GUIDELINE FOR AGRONOMY AND SOIL FERTILITY DATA COLLECTION IN ETHIOPIA: NATIONAL STANDARD

EIAR
Ethiopian Institute of Agricultural Research

ግብርና ሚኒስቴር
MINISTRY OF AGRICULTURE

Ethiopian Institute of Agricultural Research (EIAR)

EIAR's mission is to conduct research that will provide market competitive agricultural technologies that will contribute to increased agricultural productivity and nutrition quality, sustainable food security, economic development, and conservation of the integrity of natural resources and the environment.

www.eiar.gov.et

Citation:
Abera D; Liben FM; Shimbir T; Balemi T; Erkossa T; Demiss M, Tamene L. 2020. Guideline for Agronomy and Soil Fertility Data Collection in Ethiopia: National Standard. Ethiopian Institute of Agricultural Research (EIAR). Addis Ababa, Ethiopia. 31 p.

This document was peer-reviewed by Dr. Kindie Tesfaye, International Maize and Wheat Improvement Center (CIMMYT).

Cover photo:
CIAT/Georgina Smith

Design and layout: Communications team, Alliance of Bioversity International and the International Center for Tropical Agriculture (CIAT).

Content contributors: Task force members of the Coalition of the Willing (CoW).

September 2020

PO Box 2003
Addis Ababa, Ethiopia
Tel. (+251) 116 454452

GUIDELINE FOR AGRONOMY AND SOIL FERTILITY DATA COLLECTION IN ETHIOPIA: NATIONAL STANDARD

Dejene Abera, Feyera M. Liben, Tesfaye Shimbir,
Tesfaye Balemi, Teklu Erkossa, Mulugeta Demiss, and Lulseged Tamene

EIAR
Ethiopian Institute of Agricultural Research

ግብርና ሚኒስቴር
MINISTRY OF AGRICULTURE

Acknowledgements

We wish to acknowledge the technical and financial support from the International Center for Tropical Agriculture (CIAT) (now part of the Alliance of Bioversity International and CIAT) and the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) Ethiopia. The technical and institutional support from the Ethiopian Institute of Agricultural Research (EIAR), particularly that of Dr. Temesgen Desalegn, is also highly valued. We also appreciate the engagement and contributions of the members of the Coalition of the Willing (CoW) in the effort to support agricultural transformation through digital solutions. Prof. Mitiku Haile has played a very important role by providing technical support and coordinating the key moments of the process.

Photo: CIAT/G. Smith

Contents

Preface

Recently, recognition has been growing of the power of data and information for better decision-making and service provision in agriculture. To ensure good data quality, an agreed standard to collect, store, and share data along the agricultural value chain is required.

With this background, the purpose of this guideline is to provide guidance on standardizing soil and agronomy data collection and thereby enhance temporal and spatial data interoperability.

Standard field research design, data collection, and data reporting are required for well-informed meta-analyses and syntheses of agricultural research data as well as for making these data more accessible for calibration and evaluation of process-based models. Hence, this guideline is a contribution toward enabling meta-analysis of different data collected over years and/or space to accumulate evidence and generate new knowledge or insights to facilitate informed decision-making in the agricultural sector in general and in the crop development subsector.

This guideline is compiled and intended for use by researchers, academicians, students, and other interested professionals in Ethiopia and beyond. The guideline is developed based on accepted standards and procedures in the field. Nevertheless, it is not exhaustive in its coverage of the soil and agronomic data types and crops grown in the country. Hence, additions and updates depending on the development of research facilities, the ever-changing focus of agricultural research and production systems, and advances in technology are warranted.

Rationale

Aggregates of data are sources of technology, innovation, information, and knowledge. In addition, the generation of such data through a series of research activities and their documentation in a well-organized and usable way is the most important aspect of research and development. With the advent of agricultural research in Ethiopia, a wealth of agronomic and soil fertility datasets has been collected.

Integration of these data enables new scientific discoveries, facilitates informed decision-making, and can transform the agricultural sector. Nevertheless, integration of data has been difficult because of the lack of uniformity in approaches and standards in data collection and measurement. Most data collected so far are held by individual researchers and only a few are published in journals and proceedings.

Many projects in the past several decades have generated data that are not accessible for data synthesis and model testing. Limited accessibility and non-interoperability of these datasets and poor infrastructure development have limited wider use of the data.

Ensuring the sustainability of agricultural systems has become increasingly complex and requires a coordinated, multifaceted approach in developing new knowledge and understanding. The collection of agronomic and soil fertility data, using predetermined standards, facilitates interoperability and integration and allows extended use of the data (Eagle et al., 2017; Kladivko et al., 2014). Hence, this guideline aims to set a standard in the collection of minimum datasets in research and development in agronomy and soil fertility.

The purpose and scope of this guideline are therefore limited to setting a standard for the collection of data and a minimum dataset on the major crops produced in Ethiopia. It is assumed that detailed manuals for data collection and templates will be developed following the guideline.

Photo: CIAT/G. Smith

Photo: Dejene Abera

1. Introduction

The economy of Ethiopia largely depends on the agricultural sector, whose transformation is possible only through fundamentally transforming the sector. Agricultural transformation requires evidence-based policy decisions and implementations. The Ministry of Agriculture (MoA) of Ethiopia, supported by national and international research and development partners, is striving to modernize the sector using modern agricultural technologies and evidence-based decisions. Various governmental and non-governmental organizations in the country collect data and often use them only once.

For instance, studies related to soils and agronomy have been underway since the 1950s and a great deal of data, especially those related to crop response to fertilizer applications, have been collected. However, these data are scattered across various organizations and exist in diverse formats or are unaccounted for in the worst scenarios. As a result, most of the data are inaccessible or inconvenient to combine with similar data from different sources to store and use as they lack a minimum standard. This has resulted in inefficiency, wastage of resources, and loss of energy collecting similar data for similar purposes, and it undermines innovation as people spend time collecting new data and/or are not able to analyze large datasets in an innovative manner.

