LemnaTec Scanalyzer 3D

Influence of alignment on plant bio volume

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Plant alignment in the Lemnatec Scanalyzer 3D

For reproducible assessment of plant growth based on plant volume LemnaTec recommends to align the plants in a constant way to provide best data for later plant volume calculation.

Theory

Determination of the error for the volume calculation of non aligned plants from 2 dimensional digital images

The theoretical volume V of a plant from three 2 dimensional digital images is calculated as follows:

$$V = c \cdot \sqrt{A_t \cdot A_1 \cdot A_2} = c \cdot \sqrt{A_t} \cdot \sqrt{A_1 \cdot A_2}$$

where A_t is the measured top view area and A_1 and A_2 are the 2 measured side view areas and c is the calibration factor.

As A_t is independent from the alignment of the plants, $\sqrt{A_t}$ can be considered as a constant factor, which is not interesting for the determination of the error for the volume calculation of non aligned plants (same as c)

But A_1 and A_2 are depending on the alignment of the plants.

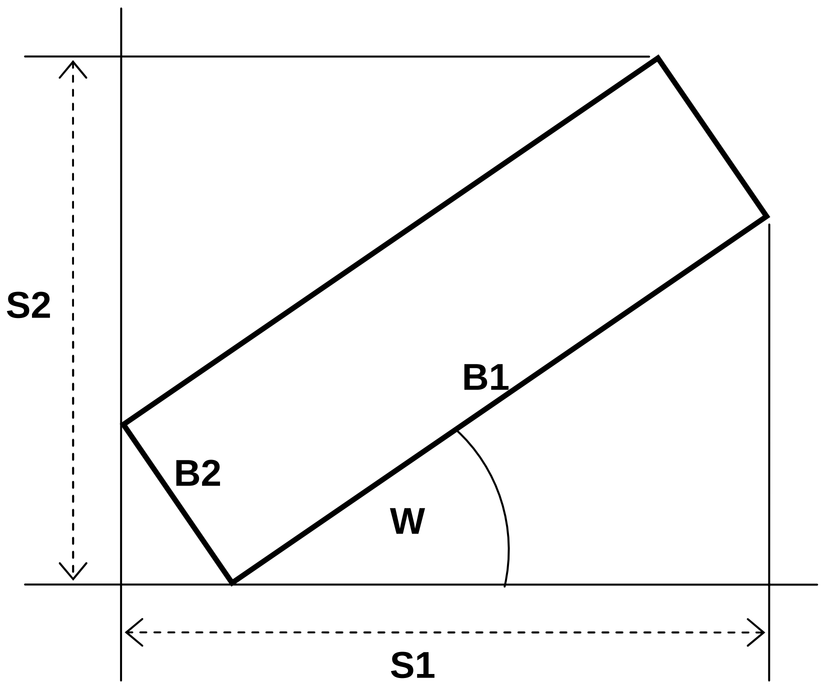
$$A_1 = h \cdot B_1$$
$$A_2 = h \cdot B_2$$

where h is the height of the plant and B_1 and B_2 are the real widths in the 2 projections. Insert A_1 and A_2 in V

$$V = c \cdot \sqrt{A_t} \cdot \sqrt{h \cdot B_1 \cdot h \cdot B_2} = c \cdot h \cdot \sqrt{A_t} \cdot \sqrt{B_1 \cdot B_2}$$

Again h is independent from the alignment of the plants and thus can be considered as a constant factor, which is not interesting for the determination of the error for the volume calculation of non aligned plants (same as c)

But B_1 and B_2 are depending on the alignment angle W.



With $W = 0$ for ideal alignment the 2 measured widths S_1 and S_2 at any alignment angle W are:

$$S_1 = B_1 \cdot \cos(W) + B_2 \cdot \sin(W)$$
$$S_2 = B_1 \cdot \sin(W) + B_2 \cdot \cos(W)$$

