Soil Moisture and Vegetation Measurement Guideline

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Contents

This document explains the recommended methodologies for measuring soil moisture, soil surface roughness, leaf area index (LAI), biomass and vegetation water content. It serves as a guideline for the field measurements undertaken as part of the Joint Experiment of Crop Assessment and Monitoring (JECAM) inter-SAR comparison initiative.

1. Number of fields

Determining the number of fields and samples points is not a straightforward exercise. Enough measurements must be collected to develop a strong semi-empirical model. The robustness of this model will be only as good as the quality and quantity of the data used to formulate the model. It is important to acquire an adequate number of points (points = fields x sample points per field). It is also important that measurements and samples capture a full range of vegetation and moisture conditions. This representativeness will ensure that any model created and inverted, will produce good results over a range of conditions.

Field data collection is demanding in terms of resources (people and time) needed. We would suggest that rather than collecting a few sample points over a larger number of crop types, JECAM leads focus on a more limited number of crops, as resources allow. For example, it is more desirable to have a sufficient amount of data for one crop type, than inadequate data for multiple crop types. The general instructions are as follows:

- **The fields should be relatively flat to simplify the interpretation. For the benefit of the field crews, fields should be easy to access.**

- **Measurements should start just after seeding and continue until harvest. With this strategy field data will capture a wide range of crop conditions (from low to high biomass and LAI). It is also recommended that seeding and harvest date be recorded.**

- **We would recommend selection of at least 5 fields for each crop type. This assumes that as a minimum, three sample points (see section 2) can be placed in each field (yielding a minimum of 15 sample points for each crop type per field sortie).**

2. Number of sample points per field

The general goal is to gather data for **at least** 15 points per crop type, per field sortie. If fields are large and far apart, it may be preferable to place more than one site in each field, and sample fewer fields. For example, if 5 fields per crop are selected, collect data at 3 points in each field. If multiple points are located in each field, these sites must be placed strategically such that variability in crop growth across the field (due to soils/topography etc.) is captured. When the backscatter is extracted for each sample site, typically a window of pixels is selected in order to reduce the impact of SAR noise. As such, we would recommend locating sample points at least 60 m from the edge of the field, and at least 100 m from each other.

- **Considering the resolution of Sentinel-1, points should be at least 60 metres from field edges and 100 m from each other.**

- **Sample points should be located such that they capture the variance in soils and crop growth present across the field. Figure 1 provides an example, however the natural variance should dictate where these points are located. The location of each point can be pre-loaded into a GPS for easy navigation back to the point during each field sortie. Alternatively, point locations can be flagged.**

Figure 1. An example of placement of sample points to capture the variance in soils and crop growth

Table 1. Overview of sampling design

Filed conditions	Relatively flat and easy access to it.
Total number of sample points	**Minimum** of 15 sample points per crop type, per field sortie. The exact same sites should be revisited for each field sortie. Use pre-loaded GPS locations for crews to navigate back to the same point, or use flags to indicate point location
Number of fields	At least 5 per crop type
Number of sample points in each field	Depends on number of fields. For example for 5 fields, place 3 sample points in each field (yielding 15 points); 60 m from field edge and 100 m from each other
Seeding and Harvest	Record the date of seeding and the date of harvest

3. Soil moisture sampling

For calibration of the Water Cloud Model (WCM), both soil moisture and vegetation must be sampled. To model LAI, soil moisture AND LAI must be measured at each site. To model biomass, soil moisture AND biomass measures are needed.

General guidelines for soil moisture sampling are as follows:

1. Soil moisture varies quickly over time. As such moisture must be measured near coincident to the SAR overpasses. There are two possible ways to go about this. If data are being collected by field crews, we recommend measuring moisture plus or minus two (2) hours of the SAR overpass (local time). Local overpass times vary slightly but for RADARSAT-2 and Sentinel-1 these times are approximately 6 PM (UTC) for ascending orbit and 6 AM (UTC) for descending orbit. As such moisture should be measured between 4 AM (UTC) and 8 AM (UTC) (descending) and 4 PM (UTC) and 8 PM (UTC) (ascending). An alternative approach is to install temporary soil moisture stations which can record soil moisture at the exact time of the SAR overpass.
2. If using dielectric probes, Stevens Hydra Probes or Delta-T Theta Probes are recommended (Figure 2). The tines on the head of the probe measure moisture at a depth of 5.7 cm. Information on these probes can be accessed at http://www.stevenswater.com/products/sensors/soil/ and https://www.delta-t.co.uk/product-category/soil_science/soil_moisture_sensors/. We highly recommend calibration of the dielectric probes. Both Stevens and Delta-T provide general calibration equations to convert measured dielectric to volumetric soil moisture. However, depending on soil textures, site specific calibration equations may improve the accuracy of moisture measurements. The calibration approach is discussed in Section 4.
3. As an alternative to dielectric probes, moisture can be measured gravimetrically by collecting soil cores of known volume. Gravimetric sampling is a lower cost option, but can be more time consuming to collect in the field and process in the lab (weighing and drying). To be consistent with JECAM sites which are using dielectric probes (5.7 cm in length), we recommend manufacturing aluminum soil cores to collect samples at the same depth (0 to 5.7 cm) as the dielectric probes. This will provide a consistent measurement depth among all JECAM partners. The volume of each core is needed to convert the gravimetric sample to volumetric soil moisture.

Specific instructions for soil moisture sampling using **dielectric probes** are as follows:

1. Take three replicate measurements at each sample point. If row structure exists, take one measure on the top, bottom and mid-slope (Figure 3). If no structure exists, take one measure in the plant row (between plants) and two measurements in between plant rows (Figure 4).
2. Always insert the probe perpendicular to the soil surface. Make sure that the probe is in complete contact with the soil (i.e. no air gaps between the bottom of the head of the probe, and the soil). Samplers must take care not to push the moisture probe too hard against the soil as it may cause compaction, especially if the soil is loose. Tines must be cleaned thoroughly after each measure, before re-inserting to take a new measurement.