Recently, concerned individuals and institutes engaged in dialogues aimed at alleviating the problem, which culminated in the development of the Coalition of the Willing (CoW) for data sharing. The CoW members have agreed to share their data, and approved an internal data-sharing guideline. Inspired by the effort of the CoW, the MoA has developed a soil and agronomy data policy and a corresponding implementation

guideline. The implementation of the policy and guideline requires that data collection follow a minimum standard. This guideline provides the minimum data that need to be collected for soil- and agronomy-related studies. The guideline suggests what needs to be collected and users can refer to the relevant manuals for details on how to collect the data. The guideline has three main components: (i) site and system description, (ii) soil sampling and analysis, and (iii) crops and agronomy. Although this guideline provides details for agronomic parameters under rainfed agriculture, users are referred to the guideline for agricultural water management for irrigation agronomy.

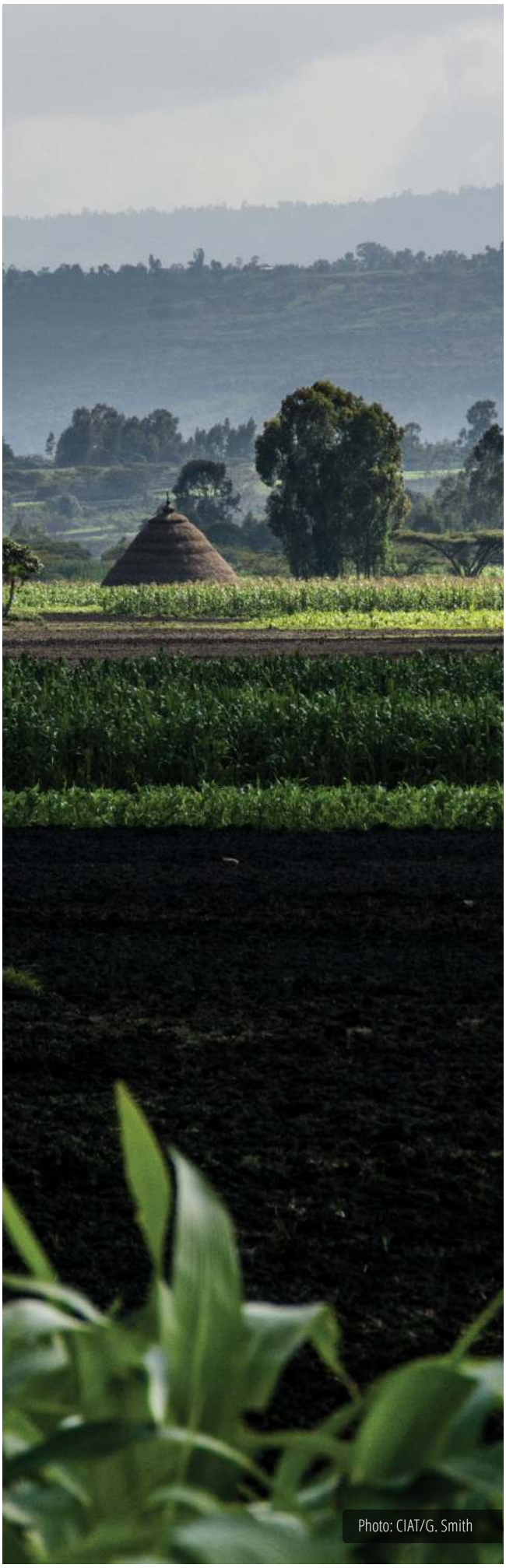

Photo: CIAT/G. Smith

Photo: CIAT/G. Smith

2. Site description

The following site descriptors need to be collected for any soil or agronomic experiments conducted under on-station and on-farm conditions. Note that the "non-numbered" tables are used for presentation purposes and not as formal templates to be followed in the guideline. Users can organize their datasets in a convenient and appropriate manner. An automated data entry tablet will also be developed to simplify and better standardize data collection.

2.1 Administrative and geographic descriptors

COUNTRY	REGION	ZONE	WOREDA	KEBELE
Site Name	Latitude (decimal Degrees)	Longitude (decimal Degrees)		Elevation (m)

The geo-locators are recorded using a global positioning system (GPS) device, which is set by Adindan Ethiopia or World Geodetic System 84 (WGS 84) at zone 37N.

2.2 Topographic descriptors

SLOPE (%)	SLOPE ASPECT*	DRAINAGE CONDITION**	CURVATURE AS THE DIRECTION OF THE BEND (IF POSSIBLE)			
			Flat	Concave	Convex	Other (specify)

*Orientation of slope, measured clockwise in degrees from 0 to 360, where 0 is north-facing, 90 is east-facing, 180 is south-facing, and 270 is west-facing.
**Should be described as well drained, medium, and poorly drained.
For detailed topographic parameters, please refer to FAO (1990).

2.3 Weather data

Weather represents important data for any study and these data can be collected from analogue or automatic weather stations located at the target site or from nearby stations, 5-25 km depending on topography (WMO, 2006). The major data that need to be part of the data collection sheet are the following:

- Name of weather station
- Geo-location of the weather station (latitude, longitude, altitude)
- Distance from experimental site [km]
    - Rainfall [mm]
    - Maximum temperature [°C]
    - Minimum temperature [°C]
    - Sunshine hours [hours] or solar radiation [MJ/m^2]
    - Relative humidity [%] (if possible)
    - Wind speed [m/s] (if possible)

If solar radiation is not measured, it can be calculated from sunshine hours with the Angstrom formula, which relates solar radiation to extra-terrestrial radiation and sunshine duration as follows (FAO, 1998):

$$R_s = \left(a_s + b_s \frac{n}{N}\right) R_a$$

where

R_s is solar or shortwave radiation [MJ/m^2/day],

n is actual measured duration of sunshine [hours],

N is maximum possible duration of sunshine or daylight hours [hours],

R_a is extra-terrestrial radiation [MJ/m^2/day],

a_s is a regression constant, expressing the fraction of extra-terrestrial radiation reaching Earth on overcast days (n = 0), and

a_s+b_s is the fraction of extra-terrestrial radiation reaching Earth on clear days (n = N).

Depending on atmospheric conditions (humidity, dust) and solar declination (latitude and month), the Angstrom values a_s and b_s will vary. In areas where no actual solar radiation data are available and no calibration has been carried out for improved a_s and b_s parameters, the values a_s = 0.25 and b_s = 0.50 are recommended.

