INTRODUCTION

SLIDE 1 [00.33]:

Speaker:

Today I’m going to talk about Non-destructive measurements of Leaf Area Index. This presentation will be a general introduction to the Gap Fraction Technique for determining plant canopy leaf area, and orientation. We will explain what is meant by canopy gap fraction shortly, but for now, we want to point out that although plant canopy gap fraction measurements can be obtained using a number of different methods, such as the LAI-2200 hemispherical photography Light-bar, etc.

The mathematical concept for extracting information about leaf area and angle distribution from gap fraction measurements themselves, are the same regardless of what instruments are used to collect the initial gap fraction data.

SLIDE 2 [1:17]:

Before we start, a quick explanation of terminology, and what we mean by Leaf Area Index, for those who might not be familiar with this term. The leaf area index or LAI of a plant canopy is, the one sided leaf area per unit ground area. So, for example, if per unit ground area, per square meter the plant canopy has a total foliage area of 3 square meters then that plant canopy has a leaf area index of 3. LAI has no units, as the square meters of the leaf area cancel out with the square meters of the ground area. One more piece of terminology,

SLIDES 3 & 4 [1:57]:

Apart from estimating plant canopy leaf area the gap fraction method is also useful for determining Leaf Orientation or leaf Tilt Angle. This slide illustrates what we mean by Leaf Tilt Angle. The leaf tilt angle is the angle of the leaf with respect to the horizontal plane.

SLIDE 5 [2:18]:
So, a perfectly horizontally oriented leaf has a tilt angle of 0°.

SLIDE 6 [2:24]:

Whereas, a perfectly, vertically oriented leaf has a tilt angle of 90°.

SLIDE 7 [2:30]:

The mean in this expression, the Mean Tilt Angle, refers to the fact that it’s a Mean for all the leaves in the canopy.

SLIDE 8 [2:36]:

So why measure Leaf area index? They’re are many reasons why Scientist want to measure leaf area index. Here are just a few of these reasons.

SLIDE 9 [2:45]:

Leaves are the primary means of capturing solar energy, and performing Photosynthesis. So LAI is a fundament interest of Scientists, since Photosynthesis is ultimately the source of food for almost the entire biosphere.

SLIDE 10 [3:00]:

Leaf Area Index determines how light is distributed within a Plant Canopy, modeled whole plant canopy photosynthetic rates using exponential decline in light intensity with increasing leaf area index, starting from the top of the canopy, down to the base. So modelers are usually, very interested in knowing the leaf area index of a canopy.

SLIDE 11 [3:23]:

Leaf area influences evaporation of water, and canopy temperature, two variables which are important in crop irrigation scheduling and drought stress development in crops.
SLIDE 12 [3:36]:

A change in leaf area index can be used to quantify the effect of a treatment or a stress. Such as—for example, defoliation by insect pest. So, entomologist might be interested in knowing changes in LAI with insect infestation.

SLIDE 13 [3:52]:

LAI is a measure of foliage density, and can be used as an analog of growth and biomass production.

SLIDE 14 [4:01]:

LAI also influences the soil temperature, the air temperature, the humidity, in fact the entire microclimate of the plant canopy. So all the organisms, microbes, insect pests, fungal diseases, etc., within the canopy and within the soil are effected by leaf area index. So LAI can have a profound effect on the ecology and its productivity.

SLIDE 15 [4:25]:

So, why use non-destructive measurements of LAI, when destructive measurements are surely the only real measurement? Well, here are some reasons why non-destructive approach may be preferable in certain circumstances.

SLIDE 16 [4:39]:

With destructive sampling, we can’t obviously come back to the same place again. So, for example, to look for small changes over a very short period of time.

SLIDE 17 [4:53]:

With non-destructive measurements, we can come back again and again to the same place as many times as is necessary.
SLIDE 18 [5:00]:

Also, measuring the LAI of forest canopy for example, destructively is very difficult if not impossible. Imagine cutting down a square kilometer of a forest and feeding through a leaf area meter such as the LI-3100. Or just imagine trying to sample one square meter of a forest without determining LAI. Which square meter would you select, and how would you sample it? How reliable would the results be?

SLIDE 19 [5:30]:

Another reason, is the sampling errors. Is that sampling errors involved in destructive measurements can be very, very, large. The typical coefficient to variation, even for a uniform agronomic plot is mostly greater than about 10%. And many destructive samples may be required to obtain a reliable site mean.

