

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

**SOP ID:** 008

**Version:** 1

**Crop:** Maize/corn (*Zea mays*)

**Relevant KPIs:** Productivity — yield

**R&D stage (example of activities):**

- Pilot stage (nutrient-omission trials, on-station and on-farm in small plots, or other agronomic trials)
- Proof-of-concept stage (testing of improved agronomic practices in on-station and/or on-farm trials)
- Scaling stage (on-farm trials)

## Required equipment

- Scales/balances that can accurately measure weights of smaller samples (grain and stover moisture subsamples) and larger samples (plant sample, grain sample, stover sample)
- Sheller (manual or mechanized)
- Lengths of pre-measured twine (60 cm recommended)
- Machete or large knife
- Large cloth sacks
- Medium-sized cloth bags
- Large paper (grocery) bags
- Markers and labels
- Plastic bucket
- Data recording notebook/sheet and pen/pencil
- Grain moisture meter (optional).

See also the equipment list in SOP001 Determination of the minimum number of plants and the minimum area to be harvested for correct crop yield determinations.

All measuring equipment requires calibration. Proper calibration requires additional equipment not listed here. We recommend consulting guidance published by The United States Bureau of Reclamation (USBR, 1989a,b,c): USBR-1000-89, USBR-1012-89, USBR-1020-89; the National Institute of Standards and Technology Office of Weights and Measures (NIST OWM, 2019a,b,c,d,e) standard operating procedures Nos 4, 5, 7, 8, 28; NIST Special Publication 250-31 (Davis, 1989); NIST Handbook 44 (Butcher *et al.*, 2022); and NIST Handbook 159 (Lee and Olson, 2017).

Record information about each measuring instrument: manufacturer, model number, date of last calibration certification, precision, weight limits, etc.

At each experimental site, set up a processing area in the field. This area should be equipped with calibrated measuring equipment. Reserve at least one bag of each type as well as a few lengths of twine and any labels to tare the scales.

## Module 1: Aboveground biomass measurements at physiological maturity

Measurements in this module are used to calculate harvest index and average aboveground biomass per plant. These metrics are used in Module 3 to calculate biomass yield per unit area. Conventionally, measurements in this module are performed at growth stage R6 on a small sample of plants from the harvest area in each experimental unit.

## 1.1 Procedure

**Step 1:** Delineate the harvest area and record its dimensions.

We recommend determining the size of the harvest area based on characteristics of individual experimental sites. Important factors are plant density and yield level (see SOP001 Determination of the minimum number of plants and the minimum area to be harvested for correct crop yield determinations).

**Step 2:** Determine the number of plants to sample.

We recommend a minimum of six plants (Kladivko *et al.*, 2014); however, in low-yielding treatments, more plants may be needed to provide sufficient material to be within the calibrated ranges of measuring equipment. We recommend testing the number of plants needed by sampling the border area of the treatment that is likely to be the lowest yielding. Start with six plants and go through all the steps in this module to determine whether there is sufficient material for all measurements. If not, incrementally add more plants, running through all steps each time, to determine the number of plants required. Once the number of plants required is determined, use this number consistently across all treatments at a given site. In the following steps, we use six plants, but substitute the number you determine to be required. *Do not use less than six plants.*

If barren plants are present, barren and productive plants will require separate samples. Identify barren plants by first determining whether an ear has been formed. If not, the plant is barren. If an ear was formed, the plant is barren if no grain has fully developed on the cob. Examine the rigidity of the ear. A thin, flexible ear is indicative of poor grain fill or barrenness. Squeeze the ear gently to feel for grain and, if necessary, gently and carefully peel back part of the husk to visually inspect the ear. If no fully developed grain is present on the ear, the plant is barren.

When determining the number of plants that need to be sampled, perform this step for both barren and productive plants, since the numbers of plants required may differ.

**Step 3:** Record the growth stage.

Scientific convention is to measure aboveground biomass at physiological maturity (R6). Determining when this growth stage occurs requires frequent (daily) monitoring after stage R5. A maize *plant* is at R6 when 95% or more of the kernels in the ear have formed a black layer. For a *population* of maize plants, R6 is defined as 50% of all plants at this stage of development. On each day after a few plants have reached R6, evaluate 10 representative plants to determine the percentage at R6. Because destructive sampling is involved, take measurements from plants in border areas (outside the harvest area). Do this each day until 50% of the plants are at R6. When daily monitoring is not possible, determine the growth stage on the day of sampling and record. If the day of physiological maturity has passed, indicate this in your records (i.e. “post physiological maturity”).