Extra-terrestrial radiation (R_a) can easily be calculated for a given latitude [decimal degrees] from the following online calculator in mm/day or W/m^2:

www.engr.scu.edu/~emaurer/tools/calc_solar_cgi.pl.

R_a [in MJ/m^2/day] can be obtained by multiplying the calculated value by 2.45 mm/day or dividing it by 28.4 W/m^2.

The value of N can be obtained from this site [www.solartopo.com/daylength.htm] using the latitude and longitude values of the site (separated by a comma) or selecting the site using the map explorer.

2.4 Agro-ecological zone and cropping system

- Name of agro-ecology (based on MoA, 1998; EIAR, 2011)
- Name of agro-ecology-traditional: (lowland: below 1,500 m; midland: 1,500-3,200 m; highland: higher than 3,200 m)
- Agricultural classification:

Cereals	Pulses	Oilseeds	Vegetables	Fruits	Nuts	Sugars & Starches	Fibers	Others (specify)

- Specify which cropping system is prevalent in the area and the spot of sampling as applicable. The following are the major cropping systems common in Ethiopia:

Monoculture	Rotation	Intercropping
Mixed Cropping	Others (Specify)	

- Record the cropping history or the land use at least for the past three years for the sampling spot (area).

2.5 Type of study

Data can be collected under various environmental conditions and study types. The following are common in the Ethiopian research and development landscape:

On-farm	On-station	Nursey	Greenhouse
Glasshouse	Laboratory	Other (Specify)	

2.6 Water management system

Rainfed	Irrigated (specify application methods)

Photo: CIAT/G. Smith

Photo: CIAT/G. Smith

3. Soil Sampling and Analysis

Some of the soil parameters can be obtained from a high-resolution soil map, especially for general purpose studies. Reference should be made to the guideline for standardization of a soil survey and mapping for a detailed approach to be followed to characterize soils. A brief description is provided here as follows.

3.1 General

The following general information should be recorded about the soil of the sampling spot:

Local name of the soil	Soil order (FAO soil classification)
Soil profile depth [cm]	Level of rocks on the field (FAO, 2006)

For *in situ* estimation of some soil characteristics, please refer to the Guidelines for Soil Description (FAO, 2006) (if required).

3.2 Soil Sampling

- Remove plant residue or other unwanted material from the soil surface before obtaining the soil sample core.
- Make a composite soil sample sufficiently representative of an experimental site as presented in Table 1 or refer to a standard soil survey and mapping guideline. The number of soil samples to be collected depends on the nature of the experiment and the variability of the field. Collect an equal volume of subsamples up to the desired depth by means of suitable sampling tools (auger, core sampler).
- Consider the history of fertilization, tillage, and other management practices to determine how to obtain representative samples.

- For fields having standing crops (such as maize planted in a row) and to which fertilizer is applied in a band (along the row), collect samples between plants, 5 cm away from the standing plants. For small cereals that are planted by a drill and to which fertilizer is applied in the plant rows, samples will be collected between the rows, 5 cm away from the plant roots.
- In furrow-irrigated agricultural fields, the movement of water and dissolved plant nutrients can create unique nutrient distribution patterns. Hence, it is recommended to obtain samples from the hilltop, the mid-point between the hilltop and furrow bottom, and from the furrow bottom.

Table 1: Minimum soil subsamples required for composite soil sample collection.

TYPE OF EXPERIMENT	SAMPLING UNIT	NUMBER OF SUBSAMPLES TO MAKE A COMPOSITE SAMPLE**	METHOD OF SAMPLING
Soil test crop response-based fertilizer recommendations, integrated nutrient management, lime and gypsum rate recommendation, and agronomic trials	Experimental field	20	Zigzag/random/purposive
	Plot level	5	Crisscross
Cropping sequence*	Experimental field	20	Zigzag/random/purposive
	Main plot level	5	Crisscross
	Subplot level	5	Crisscross
Nutrient management in perennial crops	Experimental field	20	Zigzag/random/purposive
	Plot level	5	Crisscross

** The main plots are established in the first year, whereas the subplots are plots that are established in the second year of the experiment.*
***For experiments designed to consider wider areas such as a watershed or landscape, refer to a standard soil survey manual for the number of soil samples to sufficiently represent the target area.*

To prepare a composite soil sample to be sent to a laboratory, reduce the bulk sample to about 1 kg by a quartering process (Fig. 1). For this, spread out the entire soil mass, mix thoroughly by hand, divide into four quarters, discard two opposite ones, and remix the remaining two. Repeat this process until the desired sample amount is achieved.

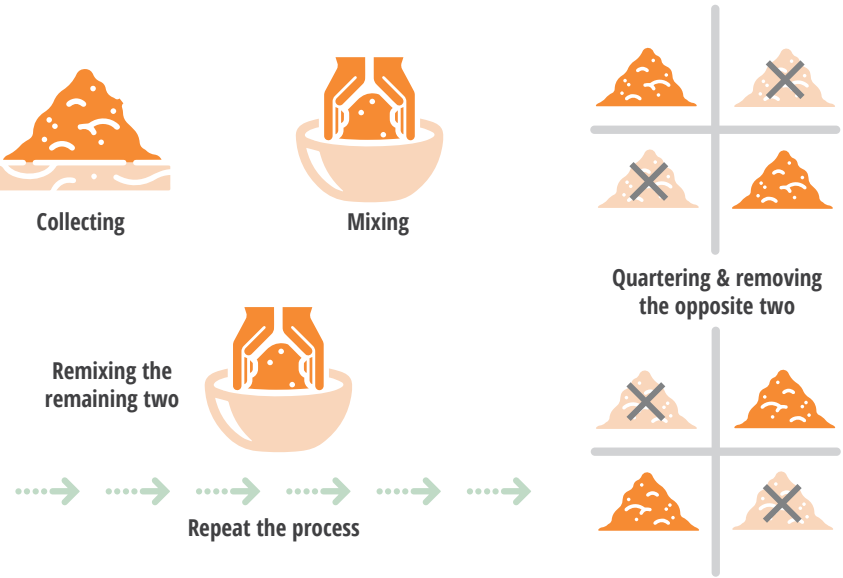

Fig. 1: Soil sample mixing for composite soil sample preparation.