SLIDE 20 [5:54]:

With non-destructive measurements, it’s possible to take many measurements very quickly, to provide a more reliable and more stable mean. Anyone, who ever disputes using a non-destructive approach, should first try the destructive measurements for themselves to get a good feel for just how much uncertainty there is in destructively sampled harvests. Not to mention how much time and effort it takes.

SLIDE 21 [6:18]:

As we said, this talk is about the Gap Fraction Method for non-destructive Plant Canopy Leaf Area Measurements. So, what do we mean by the Gap Fraction Method?

SLIDE 22 [6:30]:

Well, has anyone ever shown you how to play the 52 card pick-up game? That’s what a good friend of mine once asked me when he saw that I had a new pack of cards for an upcoming social event.

SLIDE 23 [6:47]:
My friend proceeded to show me how to play the 52 card game pick-up, by scattering the cards onto the floor, just like in this photograph here.

**SLIDE 24 [6:56]:**

Well, there is a lesson to be learned from the 52 card game, pick-up. You see, that a, assuming the cards all fall randomly onto the floor, overlapping each other to varying degrees, it can be shown from statistical theory the Poisson distribution, that the total gap fraction between the cards, is an exponential function of the total card area. In other words, the total gap area decreases exponentially as more and more cards fall randomly onto the floor, as shown in this slide. The rate of decline of the gaps, would obviously depend on the total area over which the cards are to be scattered. In this example, the first card decreases the unobstructed floor area, i.e. the gap fraction from 100 down to about 93.5%, or the gap fraction is decreased by about 6.5%. So, the total area from which you would be picking up all of the cards, would in this case have been only about 15 times bigger than the size of the individual card. This estimate of the size of the floor you can derive by dividing 100 by 6.5. This is an example of my kind friend showing me the game in a nice way, in a kind way. We can see that, with increasing number of cards falling to the floor randomly, the effect of each card incurring the floor, or in reducing the gap fraction decreases exponentially. And that is because, with increasing number of cards falling to the floor, there is an increasing chance of cards overlapping each other, and this reduces the cards individual ability to obscure the floor, as more and more cards fall on floor.

**SLIDE 25 [8:47]:**

Well, the leaves suspended in a plant canopy, can be thought of in the same way as cards falling randomly on the floor. Except that we are now dealing—we are now looking upwards toward the sky instead of looking down towards the floor, and the leaves are not all orientated horizontally and they are not all located in one narrow plain at the top of the canopy. Instead the leaves are suspended in a volume of space above the ground. And there are additional complexities we need to deal with before we can have a proper handle, a quantitative handle on this problem.

We have to go from a two dimensional case of cards, flat on the floor, to a more complicated three dimensional case of a canopy having a volume.

**SLIDE 26 [9:40]:**

The first of these complexities involve explaining the look direction, within the canopy volume. Any particular direction, are either look angle or the probe angle that we will refer to later in this talk. Within
the canopy can be referenced with respect to an Azimuth angle and a Zenith angle. Now, what do we mean by Azimuth and Zenith angle. Well, the Azimuth is the angle on the horizontal plain, just like the compass bearing, so for example the Azimuth angle of 0° would be looking directly north. Whereas an Azimuth angle of 180° would be looking directly south.

The Zenith Angle, is the angle away from the perpendicular, the Z direction shown here. So for example, a Zenith angle of 0° would be looking directly up towards Z in this diagram. Using the Azimuth and Zenith Angle terminology, we can refer to any particular look angle within the hemisphere above the ground, or, within the plant canopy.

In this example the sun is located at a Zenith Angle of Theta I, with respect to the vertical, and at a Azimuth angle of Phi I with respect to the north direction. And that’s where the direction of the incident beam I, is coming from, as illustrated in this diagram. We also see a strong reflected component, leaving the plain in the direction marked by R which is located at the Zenith Angle of Theta Nu, Azimuth Angle of Phi Nu.

SLIDE 27 [11:24]:

One more complexity we have to deal with when considering leaves suspended in a Plant Canopy instead of a pack of cards scattered on a floor, is the fraction of the total area of the leaf area projected in any particular look direction, since the leaves are not all lying flat. We refer to this fraction, as G of Theta, where Theta is the look angle. So, in this example, we see in the first case, that 100% of the leaf area is projected in the look direction, so G of Theta has a value of one. This is similar to the card example. In the second example, the leaf is pointed edgewise to the look angle, and a very small or close to zero fraction of the total leaf area is projected towards the look direction, so G has a value close to zero.

