LemnaTec Scanalyzer 3-D

The Influence of Alignment on Plant Bio Volume

Dr. Jörg Vandenhirtz
Matthias Eberius
LemnaTec GmbH
Schumanstr. 18
52146 Würselen
+49 (0)2405-4126-12
joerg@lemnatec.de
www.lemnatec.com

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Plant Alignment in the Lemnatec Scanalyzer 3-D

For the reproducible assessment of plant growth based on plant volume, LemnaTec recommends a consistent alignment of the plants to obtain optimal data for subsequent plant volume calculation.

Theory

Error determination of image-based bio-volume calculation for non-aligned plants

The image based bio-volume *V* of a plant can be calculated from three 2-dimensional digital images as follows:

$$V \; ? \; c \, ? \sqrt{A_t \, ? A_1 \, ? A_2} \; ? \; c \, ? \sqrt{A_t} \; ? \sqrt{A_1 \, ? A_2}$$

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 of the plant alignment, $\sqrt{A_t}$ can be considered as a constant factor, which is not interesting for the error determination for the volume calculation of non-aligned plants (same applies to *c*).

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

$$A_1 \; ? \; h \, ? B_1$$
$$A_2 \; ? \; h \, ? B_2$$

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*:

$$V \; ? \; c \, ? \sqrt{A_t} \; ? \sqrt{h \, ? B_1 \, ? h \, ? B_2} \; ? \; c \, ? h \, ? \sqrt{A_t} \; ? \sqrt{B_1 \, ? B_2}$$

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

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

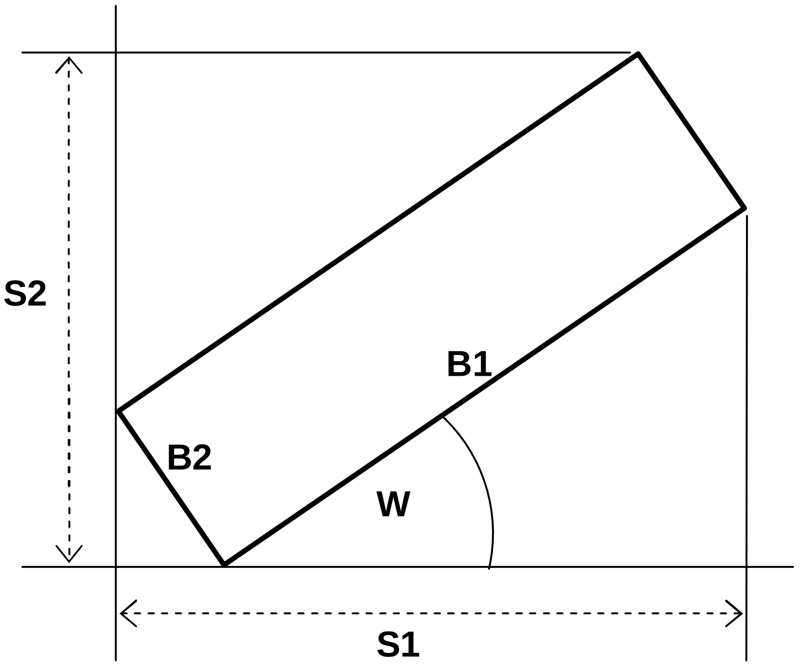

Figure 1: Dependency of S1 and S2 from the angle W.

With *W = 0* for ideal alignment, the two 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 $B_1/B_2 = 1$ $(B_1 = B_2)$