3.2.1 Time of sampling

For fields for where there is no previous information to refer to or problems are expected, the initial or before-planting/treatment application samples should be collected 60 to 90 days before planting and the laboratory analysis results should be readily available 45 to 60 days before planting to have enough time to make pre-planting decisions such as appropriate amendment application and adjusting treatment rates or doses. To obtain the most accurate estimates of nitrogen availability, obtain samples as close to planting time as possible.

For soil test P and K calibration studies, collect the soil sample 21 days after planting and immediately after harvest (within a week) for residual effect studies.

For field characterization studies, soil samples can be obtained 30 days after applications of fertilizer, lime, or sulfur.

3.2.2 Sampling frequency

The number of times that a soil sample should be obtained for analyses depends on the nature and objective of the experiment and the type of soil parameter. For analyses of soil parameters that are relatively less sensitive to management practices (e.g., soil texture and bulk density), sampling once in a season (before planting) is sufficient, unlike for the management of sensitive parameters such as pH, soil organic carbon, nutrient status, and others.

3.2.3 Sampling depth

Sampling depth for most soils is typically tillage depth (which can vary depending on soil type) at an interval of 20 cm. The top 20 cm of soil has the most root activity, and this is the depth at which fertilizer, lime, and gypsum applications are made. On the other hand, abundance of plant roots in the soil depth is an important consideration in deciding the sampling depth. Therefore, the following depths can be considered:

- For most annual crops such as cereals, pulses, and vegetables, composite soil samples should be collected from 0-20, 20-40, and 40-60 cm depths.
- For deep-rooted perennial crops (fruit trees, sugarcane, coffee, plantation crops, and others), composite soil samples should be collected from 0-20, 20-50, 50-80, and 80-110 cm depths using four to five pits.
- For nutrient calibration studies, soil samples should be collected from 0-15 cm depth at 21 days after planting.

> Since acidity can vary along the soil depth in acidic soils, soil sampling for pH and exchangeable acidity analysis should be done at least to a depth of 30 cm divided into 0-15 and 15-30 cm depths.

Sampling beyond 30 cm depth in a single sample could seriously underestimate a soil acidity problem in the critical root zone.

3.2.4 Sampling tools and accessories

Proper soil sampling should be done using appropriate soil sampling kits. Different tools are used in soil sampling. It is commonly recommended to use a soil auger to collect samples for agronomy, soil fertility, and fertilizer recommendation experiments depending on field conditions as indicated below.

- A tube auger and spade are appropriate tools for sampling of soft and moist soils.
- A screw-type auger is more convenient for hard or dry soils.
- A post-hole auger is preferable for sampling excessively wet (waterlogged) soils.
- Core samplers are used to collect undisturbed soil samples for bulk density and moisture content analysis.

3.2.5 Sample labeling

Proper labeling of soil samples is as important as the care needed to obtain the samples. Samples need to be labeled properly for identification. A label of thick paper with an identification mark and other details should be put inside the sample bag, and another one carrying the same details tied/pasted outside the bag. In case the soil sample is wet (for calibration studies), the label should be written with a lead pencil or a permanent ink marker, or put inside a small separate plastic bag before air-drying. With the advance of digital technology, it is advisable to use barcoded or digitized sample labeling and tracking procedures in all soil and agronomic research activities. A sample label should contain the following:

- Name of trial/experiment or production and cropping system

- Site name: district, kebele, and farmer's name
- Site geographic coordinates (latitude and longitude in decimal degrees). See above (Section 3.1) for the geodetic datum you need to use.
- Altitude [m]
- Sampling date[dd/mm/yyyy]
- Sampling depth [cm]
- Plot number
- Crop type and growth stage

3.2.6 Soil sample record sheet

In addition to location descriptors (see Sample labeling above), relevant information about slope, irrigation, drainage, previous cropping history, fertilizer and manure applied, and other relevant information must be recorded and sent along with the soil samples as required (see Table 2).

Table 2: Soil sample information submission sheet for laboratory.

Sample Collector Name: _____ **Cell Phone:** _____ **E-mail:** _____

Organization/affiliation: _____ **Telephone:** _____

GPS datum: _____ *(Adindan Ethiopia or WGS 84)*

SAMPLE CODE	SAMPLING DATE [DD/MM/YYYY]	SAMPLING DEPTH [CM]	*LATITUDE [DD]	*LONGITUDE [DD]	ALTITUDE [M]

SLOPE [%]	LANDSCAPE POSITION (UPPER, MIDDLE, LOWER)	LOCATION (REGION/ ZONE/ DISTRICT/ KEBELE)	PRODUCTION SYSTEM (IRRIGATED/ RAIN-FED); LAND USE	PREVIOUS SEASON CROP OR LAND USE	PARAMETERS TO BE ANALYZED AND METHOD (IF REQUIRED)	REMARKS

dd = decimal degrees.

3.2.7 Precautions during collection and storage of soil samples

Special care in collecting and handling the soil samples is required to prevent contamination. The following precautions should be taken to minimize error:

- Avoid contact of the samples with chemicals, fertilizers, manure, or other contaminants.
- Use stainless-steel augers instead of rusted-iron spades for obtaining soil samples for micronutrient analysis.
- Do not use containers (bags or boxes) previously used for storing fertilizer, salt, or other chemicals.
- Store soil samples in clean, preferably new, cloth or polythene bags.
- Do not store wet samples for a long time in restricted/closed conditions. Keep soil samples in plastic bags to air-dry by opening and keeping them on a shelf.
- Use a glass, porcelain, or polythene jar for long-duration storage.

3.3 Soil Analysis

3.3.1 Soil physical parameters

For field experiments, these parameters are analyzed before treatment applications and/or at the end of the experiment to determine treatment effects. The key primary and derived soil physical characters and their recommended methods of determination include the following:

Soil texture: Soil texture refers to the relative proportion of mineral particles of various sizes (soil fractions): sand, slit, and clay, expressed as a percentage. The basis of the hydrometer method is particle size and its mass, as related to settling time when dispersed in solution (Bouyoucos, 1962). Soil texture classes are determined by plotting the percentage of sand, silt, and clay on the texture triangle indicated in FAO (1990, 2006).

