Studying Hops Growth
with Airborne Hyperspectral Imaging

Hops are a perennial crop. Only the female hops plants grow the cones used for brewing beer. Production takes place in hops yards, and plants can grow up to seven meters in 70 days. It's one of the fastest growing land plants.[1]

HOPS DISEASES AND PESTS

Economically, *Pseudoperonospora humuli, Phorodon humuli, sphaerotheca macularis,* and *Tetranychus urticae* are the most relevant threats to hops due to the high damage potential. They occur annually with varying intensity, depending on weather conditions. They are easy to control with integrated pest management, which is necessary to produce hops of high quality for brewing.

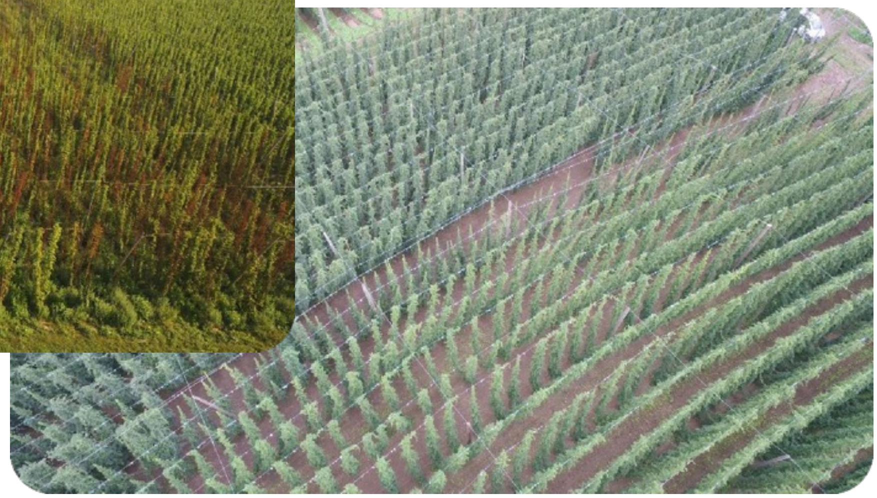
SEVERE DISEASES

Verticillium nonalfalfae and *citrus bark cracking viroid* (CBCVd) are also economically relevant due to high damage potential, which builds up year after year. The plants stay infected and infectious until the death of the of the plant and cannot be controlled with any known plant protection product.

CBCVd causes the plants to be stunted and not reach the full height of seven meters, decreasing yields.

Left: Fungal diseases- downy mildew and powdery mildew.
Right: Hop aphids and spider mites, the two most important pests.

Verticillium nonalfalfae is a soil-borne fungus initially detected in 1952. A more aggressive strain was discovered in 2005 which affects even tolerant hops varieties.



Left: *Verticillium nonalfalfae*
Right: *Citrus bark cracking viroid*

PLANT PROTECTION

In the area of plant protection, a new application rating system was validated (leaf wall area) for the conversion of plant protection products from other plant types like grape vines or apples. Plant protection products will be used from these cultures on hops in the future. LiDAR data was used to measure the cross-section, the pixels were counted, and the cross-section per hectare ground surface was calculated. The cross-section area was then compared with the measured leaf surface area, as well as to the calculated leaf wall area.

There were high correlations between all three of these values. The cross-section area is nearly 100% the same surface as what was calculated for the default area, showing a connection between the calculated and measured values.

VERTICILLIUM WILT

Verticillium wilt assessment takes a lot of time. For the best treatment, early detection of infected plants is extremely important, so the infected plants can be removed as soon as possible and prevent the fungus in the soil from spreading.

Hyperspectral imaging data was measured by a Headwall sensor mounted to a drone. High resolution images were needed because there are only about 4000 plants per hectare. Hyperspectral data captured by satellite could not be used because the 10-meter resolution currently available is not sufficient.

Hops plants also needed to be distinguished from the soil, as well as the intercrop growing between the rows to reduce erosion. Individual vegetation indices identifying *Verticillium* were calculated.

The vegetation index was validated by additional data collected through conventional assessments. This method needs to be further developed and the research on this topic has only started.