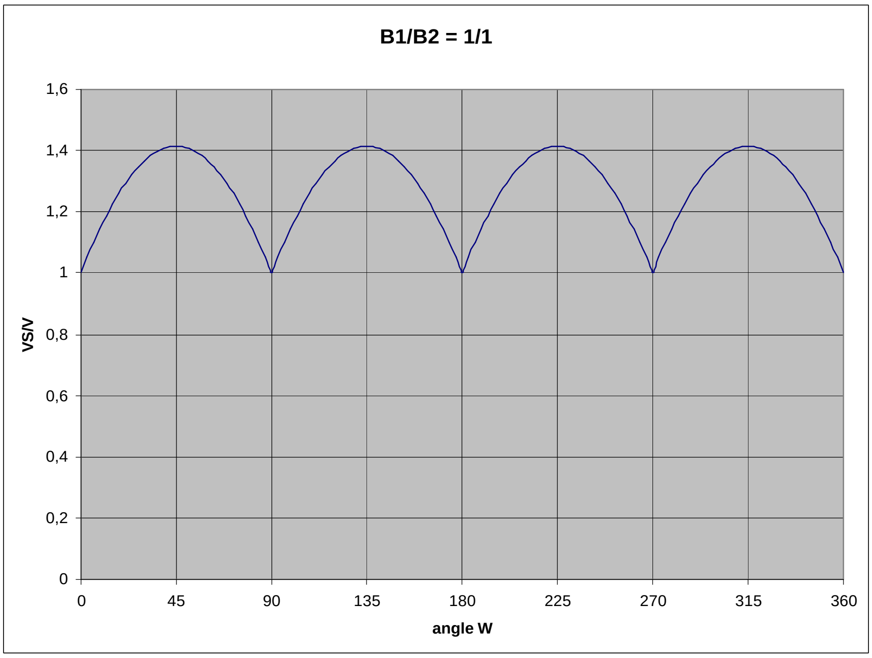

Figure 2: Dependency of the ratio of measured Vs and the real volume received by consistent orientation along the main axis from the angle of photographing the object. Here a cubic structure is analysed (B_1 = B_2).

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 that the error is systematic: $V_S/V ? 1$ 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 $B_1/B_2 ? 10/1$:

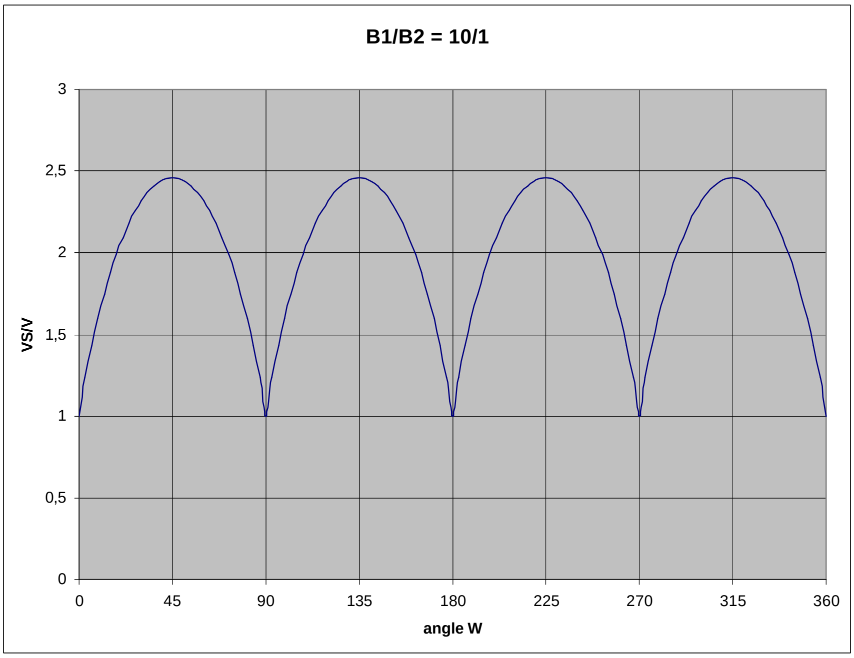

Figure 3: Dependency of the ratio of measured Vs and the real volume received by consistent orientation along the main axis from the turning angle W. Here a fairly flat structure is analysed (100 B_1 = B_2).

With $\sin(45°) = \cos(45°) = 1/\sqrt{2}$ and $B_2 = 1$ the maximum error only depends on B_1

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

The last diagram shows the maximum error (at misalignment angle W = 45°) for B_1 between 1 and 100 and $B_2 = 1$. As can easily be seen 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).

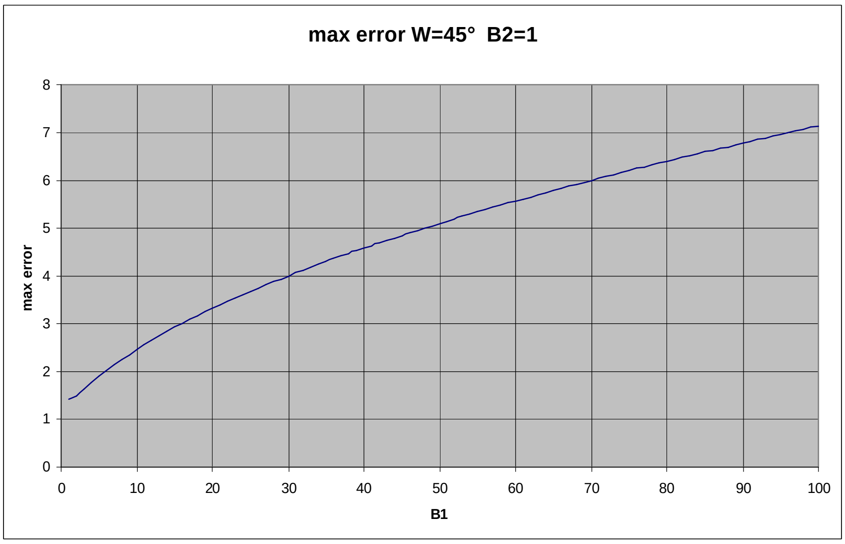

Figure 4: Dependency of maximum error for 45° from the ratio between B1 and B2 (here $B_2 = 1$).

