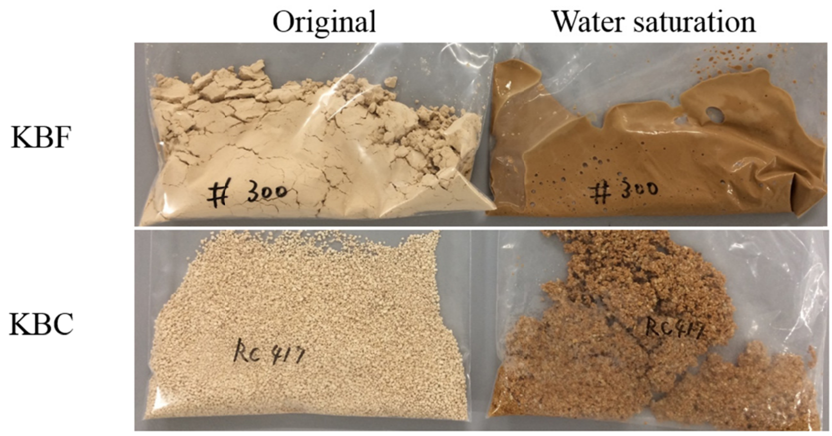

Figure 9. Kieselguhr before and after water saturation

The optimal amount of KBC to be applied to increase hop yield has been under study since 2017 with the ultimate aim of application by hop growers in their hop gardens. Application of 14, 8, and 2 L KBC was undertaken in April 2017 (Table 2). The same level of yield increase observed with 20 L application was also confirmed in the smaller application (Figure 10). Moreover, the soil water content following the application of 2, 8, and 14 L KBC was higher than that of the control (data not shown). It was found that 2 L of KBC could contain 1 160 mL of water from WAC (Figure 8) and this amount of water was maintained near the hop roots, thereby facilitating yield stabilization. If a grower applied 4 L of kieselguhr and 20% yield increase was achieved every year, then the initial investment (*i.e.*, the cost of kieselguhr) would be realized within 3 years. This cultivation technology would stabilize the income of the growers, procurement by hop suppliers and brewers, and might contribute to the sustainable development of both the hop and beer industries.

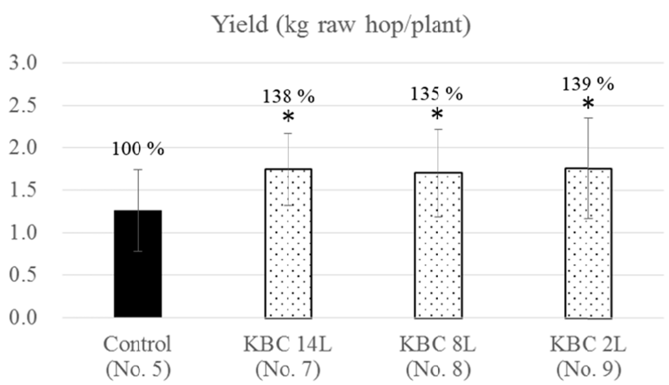

Figure 10. Average raw hop yield per plant. Calculation based on 16 plants. Asterisks indicate significant differences, $P < 0.05$ as compared with control yield (No. 5). KBC application was done in 2017

4. Conclusion

The addition of KBC near hop roots increased yield over three consecutive years without affecting quality. KBC might contain water in its porous space and facilitates both watering and aeration continuously. This technology stabilizes the activities of hop growers, suppliers, and brewers, and might facilitate sustainable development of both the hop and beer industries. In addition, it is expected that this technology would contribute to the development of other crops with high water requirements.

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