Healthy hops in Bavaria, Germany

The Headwall Nano HP hyperspectral imaging sensor mounted on the DJI M350 drone, with LiDAR

STATIONARY SENSOR

Additional research was conducted using a stationary hyperspectral sensor—the **Headwall MV.C VNIR**—and the **perClass Mira® Stage** to achieve control compositions or "ground truth."

Experiments were conducted on the early detection of powdery mildew and spider mites, in the hope that these pests and similar diseases can be evaluated in the same way as verticillium in the future. Once the plant is affected, changes can be seen in the reflectance using hyperspectral imaging. The hops-specific index can then be calculated in these areas. However, the data is still in the process of being fully analyzed.

The Headwall MV.C VNIR hyperspectral imaging sensor mounted on the perClass Mira® Stage

OPPORTUNITIES AND CHALLENGES

Obstacles like shadows inside the hops yard because of the plant height, and also when direct sunlight is not at its center, can be a challenge, and expertise was needed with the evaluation of data. The University of Eichstätt, who also work with Headwall reseller **geo-konzept**, GmbH, assisted with this. Non-destructive observation in big, observed areas has vast potential, and could potentially be automated in the future.

The high growth rates of hops are especially important because of climate change and globalization. It's only a matter of time before the next pest or disease arrives. With the help of remote sensing, the spread can be monitored.

Headwall

LEAF PHYSIOLOGICAL DIFFERENCES BETWEEN SIX HOPS SPECIES USING HYPERSPECTRAL UAV DATA AND TERRESTRIAL CHLOROPHYLL MEASUREMENTS[2]

This study was conducted in Bavaria, Germany, near Adelschlag, at Hallertau Stadelhof. The study area was about 12,500 square meters, with 20 different hops species planted there. Six of them were studied.

DATA SAMPLING METHODS

Two different data sampling methods were used. First, hyperspectral flight with UAV, and the day after, terrestrial chlorophyll measurements. For hyperspectral data sampling, a DJI M600 UAV with a **Headwall Nano Hyperspec®** sensor were used with 400-1000nm range.

The area flown was seven lanes with an overlap of 40%. For the test scanning, a pushbroom scanner was used. There were some cloud formations during the data flight, which resulted in some shadowing.

Hops Type	PER	HMG	HKS	HEB	MBA	Tango
1.50m	44,9	50,8	51,9	46,7	54,4	48,0
2.50m	43,7	48,2	50,6	48,1	53,8	47,2
4.00m	44,9	47,9	48,3	46,7	52,3	43,7
Ø	**44,5**	**49,0**	**50,3**	**47,2**	**53,5**	**46,3**
Ranking 1.50m	6.	3.	2.	5.	1.	4.
Ranking 2.50m	6.	3.	2.	4.	1.	5.
Ranking 4.00m	5.	3.	2.	4.	1.	6.
Overall ranking	**6.**	**3.**	**2.**	**4.**	**1.**	**5.**

Plant No. / Hops Type	PER	HMG	HKS	HEB	MBA	Tango
P1	44,9	49,6	51,5	46,6	54,1	46,9
P2	45,3	48,0	50,2	46,2	52,7	45,3
P3	44,9	47,6	51,0	49,4	54,2	47,3
P4	44,9	47,5	49,1	47,6	53,5	46,5
P5	43,3	47,6	49,0	49,5	50,6	46,2
P6	43,8	49,5	50,6	46,8	51,3	49,0
P7	44,1	48,9	52,7	42,6	54,5	47,2
P8	40,9	48,7	47,0	47,8	53,7	47,0
P9	48,4	49,2	49,5	49,3	52,9	45,9
P10	43,1	51,2	48,1	48,3	50,4	46,2
P11	43,8	46,5	48,2	47,8	54,3	47,4
P12	44,9	50,1	51,4	50,3	53,8	48,2
P13	44,4	50,5	48,9	48,1	55,0	43,3
P14	44,4	51,4	52,5	47,9	56,5	46,2
P15	43,9	47,6	49,4	44,0	55,0	47,1
P16	44,0	48,1	52,6	48,8	54,1	50,0
P17	45,3	50,3	51,0	46,0	55,1	37,8
P18	43,8	49,3	51,3	47,1	52,0	45,2
Ø	**44,3**	**49,0**	**50,2**	**47,4**	**53,5**	**46,3**
Overall ranking	6.	3.	2.	4.	1.	5.