**Step 4:** Measure the fresh weight of the six-plant samples for both barren and productive plants.

Use a large knife to cut six representative plants about 2 cm above the soil surface from random locations within the harvest area. Representative plants should have the same stalk diameter, plant health, and stage of development as the majority of plants in the harvest area. Tie the plants together to form a bundle, attach a label, and weigh on a tared scale. Record weight in grams. Do this separately for barren and productive plants — one bundle for each.

**Step 5:** From the bundle of productive plants only, remove the ears from the six-plant sample.

Untie the bundle of productive plants, carefully remove the ears, keeping the husks attached to the stalks. Ensure all plant material other than the ears stays together. Re-tie the bundle, ensuring the label is attached. Reserve.

**The following steps are for measurements on maize ears taken from the productive plants.**

**Step 6:** Measure the number of ears in the six-plant sample of productive plants.

Count and record the number of ears.

**Step 7:** Measure the fresh weight of the six-plant ear sample.

Place ears into a large labeled paper bag and weigh on a tared scale. Record the weight in grams.

**Step 8:** Measure the fresh weight of the six-plant grain sample.

Using a sheller, remove the grain from the ears. Shell into a plastic bucket, ensuring no grain is lost. Pour all the grain into a large labeled paper bag and weigh on a tared scale. Record the weight in grams. Reserve.

**Step 9:** Measure the fresh weight of the six-plant cob sample.

Place the shelled cobs into a large paper bag and weigh on a tared scale. Record the weight in grams. Transport to a drying facility.

**The following steps differ depending on whether or not a calibrated grain moisture meter is available.**

**If a moisture meter is available:**

**Step 10:** Measure the six-plant grain sample moisture.

Mix the six-plant grain sample thoroughly. Follow the manufacturer's instructions and record grain moisture as a percentage.

**If a moisture meter is not available or as an additional quality-control step:**

**Step 11:** Take a subsample from the six-plant grain sample and measure its fresh weight. This subsample will be used for moisture determination.

Mix the six-plant grain sample thoroughly. Place a medium-sized cloth bag on the scale and tare. Add grain until there is at least 300 g in the bag. Record the exact weight in grams. Transport to a drying facility.

**The following steps are for measurements on bundled plant material (both barren and productive).**

**Step 12:** From the bundle of productive plants only, measure the fresh weight of the six-plant stover sample (the material left after the ears were removed in Step 5). For barren plants, this step is not necessary, since the corresponding measurement was already taken in Step 4.

Weigh the bundle on a tared scale. Record the weight in grams.

**Step 13:** Take separate subsamples from barren and productive bundles and measure their fresh weights. These subsamples will be used for moisture determinations.

For each bundle, untie the twine and select three representative plants. Remove the leaves from those plants and cut into small (5 cm) pieces and place in a labeled, medium-sized cloth bag. Remove and cut the husks (plus barren ears in the case of barren plants) into small pieces and add to the leaves. Cut the remaining stalks and add to the rest of the cut material. Ensure no plant material is lost during cutting. Weigh immediately on a tared scale. Record the weight in grams. Perform this procedure for each bundle, recording the weights separately for each one. Transport to a drying facility.

**Step 14:** Perform quality-control checks during sampling.

While in the field, determine the percentage error in the following measurements. We suggest that if the error is greater than  $\pm 5\%$  in each determination, then recalibrate the equipment and reweigh the samples. Resampling may also be necessary.

a. Determine the percentage error in fresh weight of the six-plant ear sample.

Let  $ear\_fw$  = fresh weight (g) of the six-plant ear sample (Step 7)

Let  $grain\_fw$  = fresh weight (g) of the six-plant grain sample (Step 8)

Let  $cob\_fw$  = fresh weight (g) of the six-plant cob sample (Step 9)

Let  $ear\_fw\_e$  = percentage error in fresh weight of the six-plant ear sample (the quantity to be calculated)

$$ear\_fw\_e = \frac{grain\_fw + cob\_fw - ear\_fw}{ear\_fw} \times 100 \quad (1)$$

b. For the productive plant bundle only, determine the percentage error in the fresh weight of the six-plant sample — method 1.

Let  $plant\_fw$  = fresh weight (g) of the six-plant sample (Step 4)

Let  $ear\_fw$  = fresh weight (g) of the six-plant ear sample (Step 7)

Let  $stover\_fw$  = fresh weight (g) of the six-plant stover sample (Step 12)

Let  $plant\_fw\_e1$  = percentage error in the fresh weight of the six-plant sample (the quantity to be calculated)

$$plant\_fw\_e1 = \frac{ear\_fw + stover\_fw - plant\_fw}{plant\_fw} \times 100 \quad (2)$$

c. For the productive plant bundle only, determine the percentage error in the fresh weight of the six-plant sample — method 2.

