Measurement of soybean grain yield and aboveground biomass at maturity by crop cut at plot level

SOP ID: 012
Version: 1
Crop: Soybean (*Glycine max*)
Relevant KPIs: Productivity — yield; Resource use efficiency — nutrient use efficiency
R&D stage (example of activities):

- Discovery stage (yield decomposition)
- Proof-of-concept stage (testing of improved agronomic practices in on-station and/or on-farm trials)
- Pilot stage (on-farm participatory trials, randomized control trial)
- Scaling stage (panel studies, yield predictions at scale using crop models and GIS, ex-post impact assessment)

Background

Soybean is an important grain legume, providing high-protein food to humans and animals (Fig. 1). Some varieties have a high oil content. Due to its ability to form nodules with rhizobia and to fix atmospheric nitrogen (N_2), it does not require large amounts of N-fertilizer and can have positive effects on the soil fertility. However, in soils in which soybean has not been grown before, inoculation with compatible rhizobia may be required to effectively fix N_2. Soybean is a medium-duration grain legume, of which there is a large number of varieties. Soybeans mature in 115–125 days after sowing (DAS). Thus, the harvest should be planned according to the maturity type sown.

Figure 1. Top: Well-developed soybean field at the early flowering stage.
Bottom: Soybean crop with a large portion of senescent leaves just before harvest

Required equipment/materials

- Field plan (if a trial is to be harvested)
- Measuring tape
- Pegs
- String or rope (non-stretching)
- Cloth or woven poly sacks
- Paper bags
- Twine
- Markers
- Cutlass or sickle
- Digital weighing balance
- Grain moisture meter (optional)
- Data recording tools/sheet.

Module 1: Determination of soybean grain yield

1.1 Determination of the right time to harvest soybean

Field observations should be done before the anticipated maturity because weather conditions, pests and diseases may require modifying the harvest date. Soybean ripens within a relatively short phase during which the leaves dry and are shed and the pods become visible. Pods are ready for harvest when the green pods turn yellow (Fig. 2, left). At that time, the pods will open easily with a crackling noise, and grains detach easily from the pod. In most soybean varieties, there is a risk of pod shattering (Fig. 2, right), which is increased by conditions of repeated wetting and drying of the crop before harvest.

Figure 2. Left: Mature soybean pods. Right: Mature soybean pods open before being harvested, risking grain losses. Small gusts of wind and the harvest operation can detach the grains from the pods

Harvesting immediately when the pods turn yellow is essential. Besides varieties' genetic disposition, shattering occurs when mature pods are left in the field beyond the appropriate harvest date.

1.2 Determination of the grain yield of soybean

Step 1: Locate and demarcate the net harvest area and the required border rows or space following instructions in SOP001 Determination of the minimum number of plants and the minimum area to be harvested for correct crop yield determinations. The net harvest area should be representative of the entire plot. In trials sown in rows, at least one row on each side of the plot and all plants at the start and end of each row within the same length as the distance between rows need to be discarded as border (Fig. 3). The dimensions of the net harvest area across the rows need to be a multiple of the distance between rows and the length of one row distance needs to be removed at the start and end of the remaining rows. If the crop was sown by broadcasting, plants are randomly distributed. In such cases, the border around the net harvest plot should be about as wide as one-row distance by local recommendations. For details on the determination of border spaces, refer to SOP001 equations 6 and 7.

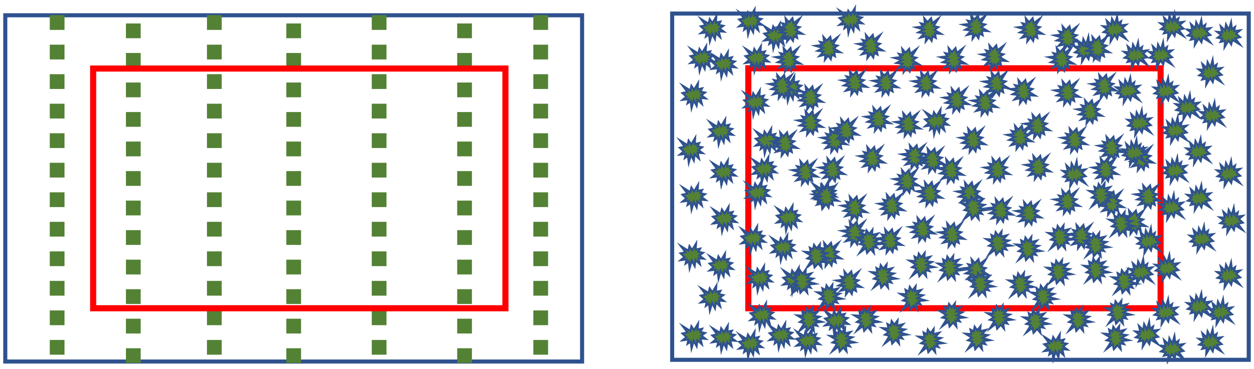

Figure 3. Examples of how to locate and demarcate the net harvest area (red box) in row-sown (left) and broadcast (right) soybean plots