The measured Volume V_S at any alignment angle W is then:

$$V_S = c \cdot h \cdot \sqrt{A_t} \cdot \sqrt{S_1 \cdot S_2}$$

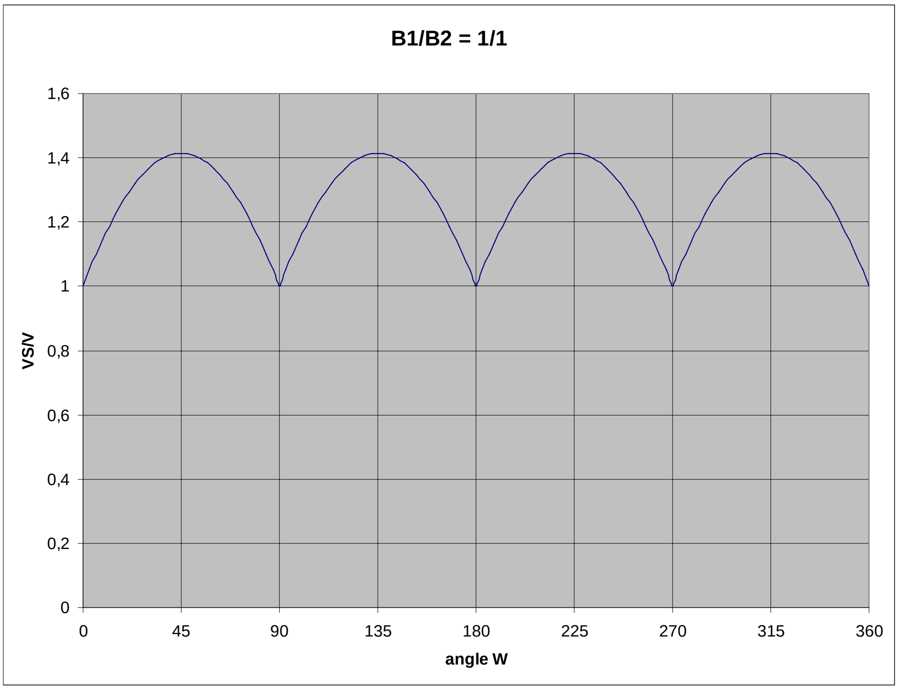
Insert S_1 and S_2 in V_S

$$V_S = c \cdot h \cdot \sqrt{A_t} \cdot \sqrt{\left(B_1 \cdot \cos(W) + B_2 \cdot \sin(W)\right) \cdot \left(B_1 \cdot \sin(W) + B_2 \cdot \cos(W)\right)}$$

Thus the ratio of the measured Volume V_S (at any alignment angle W) and the real Volume V (at alignment angle $W = 0$) is:

$$\frac{V_S}{V} = \frac{\sqrt{\left(B_1 \cdot \cos(W) + B_2 \cdot \sin(W)\right) \cdot \left(B_1 \cdot \sin(W) + B_2 \cdot \cos(W)\right)}}{\sqrt{B_1 \cdot B_2}}$$

This ratio is depending on the alignment angle W and on the ratio B_1 / B_2
The following figure shows the ratio V_S / V for $B_1 / B_2 = 1 \quad (B_1 = B_2)$



For misalignment angles of 90°, 180°, 270° and 360° $V_S/V = 1$ $(V_S = V)$ which is obvious (no alignment angle error)

The maximum error is at misalignment angles of 45°, 135°, 225° and 315° which is also obvious.

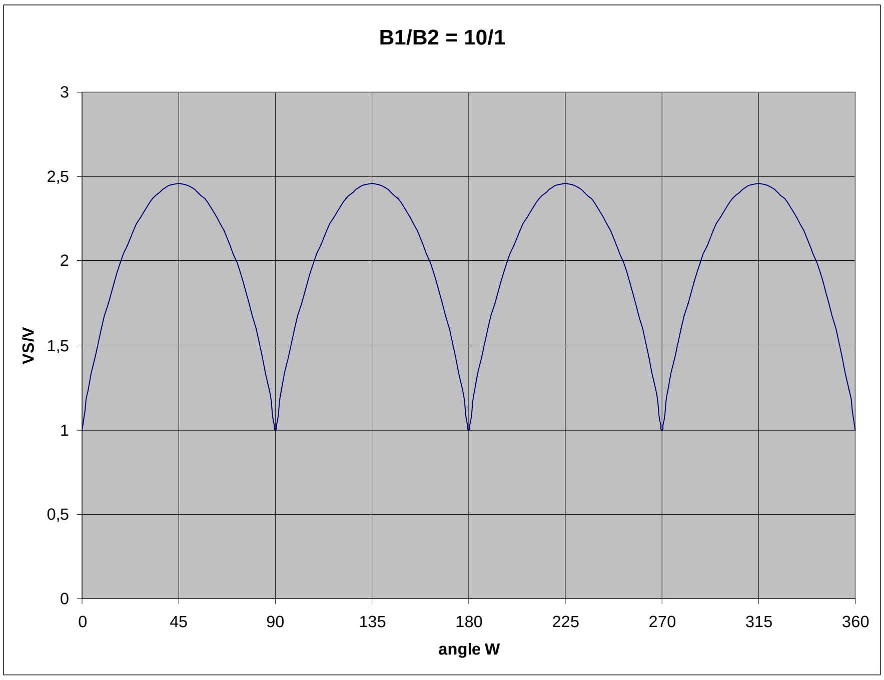
Apart from this the error is systematic: $V_S/V \geq 1$ for all alignment angles *W*. This means that the measured volume *Vs* is always greater as or equals the real volume *V*