Bulk density [g/cm^3]: Soil bulk density (BD), also known as dry bulk density, is the weight of oven-dry soil divided by the total soil volume. Soil BD is measured by collecting a known volume of soil using a metal ring pressed into the soil (intact core) and determining the weight after drying at 105 °C (Blake and Hartge, 1986a). The bulk density report must be the average of sufficient representative (at least three) measurements of the field.

Particle density [g/cm^3]: The weight of an individual soil particle per unit volume is called particle density. It is measured by a pycnometer (Blake and Hartge, 1986b; Richards, 1954). The particle density report must be the average of sufficient representative measurements of the field. A literature-based average value for particle density (2.66 g/cm^3) can be used if measurement is not possible.

Soil color: Soil color is determined using the standard Munsell Soil Color Book and moisture condition (dry, moist) at the time of measurement must be indicated.

Volumetric soil moisture content **[mm]:** This can be determined by direct and non-destructive methods. If available, a direct method via a time-domain reflectometer (TDR), such as a hydroprobe, can be used after calibration using a gravimetric method. The gravimetric method is a classical established and truly direct method for determining water content. Gravimetric data, often reported in percentage, should be converted to volumetric data using the bulk density of the soil.

Water-holding capacity [mm/m] is also called plant-available water capacity (PAWC) and is calculated as the difference between field capacity (FC) and the permanent wilting point (PWP) (PAWC = FC - PWP) of the soil. Field capacity (at -0.33 bars pressure) and PWP (at -15 bars by % v/v) are determined by a pressure plate apparatus (Cassel and Nielsen, 1986).

3.3.2 Soil chemical parameters

The parameters listed below need to be determined at planting or at treatment application and/or at harvest depending on the objective of the study. For standard laboratory procedures, refer to the Guideline for Standardization of Soil, Plant, and Water Testing. In reporting of soil chemical characteristics, indicate the standard laboratory procedure used for the following:

- Soil total N [%]
- Soil available P [mg/kg soil]
- pH (1:2.5)
- EC (1:2.5) [dS/m]
- Water-soluble K [cmol (c)/kg soil]
- Exchangeable K [cmol (c)/kg soil]
- Soil organic carbon (SOC) [%]
- Cation exchange capacity (CEC) [cmol (c)/kg soil]

- Exchangeable cations (Na, K, Ca, Mg) [cmol (c)/kg soil]
- Micronutrients (Cu, Zn, Fe, Mn, B) [mg/kg soil]
- Available sulfur [mg/kg soil]

The choice of parameters to consider and the time of sampling (at-/before-planting and/or at-/after-harvest) depend on the objectives of the study and the soil parameters as described below.

Soil pH, OC, total N, available P, and CEC should be determined before planting for soil fertility-related agronomic trials.

Exchangeable sodium percentage (ESP) is calculated from the exchangeable Na and CEC using the following equation (Richards, 1954):

$$ESP\ (\%) = \frac{\text{Exchangeable Na}}{\text{CEC}} * 100\%$$

where exchangeable Na and CEC are given in cmol (c)/kg soil.

In alkali and salt-affected soils and in irrigated agriculture, soil pH, electrical conductivity (ECe), soluble cations (Na, K, Ca, Mg), and soluble anions (Cl^-, SO_4^{2-}, HCO_3^-, and CO_3^{2}) need to be analyzed in saturated soil paste extract using deionized water (Richards, 1954). Then, sodium absorption ratio (SAR) is calculated (Richards, 1954):

$$SAR = \frac{Na^+}{\sqrt{\frac{Ca^{2+} + mg^{2+}}{2}}}$$

where Na, Ca, and Mg, respectively, are sodium, calcium, and magnesium concentration of soil solution given in mmol (c)/liter.

Calcium carbonate ($CaCO_3$) and boron in saturation extract need to be determined in alkali and salt-affected soils and in irrigated areas.

In acidic soils, aluminum (Al) and manganese (Mn) toxicity and Ca, Mg, and Mo deficiency are important attributes (Rowell, 1994; McCauley et al., 2017). Hence, laboratory analysis of these parameters is important in acidic soils.

Soil pH is measured in water or 0.01 M $CaC1_2$. For acidic soils, soil pH in $CaCl_2$ is preferred as it is less affected by soil electrolyte concentration (Bache, 1974; Minasny et al., 2011). Soils with low total salts show large seasonal variation in pH if they are measured in water.

Effective cation exchange capacity (ECEC) is calculated as the sum of exchangeable acidity (Al^{3+} and H^+) and exchangeable basic cations (Ca^{2+}, Mg^{2+}, K^+, and Na^+).

Total exchangeable acidity and ECEC determined in the same soil samples can be used to calculate acid saturation (AS) as follows:

$$AS\ (\%) = \frac{\text{Exchangeable acidity}}{\text{ECEC}} * 100\%$$

where exchangeable acidity and ECEC are given in cmol (c)/kg soil.

Photo: Dejene Abera

Photo: Dejene Abera

4. Plant parameters

4.1 Planning field experiments

Standard procedures for designing field experiments must be followed for randomization, replication, and error control/blocking.
Plot size varies depending on the nature of the experiment, availability of land and planting materials, crop type, and production system (furrow irrigated, rainfed, etc.). Securing a minimum of three net harvestable rows and a minimum of 3-meter row length for small cereals and higher for other crops is advised to have a sufficient plant population for data collection. A minimum of 6 m^2 harvestable plot size for small grains and about 30 plants per plot for maize, sorghum, tomato, and pepper are a common practice used in most field experiments.

The net harvestable plot commonly excludes the outer rows and the outer plants in each row. For perennial fruit tree crops, the spacing depends on the canopy, growth stage, agro-ecological zone, and soil type of the study site. Nevertheless, it is recommended to fulfill the minimum requirement and indicate the net harvested area in m^2 or in number of plants harvested per plot.

When running field experiments, the data or information that need to be recorded using a customized data collection sheet (digital or non-digital) are listed below.