SLIDE 28 [12:25]:

In other words, when you’re looking edgewise you’re not seeing much of the leaf area. One more point of terminology for real canopy that we have to deal with before we can quantify canopy leaf area and orientation is Foliage Area Density which is given a symbol of µ. Mu is the foliage area per unit canopy volume. So in this example of a tree, µ would be the total area of all the leaves in the tree, divided by the tree crown volume. The units of µ would be, per meter.

SLIDE 29 [13:00]:
In a horizontally continuous canopy, such as a wheat or a rice crop canopy, the foliage density $\mu$, would be the leaf area index divided by the canopy height.

**SLIDE 30 [13:13]:**

So, having introduced the basic terminology, we are now ready to deal with the theory of the Gap Fraction Technique, as applied to the real plant canopies.

In a real canopy, as a beam of light travels through the foliage, the probability of it encountering a leaf will mainly depend on the foliage density $\mu$.

**SLIDE 31 [13:34]:**

the distance traveled through the canopy, or the path length, which we’ll denote as $S(\Theta, \Phi)$ for particular angle Theta and Phi, and the probability of encountering a leaf will also depend on the factor $G$, the fraction of the foliage that is projected towards the look angle. We can see for example, that as foliage density increases, there is more leaf material per unit volume, and the chance of encountering a leaf increases. Or the chance of passing through or being transmitting through the canopy decreases. Also we see, the longer the distance traveled through the foliage, the higher the chance of meeting a leaf. And, we see that the chance of encountering the leaf increases if the greater proportion of the total area is projected or oriented perpendicular to the direction of the beam.

We should bear in mind that the random overlapping of the leaves, leads to an exponential decline in the light passing through the canopy, because the Gap Fraction decreases exponentially with increasing leaf area index, as there is more overlapping. This is just like the card example, except that we are now quantifying the effects of foliage density within the canopy volume, the distance traveled through the canopy, and the fraction of area projected through—towards a particular look angle.

**SLIDE 32 [15:02]:**

We’re now ready to express these thoughts, about randomly overlapping leaves suspended in the air, having a certain foliage density, with a certain fraction of the leaf area orientated in a particular look direction, etc.

**SLIDE 33 [15:20]:**
We can put all this into a quantitative expression, with an exponential response. This is analogous to the exponential decline of the gaps on the floor, with increasing number of cards falling randomly on the floor except, we have extended our thoughts from two dimensional case, of a flat surface, to a three dimensional situation of a canopy having a volume.

SLIDE 34 [15:43]:

Also, instead of using the probability of beam of light being intercepted, we will refer to the probability of the beam being transmitted or in other words; we will use canopy transmittance. \( T(\Theta,\Phi) \).

Transmittance is the probability of the beam passing through,

SLIDE 35 [16:00]:

and Transmittance is just the converse of Interceptance, what’s not intercepted is transmitted.

SLIDE 36 [16:08]:

Also, --if the leaves are totally opaque, and don’t allow any of the light they intercept to pass through them, then canopy transmittance would be equivalent to the Gap Fraction. This is why this technique is referred to as the Gap Fraction Technique, rather than as the Canopy Transmittance Technique.

SLIDE 37 [16:31]:

So, mathematically we can write the Canopy Transmittance \( T \) for angles, Theta Phi for a particular Zenith and Azimuth Angle decreases exponentially, with increasing Fraction of Foliage \( G'' \) of Theta Phi, and with increasing foliage density, the distance and the distance \( S \), travel through the canopy.

SLIDE 38 [17:01]:

The negative sign, just in front of the \( G \) tells us that Transmittance decreases in response to these three factors. By averaging over the Azimuth, we can now, eliminate having to deal with Azimuth Angle. And make the expression simpler, by dropping the use of \( \Phi \). In other words, we are really assuming, what we are doing, we are assuming that the canopy is uniform over the range of the Azimuth Angles under consideration. We don’t have to assume that the canopy is completely uniform all around.
Just that it’s uniform within the Azimuth sector we are taking a measurement. Next we take natural logs and regroup, and get an expression for $G$, of $\Theta$ times $\mu$, which equals the log of the transmittance, divided by the path length S. This ratio $K$ of $\Theta$ is called contact frequency in the literature, or the contact number in LAI-2000 data pages.