3. Although both the Stevens and Delta-T probes are used with data loggers, we recommend also recording the measured volumetric soil moisture on data sheets, to avoid any loss that could occur when downloading data from the loggers.

(a) (b) (c)

Figure 2. Stevens Hydra Probe with PDA (a), Stevens Hydra Probe POGO (b) and Delta-T Theta Probe (c).

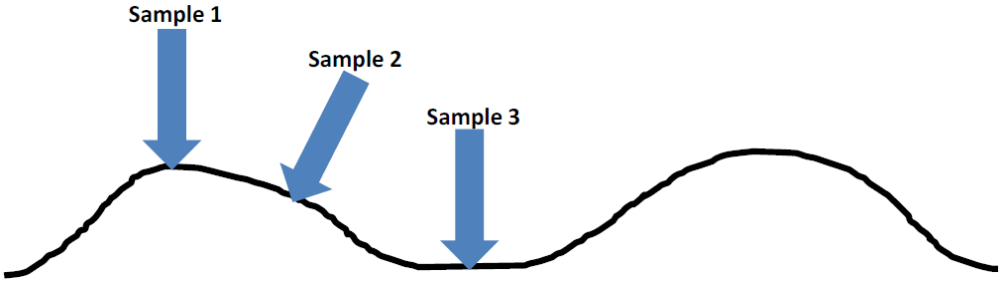

Figure 3. Location of replicate soil moisture measurements at each site when tillage or planting structures are visible.

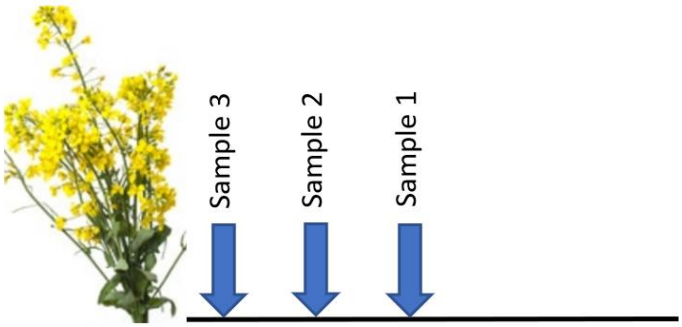

Figure 4. Location of replicate soil moisture measurements at each site when no tillage or planting structure is present.

Specific instructions for soil moisture sampling using **gravimetric soil cores** are as follows:

1. Take three replicate samples at each sample point. If row structure exists, take one sample on the top, bottom and mid-slope (Figure 3). If no structure exists, take one sample in the plant row (between plants) and two samples in between plant rows (Figure 4).
2. Push the aluminum soil core vertically into the soil until fully inserted (Figure 5). Gently remove the core by inserting a trowel underneath to loosen the soil. Once removed, trim the soil sample on both ends to ensure the exact volume of soil has been removed. If new cores are being used at each site, the entire core (with soil still intact) can then be placed into a paper bag, and then into a sealed plastic bag. If soil cores are being reused, remove all soil from inside the core using a knife. Place the core in the paper bag while the soil is being removed as this approach will avoid any loss of soil while cleaning out the core. Place paper bag in sealed plastic bag. The plastic bag ensures minimal moisture loss until samples can be weighed.
3. Once at your lab, the weight of the wet soil sample must be recorded. We recommend placing the entire sample (paper bag + core + soil + plastic bag) on the scale. The weight of the paper and plastic bags will need to be recorded in order to subtract this weight from the total wet weight. Once weighed, remove the plastic bag. Place the paper bag in a soil drying oven for at least 48 hrs at 105°C. It is recommended to then remove the dry sample and record its weight. The sample is then dried for another 12 hrs and re-weighed. If the dry weight has not changed after the 12 hrs, the sample is now completely dry. If the weight has changed after the 12 hrs, place back in the oven until re-weighing establishes that the dry weight is no longer changing.
4. The gravimetric moisture content is determined for each individual sample as the mass of water divided by the mass of oven-dry soil. The bulk density of each individual sample is determined as the oven-dry mass of soil divided by the soil core volume. The average bulk density is multiplied by the gravimetric moisture content of each individual sample to calculate the volumetric moisture content of each core sample.

(1) (2) (3) (4)

Figure 5. Soil core sampling: (1) Core ready to be inserted to the soil, (2) Core fully inserted, (3) Loosening a sample core to remove the sample from the soil, (4) A sample that has been trimmed to size and now ready to be transferred to the sample bag or container.

4. Soil core sampling for calibration of soil dielectric probes

We recommend conducting this calibration exercise during field sorties. In this case, take one additional soil core per field, per sortie. If time does not permit, collection of soil cores to calibrate these instruments can occur before or after the field campaign. In any case, make sure that calibration samples are taken over a full range of moisture conditions (from dry to wet). This will ensure the development of a robust calibration curve.

The instructions are as follows:

1. Push the core into the soil as described in section 3. Leave the core inserted.
2. Take three Hydro probe or Theta probe readings around each soil core sampling location, within about 10 cm of the soil core. The probe should not come into contact or be too close to the core.
3. Remove the soil core as described in section 3. Process gravimetric sample at the lab, as described in section 3.
4. The volumetric soil moisture content for each core sample is used with the adjacent dielectric probe readings to create a calibration function. Volumetric soil moisture is a linear function of the square root of real dielectric permittivity (Equation 1) (Rowlandson et al. 2013).

$$\theta_v = a(\varepsilon)^{0.5} + b \quad (1)$$

where θ_v is volumetric soil moisture and ε is soil dielectric permittivity.

5. Soil roughness

The WCM does not model roughness, however roughness does impact SAR responses. Thus measures of roughness are recommended if resources allow. If quantitative measures are not possible, we recommend taking photos and notes to record roughness conditions. If roughness appears smooth (root mean square height of less than 1.0 cm), measures would not be required, but notes and photos of the roughness are still recommended.