4.2 Crop information

Crop type	Cultivar/variety name	Cultivar/variety maturity group [days]		
		Early	Medium	Late

4.3 Crop management information

- Tillage type (oxen plow, tractor, no-till, etc.)
- Tillage frequency
- Planting date or transplanting date [dd/mm/yyyy]
- Type of planting (row, broadcast)
- If row, inter- and intra-row spacing [cm]
- If broadcast, seed rate [kg/ha]
- Fertilizer type [name]
- Rate of fertilizer applied for each type [kg/ha]
- Fertilizer application method (band, broadcasting, strip, etc.)
- Fertilizer application time in terms of crop growth stage
- Type of organic amendments (manure, compost, crop residue, etc.)
- Rate [kg/ha] and time [dd/mm/yyyy] of organic amendment application
- Herbicide type [name], rate for each type [L/ha], and time [dd/mm/yyyy] of application
- Pesticide type [name], rate for each type [L/ha], and time [dd/mm/yyyy] of application
- Disease/insect pest type: give local and scientific name and causal organisms
- Disease/insect incidence [%] during the growing period or at early and later growth stages of the crop (stage incidence occurred, plant part damaged, extent of damage in %, etc.)
- Weed management: type and frequency
- Pruning and training practices (for tree crops)
- *In situ* moisture conservation type (tied ridge, skip-row, *shilshalo*, etc.) and timing
- Harvesting date or method [dd/mm/yyyy] and frequency (for tomato, pepper, and perennials)

4.4 Specific crop parameters

4.4.1 Cereal and pulse crops

A. Phenology (based on IPGRI and ICRISAT, 1993; IBPGR, 1991; IPGRI, 1981, 1982, 1994)

Recording dates of events in plant development will enable you to calculate days from some consistent start date until a specific subsequent date or dates.

- ***Days to emergence*** [days]: Count and record the number of days from planting to when 50% of the plants in a plot show a first leaf (coleoptile) above the soil. Under dry planting conditions, days to emergence is counted from the first day of effective rainfall or irrigation that is sufficient for seed germination.
- ***Days to tasseling and heading*** [days]: Count and record the number of days from planting until the date on which 50% of the plants in a plot have started tasseling for maize and heading for small cereal crops.
- ***Days to first flowering for pulse crops*** [days]: This refers to the days to beginning flowering, and is counted and recorded as days from planting to when the first flower appears.
- ***Days to first pod set for pulse crops*** [days]: This refers to the days to first pod setting, and is counted and recorded as days from planting to when the first pod appears.
- ***Days to first peg for peanut crop*** [days]: This refers to the days to beginning pegging for peanut and is counted and recorded as days from planting to when the first peg appears. Peg is the budding ovary that grows down and away from the plant forming a small stem that extends to the soil.
- ***Days to anthesis*** [days]: Count and record the number of days from planting until the date on which 50% of the plants in a plot have started flowering (pollen shade).
- ***Days to physiological maturity*** [days]: Record the number of days from planting until the date on which 90% of the plants in a plot have physiologically matured.

B. Shoot parameters (based on IPGRI and ICRISAT, 1993; IBPGR, 1991; IPGRI, 1981, 1982, 1994)

- ***Stand count*** [number of plants per m^2]: Count and record the number of plants per net plot after thinning (initial stand count) and at physiological maturity (final stand count) and calculate the number of plants per m^2 using the net plot size.
- ***Number of tillers for tillering crops*** [number of tillers per m^2]: Count the number of tillers per seed within a net plot and calculate the number of tillers per m^2 using the net plot size.
- ***Maximum green leaf area*** [cm^2]: Measure fully expanded green leaf area for all plants in a unit area [m^2] using a leaf area meter at flowering for pulse crops and at anthesis for other crops. When you have no access to a leaf area meter, estimate leaf area using the following equation:
- ***Leaf area (LA)*** [m^2] = [Leaf length × leaf width × K]. Leaf width is for the widest portion of the sampled leaf. K is a constant value developed for the variety or canopy class and it is different for different crops.
- ***Maximum leaf area index (LAI)*** is calculated as the total leaf area of the given canopy at flowering for pulse crops and at anthesis for other crops and then it is divided by the total plot area of the canopy. LAI can range from 0 (bare ground) to more than 10 (dense conifer forests).
- ***Plant height*** [cm]: This is the mean height of 10 randomly selected plants at physiological maturity measured from the base of the stem of the main plant to where tassel branching begins for maize and to the tip of the main shoot/spike, excluding awns, for other crops using a yardstick.
- ***Number of nodes per plant*** [number/plant] for pulse crops: Record the mean number of nodes from 10 randomly selected plants per plot for pulse crops.
- ***Fruit-bearing nodes*** [number per plant] for pulse crops: Mean fruit-bearing nodes are counted for 10 randomly selected plants at physiological maturity.
- ***Leaf number per stem*** [number per plant]: Green leaves are counted from 10 randomly selected plants per plot at anthesis or flowering or until any desired growth stage of the crop, divided by the number of selected plants.
- ***Canopy (tops) weight/total aboveground dry matter (DM) yield*** [kg DM/ha]: This represents the weight of all biomass harvested in the net plot or of 10 randomly selected plants within the net plot at physiological maturity, which is commonly air-dried to constant weight.

C. Root parameters

- ***Root fresh weight (FW)*** [kg FW/ha] and ***root dry matter weight*** [kg DM/ha]: These are the means of the weight of 5 to 10 randomly selected plant roots at harvest maturity recorded when constant weight is attained with an oven- or air-drying method. This is measured for both in-field and pot experiments.
- ***Total root length*** [m]: The line intersection method (Newman, 1966; Tennant, 1975) can be used. Modern methods such as digital image processing can be used if facilities are available. A review paper is available on advances in root growth measurement technologies (Judd et al., 2015). You must indicate which method is used.
- ***Taproot length*** [m]
- ***Root volume*** [m^3] is measured by the displacement method.

D. Yield components (based on IPGRI and ICRISAT, 1993; IBPGR, 1991; IPGRI, 1981, 1982, 1994)

- ***Number of cobs per plant*** [number per plant]: The mean number of cobs of 10 randomly selected maize plants is counted from a net plot area at physiological maturity. Do this after removing husks.
- ***Cob/ear weight*** [kg]: The mean cob weight from 10 randomly selected maize plants is measured from a net plot area at physiological maturity after removing husks.
- ***Number of spikelets per spike for small cereals*** [number per plant]: The average number of spikelets per spike from 10 randomly selected plants is counted from a net plot area at physiological maturity.
- ***Head weight*** [kg]: The mean head weight of 10 randomly selected sorghum plants is measured from a net plot area at physiological maturity.

