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INSTALLATION OF SAP FLOW SENSOR ON MAIZE PLANTS

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Over the last 3 years a considerable effort has been implemented to upgrade the maize sap flow installation. There are new SGEX sensors which make the installation on corn very efficient, to minimize and completely reduce adventitious roots. The ability to install and leave stems without maintenance can be increased from 2 weeks to 4 to 6 weeks, depending on the growth stage. Previously researchers applied the SGB and the SGC sensors to corn, and were damaged due to the squeeze on the sensors, and due to other moisture from the stem. Both adventitious roots and damage from the “squeeze” on the sensor is eliminated by going with the more flexible SGEX sensors.

1 Preparation

1.1 The bottom two leaves should be removed form the stem leaving three segments with no leave between the three nodes. The sensor installation will be between the 2 and 3 node. The bottom 2 leaves will die out anyway, will not be a significant part of any transpiration, and they can clearly cause an interference of the sap flow sensor heat balance.

1.2 The objective is to have a clear stem, a) so that the thermocouples and heater will fit securely and enclose the securely to the stem; b) and to leave as much distance from the ground to the sap flow sensor.

1.3 Measure the stem and record the diameter size selection on the 2-3 node. The stem is oval shaped usually, so measure twice and take the average. If you wish the circumference may be measures, and the diameter estimated. Many well watered stems will be 19 mm diameter, up to 25 mm dimeter when fully grown.

1.4 Test by applying the sap flow sensor on the section of stem. The heater strip overlaps from 145% (at the most) around the circumference of the stem, or less. If the heater wraps too much it may buckle or crimp and a lower sized stem sensor need to be selected. If the heater does not wrap 100 % around the circumference of the stem and overlaps a bit, then the sensor is too small. You will need to go to the next higher sensor diameter.

Parts and Tools:

Caliper in metric (Or flexible measuring tape)

Scissors

Tape—office clear magic tape (1/2 in to 3/4 in. (13-19 mm))

Zip Tie Wraps— Some 12 " or 18 " to wrap the Reflectrix (aluminum bubble heat shield), and

Some 6 " tie wraps

Wrapping tape—2 inch packaging tape or flexible rubber tape.

Flexible electrical tape or stretch 1/2 or 3/4 in tape (13-19 mm)

G4 Grease (silicone electrical compound)

1.5 The trial fit of the sensor, showing that the Stretch Velcro starts at the middle. You will need to cut the stretch Velcro in half to do this. This is a trial fit ONLY. If the stem gage fits, remove it and proceed to the next step. After a few trials you can just check the fit very quickly.

2.0 Install "Food Wrap" stretchable plastic sheet (Saran Wrap).

2.0 Take a piece of food wrap, cut to the size of space between the two nodes #2 and # 3. The plastic wrap will prevent moisture from entering the stem section, and easily corrode the sensor or cause roots to grow. Roots will damage the sensor, and puncture the heater, or cause electronics to fail. The plastic wrap will be taped to the stem underneath the 3rd node, and above the 2nd node.

2.1 As shown DO NOT WRAP THE third node, as the moisture will cause the roots to grow out and damage sensors. Wrap only the purple marked part of the stem.

2.2 Stretchable food wrap is usually .25 X 10 –3 in. (.00025 in) will have insignificant delay in heat transfer of conduction.

3.0 Install sensor

3.1 Install G4 (electrical silicone compound) on the heater on the sensor and around the thermocouples. This will prevent sticking and corrosion. (Usualy 1/2 to 1 g)

Place the sensor onto the stem, about 1", (25 mm) below the 3rd node; and make sure the free end of the heater is wrapped underneath the opposite end of the sensor. Make sure that you do not crimp or fold the heater strip (and severe folding may be damage the heater and loose continuity).

3.2 Cut the Velcro Stretchable attachment (loop) into two pieces, and start by wrapping from the affixing hook strip around the heater, in the middle of the stem gage, and spiral clockwise upwards as you wrap around the stem. Only stretch the Velcro 25 % (pull hard to estimate 100 % first), then only stretch a little, since we want the plant to grow and not interfere with growth or constrict the stem.