Let  $plant\_fw$  = fresh weight (g) of the six-plant sample (Step 4)

Let  $grain\_fw$  = fresh weight (g) of the six-plant grain sample (Step 8)

Let  $cob\_fw$  = fresh weight (g) of the six-plant cob sample (Step 9)

Let  $stover\_fw$  = fresh weight (g) of the six-plant stover sample (Step 12)

Let  $plant\_fw\_e2$  = percentage error in the fresh weight of the six-plant sample (the quantity to be calculated)

$$plant\_fw\_e2 = \frac{grain\_fw + cob\_fw + stover\_fw - plant\_fw}{plant\_fw} \times 100 \quad (3)$$

**Step 15:** Dry samples to constant weight.

Transport the following samples to a drying facility: (i) six-plant cob samples from Step 9; (ii) if Step 11 was followed, the six-plant grain moisture subsamples; (iii) the stover moisture subsamples from Step 13 (two of these samples if both productive and barren plants were present). The drying facility should be equipped with a forced-air oven calibrated to 70°C and with enough space for the samples to have air space between them. Also place bags and tags of each type into the oven to use for taring scales. After at least 24 hours in the oven, select three samples of each type and record the weights. Repeat with the same samples on each subsequent day. When the weight of each sample does not change from day to day, the samples have been dried to constant weight and drying is complete.

**Step 16:** Measure the dry weight of the six-plant cob sample.

Weigh the six-plant cob subsample (from Step 9) immediately after removing from the oven. Record the weight in grams.

**Step 17:** Measure the dry weight of the six-plant grain moisture subsample (if Step 11 was followed).

Weigh the six-plant grain moisture subsample (from Step 11) immediately after removing from the oven. Record the weight in grams.

**Step 18:** Measure the dry weight of the stover moisture subsamples.

Weigh the stover moisture subsamples (from Step 13) immediately after removing them from the oven. Record the weight in grams. If both productive and barren plants were present, there will be two of these subsamples.

## 1.2 Calculations

The goal of these calculations is to determine (i) the average (mean) non-grain, aboveground biomass per plant (for barren and productive plants), and (ii) the harvest index (for productive plants only). The harvest index is the unitless ratio of the grain dry matter to the dry matter of the entire aboveground plant biomass. We use this ratio in Module 3. The aboveground biomass, as sampled, is partitioned into stover, grain and cob. Because we dried subsamples, rather than entire samples, of grain and stover, we determine the dry matter fraction of each of those subsamples and multiply that fraction by the fresh weights of each of the corresponding larger samples to calculate the dry matter biomass of those larger samples. Because all cobs, rather than a subsample, were dried, we simply use the oven-dry weight for the dry matter biomass of the cobs.

**Step 1:** For productive plants only, calculate the total and mean non-grain, dry matter biomass per productive plant (g/[productive plant]) in the six-plant sample.

Let  $plant\_num\_p$  = number of productive plants determined in 1.1 Procedure Step 2 and used in 1.1 Procedure Step 4

Let  $stover\_fw\_p$  = fresh weight (g) of the six-plant stover sample of productive plants (1.1 Procedure Step 12)

Let  $stover\_sub\_fw\_p$  = fresh weight (g) of the stover moisture subsample taken from the productive plant bundle (1.1 Procedure Step 13)

Let  $stover\_sub\_dw\_p$  = dry weight (g) of the stover moisture subsample taken from the productive plant bundle (1.1 Procedure Step 18)

Let  $cob\_dm\_p$  = dry weight (g) of the six-plant cob sample taken from the productive plant bundle (1.1 Procedure Step 16)

Let  $stover\_dm\_p$  = total non-grain, dry matter biomass (g) of the six-plant sample taken from the productive plant bundle (the quantity to be calculated)

Let  $stover\_dm\_p\_mean$  = mean non-grain, dry matter biomass per productive plant (g/[productive plant]), the quantity to be calculated)

$$stover\_dm\_p = cob\_dm\_p + \frac{stover\_sub\_dw\_p}{stover\_sub\_fw\_p} \times stover\_fw\_p \quad (4)$$

$$stover\_dm\_p\_mean = \frac{stover\_dm\_p}{plant\_num\_p} \quad (5)$$

**Step 2:** For barren plants only, calculate the total and mean dry matter biomass per barren plant (g/[barren plant]) in the six-plant sample.