If roughness is to be measured:

1. Measure soil roughness at the beginning of the field campaign, after seeding but before the crop canopy is significantly developed.
2. For each field, we recommend measuring roughness at two sites, to capture any spatial variances in roughness across the field.
3. Either a pin board or gridded board can be used (Figure 6).
4. At each roughness site, a 3-metre profile is needed. Boards are typically 1-metre in length. As such we recommend taking one photo of the board, then moving the board laterally to capture two more photos. Post processing, these 3 adjacent photos can be stitched together to synthesize a 3-metre long roughness profile.

The specific instructions are as follows:

1. Place the board parallel to the look direction of Sentinel-1 and RADARSAT2 (descending mode ~ 271 degrees and ascending mode ~ 67 degrees) (Figure 7).
2. Before taking the photo, if vegetation obstructs the view of the board flatten the vegetation and take a photo at a distance of around 1.5 m (Figure 6).
3. The board is moved such that the end of the first measurement becomes the start of the second measurement and the second photo is taken.
4. Repeat step 3 until a 3-metre profile is achieved.
5. At the lab, the photos are post-processed to obtain the roughness parameters (i.e. root mean square height and correlation length).

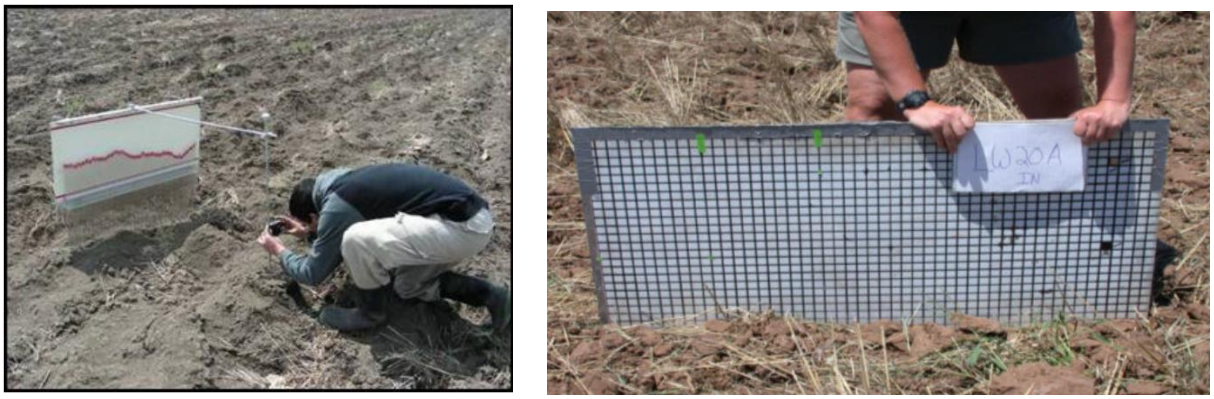

Figure 6. Pin board (left) and gridded board (right) used to measure surface roughness.

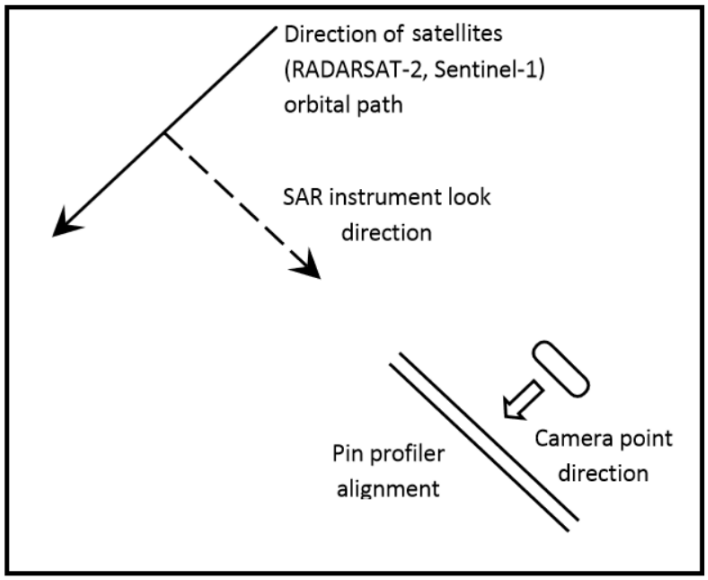

Figure 7. An example of the placement of the roughness board.

6. Vegetation sampling

Planting density, row spacing and row direction must be determined for each sample field.

6.1 Plant density

For row crops, both plant spacing (distance between plants in each row) and row spacing (distance between one plant row and the next) are needed to determine planting density. Density is needed to scale biomass samples to unit area (i.e. kilograms of plant per metre squared). Determination of plant and row spacing can be accomplished any time during the season, as resources permit.

Measuring plant spacing (only applicable for row crops):
For wider-spaced row crops (corn, soybeans, sunflower …)

1. Use a tape measure and flag a distance of 10 metres along one row (tie flagging tape to first and last plant, or use field flags to delineate first and last plant)
2. For each of 10 consecutive rows, count the number of plants along the 10 m distance.
3. The average of these measures will determine the plant spacing

For narrow-spaced row crops (wheat, barley, oats, …)

1. Use a tape measure to flag a distance of 1 metre along one row (tie flagging tape to first and last plant, or use field flags to delineate first and last plant)
2. For each of 10 consecutive rows, count the number of plants along the 1 metre distance.
3. The average of these measures will determine the plant spacing

Measuring row spacing (only applicable for row crops):

1. Row spacing is determined by measuring the distance between rows, replicated for 10 rows.
2. Use a tape measure to record the row spacing for each of the 10 rows used to determine the plant density.
3. Measurements are to be taken at the soil level, as the distance between the centre of the plant in row one to the centre of the plant in row two.
4. The average of these measures will determine the row spacing

Plant density (PD) for row crops is calculated using equations 2 and 3 for narrow-spaced row crops and wider-spaced row crops, respectively:

$$Plant\ Density\ (PD) = \frac{Average\ Number\ of\ Plants\ in\ 10\ Rows}{(Average\ Row\ Width\ over\ 10\ Rows)\times 1m} \quad (2)$$

$$Plant\ Density\ (PD) = \frac{Average\ Number\ of\ Plants\ in\ 10\ Rows}{(Average\ Row\ Width\ over\ 10\ Rows)\times 10m} \quad (3)$$

6.2 Planting Row Direction

For row crops, the direction of planting is recorded (in degrees) using a compass and using magnetic North as a reference. Thus, you will need to line up your N direction to the magnetic needle and record the

direction of the row based on that reference. Correction of these readings to true North can be done afterwards.