- ***Number of pods per plant*** [number per plant] for pulse crops: This is the mean number of pods of 10 randomly selected plants at physiological maturity.
- ***Number of seeds per pod*** [number per pod] for pulse crops: This is the mean number of seeds of 10 randomly selected plants at physiological maturity.
- ***Pod weight*** [kg/ha] for pulse crops: This is the mean pod weight of 10 randomly selected plants at physiological maturity.
- ***Grain moisture content*** [%]: This is measured at the time of harvest using a grain moisture tester.
- ***Thousand-seed/-grain weight*** [g] for cereals: This is the weight of 1,000 seeds/grains randomly selected from the net plot harvest and is used to calculate the adjusted yield of the harvest at 12.5% grain moisture content (note that this can vary depending on crop type). For pulse crops, hundred-seed/-grain weight [g] adjusted to 10% grain moisture content is mostly used. This can be done by counting seeds using an electric seed counter and weighing them with an electronic balance.
- ***Threshing % at maturity*** for pulse crops:

$$\text{Threshing \%} = \frac{\text{Weight of grains}}{\text{Weight of pods}} * 100\%$$

where the two weights are measured from a common plot.

- ***Number of seeds*** [count/m^2]: Total seed number is counted for the main and productive tillers in a unit area [m^2] for small grain crops.
- ***Lodging susceptibility*** [%]: This is a permanent displacement of plant from their upright position and scored at seed maturity (percentage of plants lodged):
  - 0 = None (all plants standing)
  - 3 = Low
  - 5 = Medium
  - 7 = High
- Severity of lodging can be indicated in detail by measuring the plant angle of leaning from the vertical position (Berry and Spink, 2012; Caldicott and Nuttall, 1979).
  - Percent of crop area upright (crop at an angle up to 4° from the vertical);
  - Percent of crop area leaning (crop leaning between 5° and 44° from the vertical);
  - Percent of crop area lodged (crop lodged between 45° and 90° from the vertical);
  - Percent of crop area lodged flat (severe lodging).

Then lodging score (ranging from 0-100) can be calculated as indicated by Fischer and Stapper, 1987.

$$\text{Lodging score} = \%\ \text{of plot area lodge} * \frac{\text{angle of lodging (in}^\circ)}{90^\circ}$$

E. Yield parameters (based on IPGRI and ICRISAT, 1993; IBPGR, 1991; IPGRI, 1981, 1982, 1994)

- ***Aboveground biomass*** [kg/ha]: This is measured by obtaining the weight of the aboveground biomass for plants in a net plot area at harvest maturity and converting it to kg per hectare. This is also called biological yield.
- ***Grain yield*** [kg/ha]: This is measured by obtaining the weight of the grains for plants in a net plot area at harvest maturity and converting it to kg per hectare after adjusting the grain to 12.5% moisture content. Indicate the moisture content at which the yield is expressed. This is also called economic yield.

Yield (at 12.5% grain moisture) =
Grain yield x (100 - actual grain moisture %) / 87.5

Note that the 12.5% in the equation is the moisture to which the grain is converted. The value is subtracted from 100 to give 87.5% in the right-hand side of the equation. If different grain moisture content is used, such as for pulse crops, indicate the value and accordingly adjust the right side of the equation.

- ***Straw yield*** [kg/ha]: This is the weight of biological yield after the grain is removed and is recorded when constant weight is attained with oven- or air-drying.
- ***Harvest index*** [ratio] is calculated on a plot basis as the ratio of grain yield to total aboveground biomass yield.
- ***Shelling percentage*** [%] is the ratio of grain weight to ear weight (excluding husks) multiplied by 100 for a maize crop.

Weed count: For experiments designed for fertilizer or weed study, measure weed density by counting the number of weeds per unit area and type at different crop growth stages, and weed biomass as the weight of aboveground dry biomass of weeds.

F. Plant tissue analysis data (based on Flynn et al., 1999; Spectrum Analytic Inc., 2009; and expert knowledge): For further information, refer to Appendix Table 1.

- ***Root total N, P, K…*** [mg/g DM] is measured as the mean of tissue analysis from the roots of 10 randomly selected plants at physiological maturity.
- ***Aboveground N, P, K…*** [mg/g DM] is measured as the mean of aboveground tissue analysis from 10 randomly selected plants at physiological maturity.
- ***Grain N, P, K…*** [mg/g DM] is measured as the mean of grain tissue analysis from 10 randomly selected plants at physiological maturity.

G. Nutrient-use efficiency calculations (based on Moll et al., 1982; Fageria and Baligar, 2003; Dobermann, 2005; Weih et al., 2011)

The following parameters are determined for agronomic experiments.

Nutrient-use efficiency is categorized into two components (Moll et al., 1982):

- ***Uptake efficiency*** is the ability of the plant to extract a nutrient from the soil.
- ***Use efficiency*** is the ability of the plant to convert the absorbed nutrient into grain yield.
- ***Nutrient-use efficiency*** is the product of uptake efficiency and use efficiency.
- ***Agronomic efficiency (AE)*** is expressed as the additional amount of economic yield per unit nutrient applied (Baligar et al., 2001).
- ***Physiological efficiency (PE)*** is expressed as the ratio of grain yield per unit of nutrient in grain yield (Dobermann, 2005).

The different nutrient uptakes and efficiencies are given in Table 3.

Table 3: The most common nutrient uptake and use indices and their calculations using nitrogen (N) as an example.