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 examples 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 for the creation of plant areas was done by LemnaTec Bonit HTS.
The size of the area from top has remained constant.
The following images show the plant from two angles (0° and 90° after turning in the Scanalyzer 3-D) and from the top.

Fig. 1 Images of the plant analysed from broad side (0°), after a 90° turning and from the 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 shown by the theoretical analysis above.
For a larger set of plants this value may range between 1 and 20.

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

	Side 1 area	Side 2 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, depending on the turning angle of the plant before the first imaging. The second image is taken after a 90° turn.

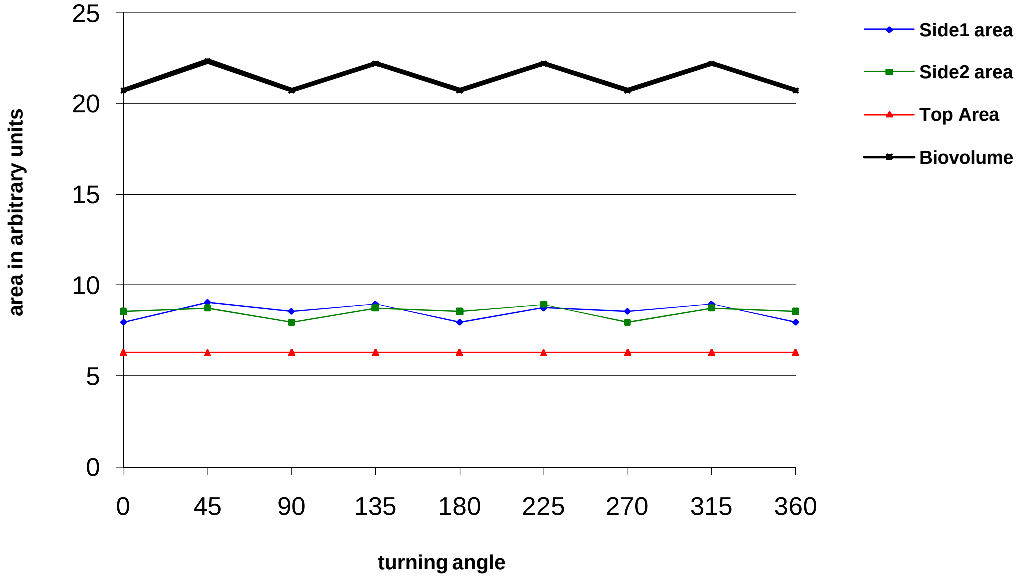

Fig.2: Areas and bio volume, depending on the turning angle of the plant before the first imaging. The second image is taken after a 90° turn.

For the plant shown, the difference between bio volume for optimal and worst alignment (45°) is about 10 %, meaning that it is less than the predicted theoretical value, which is a 40 % error for "straight" plants with B_1/B_2 ? 1. For plants growing under near field conditions with fully oriented leaves in one plane, the practical error will be much closer to the 40 % of the theory than to the 10 % measured here.

Conclusion

LemnaTec Scanalyzer 3-D imaging and greenhouse management systems provide a technology for high-precision measurements. Cultivation of plants in round pots, use of accurately oriented cars on conveyor belts and automatic turning devices allow pre-orientation of plants in the cars by hand, which is kept as long as the plants remain on the belts (or are reoriented due to biological reorientation, particularly with young plants). Additionally, an automatic reorientation scheme is available as a separate, customised add-on.

In all cases a defined orientation of the plant can massively increase the significance of quantitative results and allow detection of much smaller differences between plants and treatments, while reducing standard deviations for each single plant and within genetic or treatment groups.

For any questions or the development of customised solutions tailored to your particular needs, please contact LemnaTec.

LemnaTec GmbH
Dr. Jörg Vandenhirtz
Matthias Eberius
Schumanstr. 18
52146 Würselen
Germany
+49 (0)24 05-4126-15
matthias.eberius@lemnatec.com
www.lemnatec.com