Let  $plant\_num\_b$  = number of barren plants determined in 1.1 Procedure Step 2 and used in 1.1 Procedure Step 4

Let  $stover\_fw\_b$  = fresh weight (g) of the six-plant sample of barren plants (1.1 Procedure Step 4)

Let  $stover\_sub\_fw\_b$  = fresh weight (g) of the stover moisture subsample taken from the barren plant bundle (1.1 Procedure Step 13)

Let  $stover\_sub\_dw\_b$  = dry weight (g) of the stover moisture subsample taken from the barren plant bundle (1.1 Procedure Step 18)

Let  $stover\_dm\_b$  = total dry matter biomass (g) of the six-plant sample taken from the barren plant bundle (the quantity to be calculated)

Let  $stover\_dm\_b\_mean$  = mean dry matter biomass per barren plant (g/[barren plant]), the quantity to be calculated)

$$stover\_dm\_b = \frac{stover\_sub\_dw\_b}{stover\_sub\_fw\_b} \times stover\_fw\_b \quad (6)$$

$$stover\_dm\_b\_mean = \frac{stover\_dm\_b}{plant\_num\_b} \quad (7)$$

**Step 3:** For productive plants only, calculate the dry matter weight (g) of the six-plant grain sample.

Let  $grain\_fw$  = fresh weight (g) of the six-plant grain sample (1.1 Procedure Step 8)

Let  $grain\_dm$  = dry matter weight (g) of the six-plant grain sample (the quantity to be calculated)

**If a moisture meter was used** (1.1 Procedure Step 10):

Let  $grain\_moist\_m$  = six-plant grain sample moisture (%) measured with a moisture meter (1.1 Procedure Step 10)

$$grain\_dm = \frac{100 - grain\_moist\_m}{100} \times grain\_fw \quad (8)$$

**If a grain subsample was taken to determine moisture content** (1.1 Procedure Steps 11 and 17):

Let  $grain\_sub\_fw$  = fresh weight (g) of the six-plant grain moisture subsample (1.1 Procedure Step 11)

Let  $grain\_sub\_dw$  = dry weight (g) of the six-plant grain moisture subsample (1.1 Procedure Step 17)

Let  $grain\_moist\_d$  = six-plant grain sample moisture (%) measured by oven-drying (a quantity to be calculated)

First calculate  $grain\_moist\_d$ :

$$grain\_moist\_d = \frac{grain\_sub\_fw - grain\_sub\_dw}{grain\_sub\_fw} \times 100 \quad (9)$$

Then calculate  $grain\_dm$ :

$$grain\_dm = \frac{100 - grain\_moist\_d}{100} \times grain\_fw \quad (10)$$

**Step 4:** For productive plants only, if 1.1 Procedure Steps 10, 11 and 17 were performed, determine the percentage error of the moisture meter readings, using oven-dried moisture as the standard. This is a quality-control measure.

Let  $grain\_moist\_m$  = six-plant grain sample moisture (%) measured with a moisture meter (1.1 Procedure Step 10)

Let  $grain\_moist\_d$  = six-plant grain sample moisture (%) measured by oven-drying (Equation 9)

Let  $grain\_moist\_e$  = percentage error (%) of the moisture meter readings (the quantity to be calculated)

$$grain\_moist\_e = \frac{grain\_moist\_m - grain\_moist\_d}{grain\_moist\_d} \times 100 \quad (11)$$

**Step 5:** For productive plants only, calculate the harvest index (unitless fraction).

Let  $stover\_dm\_p$  = total non-grain, dry matter biomass (g) of the six-plant sample taken from the productive plant bundle (Equation 4)

Let  $grain\_dm$  = dry matter weight (g) of the six-plant grain sample (Equation 8 or 10)

Let  $HI$  = harvest index (the quantity to be calculated)

$$HI = \frac{grain\_dm}{stover\_dm\_p + grain\_dm} \quad (12)$$

## Module 2: Measurement of grain dry matter yield at harvest

### 2.1 Procedure

**Step 1:** Delineate the harvest area and record its dimensions.

We recommend determining the size of the harvest area based on characteristics of individual experimental sites (see SOP001 Determination of the minimum number of plants and the minimum area to be harvested for correct crop yield determinations). If Module 1 was performed, use the dimensions from 1.1 Procedure Step 1 in that module. Important factors are plant density and yield level. In low-yielding treatments, more plants may be needed to provide sufficient material to be within the calibrated ranges of measurement equipment (refer also to 2.1 Procedure Step 2, below). We recommend testing the harvest dimensions in the treatment that is likely to be the lowest yielding. Start with a given harvest area and go through all the steps in this module to determine whether there is sufficient material for all measurements. If not, incrementally increase the dimensions of the harvest area, running through all the steps each time, to determine the area required. Once appropriate dimensions have been confirmed, record the area (square meters). Use this area consistently across all treatments at a given site.