6.3 Biomass sampling, determination of vegetation water content and plant phenology staging

Ideally, biomass should be collected at the same time as SAR overpasses and coincident with soil moisture measurements. However if resources do not permit, biomass can be collected within three days of the SAR overpass. The assumption is that biomass and vegetation water content vary more slowly over time relative to soil moisture. The goal would be to revisit each field once every 1-2 weeks to capture changes in crop development (from emergence to harvest). All above ground crop biomass is to be collected. Residue and weeds should be excluded. Consider taking biomass samples 2-3 m away from the soil sample locations to minimize disturbance at these sites.

Instructions for sampling biomass for wider-spaced row crops (i.e. corn, soybean, sunflower etc.)

1. Select 10 plants for manual harvest (we recommend 5 plants along two rows). Plant density will be used to scale biomass (kg) to unit area (m^2).
2. Cut each plant at ground level.
3. Place all plants in paper bag, and then in sealed plastic bag. The plastic bag ensures minimal moisture loss until plants are weighed. If available, mesh bags can be used instead of paper bags. These mesh bags, when placed in a drying room or drying oven, provide increased air flow which speeds up the drying process.

Instructions for sampling biomass for narrow-spaced row crops (wheat, barley, oats, canola …)

1. Place a 0.5 m x 0.5 m biomass square over the canopy. Biomass (kg) per unit area (m^2) is calculated by applying a factor of 4.
2. Cut each plant at ground level.
3. Place all plants in paper bag, and then in sealed plastic bag. The plastic bag ensures minimal moisture loss until plants are weighed. If available, mesh bags can be used instead of paper bags. These mesh bags, when placed in a drying room or drying oven, provide increased air flow which speeds up the drying process.

Lab instructions

1. Weigh wet plant samples as soon as possible as plant matter can degrade quickly. If available, put wet samples in cool location (cooler or cold room) until plants are wet weighed.
2. Place samples (biomass + paper/mesh bag + plastic bag) on scale and weigh. The weight of the plastic bag will have to be determined and subtracted from this wet weight.

3. Take the paper/mesh bag out of plastic bag, and open paper/mesh bag in order to determine crop phenology. If plants must be removed from paper/mesh bag, be careful not to lose any plant material in the process.
4. BBCH stage is recommended for crop staging. If individual plants are at different BBCH stages, enter the BBCH stage of the majority of plants. The BBCH manual is available at JECAM website (http://www.jecam.org/?/jecam-blog/sar-inter-comparison-experiment).
5. For wheat crops only, we recommend that after weighing the entire wheat sample, each sample should be segmented into heads and leaves/stems. Research by AAFC has demonstrated the potential of estimating the biomass of the wheat heads using C-band RADARSAT-2 data (Hosseini et al., 2017). Therefore, for the JECAM SAR Inter-Comparison Experiment we would like to further adapt and validate the WCM model to estimate the biomass specifically for the heads of wheat. If samples are segmented, cut the heads off the wheat crops, and place the heads in one paper bag and leaves/stems in a separate paper bag. Weigh each bag separately (heads and leaves/stems). Thus you should have recorded a total wet biomass for wheat (entire plant), wet biomass weight for wheat heads, and wet biomass weight for wheat leaves/stems.
6. Samples can be dried either in a crop drying room, or an oven (Figure 8). Crops will take longer to dry in the drying room, but volume of biomass and equipment availability may not allow for drying by oven.
7. Samples should be periodically re-weighed to determine if dry weights are stable. The samples are put back into the drying facility/oven until dry weights remained unchanged, signaling that drying is complete.

   Note: Air drying in a drying room, typically does not remove all of the crop water. As such, samples should be collected after air drying to determine an oven drying correction by crop type and growth stage. For that, a small air dried sample is collected, re-weighed then placed in an oven at 60°C for 48 hours. This provides an oven-dry weight to air-dry weight correction for each crop type and crop stage.

The plant water content (PWC) is calculated as follows:

$$Plant\ Water\ Content\ (PWC) = [Wet\ Weight\ (g) - Plastic\ \ Bag\ Weight\ (g)] - Dry\ Weight\ (g) \quad (4)$$

$$Area\ PWC\ (gm^{-2}) = \frac{(PWC)(g)}{Number\ of\ plants\ collected} \times PD\ (plants\ per\ m^2) \quad (5)$$

Note. The above formula is for wider-spaced row crops (i.e. corn, soybean, sunflower etc.) only. For narrow-spaced row crops, if a 0.5 m x 0.5 m biomass square is used, we only need to multiply by 4 to get biomass and PWC per unit area.



Figure 8. Mesh bags containing crop samples hanging in drying room (left), larger ovens to dry crop samples (centre), and smaller drying oven for use in determining oven-dry correction (right).

6.4 LAI determination

As with biomass, the temporal change in LAI is less than what is expected with soil moisture. As such, measurement of LAI can be timed with that of biomass collection; within 3 days (plus or minus) of SAR overpass, every 1-2 weeks. It would be most efficient to measure LAI at the same time that biomass samples are taken. There are different methods to measure LAI. Here we recommend using hemispherical photos. Collection using an LAI-2000 type instrument leads to high errors when canopies are very small, as it is difficult to position the LAI lens far enough from crop leaves. Hemispherical photos are quick to acquire in the field and provide a photographic record of the leaf area. However, post-processing of the photos is time consuming.