Trim any excess Velcro at the top to the stem wrap.

Start at the middle, and wrap the bottom part in the same direction, clockwise, as the top. The sensor will **not move** very easily with a twisting motion.

4.0 Install Goretex (moisture micro-pore barrier)

4.1 A white moisture barrier shield is wrapped around the sap flow gage, and is taped on the top of the stem and once above the second node. Liquid Water will not penetrate the moisture barrier, however any water vapor from the stem will pass through the barrier and be evaporated or excluded from the sensor affixing section.

4.2 Goretex may be left open at the bottom, to allow any moisture drop to shed below to the ground.

5.0 Install Insulation

4.1 Add at least the two insulation shields to prevent rapid temperature changes to the stem test section. There are three provided with each sap flow sensors.

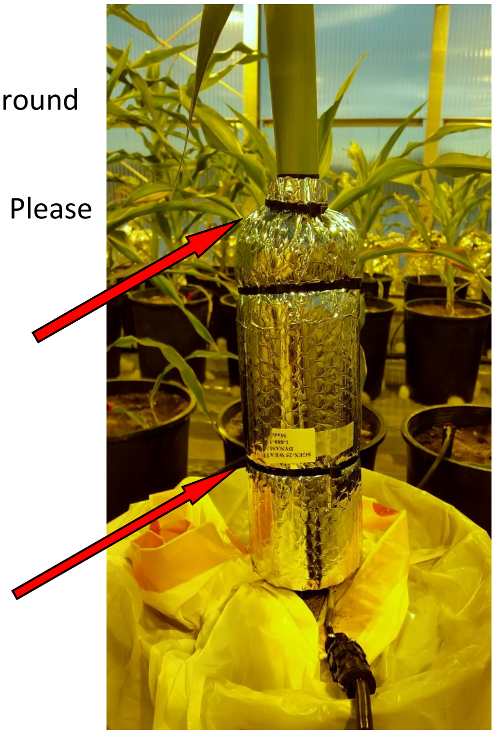
4.2 The bottom insulation is left off to allow the sap temperature to stabilize .

4.3 Plants are wrapped in plastic and tied off at the bottom of the plant to prevent evaporation when using a lysimeter device. Scale losses of each plant were within 6% of the sap flow computation over 43 complete day weight loss vs the daily sensor's accumulated transpiration. See page 10.

6.0 Install Heat Shield

6.1 Trim and wrap the reflector bubble shield at least 1.5 times around the insulation, and leave the bottom open.

6.2 Put tie wrap at the top, to make sure the heat shields secure. Please do not secure too tightly to restrict growth.



6.3 Wrap elastic tape or packing tape around the top layer of the stem, to ensure there will be no water or irrigation running into the plant—sap flow sensor junction. Any minimal leakage will be shed by the water micro pore protections.

7.0 Install and secure water protection on connector

7.1 Please secure the connection to a nearby plant, or stake that secures the cable to a wire-tie and prevents an accident from pulling on the connection.

7.1 As the connection is low to the ground, please verify the connector has a grey ring inside the male part, and that both the male has at least 1 g of G4 Electrical grease inside the connection to protect the contacts, and prevent moisture.

7.3 For longer exposure in very wet conditions, wrap an electric tape around the connector or in severe cases, you will need to wrap a rescue tape and layers of electrical tape.to secure the connector from flooding. The MEC connectors are reliable and rated for splash protections, thus if flooding or swamping over 30 minutes is expected, please refer to ftp.dynamax.com/sapip-support/Weather-Proofing-Connectors.pdf