Some of the early work on the Gap Fraction Technique involved estimating Gap Fraction, by pushing metal needles through Plant Canopies at different angles. In that case $K$ of $\Theta$, the contact number or the contact frequency, will be the number of times the needle contacted a leaf as it was pushed through the canopy. Of course, it’s much easier to use light and modern electronics than to push metal needles through Plant Canopies.

So you can see that these are well established concepts, that predate modern electronics and instrumentation.

Miller integrated this equation, for values of $\Theta$ from 0-90°, or from 0 to $\pi$ over 2 radians as shown here. To give a solution for canopy foliage density $\mu$. This comes out as 2 times the integer of the contact frequency, $\sin \Theta d\Theta$.

Also, from the definition of LAI and foliage density, we can see that for an extended canopy, LAI is just $\mu$ times the canopy height $z$ and the distance $s$ through the canopy for any particular angle $\Theta$ is canopy height $z$ divided by cosign of $\Theta$.

Substituting for these relationship shows that LAI is 2 times integral from 0 to 90° of the negative log of Transmittance times cosign $\sin \Theta d\Theta$. 
For an extended Canopy of uniform height, we can substitute one of a cosign Theta for the distance, for the distance is giving us an LAI instead of a foliage density. On the right I’ve shown five Look Angles employed in the LAI-2200, and their relationship to canopy height $z$, and the path length $s$.

**SLIDE 44 [20:03]:**

In the LAI-2200 the integration for computing LAI, is performed by summing up over the five view angles, denoted here by $I$, 1 up to 5 employed in the LAI-2200. The Leaf Area Index, is simply 2 times the sum of the products of contact numbers $K_I$, and the weighting factors $W_I$. As mentioned before the contact number for a particular Look Angle is the negative log of the Transmittance divided by the distance traveled through the Canopy. And the weighting factors $W_I$ simply computed from the sign $\sin \theta d\theta$, for each angle $I$.

**SLIDE 45 [20:48]:**

The center point between the adjacent angles being used to determine sign, or the width of $d\theta$ for each of the 5 angles used in the LAI-2200. The weighting factors are all normalized so that their sum is equal to 1. And, this information is permanently stored in the LAI-2200 embedded software. In the box on the lower right hand side, are shown the five Look Angles used in the LAI-2200, these are, 7°, 23°, 38°, 53° and 68° these are the Look Angles employed by this instrument.

**SLIDE 46 [21:35]:**

The distances or the path length through the Canopy i.e. the $1/\cos(\theta_i)$ are in the middle column.

**SLIDE 47 [21:43]:**

And the weighting factors $W_I$ are on the right, in the right hand column of this box. All that is needed to compute the canopy

**SLIDE 48 [21:51]:**

LAI values are then the logs of the Transmittances, for computing the contact numbers from which LAI values are easily calculated. Well, here is a summary of the main assumptions of the LAI-2200 in relation to the Gap Fraction Technique.
So, the foliage, we assume that the foliage is black, and except when foliage is brightly lit by the direct beam of the Sun, this is a reasonable assumption, because the optics of the LAI-2200 are filtered to receive light in the blue part of the spectrum, where leaves Transmittance is very close to zero. This means that canopy Transmittances are really equivalent to Gap Fraction Measurements.

The leaves are also – we assume that the leaves are horizontally, in the Azimuth direction, or randomly oriented, giving an exponential decline in the Gap Fraction, with increasing foliage density, and increasing leaf overlapping.

We can allow for clumping of foliage, for example, within rows of crops or crowns of trees, and between the crowns of trees. Providing that, leaves are randomly distributed within the clumps. The dense clumps or rows of crops, should however, be sampled individually. The dense and the sparse segments should not all be averaged in one measurement view.

And the main reason for this is, that Leaf Area Index is proportional to the log of the Transmittance, and not the Transmittance. And when we—for example, do an average of Transmittances and then compute the logs, that number comes out a little bit smaller than computing the logs, and finding their averages. And so, if we average a large view and then, calculated the Transmittances, we end up with a slight under estimation typically, of full Leaf Area Index. We also, assume, that the foliage elements are small compared to the to view area, so we don’t just have one or two individual leaves, or gaps, dominating the entire view.
This shows you the assumption—illustrates the assumption that we are making about leaves being opaque. While leaves do transmit a little bit of the green part of the spectrum, that’s why they appear green in transmission and they also reflect a reasonable amount of green light,

**SLIDE 54 [24:26]:**

so they look green. In the blue part of the spectrum—they absorb nearly all of the light and so, assuming the leaves are black or opaque is quite reasonable.