Fig.1–2: SPAD values measured with the SPad 520 Plus

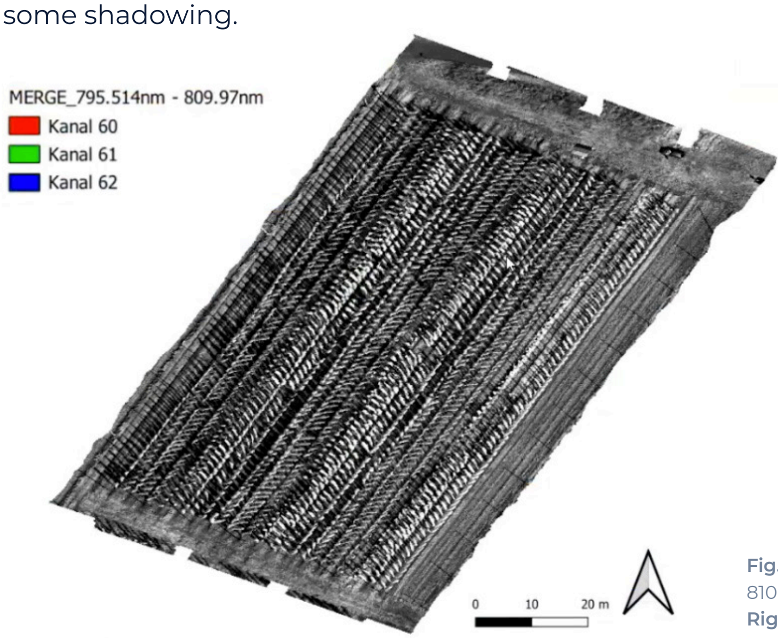


Fig. 3: Left: Merged hyperspectral data within the wavelengths of 796nm - 810nm for better distinction between plants and shadows.
Right: A zoomed-in image of the scene from the left.