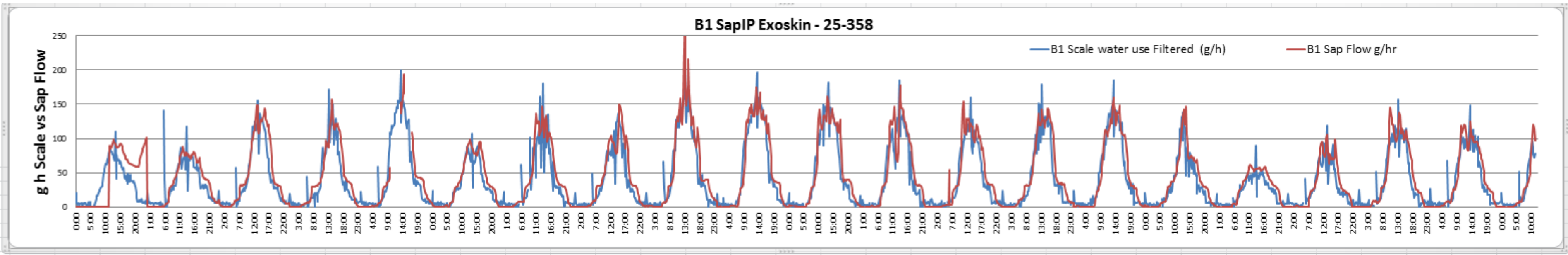
8.0 Conditions with Exo-Skin sealing method compared to Dynagage Sap Flow sensor.

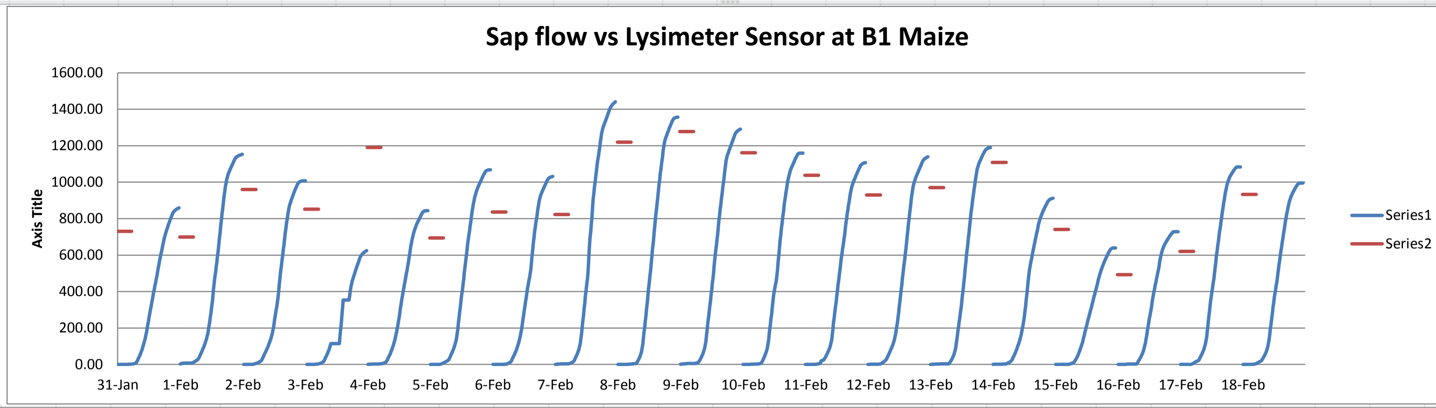
During the consultation and testing with USDA in Ft Collins, Dr. Louise Comas,   and with USDA in Bushland TX, Judy Tolk, we were able to confirm various aspects of the performance. The results were able to determine that the sap flow sensors, when applied at this protocol were very accurate, and sap sensors can last in the field for 4 to 5 weeks without damage or interruption of data set. Continuous operation of the data set was due to exclusion of moisture, and maintenance of the sensors.