**SLIDE 55 [24:43]:**

This shows you in fact, the figure here, the spectral transmittance and reflectance of a typical green leaf.

**SLIDE 56 [24:52]:**

We can see the transmittance in the blue part of the spectrum is negligible. The LAI-2200 Sensor head has filters in it to receive—to make sure only the blue wavelengths, wavelengths below about 490 (nm) are received by the detector.

**SLIDE 57 [25:10]:**

By random distribution of leaves in the Azimuth direction, we mean that leaves are not all aligned behind each other. This is generally true, leaves, tend to avoid being behind each other. In other words they don’t want to be in each other’s shade. They tend to distribute themselves evenly around a tree crown for example, to maximize light interception.

*Moderator:*

Tanvir, I’m going to stop you here. And, I have a question from Tom, and Tom asks, what about foliage that is uniform, like Conifers?

*Speaker:*
Okay, Conifers, that’s a very good question. When you have foliage that is not randomly distributed, there might be a lot of overlapping, all the needles are clumped on one shoot, when you take an interception Gap Fraction measurement, really you are taking the entire shoot, gap fraction. And so, you might have two or three layers of needles lying behind each other. In this case, you really would be under estimating the needle area index. And so, there are some corrections you can do, for example, you might take a few shoots, feed the needles through a leaf area meter, such as the LI-3100, and determined that the shoot area to total needle area is one to three, for example. And so, you would have to adjust your field measurements by that. That’s just one way of dealing with that, and there are other methods some quite clever methods under progress, by measuring the canopy gap distribution, from which you can also learn more information about this phenomenon and perhaps that—another time we can deal with that. That’s a more advanced question, but that was a very good question, thank-you.

SLIDE 58 [27:05]:
Okay, continuing back on to our presentation. This slide shows the sensor head of the LI-2200. It consists of a fish-eye lens arrangement, and a mirror, which reflects the image from above--focuses the image onto five circular detectors.

SLIDE 59 [27:26]:
This is in fact what the image looks like when focused on the five ring detectors of the LAI-2200 Sensor head.

SLIDE 60 [27:35]:
The sensor head outputs five values corresponding to the output of the five detector rings. Now, we mentioned earlier, that it was also possible to get information about leaf orientation, or mean leaf tilt angle from the Gap Fraction Technique. So, you might be wondering, what about that, how is that done?

SLIDE 61 [27:57]:
Here you see the top figure developed by Warren Wilson, shows how G the projected area, changes with look angle, or probe angle as it is shown here, the probe angle being Theta. For a hypothetical set of surfaces, tilted at angles, going from 0 to 90° shown on the right here, in steps of 10°. So, what we
are seeing here is how the projected area changes with look angle for hypothetical surfaces, tilted at ten different angles, from 0 to 90°. The lower figure here, shows the tilt, or the tip angle as labeled here, plotted against the slopes of the curves, from the top figure, i.e. we are showing the rates of change of G, with Theta for these ten hypothetical surfaces. In other words, the data for the lower figure is extracted from the top figure, showing the rate of change of G, i.e. dG/dΘ on the X-axis, plotted against the ten hypothetical leaf elements, titled at angles ranging from 0 to 90°.

In the LAI-2200 a fifth order, polynomial, fitted to the data in this lower figure, is stored permanently in the embedded software.

**SLIDE 62 [29:25]:**

Now, if we look again at the original equation,--which shows the relationship between G, foliage density, transmittance and the path length. We can see that once we have measured the values, determined the value of transmittance, and have computed the leaf area and the contact numbers, we can determine values for G for each angle Theta. These values of G are then regressed against Theta. Theta here is shown in radiance by the way. And the slope of this regression is the mean value, of the rate of change of G with angle for this canopy. We can now, substitute the value of this slope into the fifth order polynomial, which describes the mean tilt angle against the rate of change of G with Theta and compute the canopy mean leaf tilt angle.