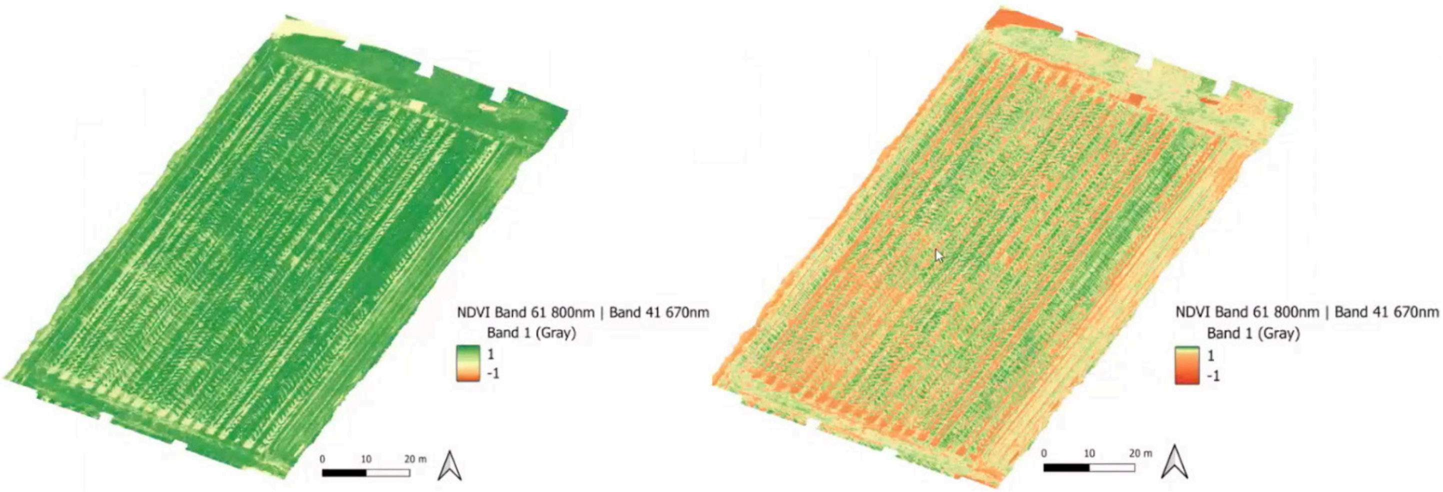


Fig. 4: Left: NDVI of the study area with a linear colour optimisation. **Right:** NDVI of the study area with a quantile colour optimisation.

Figure 1 shows the difference in height levels of the plants: 150 meters to 254 meters. Every plant in the test area was planted in the ground and has two strings fixed on the top. For every strain, there were six measurements on both sides of the plant at 150 meters high.

Two additional measurements were made on the 250 meter side and the last two at four meters high. For the height level, the leaf closest to the string was measured, and then on the leaf most distant from the string to illustrate this specific height level. Twelve different measurements were taken per plant. A ranking system was made for every hops type, to show which kind of hops are best and adapted to the climate.

The other measurements were in the hyperspectral flight. The sampling is a merge of hyperspectral data with wavelengths between 796nm and 110nm. Bands 61 and 62 were used since those make it very easy to see the distinction between a plant and its own shadow. All plants are highlighted in white and the shadows are black (Figure 3).

For the indices so far, a basic one was calculated that shows the normalized difference in vegetation in NDVI (Figure 4). The left side has many plants and the vegetation rate is very high. There is a lot of dry vegetation on the ground but the hops were rather low. It's a completely green area with a linear optimization that makes it hard to distinguish which plant is which.

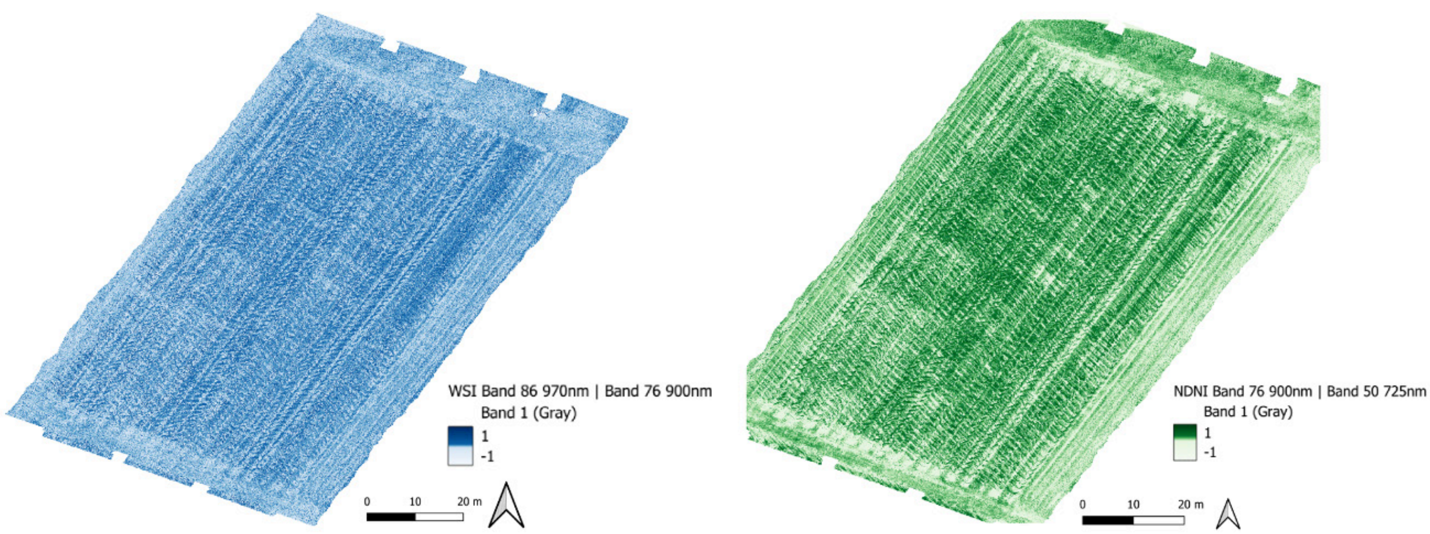


Fig. 5: Left: WSI of the study area with a linear colour optimization. **Right:** NDNI of the study area with a quantile color optimization.