The specific instructions for LAI sampling are as follows:

1. Take 14 photos per sample point (7 along each of 2 rows) (Figure 9).
2. The camera is held over the canopy, with the lens pointed down. The lens must be at least 50 cm above the highest point of the canopy (Figure 10). We recommend constructing a pole which can extend and ensure that the camera can be positioned high enough above the canopy. This is of particular interest for high canopies, like corn. When taking the photos, the pole should be leveled.
3. In the case of row crops, photos are taken in the middle of the crop row.
4. Photos should be spaced at least 5 metre apart along each transect.
5. When taking the photo, the sun should be in front of or to the side of the operator. This will avoid the shadow of the operator appearing in the photo. The operator should always face parallel to the row direction.
   Note. Shaded vegetation could be misclassified as non-vegetation, leading to a underestimation of the vegetation variables.
6. Record the photo numbers and the time on a data sheet.
7. Mark the sun direction on the data sheet.

At the lab, these photos are post-processed to estimates of LAI using the CanEye software. Please note that the CanEye software provides Plant Area Index (PAI) and not LAI. Other parameters that are estimated using CanEye are Fraction of Absorbed Photosynthetically Active Radiation (FAPAR) and

Vegetation Cover Fraction (FCover) (Appendix 2). CanEye software can be downloaded from: https://www6.paca.inra.fr/can-eye/Download. Its manual is available at Appendix 3. A detailed manual is also available at JECAM website (http://www.jecam.org/?/jecam-blog/sar-inter-comparison-experiment).

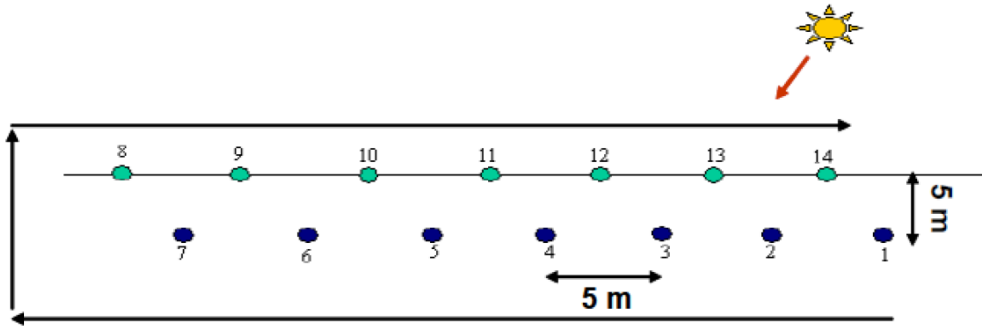

Figure 9. Sampling transect for hemispherical photos to measure LAI.

Figure 10. LAI camera suspected over corn canopy (left) and fish eye photo of a soybean crop (right)

6.5 Crop height

Crop height will be measured on each of the 10 plants harvested for biomass, or for 10 plants randomly selected within the 0.5 x 0.5 m biomass square.

Use a tape measure to record the distance from the soil to the highest point of the plant. Do not extend leaves. Leaves should remain in their naturally occurring position/orientation during measurement.

7. Reporting

The campaign should result into two documents:

1- A general description of the site and the measurements. This should take the form of a small report where the following information should be given. Please fill in Table 2.
   - Location (lat-lon) and extent (km). A google earth extract with the limits of the site indicated could be very useful.
   - Date of measurements: The start and end dates of the measurements and the seeding and harvest dates.
   - Topography: describe the topography of the site.
   - Describe the sampling approaches. Geo-located sample points over the google earth image would be very efficient.
   - Devices used for the measurements.
   - Any issues encountered or anomalies in the data collection

2- A file containing the ground measurements. A template is proposed for the database (see Appendix 1). It is also very useful to have a shapefile with the locations of the sampling points.

Table 2. General report of the campaign.

Column	Variable Name	Comment
1	Field #	Number of fields
2	Sampling #	Number of sampling points
3	Coordinates	Geographic coordinates of the area (WGS84)
4	Crop Type	Details of crop types
5	Date	Dates of seeding and harvest and also start and end dates of campaign
6	LAI	Instrument
7	Soil Moisture	Instrument

Table 3. Summary table of vegetation measurements.

Parameter	Replicates per point	Options (Instruments)	Temporal Frequency	Equipment needed
Soil moisture	3	a. Stevens Hydra Probe b. Delta-T Theta Probe c. gravimetric samples	At exact overpass time (for temporary stations) or +/- 2 hours of overpass (for field sampling)	- dielectric probes - soil cores - trowel & knife - paper and plastic/mesh bags - weighing scale - drying oven
Roughness	3	a. pin board b. gridded board c. photo	Once after seeding and before significant crop growth	- pin board - grid board - camera - roughness processing software
Plant density	1		Once after crop has fully emerged	- tape measure
Plant row direction	1		Once after crop has fully emerged	- compass
Biomass	1	Destructive sampling	+/- 3 days of SAR overpass; Aim to collect sample every 1-2 weeks	- 0.5x0.5 m square - knife - paper and mesh/plastic bags - weighing scale - drying room or oven
Crop phenology	1		Completed in lab; each biomass sample is staged for phenology	
LAI	1	Hemispherical photos	+/- 3 days of SAR overpass; Aim to collect sample every 1-2 weeks	- camera with hemispherical lens - extension pole
Crop height	1		+/- 3 days of SAR overpass; Aim to measure every 1-2 weeks	- tape measure

8. References

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Appendix 1. Datasheet template

Date	Field No.	Site No.	Crop type	X (UTM)	Y (UTM)	VSM	Effective LAI	True LAI	Total Dry Biomass_g_m2	Total Wet Biomass_g_m2	Heads Biomass_Wheat_g_m2	VWC_PCT	VWC_g_m2	Crop Height (cm)	Phenology Stage	RMS Height (cm)	Correlation Length (cm)	FCOVER	FAPAR