**Step 2:** Determine the ear sample size (number of ears required).

Steps 9 and 10 (below) require grain samples of certain quantities. As you determine the harvest area, make sure the number of ears in the harvest area will provide more than enough grain for the measurements in those steps. Start with six ears. Once the number of ears is determined, record it as the ear sample number. Use this number consistently across all treatments at a given site. *Do not use less than six ears.*

**Step 3:** Confirm that physiological maturity (R6) has occurred.

A maize *plant* is at R6 when 95% or more of the kernels on the ear have formed a black layer. For a *population* of maize plants, R6 is defined as 50% of all plants at this stage of development. Harvest occurs after physiological maturity when the grain has dried to 18% moisture content or less. If a grain moisture meter is available, take samples of grain from the border areas of what are likely to be higher- and lower-yielding treatments and determine whether the grain is at or below 18% for both treatments.

**Step 4:** Take the ear harvest sample and count barren and productive plants.

Move sequentially from plant to plant through the harvest area. Categorize each plant as barren or productive and keep a running tally of the number of plants in each category. Barren plants either produce no ear or produce an ear with no fully developed grain. Remove all ears (grain and cob) from the productive plants in the harvest area and place them into a large, labeled cloth sack. If Module 1 was used, this will be all the ears except those from previously sampled plants. Record the number of barren and productive plants.

**Step 5:** Count the number of ears harvested.

Count and record the number of ears harvested and replace them into the large, labeled cloth sack.

As a quality-control measure, ensure the number of ears is equal to or greater than the number of productive plants. The number of ears should not be less than the number of productive plants. If it is, a recount of ears and/or productive plants is required.

**Step 6:** Measure the fresh weight of the ear harvest sample.

Weigh the ear harvest sample on a tared scale. Record weight in kilograms. Reserve.

**Step 7:** Measure the fresh weight of the ear sample.

From the ear harvest sample, select the number of representative ears determined in Step 2 (minimum six). Place ears into a large, labeled paper bag and weigh on a tared scale. Record weight in grams.

**Step 8:** Measure the fresh weight of grain in the ear sample from Step 7.

Using a sheller, remove the grain from the ears. Shell into a plastic bucket, ensuring no grain is lost. Pour all the grain into a large, labeled paper bag and weigh on a tared scale. Record weight in grams. Reserve.

**The following steps differ depending on whether or not a calibrated grain moisture meter is available.**

**If a moisture meter is available:**

**Step 9:** Measure the ear sample grain moisture content.

Mix the ear sample grain thoroughly. Follow the manufacturer's instructions and record grain moisture content (%).

**If a moisture meter is not available or as an additional quality-control step:**

**Step 10:** Take a subsample of the grain in Step 8 and measure its fresh weight. This subsample will be used for moisture determination.

Mix the ear sample grain (from Step 8) thoroughly. Place a medium-sized cloth bag on the scale and tare. Add grain until there is at least 300 g in the bag. Record the exact weight in grams. Transport to a drying facility.

**Step 11:** Dry the ear sample grain moisture subsample to constant weight.

The drying facility should be equipped with a forced-air oven calibrated to 70°C and with enough space for the samples to have air space between them. Also place bags and tags of each type into the oven to use for taring scales. After at least 24 hours in the oven, select three samples and record the weights. Repeat with the same samples on each subsequent day. When the weight of each sample does not change from day to day, the samples have been dried to constant weight and drying is complete.

**Step 12:** Measure the dry weight of the ear sample grain moisture subsample.

Weigh the ear sample grain moisture subsamples (from Step 11) immediately after removing from the oven. Record weight in grams.

## 2.2 Calculations

**Step 1:** Convert harvest area in square meters (m<sup>2</sup>) to harvest area in hectares (ha).

Let *harvest\_area* = harvest area (m<sup>2</sup>) (2.1 Procedure Step 1)

Let *harvest\_area\_ha* = harvest area (ha, the quantity to be calculated)

$$harvest\_area\_ha = \frac{harvest\_area}{10,000} \quad (13)$$

**Step 2:** From the ear sample, use the ratio of the fresh weight of grain (2.1 Procedure Step 8) to the fresh weight of the ear (2.1 Procedure Step 7) to estimate the fresh weight of grain of all the ears collected in the harvest sample (2.1 Procedure Step 6).