**SLIDE 63 [30:51]:**

We also mentioned at the beginning of this presentation, that there were a number of different ways to obtain Canopy Gap Fraction measurements for use in determining leaf area index and orientation. Here is a list of some of the methods employed for measuring non-destructive the canopy gap fraction. We have, typically a popular method is use of digital hemispherical photography, of course we have the LAI—2200. Another method used is the Line quantum sensor, that’s just a long detector, light detector, and in some designs the fraction of the detector, lit by sun flecks is a measure of the Gap Fraction. There’s another instrument from Australia called the Demon, and in this instrument, it has a very narrow view angle and you point it at the Sun and keep it pointed at the sun, while you walk underneath the canopy, such as a forest, and so forth. And there is the original, ever popular, maybe not so popular anymore, is to push rods through the canopy and look at the at how many times they hit the leaf as you push the rod further towards--into the ground, towards the ground.

**SLIDE 64 [31:54]:**
Now here is a digital photo of a tree canopy. Now, if the optics and detector system of a camera are not able to resolve the small gaps high up in the tree, in the trees here, then, we will just end up with a shoot index, and this really relates to the question, that we had before, what do with needles and things like that. So just imagine when you have shoots and branches high up in the distance, you’ll not be able to resolve the small gaps very easily. The leaf area in this case, could be grossly under estimated; you really would just end up with a shoot area index, which would be several times smaller than the leaf area index.

A short crop canopy, such as for example, a corn canopy or soybean canopy, would be much less challenging than this situation shown in this forest photograph. So, digital photography, really works quite well for short canopies with large leaves. For tall canopies with small elements, leaves or needles, very high-up in the canopy, you would need high resolution to delineate the small gaps that are far away. Also, photography works best under overcast conditions, to maximize the contrast between the leaves and the sky. Digital photography does also require some significant computing power when their images are high resolution.

SLIDE 65 [33:32]:

These two photos of a tree canopy were taken just a few minutes apart, they illustrate how overcast conditions – why overcast conditions provide the best conditions for –and the best contrast for measuring gap fraction. And this is true whether you are using digital photography or the LI-2000. The photo on the left was taken with the sun obscured by a cloud; the photo on the right was taken with the foliage illuminated with the direct beam of the sun. The red circles show places in the image, where the under estimation of the gap fraction is particularly noticeable under conditions of bright illumination. And this kind of situation is scattered throughout this image. So that you can see, that under brightly illuminated, brightly lit foliage, there is a tendency for over estimating the gap fraction, and in fact under estimating the leaf area index.

SLIDE 66 [34:31]:

* Moderator:

Tanvir, I have another question for you, and this one from Gina. She says, what should I do if I absolutely have to take measurements under a sunny sky?
That's a very good question. A question that I'm asked quite frequently, during my work here at LI-COR. Well, one way to deal with this kind of situation is take measurements when the sun is low in the sky. In most cases, once the sun is about 15° above the horizon, in other words, the solar elevation is less than 15°, most of the leaves are then shades by other leaves. So, taking measurements—taking measurements with your back to the Sun, and of course use an appropriate view restrictor to block yourself out of the view of the sensor, than you’ll be measuring leaves—you’ll be looking at leaves that are shaded by other leaves and avoid looking at any brightly lit leaves. And the under estimation problem that we saw in the—and you will avoid entirely the under estimation problem that we saw in the previous photograph of the sun lit tree.

One other way of dealing with this problem, is to go ahead and take your measurements under whatever conditions, sunny conditions, if that’s what you have, and then, you’ll typically find there is, like a 10 to 15% under estimation of LAI for typical canopies when the foliage is brightly lit. And then what you do, you take measurements on the same plots, one or two plots—would be adequate, just before sunset, or under cloudy conditions when most of the leaves are not lit by the direct beam of the sun. And, so then you would compare these measurements with those measurements that were taken under the sunny conditions, and you’ll get the typical sort of under estimations that occurs when taking measurements with the brightly lit foliage. And of course then you can make your adjustments to all the rest of your measurements.

Well, getting back to our presentation, sometimes, we are asked if trunks and branches in tree canopies cause over-estimation of LAI, since they will also fill in the canopy gaps. And you can see some of the branches etc. in the previous slide of the trees.

Well, I have prepared a slide here, and you will see this is not as much as a problem as you might at first think. Here is a view of a tree canopy from above. Typically, even though a lot of branches maybe visible when looking up from the ground, up towards the sky. When looking down from the top, looking down at the same trees from the top, the branches are usually hidden, totally hidden behind leaves, and are mostly not visible at all. So, these leaves would be dominating the gap fraction measurements. If you
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Tanvir Demetriades-Shah
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could just imagine for a moment, that the branches were not there, so even if the branches were not there, what you’d probably see, is more leaves as there are many more leaves than there are branches. In other words, the leaf area completely dominates the view. The branches and trunk are usually a very small fraction of the total view.