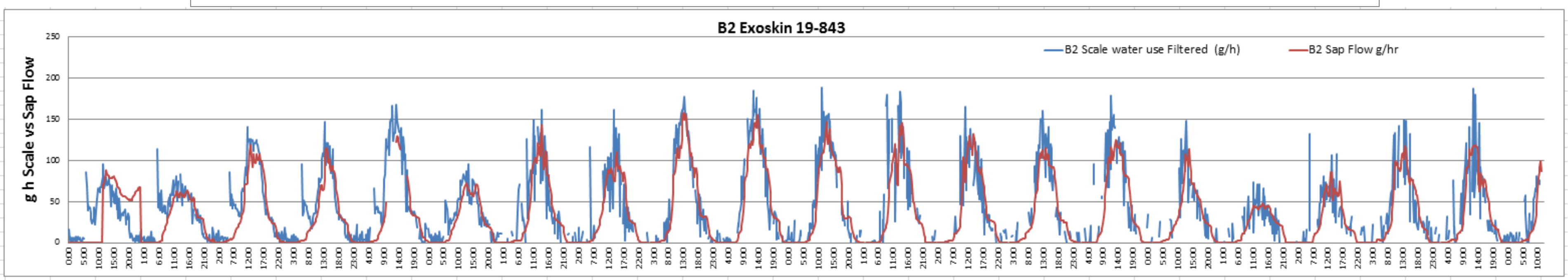
USDA in Ft Collins provided the data set on 5 Exo Skin sensors, and compared to six Dynagage sensor using a foil wrap around only the "Dynagage SGC" version of installation. In this condition the Dynagage did not have a micro-pore barrier (Gore-Tex), the insulation was not applied (only the sensor insulation), and aluminum foil was substituted for the Aluminized bubble shield. The testing in the greenhouse from Jan 30 to Feb 19, 2015, showed that the Dynagage had water collection after 4 to 5 days, and could interfere with heat distribution or shorting out the thermocouples inside the sensors.

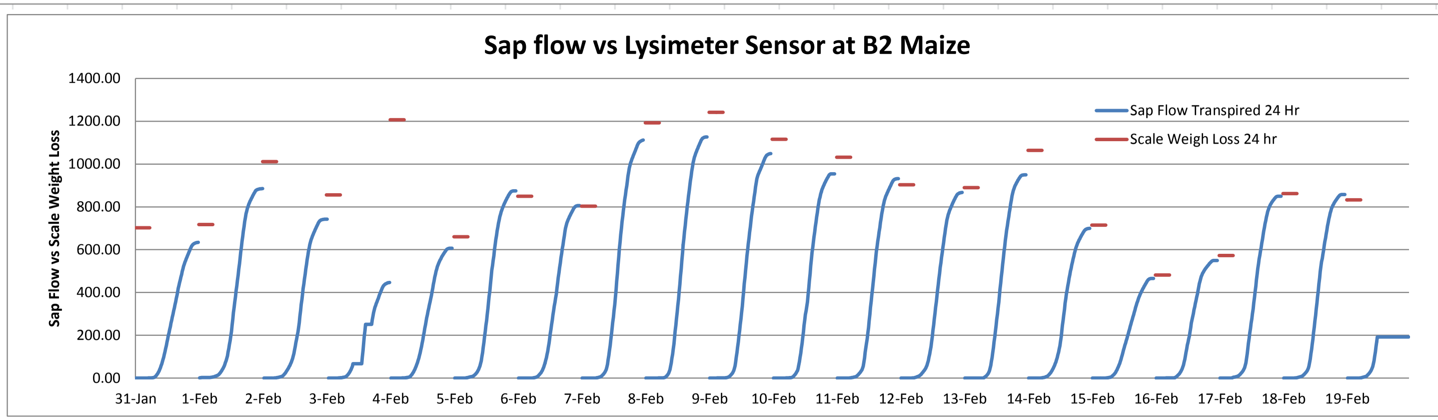
On the next page are the results of three of the Exo-skin sensors, over a three week test. One day Jan 30 is the "Ksh" setting day, and thus is excluded from comparison to the scale. All the results are downloaded exactly as the SAPIP recorded, and uploaded signals into the Agrisensors.net web site. There were no recalculation of the data set, only the typical Agrisensors.NET heat balance equations were then downloaded for each 15 minutes. That process allowed the data to be combined with the scale data very simply. The scale data reported its approximately 5 minute data, but did not always have a scheduled reporting interval.   The lysimeter scale is also affected by the 1 l irrigation interval from 5 am to and drained until 6:30. During the addition and water drainage the scale gain/loss is excluded from the data set. The lysimeter is also affected by fans putting wind pressure on the leaves, and thus there are plenty of "noise" in the quarter hourly comparison. At the end of the day, the most important detail is the daily loss comparing the two methods. On the average there is very little difference, with most sensor reading from a linear trend were 5% higher than the scale (Signal Analysis in Appendix 1). Note that on Feb 3, all the sensors were shut down for maintenance.