Step 2: In row-sown crops, place a peg in the middle between rows at one row distance from the beginning and the end of the row. Fix a string between the pegs and perform the same between the last row of the harvest area and the border row on the other side of the plot. Connect the pegs with a rope to form the square or rectangular net harvest area. When pulling the rope across the rows, ensure that only plants rooting inside the net harvest area are within the demarcated area.

Step 2a: If the crop was broadcast, determine the size of the border following instructions in SOP001, and use equations 6 and 7 of that SOP to calculate the border width. Place pegs in the corner points and pull ropes to form the net harvest area. Check along each rope so that only plants rooting in the net area are included.

Step 2b: It is recommended to remove all border plants before harvesting the net harvest area. This prevents the inclusion of plants that are rooting outside the net harvest area.

Note: If the plants are lodging, first establish a baseline by pushing a long stick under the crop, lift it and bend the plants back so the soil surface becomes visible. The pegs can be set and connected with a rope without plants crossing the rope. From each end of the baseline set two pegs at a 90° angle along the direction in which the crop is lodging. Once the two pegs are set, push the long stick again under the crop from one peg toward the other, then lift the crop to have a clear line between the pegs. Bend back into the harvest area all plants and fix a rope between the pegs. Ensure that the line is straight and that all plants within the demarcated area are rooting in the harvest area. Remove all plants that are not rooting in the harvest area. Lodging crops are usually still moist when harvested and thus need to be handled with care to prevent rotting and moldy grains.

Step 3: Harvest the plants in the net harvest area. The harvest can be conducted with different tools depending on the plot size, the data requirements and availability of the equipment.

Step 3a: Cut the plants at the soil surface, bundle them and carry them from the plot onto a tarpaulin or place them in netting or a cloth bag.

Step 3b: If the crop is wet and needs drying, the plants can be bundled and hung upside down in netting (about 2 mm mesh size) to dry. Grains from shattering pods will be recovered from the netting.

Step 4: Threshing. If the crop was harvested dry (step 3a), the plants can be threshed manually (if the sample is small) or with a mechanical thresher. To manually thresh the beans, place the plants in a large bag and hit the bag with a baton. Avoid hitting too hard as this may break the grains. Alternatively, twist or fold the bag and rub or roll it against the floor or the top of a table. This squashing motion will burst the pods without breaking the seeds. After threshing, check the sample for pods that did not open.

If the sample is too large for manual threshing, use a mechanical thresher or a plot thresher.

Step 5: Separate the grain from stover and chaff. If the sample is small, the stover can be hand picked and the broken vegetative material be separated with a sieve that has a mesh size slightly smaller than the diameter of the grains. Remaining residues can also be hand picked from the sample. If the sample is too large to hand pick the grains, use a thresher or a seed cleaner.

Step 6: Determine the grain mass (grams or kg) recovered from the net harvest area, using a digital balance placed on a horizontal surface.

Step 7: Immediately measure the grain moisture content using a grain moisture meter. It is recommended to repeat the procedure with different grains at least three times and to use the average moisture content of several measurements.

Note: Make sure the grain moisture meter is calibrated for soybean.

If a moisture meter is not available, use the gravimetric method: take a grain subsample of around 250 grams weigh fresh and dry to constant mass. When dry, weigh again and calculate the grain moisture content with equation 1 or 2.

If neither a drying oven nor a moisture meter is available, sun-dry the grains in netting. Make a note that the grains were sun-dried.

When using a plot combine-harvester, ensure that the crop is ripe and dry enough to easily separate the grains from the pods. Remove the border plants before threshing the net plot. Recover all grains and follow steps 6 and 7.

Note: If the grains need to be assessed for quality, such as protein content or other parameters, take another subsample of around 500 g and put it in a paper bag, ziplock bag or container ready for lab analysis.