Now, using the LAI-2200 in practice, is very easy but not always simple,

SLIDE 70 [38:19]:

As we said, there are a few things you have to watch-out for, like, not taking measurements under brightly illuminated conditions, keeping your back to the sun, even if it’s not brightly illuminate and of course, having a proper strategy for obtaining a good site mean. So, these are the things that usually cause problems. –The actual measurements themselves are very simple and really quiet easy.

In this example, in a short canopy such as this soybean crop, for example, what you do is, you take a reading above the—hold the sensor head above the canopy and take a reading, followed by a series of readings that you take with a sensor at the soil level, and the transmittances, or the gap fractions, the leaf area, mean tilt angle, etc. are all automatically computed by the control unit of the LAI-2200, from the ratio of these two measurements, from the above and the below measurements. The main thing you have to watch out for is, you have to take an adequate number of readings, to obtain a reliable mean, site mean for the whole plant. But it’s certainly a lot easier and quicker than taking many destructive measurements.

SLIDE 71 [39:34]:

This shows some verification data of this technique, obtained by; I’d like to say, with a lot of effort for a range of vegetation types. With the LAI-2200, no prior calibrations or assumptions about extension coefficient for any particular vegetation type is necessary. And what could take hours or even days to accomplish, can be done in just a few minutes.

SLIDE 72 [40:06]:

This photo shows, just one example of the verification efforts that went into, to validate the LAI-2200. In this example, a plot of soybeans was marked-out, the LAI-2000 measurements were taken within the marked-out area, and plants were then removed in stages, followed by more measurements with the
LAI-2000, this was done with the LAI-2000 by the way, not the LAI-2200. In other verification exercises, the entire plots were harvested in one stage after measuring with the LAI-2000. In this case the plots were allowed to grow to different stages to produce a range of canopy LAI values.

**SLIDE 73 [40:50]:**

The plants, the harvested plants of soybeans, showed in the previous slide, were then brought into the lab at each stage of the plot thinning, and they were then carefully dissected to separate out leaves and fed through our LI-3100 Leaf Area Meter. In this photo you can see, three groups of LI-COR employees hard at work to keep up with the material brought in after measuring the field plots with the LAI-2000. A lot of work was put into verify the LAI-2000,

**SLIDE 74 [41:29]**

and with good results, as you saw from the previous figure, the graph. With a Light Bar type of an instrument, the sun flecked, or the sun lit fraction of the—light sensitive bar, is the measure of the gap fraction for that particular sun angle. The measurement should be repeated a several sun angles, at the same location, to obtain the required angular information to calculate LAI and mean leaf angle. The proportion of direct and diffuse illumination may also be needed—need to be measured to determine the gap fraction for a particular solar beam angle, -- if making correction for diffusely lit part of the light bar. For tall canopies, or trees, there can also be effects of the penumbral that make it difficult to distinguish sun flecks from the shaded portions of the light bar.

**SLIDE 75 [42:31]:**

This slide for example shows, what we mean by the Penumbral Effect, this shadow, of a crash bar, that’s just 50 centimeters from the pavement here in this photo, is more distinct than the shadow of the leaves, which are projected from a tree of about 4 meters tall. The Penumbral is in fact caused by the fact that the sun is not a point source, but is subtended by about 1.5° from the distance of the Earth, so the Sun has a definite size, is not a point source, and that’s the cause of the blurring of the shadow edges as move further away from projection.

**SLIDE 76 [43:11]**
With the light bar type measurement is often also difficult to obtain several Gap Fraction readings, at the same location on one day, under sunny conditions. So, quite often the simpler was to use the light bar type of sensor, is to use the Transmittance reading in an empirical way. This involves using an Empirical crop extinction coefficient, which relates LAI to light transmission.

The empirical of crop coefficient has to be determined before hand for a particular canopy, using another method, such as destructive sampling. One advantage, or, disadvantage should I say, is this approach, is that these empirical coefficients can vary more than 50% for different species. And even within species, depending on factors such as stage, the growing conditions, the sun angle and so forth. Now, with the LAI-2200, no Empirical Crop Coefficient need to be determined, and, no assumptions are required about crop extinction.