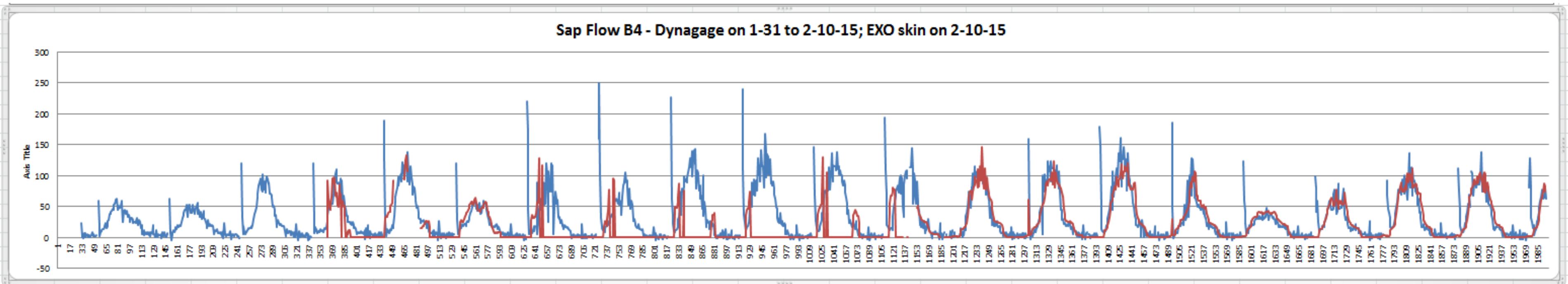
Overall the ExoSkin data standard deviation was within +/- 12 % range of the scale mean daily flow data set.

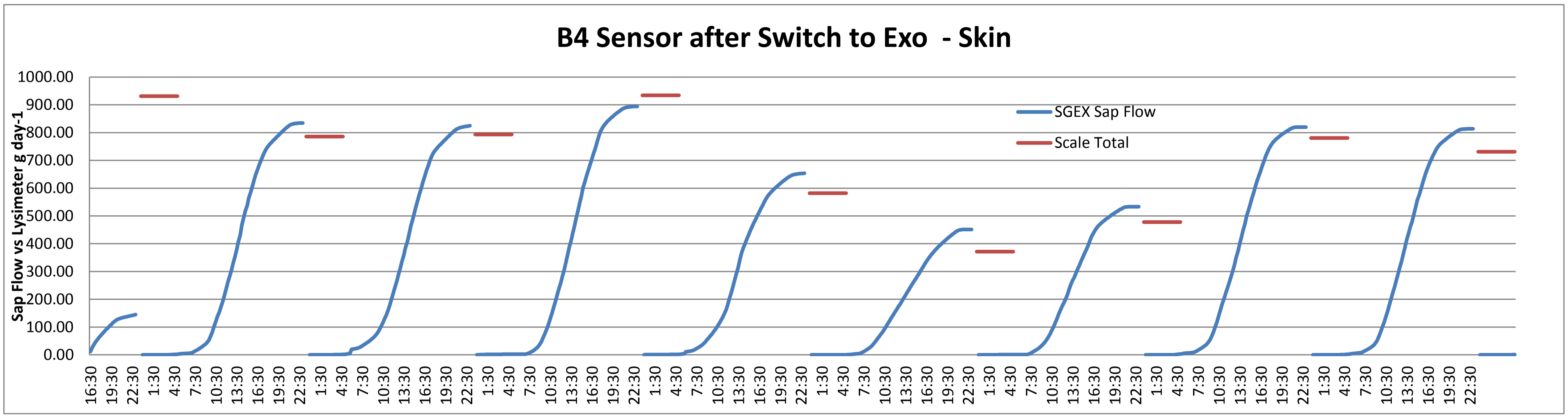

B1 SapIP Exoskin - 25-358
B1 Scale water use Filtered (g/h)
B1 Sap Flow g/hr
g h Scale vs Sap Flow