1.3 Calculations

Step 1: Calculate the proportion of dry matter in grains

$$\text{Proportion of dry matter in grain sample} = \frac{\text{Dry grain mass of subsample}}{\text{Fresh grain mass of subsample}} \quad (1)$$

If the percentage dry matter is preferred:

$$\text{Percentage dry matter in the grain sample} = \frac{\text{Dry grain mass of subsample}}{\text{Fresh grain mass of subsample}} \times 100 \quad (2)$$

Step 2: Determine the oven- or sun-dried grain yield

$$\text{Oven- or sun-dried grain yield (kg/ha)} = \text{Fresh grain yield (kg/ha)} \times \text{Proportion of dry grain in subsample} \quad (3)$$

If the use of percentage dry grain in the fresh grain subsample is preferred:

$$\text{Oven- or sun-dried grain yield (kg/ha)} = \frac{\text{Fresh grain yield (kg/ha)} \times \text{\% dry grain in subsample}}{100} \quad (4)$$

Note: the grain moisture content should be determined immediately after harvest in all cases to ensure the grain is dry enough to be stored or (if the moisture content is too high) needs to be appropriately dried to avoid grain quality losses.

Module 2: Determination of the aboveground biomass (without grains)

2.1 Background

Although the grain yield of soybean is of major importance, an additional important role of the legume in the overall cropping system is its ability to form nodules with rhizobia and to fix N_2 from the atmosphere. To assess the amount of fixed N_2 and thus the potential residual amount of N returned to the soil, the total crop biomass is required. Although the root and nodule biomass contain some of the fixed N_2, their mass at harvest is usually very low compared with the aboveground biomass and thus it is not considered here, because of the relatively large labor requirements to recover roots and nodules. Further, legumes shed leaves from relatively early stages and can lose a large portion of leaf biomass well before the pods mature. If the determination of the aboveground biomass is important, then precautions need to be taken early to recover the shed leaves before they can start decomposing and losing nutrients.

2.2 Required equipment/material

- Measuring tape
- Four pegs
- Simple or netted leaf-litter sampling frames
- String or rope
- Cloth or woven poly sacks
- Cutlass or sickle
- Paper bags
- Ziplock bag
- Digital weighing balance
- Drying oven
- Data recording tools/sheet.

2.3 Procedure

Step 1: If the total biomass is required, the shed leaves need to be sampled over a long period and this requires them being collected regularly and at short intervals, especially if rainfall events are frequent. It is recommended to use netted leaf-litter sampling frames, which can be constructed from simple squared timber and 2 mm aluminum or nylon netting. The frame dimensions need to be compatible with the row spacing. It is recommended to use frames that are of the row spacing (Fig. 4) or half the row spacing. The number and length of these frames needs to be determined by the proportion of surface area that is deemed appropriate to reflect the plot. The distribution of the sampling frames needs to consider that sampling should not be conducted in border areas. The advantage of netted frames is that they can be picked up and the leaves can be poured into paper bags without picking up individual leaves. If pods start shattering, the grains would be recovered from the netted frames. The netting prevents or reduces access by soil macrofauna such as earthworms and contamination of the leaves with soil. Leaf litter sampling with netted frames is not possible in broadcast soybean plots. If leaf litter is to be collected in broadcast plots, the sampling area can be demarcated with string or frames and all leaves need to be collected from that area.

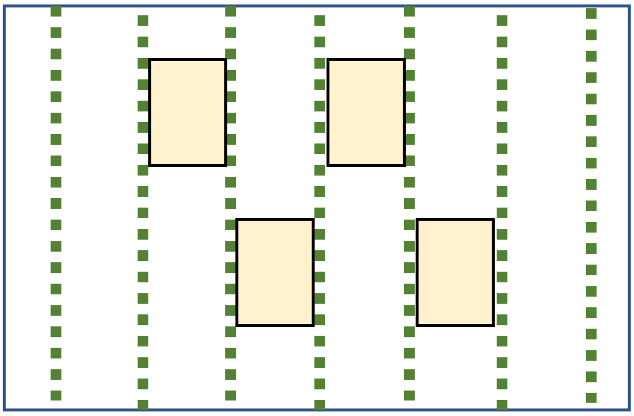

Figure 4. Example of four leaf-litter sampling frames covering the space between soybean rows. The length, number and distribution of frames needs to reflect the plot size and the required proportion of surface area to be sampled

Step 1a: Sampling shed leaves. In trials that require the sampling of leaves only at the final harvest, it is important to remember that some portion of the biomass and the nutrients may have been lost. The best estimate would be by collecting all leaves in the net harvest area. However, this is time consuming, so it is proposed to collect them from a portion of the net harvest plot. This can be done by demarcating sampling areas between the rows as in Fig. 4 or Fig. 5. The exact number and size of sampling areas needs to be selected by the scientist in charge of the trial. In broadcast soybean plots, the net harvest area can be divided into four or eight subplots by placing strings across the middle of each side length (to get four subplots) and divide the subplots again into half to get eight subplots (Fig. 5, right). Collect the leaves from every other subplot, best in a zigzag pattern, and place the leaves in a cloth or woven poly bag. Record the area from which the leaves were sampled.