**SLIDE 77 [44:22]:**

To summarize our thoughts, if you have understood, the 52 card game pick-up, and how the gap fraction of randomly overlapping cards decreases exponentially with increasing card area, then you have understood the crooks of the gap fraction technique, for determining plant canopy leaf area. And although a number of different ways are available for obtaining the Plant Canopy Gap Fraction, all use the same mathematical concepts to calculate the leaf area and orientation. In obtaining good measurements of canopy leaf area index, the main task then, is to obtain good representative measurements of the gap fraction for the canopy at hand. And of course, in the summary, I would like to say, do use the LAI-2200 Plant Canopy Analyzer for your non-destructive measurements, because, it is simple, it’s quick and gives accurate measurements when you learn how to use it properly.

**Moderator:**

Thank you Tanvir, Rod has just a few more spots for everyone. While we make the transition here, I have one more poll question: If you do non-destructive plant canopy measurements please select the instrument you prefer for this list.

**SLIDE 75 [45:36]:**

Pause for poll answers

**Speaker 2:**
Thank you for your answers, it’s always interesting to see what people are using in the field.

SLIDE 78 [46:26]

SLIDE 79 46:30:

Continuing on Tanvir mentioned the LAI-2200 Plant Canopy Analyzer a number of places in his talk. The LAI-2200 is the next generation plant canopy analyzer for LI-COR, it builds upon the proven technology of its predecessor the LAI-2000. The LAI-2200 Plant Canopy Analyzer has many new features. One new feature is the ability to do autonomous logging sensor head.

SLIDE 80 [46:50]:

In other words, someone is in a forestry or agronomic situation, like seen on the right here, could use the sensor head one to log above readings, and use the other sensor head to walk through the canopy and log the below readings. Other features of the LAI-2200 Plant Canopy Analyzer, aside from the ability to log autonomously with the sensor head, are the console itself has a new ergonomic feel; we have an updated display on the console and the ability to transfer data through the USB.

SLIDE 81 [47:36]:

For more information on the LAI-2200 Plant Canopy Analyzer and a list of applications, please visit our website shown here.

SLIDE 82 [47:41]:

Moderator:

Thanks Rod, now let’s take some time to transition into our Q & A session. The first question I have here is from Dave, and it is, can I upgrade my LAI-2000 to LAI-2200?

Speaker 2:

Thanks Dave for that question. That is a question that’s going to come up frequently. Unfortunately the people who own the LAI-2000 will not be able to upgrade to a LAI-2200 aside from buying a brand new instrument, because the technology involve in the LAI-2200 is much more modern, and so, that upgrade is not going to be possible.

Moderator:
Our next question is from Jin, and he asks, you talked about the sampling error in destructive measurements, how do you know how many readings with the LAI-2200 are enough?

*Speaker:*

That’s a very good question, one of the main sources, main causes of unreliable, unreliability and inconsistency of data collected with LAI-2200 is simply, just not taking enough measurements. As we mentioned early, the major advantage of the non-destructive technique, is that you can take a lot of measurements very quickly. So really, not taking enough measurements with the LAI-2200 instrument is almost defeating the very reason for using it. So, don’t skimp on the number of measurements. And, so to begin with take a few measurements, perhaps five or ten transmittance readings and examine the plot variability. Make sure to sample the sparse as well as the dense parts of the plot, then look at the standard error output by the LAI-2200, this is calculated already for you, so this is no big effort.

In the back of the LAI-2200 there’s also a section which gives guidelines to estimate how many measurements you should take, so you should consult that. So make sure you examine the plot variability, look at the standard deviation and calculate the standard error. And then, decide for yourself how many measurements you need to be within certain precision of your mean, of your true mean. Thank you, that’s a good question.

**SLIDE 83 [49:45]:**

*Moderator:*

Thanks Tanvir, thank you everyone for submitting your questions today. If you haven’t yet got an answer, please stick around and a panelist will get back to you as soon as possible.

*Speaker:*

I just want to add one more thing, taking enough measurements is really especially critical in short sparse canopies, because of the very small sample size. The widest angle of the LAI-2200 only goes out to 68° and so with a short canopy the sample area is very small, so there taking enough measurements is especially important.
Moderator:

Well, thanks again Tanvir and Rod, now that we have seen the theory and the benefits behind measuring Leaf Area Index, non-destructively. I’m excited to see how our customers feel about a new generation LAI-2200 Plant Canopy Analyzer, and its ability to measure LAI non-destructively.