Sap flow vs Lysimeter Sensor at B1 Maize
Axis Title
Series1
Series2


B2 Exoskin 19-843
B2 Scale water use Filtered (g/h)
B2 Sap Flow g/hr
g h Scale vs Sap Flow


Sap flow vs Lysimeter Sensor at B2 Maize
Sap Flow Transpired 24 Hr
Scale Weigh Loss 24 hr
Sap Flow vs Scale Weight Loss


Sap Flow B4 - Dynagage on 1-31 to 2-10-15; EXO skin on 2-10-15
Axis Title

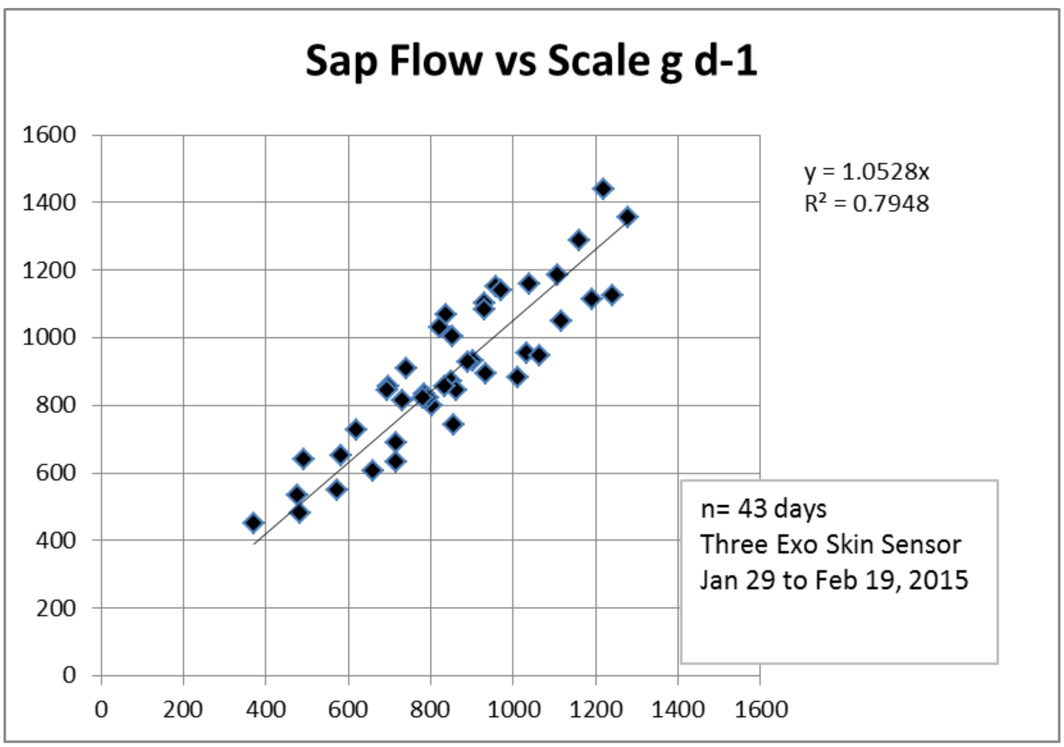

B4 Sensor after Switch to Exo - Skin
Sap Flow vs Lysimeter g day-1
SGEX Sap Flow
Scale Total

Appendix 1— Lysimeter vs ExoSkin sensor performance comparison

A trial experiment was conducted in the green house in Ft. Collins USDA, on a new installation designed by Dynamax and the USDA to minimize the water trapped inside maize stems and inside the sensors that would expedite the longevity of the SGEX ExoSkin sensors on maize. The details of the installation are described in an application report "Installation of Sap Flow sensor on Maize Plants" which may be downloaded from the Dynamax Web site (www.dynamax.com).