VSM is the calibrated volumetric soil moisture in $m^3 m^{-3}$
True LAI is the one-half of the total green leaf area in 1 square meter. So, its unit is $m^2 m^{-2}$
Effective LAI is one-half of the total area of light intercepted by leaves in 1 square meter. So, its unit is $m^2 m^{-2}$
Total Dry Biomass is total above ground dry biomass in g/m^2
Total Wet Biomass is total above ground wet biomass in g/m^2
Heads Biomass is the biomass of the heads of wheat in gram per square meter. Its unit is g/m^2
VWC_PCT is vegetation water content in percent
VWC_g_m2 is vegetation water content in g/m^2
Phenology is the crop growth phenology stage in BBCH scale. It shows the number of days after seeding of crop.
RMS Height is the root mean square height of soil surface
Correlation Length is the soil surface correlation length

Appendix 2. Definitions

Leaf Area index (LAI)

LAI is defined as one half the total leaf area per unit horizontal ground surface area (Chen and Black, 1992; GCOS, 2010). It is a dimensionless ($m^2.m$-2) variable. Green leaves correspond to vegetation matter capable of photosynthesis in ambient conditions. However, this simple definition needs some additional comments when applied to remote sensing observations.

- **Leaf/other elements.** If no distinction is made between leaves and the other elements, the proper term to use is PAI: Plant Area Index rather than LAI. Note that most indirect methods used to estimate LAI from upward looking canopy transmittance corresponds actually to PAI rather than LAI.
- **Green/non-green elements.** Canopies are made of green photosynthetically active and other elements which are not green and therefore non-photosynthetically active (senescent leaves, trunks, branches, fruits, flowers...). Since most users are interested in the green elements, the term GLAI (Green Leaf Area Index) should be used. However, the community uses commonly LAI in place of GLAI. Similarly, the green surfaces are extended to all the green elements, the term GAI (Green Area Index) should be used. Note that most remote sensing retrieval methods are mainly sensitive to GAI rather than LAI (or GLAI). GAI may be also estimated from indirect methods (e.g., digital hemispherical photography) based on downward looking measurements of the green fraction (the fraction of green vegetation seen from a given direction from above the canopy). GAI is probably the most pertinent definition to be used for remote sensing observations.
- **Effective/true LAI.** Most LAI (GAI) ground measurements used for the validation is based on indirect measurements (gap or green fraction) assuming random distribution of the elements within the canopy volume (i.e. no clumping), which corresponds to an effective LAI (GAI). To obtain the actual LAI (GAI) value, the clumping should be accounted for. Several devices such as Digital Hemispherical Photographs (DHP) or Tracing Radiation and Architecture of Canopies (TRAC) instrument allows to estimate clumping index, and then actual LAI values.

Fraction of Absorbed Photosynthetically Active Radiation (FAPAR)

Solar radiation in the spectral range 400 to 700 nm, known as Photosynthetically Active Radiation (PAR), provides the energy required by terrestrial vegetation to grow. The part of this incoming PAR that is effectively absorbed by plants is called the Fraction of Absorbed Photosynthetically Active Radiation (FAPAR). It is a non-dimensional quantity varying from 0 (over bare soil) to almost 1 for the largest amount of green vegetation. Since FAPAR is mainly used as a descriptor of photosynthesis and evapotranspiration processes, only the green photosynthetic elements (leaves, needles, or other green elements) should be accounted for. FAPAR depends also on the illumination conditions, i.e. the angular position of the sun and the relative contributions of the direct and diffuse illumination. Both black-sky (assuming only direct radiation) and white sky (assuming that all the incoming radiation is in the form of isotropic diffuse radiation) FAPAR values may be considered. Downward looking DHP provides a good estimate of FAPAR.

FAPAR products are currently mainly defined as the black-sky FAPAR value for the same sun position as that observed at the satellite overpass. Black-sky FAPAR computed at 10:00 local solar time is a good approximation of the daily integrated black-sky FAPAR (Baret et al., 2007). The fraction of intercepted radiation, FIPAR is a very close approximation of FAPAR (Baret and Guyot, 1991): FIPAR=0.94 FAPAR.

Vegetation Cover Fraction (FCOVER)
It corresponds to the green fraction as seen from the nadir direction. It is dimensionless. It is computed from the leaf area index and other canopy structural variables (leaf inclination and clumping) and does not depend on variables such as the geometry of illumination as compared to FAPAR. For this reason, it is a very good candidate for the replacement of classical vegetation indices for the monitoring of green vegetation.

FCOVER could be derived from DHPs when restricting the field of view to the 0-10° zenith angles. Similarly, the LAI2000 instrument could be also used for FCOVER measurements by exploiting the first ring.

Appendix 3. CanEye Processing Methodology

Updated by: Pedro Valentin Serrano
January 25, 2017

1. Pre-processing using ViewNX-2 (Nikon)

Before you start, set up your folder structure to organize the data you will be processing. Do so by creating an "Enhanced" folder within the same folder path where the original images are located. The basic folder structure could be:

> **Date (YYYYMMDD)**
> > **Team Number**
> > > **Field**
> > > > **Field_id**
> > > > > - Original images (JPG and NEF) go here
> > > > > - "Enhanced" folder

Place all the original images under the Field_id and leave the "Enhanced" folder empty; this is where the enhanced images are going to be stored.

Open ViewNX 2.

For space and time purposes, avoid duplication of original files from being created by going to **Edit > Options… > Dialog/Alert/Backup**. Under "Back Up JPEG/TIFF Originals", uncheck the box for "Create a backup of previously saved files in a subfolder".

In the folder tree on the left, navigate to the folder which has the original set of images. The *.JPG and *.NEF images will appear. In the top right of the screen, click **Filter**. In the drop-down, select **NEF**. Now only the *.NEF image will be shown. Select all of the images you want to use and click **Convert Files** on the toolbar. The "Convert Files" window should appear.