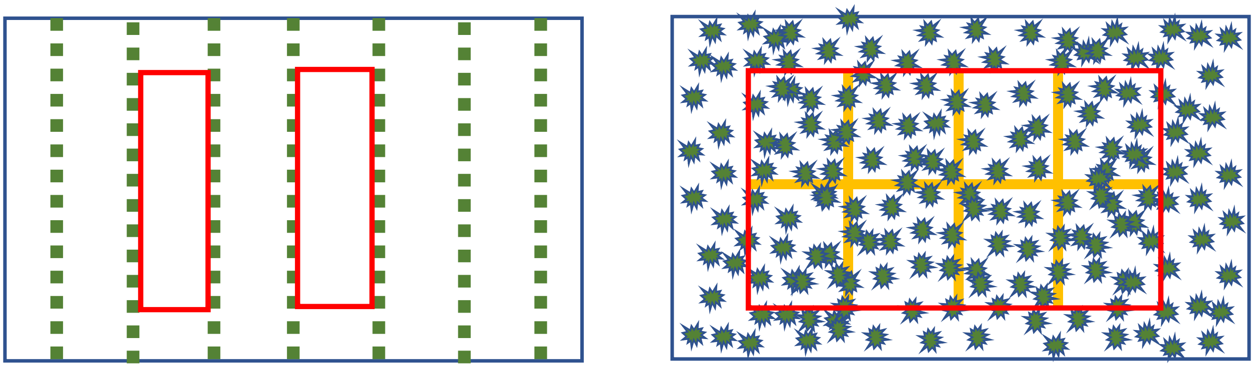

Figure 5. Left: Leaf-litter sampling areas (within the red lines) in row-sown soybean plots. Right: Net harvest area of a broadcast soybean plot, cut into eight same-size subplots to sample leaves. Leaf sampling can be done in every second subplot arranged in a zigzag pattern

Step 2: Determine the biomass sampling area. The area used for the aboveground biomass harvest should be the same as the area used for the grain yield determination.

Step 2a: However, if collecting all plants in a plot is not feasible, it is recommended to sample every other row in row-sown crops, while still respecting the border areas (from which no plants should be collected). In broadcast soybean plots, the same approach as for leaf sampling should be used (Fig. 6, right) by dividing the net harvest area into four to eight subplots and collecting the plants from every other subplot, best in a zigzag pattern. If the crop is lodging, ensure only those plants originating from inside the demarcated net plot or subplot are harvested. Shed leaves of lodging border plants could have fallen into the sampling area but this should be balanced out by leaves of harvest area plants falling into the border area. Here it is important to place the sampling frames such that all positions in the harvest area are represented.

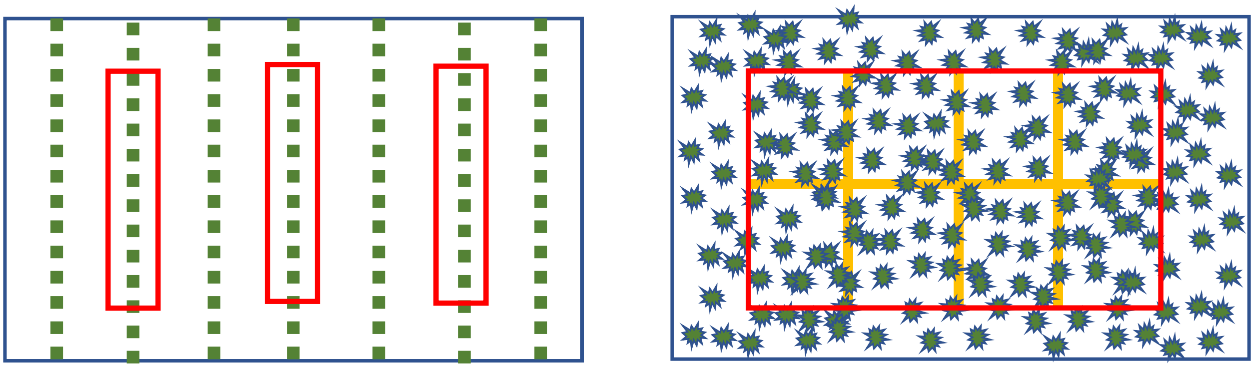

Figure 6. Left: Plant sampling areas (within the red lines) in row-sown soybean plots. Right: Net harvest area of a broadcast soybean plot, divided into eight same-size subplots to sample plants. Plant sampling can be done in every second subplot arranged in a zigzag pattern

Step 3: Harvest the plants. If the whole plot is harvested, select the net harvest area, and cut all plants at ground level, place in a paper or cloth bag, weigh and record the fresh mass.