The maximum error is minimal for $B_1 = B_2$. In this case the maximum error (at 45° misalignment) is $V_S/V = 1.41$

This means that the measured volume *Vs* is up to 1.41 times bigger than the real volume *V* for $B_1 = B_2$ (depending on the alignment angle *W*)

But for real maize plants $B_1 = B_2$ is not true, since maize plants are growing in one plane which means $B_1 >> B_2$. For $B_1 = 10$ and $B_2 = 1$ the maximum error is $V_S/V = 2.46$

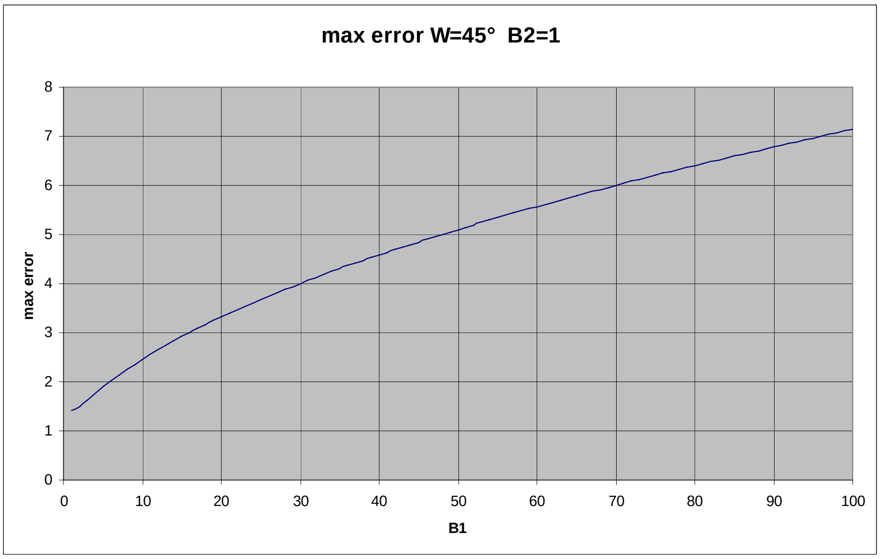
This means that the measured volume *Vs* is up to 2.46 times bigger than the real volume *V* for $B_1/B_2 = 10/1$ (depending on the alignment angle *W*)
The following figure shows the ratio V_S/V for $B_1/B_2 = 10/1$



With $\sin(45°) = \cos(45°) = 1/\sqrt{2}$ and $B_2 = 1$ the maximum error only depends on *B₁*

$$\left(\frac{V_S}{V}\right)_{W=45°} = \frac{B_1 + 1}{\sqrt{2 \cdot B_1}}$$

The last diagram shows the maximum error (at misalignment angle *W* = 45°) for *B_1* between 1 and 100 and $B_2 = 1$. As one can see the maximum error V_S/V varies between 1.4 for $B_2 = 1$ and 7.1 for $B_2 = 100$ which means that the measured volume *V_S* is up to 7.1 times bigger than the real volume *V* for $B_1/B_2 = 100/1$ (depending on the alignment angle *W*)



Praxis:

Results for a real plant

The following example and theoretical outline shows, how non alignment may influence the results of volume calculation.

All results refer to plants having significant anisotropy in growing. The example shown here are corn plants.

The real data were based on one plant as shown below turned in 45° segments and imaged each time from the side.

Image analysis to produce plant areas were done by LemnaTec Bonit HTS.
The size of the area from top remained constant.

The following images show the plant from two angles (0° and 90° after turning in the Scanalyzer 3D) and the top image.

Fig. 1 Images of the plant analysed from broad side (0°) after 90° turning and from top.