In the “Convert Files” window, the “File Format:” should be in **JPEG**, and the “Quality:” should be **Highest Quality**. Check the “Change the image size” box. Chance the long edge to **2144** pixels and short edge to **1424** pixels. (Note: Your computer may not have enough processing capability for this resolution. In CanEye stopes working, change the resolution to 1072 by 712.) Make sure that “Remove camera setting information” is **NOT** checked. Under “Save In:”, select **Specified Folder** and browse for the “Enhanced” folder you just created (figure 1). Click **Convert**.

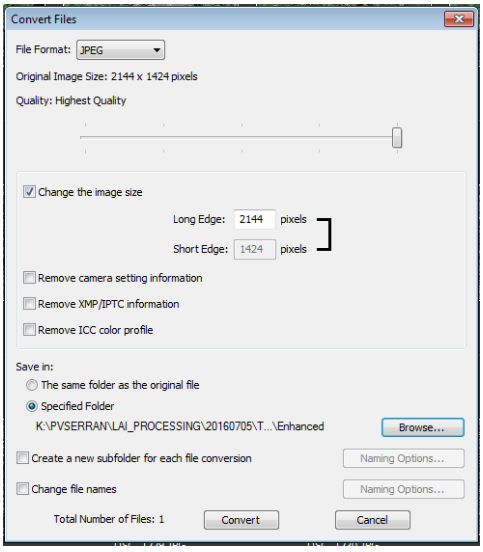


Figure 11: “Convert Files” set-up.

In the folder tree, navigate to the “enhanced” folder with the newly converted images. Turn off the NEF filter so you can see the images. Select all of them and click Adjustments in the right Menu. Scroll down and set the adjustments as necessary, some general guidelines are:

Shadow Protection: 50%
D-Lighting HS: 50%
Colour Booster: 25%**, Nature**
Axial Colour Aberration: 50%

Click the **Save** icon on the bottom right corner of the screen.

The photos should now be enhanced and ready for CanEye processing. Close ViewNX 2.

2.1 Date Set-up for CanEye Version 6.3

Open Can_Eye.exe. Go to **Hemispherical Images > RGB images > Downward** OR **Upward**, depending on which was the photos were taken. Navigate to the “Enhanced” folder.

If there is not existing parameter file for images of this size, the “CAN_EYE Parameterization” window will appear. The image size will already be defined. Under “optical Centre & Projection Function”, enter **60** as the COI. Click on **Create.**

The “Projection function characterization” window will appear (figure 2), specify the centre pixel of the image (for example, if the image is 2144 by 1424 (as set up in ViewNX 2), specify the line **712** (1424/2) and column **1072** (2144/2). Select **Polynomial Order 1.** Calculate the COI divide by the optical centre column, and enter this number in the “P1”

box. In this case, 60/1072 = **0.05597014925**. Click on the box below to make a graph appear. Click **OK.**

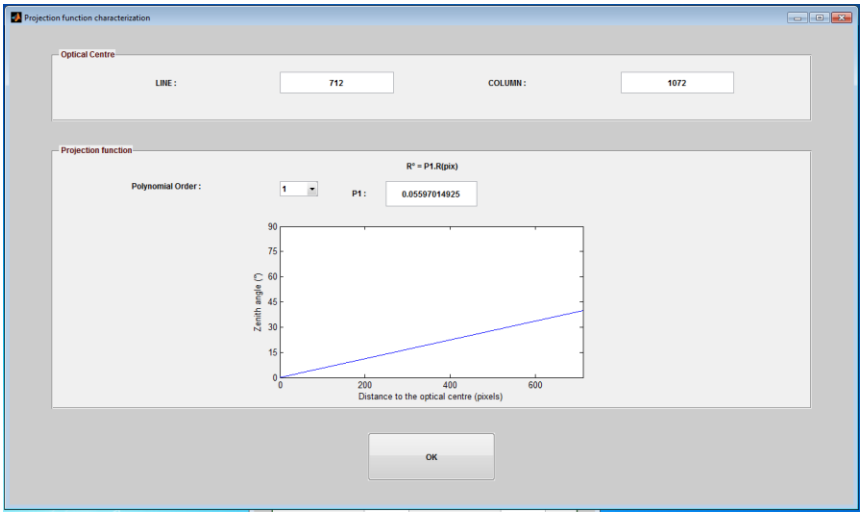


Figure 12: "Projection function characterization" window set-up

Leave the default "Angular Resolution" parameters of **Zenith 2.5**, **Azimuth 2.5**, and **FCover 10**. Under "FAPAR Computation", enter the day number of the year using a *Julian Date Calendar* and latitude at which the images were taken.

Under "Saving Data" leave **Excel** checked. Click **Save**. A COI warning window may appear regarding the exceeding maximum field of view, just click "Yes". Save the data with an appropriate name – naming it with the date at which the image was taken is suggested.

Alternatively, if there are one or more existing parameter files for images of this size, the "Defining Calibration Parameters" window will appear. Select the parameter file you want and click **OK**, or click **Create** to create a new one. For an existing parameter file, only the day number of the year and the latitude need to be re-entered (figure 3).

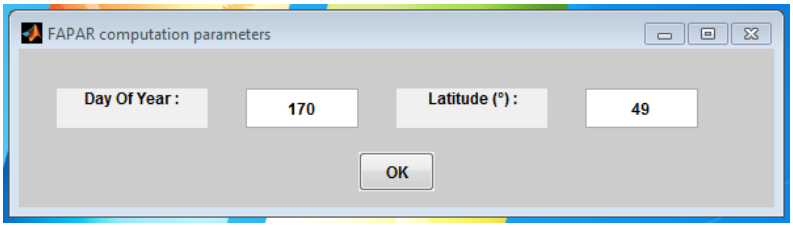


Figure 13: "FAPAR computation parameter" window. Asking for the day the latitude at which the image was taken.