Step 4: Separate the grains from the stover. As soybeans produce a large number of pods with few seeds it will be very labor intensive to pick the pods from the plants. It is better to carefully thresh them, and separate the grains without losing macerated empty pods, stem or leaf parts (i.e., do not use forced air as this may displace material; rather sieve or hand-sort the material).

Step 5: Determine the fresh mass of the vegetative biomass (stover). The remaining vegetative biomass is collected, weighed and the fresh mass recorded.

Step 6: Subsample to determine the stover dry matter content. Shred the stover, including empty pods and leaves if still attached, into small pieces, mix and take a subsample (about 500 g) to determine the moisture content. If the leaves were sampled separately or over time, it is advised to take a leaf subsample and dry separately from the stover (which usually has no leaves at grain harvest).

Step 6a: Place the stover-and-leaf subsample in the oven and dry to constant mass, weigh when dry, record the dry mass.

Step 7: If the volume or mass of the stover in a plot is too large to harvest the plot, it is recommended to randomly sample 10–15 complete plants in the net harvest area, manually remove all grains, return the empty pods to the stover and proceed with this sample as in steps 5 and 6. When removing the grain, consider step 4 to avoid vegetative biomass losses.

All bags of all subsamples should be labeled with the type of sample (pods, grains, shoot, leaves), the trial identifier (location, farm, field, trial number), the plot number and (if required) the treatment, year and (if leaves were sampled several times) the date of sampling.

2.4 Calculations

The proportion of biomass (stover and empty pods) dry matter is calculated as:

$$\text{Proportion of biomass dry matter} = \frac{\text{Dry mass of biomass subsample}}{\text{Fresh mass of biomass subsample}} \tag{5}$$

The biomass dry matter yield (kg/ha) is calculated as:

$$\text{Biomass dry matter yield (kg/ha)} = \frac{\text{Proportion of biomass dry matter} \times \text{Fresh mass of the biomass in the net plot (g)}}{\text{Net plot area (m}^2\text{)}} \times \frac{10{,}000}{1000} \tag{6}$$

Where the division by the net plot area converts to g/m^2, the division by 1000 is the conversion of grams to kg and the multiplication by 10,000 is the conversion from m^2 to ha.

The proportion of leaf dry matter is calculated as:

$$\text{Proportion of leaf dry matter} = \frac{\text{Dry mass of leaf subsample}}{\text{Fresh mass of leaf subsample}} \tag{7}$$

The leaf dry matter yield (kg/ha) is calculated as:

$$\text{Leaf dry matter yield (kg/ha)} = \frac{\text{Proportion of leaf dry matter} \times \text{Fresh mass of the leaves in the net plot (g)}}{\text{Leaf sampling area* (m}^2\text{)}} \times \frac{10{,}000}{1000} \quad (8)$$

Where the division by the leaf sampling area converts to g/m^2, the division by 1000 is the conversion of grams to kg and the multiplication by 10,000 is the conversion from m^2 to ha.

*Note that the sampling area from which the leaves are sampled may be different from the net plot area and this needs to be indicated here.

The total non-grain aboveground biomass yield is the sum of biomass dry matter yield and leaf dry matter yield:

$$\text{Total non-grain aboveground dry matter yield} = \text{Biomass dry matter yield (kg/ha)} + \text{Leaf dry matter yield (kg/ha)} \quad (9)$$

The total aboveground biomass yield is the sum of total non-grain dry matter yield plus the grain dry matter yield:

$$\text{Total aboveground biomass yield} = \text{Total non-grain aboveground dry matter yield (kg/ha)} + \text{Grain dry matter yield (kg/ha)} \quad (10)$$

The grain harvest index is calculated as:

$$\text{Grain harvest index} = \frac{\text{Grain dry matter yield (kg/ha)}}{\text{Total non-grain aboveground biomass yield} + \text{Grain dry matter yield (kg/ha)}} \quad (11)$$

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