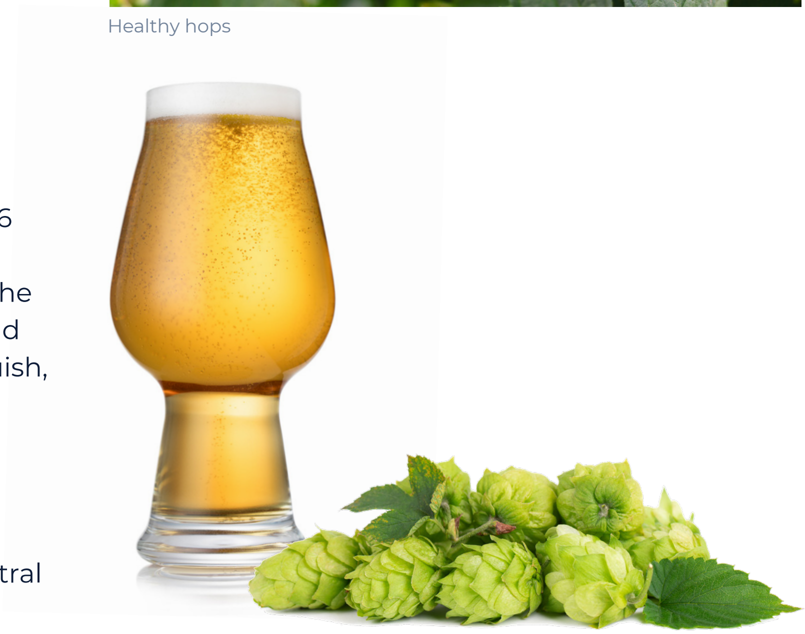
Figure 4 shows an NDVI quantile optimization color, where you can see that the range in values differs very much. The lowest value was -1, and the highest value was close to 1. There is a very wide range in the low levels, but as the top of the plants were reached, it's easy to distinguish the hops, soil, or grass, and point to a specific plant for an exact value.

Another two indices are the water stress index (WSI) and the Normalized Difference Nitrogen Index (NDNI), shown in Figure 5. Both are very relevant because they show the conditions of plants overall. On the left, you can see the water stress index. This image can be studied closely to distinguish each different plant very well. In the Figures 3-4 it's hard to distinguish the hops from the surrounding soil, or small plants like grass. But on the NDNI image, which is bands 76 to 50, and 725nm to 900nm, this worked quite well. You can differentiate between plants and the surroundings. The soil is highlighted in white and all of the hops in the middle are easy to distinguish, allowing the study of specific plants.

FURTHER OUTLOOK

More indices will be calculated correlating with plant conditions, and to evaluate the hyperspectral data in relation to these indices. In the end, a comprehensive table will be created with all hops types listed, along with the corresponding Soil Plant Analysis Development (SPAD) values and other measurements. The goal is to conclude which hops type was the best according to the data measurements. This might be interesting for the future, for example in relation to climate change, to show which hops types are more adapted to a dry environment or rapidly changing weather extremes.

Healthy hops



Beer and hops

[1] Weiß, Florian, 2024 03 12, Remote Sensing Using Multi- and Hyperspectral Sensors in Hops [Plant protection in hops], Airborne Hyperspectral Imaging in Hops Webinar

[2] Hajek, Daniel, 2024 03 12, Leaf Physiological Differences Between Six Hops Species Using Hyperspectral UAV Data and Terrestrial Chlorophyll Measurements, Airborne Hyperspectral Imaging in Hops Webinar

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