Let *harvest\_ear\_fw* = fresh weight (kg) of the ear harvest sample (2.1 Procedure Step 6)

Let *ear\_fw\_h* = fresh weight (g) of the ear sample (2.1 Procedure Step 7)

Let *grain\_fw\_h* = fresh weight (g) of the ear sample grain (2.1 Procedure Step 8)

Let *harvest\_grain\_fw* = estimated grain fresh weight (kg) of the ear harvest sample (the quantity to be calculated)

$$harvest\_grain\_fw = \frac{grain\_fw\_h}{ear\_fw\_h} \times harvest\_ear\_fw \quad (14)$$

**Step 3:** If a grain subsample was taken in 2.1 Procedure Step 10, calculate the moisture content (%) in the grain using the fresh (2.1 Procedure Step 10) and dry (2.1 Procedure Step 12) weights of the subsample.

Let  $grain\_sub\_fw\_h$  = fresh weight of the grain moisture subsample of the ear sample (2.1 Procedure Step 10)

Let  $grain\_sub\_dw\_h$  = dry weight of the grain moisture subsample of the ear sample (2.1 Procedure Step 12)

Let  $grain\_moist\_d\_h$  = ear sample grain moisture (%) measured by oven-drying (the quantity to be calculated)

$$grain\_moist\_d\_h = \frac{grain\_sub\_fw\_h - grain\_sub\_dw\_h}{grain\_sub\_fw\_h} \times 100 \quad (15)$$

**Step 4:** Convert the estimated grain fresh weight (kg) of all the ears in the harvest sample ( $harvest\_grain\_fw$ , Equation 14) into estimated grain dry weight (kg). This can be done using the percentage grain moisture determined either by a moisture meter (2.1 Procedure Step 9) or by oven-drying (Equation 15).

Let  $harvest\_grain\_fw$  = estimated grain fresh weight (kg) of the ear harvest sample (Equation 14)

Let  $harvest\_grain\_d$  = estimated grain dry weight (kg) of the ear harvest sample (the quantity to be calculated)

**If grain moisture was determined by a moisture meter** (2.1 Procedure Step 9):

Let  $grain\_moist\_m\_h$  = ear sample grain moisture (%) measured by a moisture meter (2.1 Procedure Step 9)

$$harvest\_grain\_d = harvest\_grain\_fw \times \frac{100 - grain\_moist\_m\_h}{100} \quad (16)$$

**If moisture was determined by oven-drying** (2.1 Procedure Steps 10 and 12):

Let  $grain\_moist\_d\_h$  = ear sample grain moisture (%) measured by oven-drying (Equation 15)

$$harvest\_grain\_d = harvest\_grain\_fw \times \frac{100 - grain\_moist\_d\_h}{100} \quad (17)$$

**Step 5:** Express the estimated grain dry weight (kg) of all the ears in the harvest sample on a per hectare basis (kg/ha) by dividing  $harvest\_grain\_d$  (Equation 16 or 17) by the  $harvest\_area\_ha$  (Equation 13).

Let  $harvest\_grain\_d$  = estimated grain dry weight (kg) of the ear harvest sample (Equation 16 or 17)

Let  $harvest\_area\_ha$  = harvest area (ha, Equation 13)

Let  $gy\_dm$  = dry matter grain yield (kg/ha, the quantity to be calculated)

**If Module 1 was not used prior to Module 2**, calculate dry matter grain yield as follows:

$$gy\_dm = \frac{harvest\_grain\_d}{harvest\_area\_ha} \quad (18)$$

**If Module 1 was used prior to Module 2**, then the grain collected in the six-plant grain sample in Module 1 must be added to the grain collected during harvest:

Let  $grain\_dm$  = dry matter weight (g) of the six-plant grain sample from Module 1 (Equation 8 or 10)

Let  $grain\_dm\_kg$  =  $grain\_dm$  expressed in kg (a quantity to be calculated)

First calculate  $grain\_dm\_kg$ :

$$grain\_dm\_kg = \frac{grain\_dm}{1000} \quad (19)$$

Then add it to *harvest\_grain\_d* to calculate *gy\_dm*:

$$gy\_dm = \frac{grain\_dm\_kg + harvest\_grain\_d}{harvest\_area\_ha} \quad (20)$$

**Step 6:** If 2.1 Procedure Steps 9, 10 and 12 were all performed, determine the percentage error of the moisture meter readings, using oven-dried moisture as the standard. This is a quality-control measure.

Let *grain\_moist\_m\_h* = ear sample grain moisture (%) measured by a moisture meter (2.1 Procedure Step 9)

Let *grain\_moist\_d\_h* = ear sample grain moisture (%) measured by oven-drying (Equation 15)

Let *grain\_moist\_e\_h* = percentage error of the moisture meter readings (the quantity to be calculated)

$$grain\_moist\_e\_h = \frac{grain\_moist\_m\_h - grain\_moist\_d\_h}{grain\_moist\_d\_h} \times 100 \quad (21)$$

## Module 3: Calculation of total aboveground dry matter biomass and grain yield at a specified moisture content

### 3.1 Calculations

This module requires no new measurements. It requires prior completion of the measurements and calculations in Modules 1 and 2.