2.2 Image Selection Process

On the “Selection of Pertinent images” dialog, examine the images to see if any are inappropriate or incorrect images. Click on the **Trash image** and **left-click** the images to be trashed, if any. Once completed hit **Right-click**, and click **OK** (figure 4)**.**

Note: Things to consider when trashing an image includes …

- Poorly taken images; blurriness, poor exposure.
- Tractor trace perpendicular to (or crossing against) the crop formation
- Large presence of unwanted plants (weeds, grass, etc.)

Figure 14: "Selection of Pertinent images" window. The image in white was chosen to be trashed.

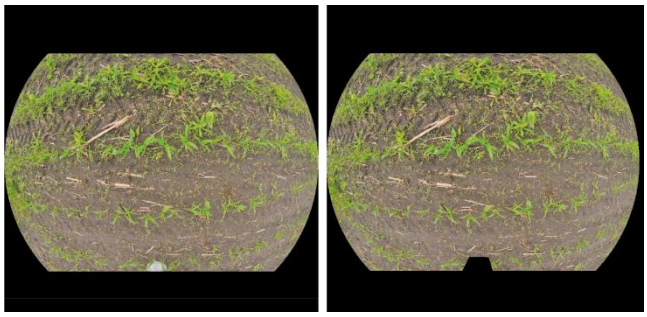
2.3 Masking

Some images may contain some small portions that need to be removed due to presence or disturbance of unwanted objects in the picture. Masking allows areas of the photo from being extracted prior to the image classification process to keep its feasibility.

On the masking screen, click **Select**, then click on an image. Click **Mask** and draw around the area where masking is required. **Right-click** to save. Click **Done**. Click **Apply All** to apply the last mask you created to all images (if appropriate). Click **Done**.

Note: Things to consider when masking includes …

- Blurry areas
- Boots, hands, poles
- Shadows (this can be optional; when that shadow is dark it sometimes interfere with the classification, lighter shadows typically does not)



An example of a *before* and *after* Masking image is shown in figure 5.

Figure 15: Before and after Masking. The boots on the bottom center of the image was Masked.

2.4 Image Classification

The "Class Definition" dialog will appear. Select **2 Classes + Mixed Pixels (This Option)**.

On the classification screen, select the circular button to the left of soil, sky, or green. The "Class Pre-selection" dialog will appear. It is recommended to click **Cancel**, as the pre-selection may be inaccurate. Click on an image to zoom in, and again select the circular button for soil, sky, or green. Classify pixels of a certain colour by clicking on them in the image. **Right-click** to save and the results of the classification so far will be shown.

To see the results on the all images, click **Display All**.

You may click on the soil, sky, or green boxes to change the colour of the classified pixels in order to see more easily.

You may click **True Colour** and **Classif** in the top left corner in order to switch between views for easier identification purposes.

You may also select pixels on the right display to classify them, if its colour is appropriate from the selected class. *The colours with red dots represent more than 5% of the pixels. The colours with the white dots represent more than 1%. It is suggested that when the classification is complete, there are no red and white dots in the mixed pixel category.* When less than 5% mixed pixels remain, click **Done**. The results will be save under the "Enhanced" folder.

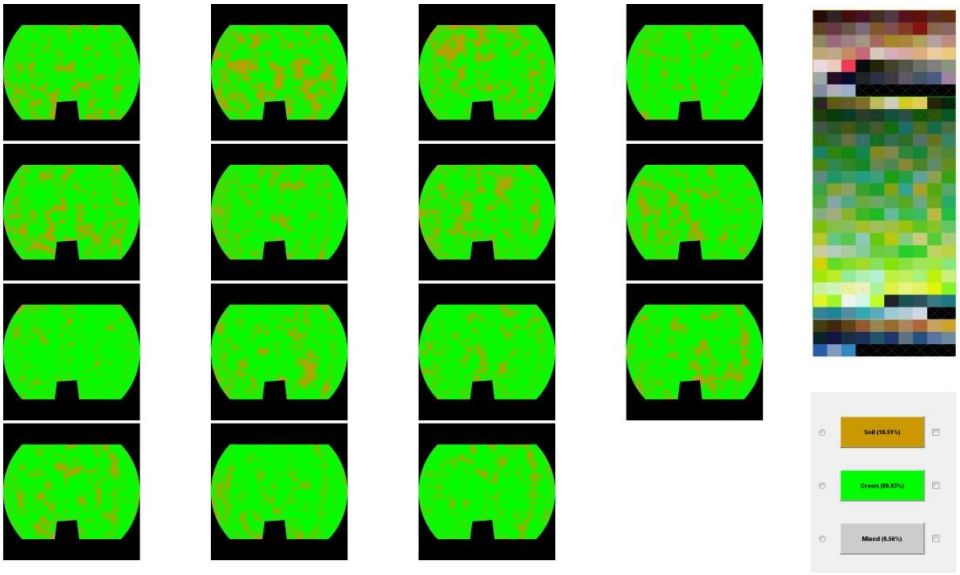


Figure 16: Classified image.

3 Data Evaluation

When examining and evaluating the results, navigate through the “Enhanced” folder. Auto-evaluating results are posted within the **HTML** file. Under the “Average Biophysical Variables” section, compare the values under **CEV5.1** and **Miller** fields in the effective PAI row (see below). The values should be within 20% of each other. If they are not, re-classification may be necessary.

AVERAGE BIOPHYSICAL VARIABLES

fCover= 17.0% (std=4.0)

Variable		CEV6.1	CEV5.1	Miller	LAI2000 (3)	LAI2000 (4)	LAI2000 (5)
PAI	Effective	NaN	0.26	0.27	0.29	0.28	NaN
	True	NaN	0.27	0.29	-	-	-
ALA (°)	Effective	NaN	47.56	80.00	-	-	-
	True	NaN	18.00	-	-	-	-

Figure 17: Average Biophysical Variables. The red box indicates the CEV5.1 and Miller within the Effective PAI row.

Additionally, you can check the “Clumping Factor” graph. A curved line is the ideal model, and the scatter plot represents the results. The scatter plot should roughly follow the curve.