The results of three sensors sap flow was compared to the weight loss on lysimeter.

A shown in the weight losses and the sap flow transpiration, the sap flow is much more predictable than the sequence of weight loss. The air in the green house is moving very quickly, and there are stresses on the plant from the air, and will disrupt the weight loss. Typically a large weight loss gathered in one period as a spike is followed by another period with a dip in weight loss, cancelling the error. Also shown in the weight loss each day is the 900 to 1100 g of water injected into each pot with the plant at 5:00 am. The weight losses stabilize and some of the water is drained out of the plant as the injected water flows out of the bottom of some plants. Thus the total weight loss is the stable total after with watering (about 6 to 6:30 am), with the difference in weight at the end of the day at midnight. These values are in red at the end of each day, and can be compared to the sap flow transpired at the end of each day.



The mean sap flow for the 43 days was 871 g d-1, and the mean lysimeter weight loss was 822 g d-1. Sap flow was consistent with sap flow realized in the field, for stems from 19 to 25 mm diameter. The average error was 6% (50 g d-1) and the error standard deviation was 103 g d-1. Sap flow is 1.05 x the lysimeter weigh loss, with r2=.79

Appendix Note 2 — Ksh Setting

The daily zero set is required to set the Ksh factor that solves the energy balance. The Ksh (thermopile radial heat loss factor) is set when there is a low or zero flow. The Ksh is calculated as the "apparent" KshApp= (Pin-Qv)/Ch. The Pin is the power input computed with the heater voltage squared divided by the heater resistance, Qv is computed according to the literature on the conducted heat, Ch is the signal (mv) coming from the radial thermopile that indicates the loss of the heater power to ambient. The zero set was computed each day as an average of the three hours from 1:30 to 4:30 am. This value will be the average of the KshApp, (not precisely the minimum value) and is then set to the Ksh-in-use at 5 am. For the remaining part of the day the power equation computes the Qr=KshInUse*Ch. The Sap Flow heat flux for the remaining part of the day is Qf=Pin-Qv-Qr.

Since the formula for the KshApp depends on Qf equal to zero at the time the sensor equation is zeroed, there is a small error if there is some transpiration from 1 to 4 am. The scale loss was inspected and during that time, and the actual weight loss was an average of 3.7 g h-1 during the three hours over 12 days. If we assume the weight loss was from transpiration and not evaporation from the pot, the computed power for 4 g/hr is about .004 W. The total power loss for a 25 mm stem sensor is about .250 W, so the error in power from Ksh error is about 1.6 %, and not a significant issue for this application.

Appendix Note 3—Computing power for the stems, adjusting for lower noise signals.

Power for the sap flow equation in the SAPIP device is a monitored with the sensor input voltage that is regulated to 1/21 times the sensor cable end signal. For example if the voltage to the sensor heater is 4.0 V dc, the SapIp is actually recording 4/21= 0.190 V. The reason for this is the analog regulators can only have a maximum of 2.5 volts into the device, and requires all voltages to be scaled down with internal resistors that are built into the device. The precision of the resistors network is .1 %.

For the 25 mm stems the voltage was set to 4.2 to 4.3 volts and thus the power = .25 to .27 W. Earlier in the season, the voltage was set to 3.7 volts, and a few sensors were having too low a signal (dT lower than 0.5 C during the day) so all sensors were adjusted remotely to 4.2 to 4.3 Volts , increasing power by 28%. Before the power was increased the temperature dT (temperature above ambient) on the stems ranged from .5 to 4 degrees C, and there were no stem damage from heat. After increasing the power, stem temperatures above ambient in the recommended range and there were no heat damage as well. In general, for 19 mm stems the voltage to the heater was set to 4.2 Volts and the power = .2 W .