**Step 1:** Estimate the aboveground dry matter biomass (kg/ha) of productive plants — method 1 (uses the harvest index).

Let *HI* = harvest index (Equation 12)

Let *gy\_dm* = dry matter grain yield (kg/ha) (Equation 18 or 20)

Let *by\_dm\_p\_HI* = aboveground dry matter biomass yield (kg/ha) of productive plants, calculated using harvest index

$$by\_dm\_p\_HI = \frac{gy\_dm}{HI} \quad (22)$$

**Step 2:** Express the mean non-grain (stover) biomass per productive plant (*stover\_dm\_p\_mean*), calculated in grams in Module 1 (Equation 5) in units of kilograms, and do the same for the mean non-grain (stover) biomass per barren plant (*stover\_dm\_b\_mean*) (Module 1, Equation 7).

#### For productive plants:

Let *stover\_dm\_p\_mean* = mean non-grain, dry matter biomass per productive plant (g/[productive plant], Equation 5)

Let *stover\_dm\_p\_mean\_kg* = mean non-grain, dry matter biomass per productive plant (kg/[productive plant]), the quantity to be calculated:

$$stover\_dm\_p\_mean\_kg = \frac{stover\_dm\_p\_mean}{1000} \quad (23)$$

#### For barren plants:

Let *stover\_dm\_b\_mean* = mean dry matter biomass per barren plant (g/[barren plant], Equation 7)

Let *stover\_dm\_b\_mean\_kg* = mean dry matter biomass per barren plant (kg/[barren plant]), the quantity to be calculated:

$$stover\_dm\_b\_mean\_kg = \frac{stover\_dm\_b\_mean}{1000} \quad (24)$$

**Step 3:** Estimate the non-grain (stover) biomass (kg/ha) by multiplying the mean, non-grain (stover) dry matter biomass per plant by the number of plants. Do this for both productive and barren plants.

Let *harvest\_area\_ha* = harvest area in ha (Equation 13)

**For productive plants:**

Let *stover\_dm\_p\_mean\_kg* = mean non-grain, dry matter biomass per productive plant (kg/[productive plant], Equation 23)

Let *plant\_num\_p\_h* = the number of productive plants counted in Module 2 (2.1 Procedure Step 4)

Let *stover\_dm\_p\_h* = total non-grain dry matter biomass yield (kg/ha) of productive plants (the quantity to be calculated)

**If Module 1 was not used prior to Module 2:**

$$stover\_dm\_p\_h = \frac{stover\_dm\_p\_mean\_kg \times plant\_num\_p\_h}{harvest\_area\_ha} \quad (25)$$

**If Module 1 was used prior to Module 2,** the number of productive plants collected in Module 1 (determined in 1.1 Procedure Step 2) must be added to the number of productive plants counted during harvest.

Let *plant\_num\_p* = number of productive plants determined in 1.1 Procedure Step 2 and used in 1.1 Procedure Step 4

$$stover\_dm\_p\_h = \frac{stover\_dm\_p\_mean\_kg \times (plant\_num\_p\_h + plant\_num\_p)}{harvest\_area\_ha} \quad (26)$$

**For barren plants:**

Let *stover\_dm\_b\_mean\_kg* = mean dry matter biomass per barren plant (kg/[barren plant], Equation 24)

Let *plant\_num\_b\_h* =

Sounding chipper

number of barren plants counted in Module 2 (2.1 Procedure Step 4)

Let *stover\_dm\_b\_h* = total dry matter biomass yield (kg/ha) of barren plants (the quantity to be calculated)

**If Module 1 was not used prior to Module 2:**

$$stover\_dm\_b\_h = \frac{stover\_dm\_b\_mean\_kg \times plant\_num\_b\_h}{harvest\_area\_ha} \quad (27)$$

**If Module 1 was used prior to Module 2,** the number of barren plants collected in Module 1 (determined in 1.1 Procedure Step 2) must be added to the number of barren plants counted during harvest.

Let *plant\_num\_b* = number of barren plants determined in 1.1 Procedure Step 2 and used in 1.1 Procedure Step 4

$$stover\_dm\_b\_h = \frac{stover\_dm\_b\_mean\_kg \times (plant\_num\_b\_h + plant\_num\_b)}{harvest\_area\_ha} \quad (28)$$

**Step 4:** Estimate the aboveground dry matter biomass (kg/ha) of productive plants — method 2 (uses dry matter summation).