The plant shown here has a side area ratio (0°/90°) of $B_1/B_2 = 1.08$
This value is very important as the theoretical analysis above shows.
For a larger set of plants this value may range between 1 and 20.

The following table shows the area values for turning different angles and the calculated bio volume $V = c \cdot \sqrt{A_t \cdot A_1 \cdot A_2}$

	Side1 Area	Side2 Area	Top Area	Bio Volume
0	7,97	8,56	6,3	20,73
45	9,06	8,74	6,3	22,34
90	8,56	7,97	6,3	20,73
135	8,95	8,74	6,3	22,20
180	7,97	8,56	6,3	20,73
225	8,74	8,95	6,3	22,20
270	8,56	7,97	6,3	20,73
315	8,95	8,74	6,3	22,20
360	7,97	8,56	6,3	20,73

Tab. 1: Areas and bio volume dependent from the turning angle of the plant before first imaging. The second image is taken 90° turned from the first one.

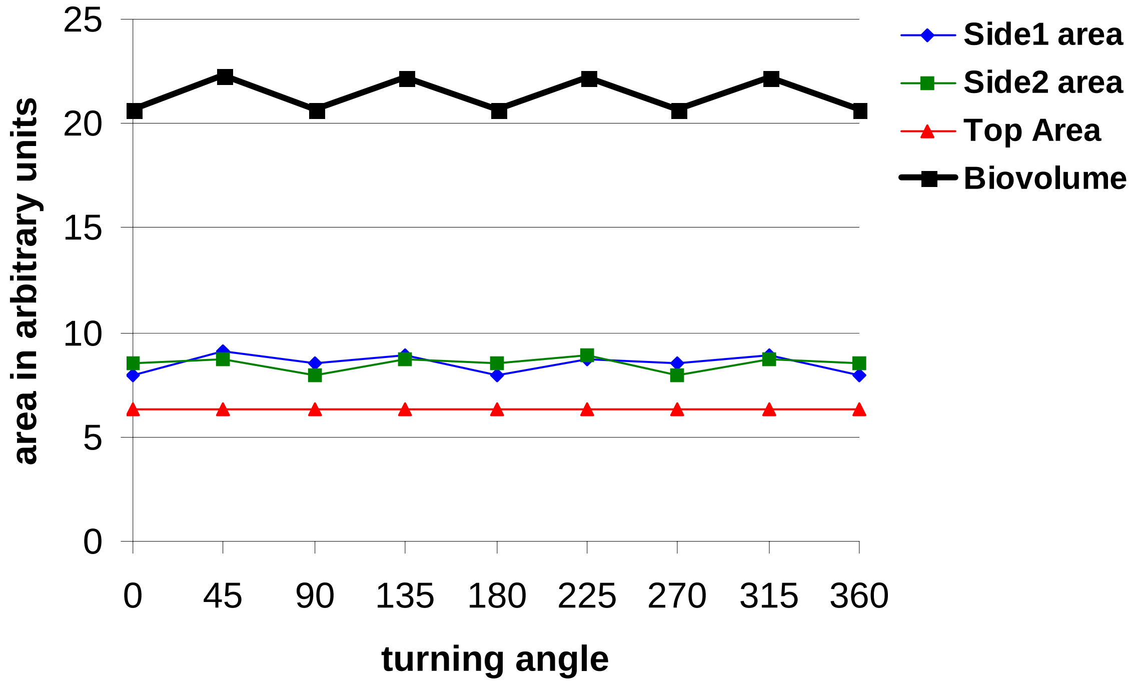


Fig.2: Areas and bio volume dependent from the turning angle of the plant before first imaging. The second image is taken 90° turned from the first one.

For the plant shown, difference between bio volume for optimum and worst alignment (45°) is about 10 % which is less than the predicted value of the theory which is 40% error for “straight” plants with $B_1/B_2 = 1$

Discussion of results

The plant shown here has a ratio of only 1.08 between the two side images. As the theory above shows the differences caused by misalignment are strongly dependent from this ratio. Testing more examples with higher ratios between the side areas may show how large this influence can get.

Even a 10 % uncertainty is much higher than the uncertainty of the Scanalyzer system thus the elimination of the alignment procedure will for sure reduce the achievable precision of the LemnaTec Scanalyzer 3D.

The higher amount of measurement noise which additionally depends from the shape of the plants can surely lower statistical significances between plants.

Other results of image analysis like any morphological assessment and e.g. length measurement of leaves or plant architecture may suffer even more from misalignment than the quite integrative bio volume.