Let  $stover\_dm\_p\_h$  = total non-grain dry matter biomass yield (kg/ha) of productive plants (Equation 25 or 26)

Let  $gy\_dm$  = dry matter grain yield (kg/ha, Equation 18 or 20)

Let  $by\_dm\_p\_s$  = aboveground dry matter biomass yield (kg/ha) of productive plants, calculated by summation

$$by\_dm\_p\_s = gy\_dm + stover\_dm\_p\_h \quad (29)$$

**Step 5:** Determine the percentage error of the aboveground dry matter biomass (kg/ha) estimates for productive plants. This is a quality-control measure. We use the calculation based on the harvest index as the standard for comparison.

Let  $by\_dm\_p\_HI$  = aboveground dry matter biomass yield (kg/ha) of productive plants, calculated using harvest index (Equation 22)

Let  $by\_dm\_p\_s$  = aboveground dry matter biomass yield (kg/ha) of productive plants, calculated by summation (Equation 29)

Let  $by\_dm\_p\_e$  = percentage error of the aboveground dry matter biomass estimates for productive plants (the quantity calculated)

$$by\_dm\_p\_e = \frac{by\_dm\_p\_s - by\_dm\_p\_HI}{by\_dm\_p\_HI} \times 100 \quad (30)$$

**Step 6:** Estimate the total aboveground dry matter biomass (kg/ha) of all plants (productive and barren).

Let  $by\_dm\_p\_HI$  = aboveground dry matter biomass yield (kg/ha) of productive plants, estimated using harvest index (Equation 22)

Let  $by\_dm\_p\_s$  = aboveground dry matter biomass yield (kg/ha) of productive plants, estimated by summation (Equation 29)

Let  $stover\_dm\_b\_h$  = total dry matter biomass yield (kg/ha) of barren plants (Equation 27 or 28)

Let  $by\_dm\_HI$  = total aboveground dry matter biomass (kg/ha) of all plants, using HI for productive plants (the quantity to be calculated)

Let  $by\_dm\_s$  = total aboveground dry matter biomass (kg/ha) of all plants, using summation for productive plants (the quantity to be calculated)

$$by\_dm\_HI = stover\_dm\_b\_h + by\_dm\_p\_HI \quad (31)$$

$$by\_dm\_s = stover\_dm\_b\_h + by\_dm\_p\_s \quad (32)$$

**Step 7:** Determine the percentage error of the total aboveground dry matter biomass (kg/ha) of all plants. This is a quality-control measure. We use the calculation based on the harvest index as the standard for comparison.

Let  $by\_dm\_HI$  = total aboveground dry matter biomass (kg/ha) of all plants, using HI for productive plants (Equation 31)

Let  $by\_dm\_s$  = total aboveground dry matter biomass (kg/ha) of all plants, using summation for productive plants (Equation 32)

Let  $by\_dm\_e$  = percentage error of the total aboveground dry matter biomass calculations for all plants (the quantity to be calculated)

$$by\_dm\_e = \frac{by\_dm\_s - by\_dm\_HI}{by\_dm\_HI} \times 100 \quad (33)$$

**Step 8:** Calculate grain yield (kg/ha) at a specified grain moisture content (e.g. 15.5% moisture).

Let  $gy_{dm}$  = dry matter grain yield (kg/ha, Equation 18 or 20)

Let  $grain_{moist}_s$  = specified grain moisture content (%)

Let  $grain_{dm}_s$  = dry matter content corresponding to the specified grain moisture content (a quantity to be calculated)

Let  $gy_{sm}$  = grain yield (kg/ha) at a specified moisture content (quantity to be calculated)

First calculate  $grain_{dm}_s$ , a unitless quantity:

$$grain_{dm}_s = \frac{100 - grain_{moist}_s}{100} \quad (34)$$

Next, divide dry matter grain yield by the dry matter content corresponding to the specified grain moisture content:

$$gy_{sm} = \frac{gy_{dm}}{grain_{dm}_s} \quad (35)$$

## Contributors

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**Suggested citation:** Murrell TS and Chivenge P. 2023. Measurement of maize grain yield and aboveground biomass at maturity by crop cut at plot level, v1. Standard Operating Procedure 008. In: Saito K, Johnson J-M, Hauser S, Corbeels M, Devkota M and Casimero M. *Guideline for measuring agronomic gain key performance indicators in on-farm trials*, v. 1. Excellence in Agronomy for Sustainable Intensification and Climate Change Adaptation Initiative.

This work was financially supported by the Excellence in Agronomy for Sustainable Intensification and Climate Change Adaptation Initiative.

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