ACRONYM, NAME	CALCULATION, UNIT	REFERENCE
NUpE, Nitrogen uptake/recovery efficiency	$N_f/(N_{soil} + N_{fert})$, g/g	Moll et al. (1982)
NUtE, Nitrogen-utilization efficiency	Y/N_f; g g^{-1}	
NUE, Nitrogen-use efficiency	$Y/(N_{soil} + N_{fert})$, g/g	
U, U_N, U_P, Nutrient (subscripts N for nitrogen and P for phosphorus) uptake efficiency	N'/N_p, g/g	Weih et al. (2011)
E, E_N, E_P, Yield-specific nutrient (nitrogen or phosphorus) efficiency	Y/N', g/g	
C, C_N, C_P, Nutrient (nitrogen or phosphorus) concentration	N_y/Y, g/g	
NAE, NAE_N, NAE_P, Nutrient (nitrogen or phosphorus) accumulation efficiency	N_y/N_p, g/g	

ACRONYM, NAME	CALCULATION, UNIT	REFERENCE
PP, Partial factor productivity	Y/N_{fert}, g/g	Dobermann (2005)
AE, Agronomic efficiency	$(Y_{F+} - Y_{F0})/N_{fert})$, g/g	
CE, Crop recovery efficiency	$(N_{fF+} - N_{fF0})/N_{fert})$, g/g	
PE, Physiological efficiency	$(Y_{F+} - Y_{F0})/(N_{fF+} - N_{fF0})$, g/g	

N_{soil} = soil N concentration [kg/ha], N_{fert} = amount of N fertilizer applied [kg/ha], Y = harvested yield (subscripts *F+* and *F0* in fertilized and unfertilized conditions, respectively) [kg/ha], N_p = N amount in perennial plant parts (e.g., seed in cereals, seed potato, winter shoots in Salix) [kg/ha], N_i = initial plant N amount at start of the main growth period [kg/ha], N_f = final or maximum aboveground plant N amount (or N yield) at the end of the main growth period (subscripts *F+* and *F0* in fertilized and unfertilized conditions, respectively) [kg/ha], N' = mean plant N amount during the growth period [kg/ha], N_y = N amount in the harvested yield [kg/ha].

H. Physiological parameters

The following are considered as important parameters in stress physiology studies.

- ***Canopy temperature*** [°C] (Balota et al., 2008; Fuchs, 1990): The surface temperature of the canopy is related to the amount of transpiration resulting in evaporative cooling. Canopy temperature is measured using a hand-held infrared thermometer (IRT) remotely positioned at a given angle, mostly 30°. Canopy temperature is measured at noon hours using a digital x-ray thermometer.
- ***Stomatal conductance*** [mmol/m²/sec] is measured on fully expanded leaves at noon hours using a porometer.
- ***Rate of photosynthesis*** is the rate of either the production of oxygen or the uptake of carbon dioxide measured on fully expanded leaves at noon hours using canopy sensors, a photosynthetic chamber or gas analyzer, or a leaf porometer.
- ***Transpiration rate*** is measured at noon hours using canopy sensors.
- In addition, ***photosynthetically active radiation (PAR), leaf temperature, transpiration rate, stomatal conductance, and photosynthetic rate of leaves*** of intact plants could be measured simultaneously using a differential CO_2/H_2O infrared gas analyzer (LC ADC BioScientific Ltd., Hoddesdon, UK) connected to a broadleaf chamber or leaf chamber porometer (LCpro+).
- ***Leaf water potentia***l is measured on fully expanded leaves using a pressure chamber or relative leaf water content (RWC) is measured using the appropriate equation. To determine RWC, fully expanded leaves sampled from the third or fourth node from the apex of the main stem or younger plagiotropic branches should be used. After measuring the fresh weight (FW) of leaves (right after abscission), they should be allowed to float on distilled water in the dark at 4 °C for 24 h to determine their turgid weight (TW). Then, the leaves should be oven-dried at 80 °C to a constant weight (DW). Finally, RWC [%] is calculated:

$$RWC\ (\%) = \frac{FW - DW}{TW - DW} * 100\%$$

where TW is leaf turgid or saturated weight, FW is fresh weight, and DW is leaf dry weight (Sanchez et al., 1998).

- ***Light interception*** by plant canopy using a light meter or light sensors.
- ***Total chlorophyll content*** using a chlorophyll spade.
- Visual scoring (on a 1 to 5 scale) for physiological disorders (crinkling of leaves, water-deficit stress development, death of leaves and branches, necrotic lesions due to stress).

- Visual scoring for nutrient deficiencies.
- Visual scoring of leaf retention capacity (same as above).

I. Grain quality parameters (based on Mariotti et al., 2008)

- ***Protein content:*** Protein content of grain is determined by near infrared spectroscopy (AACC, 2000).
- ***Moisture content*** [%]: Moisture content of grain is determined by near infrared spectroscopy (AACC, 2000).
- ***Hectoliter weight*** is estimated for each experimental unit following standard procedure (AACC, 2000) on a dockage-free basis using a laboratory standard hectoliter and electronic balance.

I. Disease score

Record damage caused by diseases using a disease severity score (on a 0-5 scale; 0 = not severe, 5 = 100% incidence) or indicate the reference used. To obtain an accurate rating of disease severity, take notes on damage late in the growing season but before the leaves begin turning brown. Rate the damage in each plot, concentrating on the diseases that are important in your region. If possible, give both the local and scientific name of the disease pathogen. Indicate the reference followed for scaling or rating.

4.4.2 Oil crops (sesame and sunflower)

A. Phenology (based on IPGRI and NBPGR, 2004)

- ***Days to emergence:*** Do as shown for cereal crops in Section 4.4.1.A.
- ***Days to first flowering:*** Do as shown for pulse crops in Section 4.4.1.A.
- ***Days to 50% flowering:*** Do as shown for pulse crops in Section 4.4.1.A.
- ***Days to first capsule/pod set:*** This is recorded as days from planting to when the first capsule/pod appears.
- ***Days to physiological maturity:*** This is the number of days from planting or first irrigation until 75% of the plants reach physiological maturity.

B. Shoot parameters (based on IPGRI and NBPGR, 2004)

- ***Number of branches*** [number per plant] is measured on 10 randomly selected plants at physiological maturity.
- ***Mean capsule length*** [mm] is measured on five randomly selected capsules from the middle of the main stem, each from a different plant at physiological maturity.
- ***Mean capsule width*** [mm] is measured on five randomly selected capsules from the middle of the main stem, each from a different plant at physiological maturity.
- ***Mean capsule thickness*** [mm] is measured on five randomly selected capsules from the middle of the main stem, each from a different plant at physiological maturity.
- ***Stem height*** [cm] is the mean height of 10 random plants from the middle of the plot measured from the base to the first branch.
- ***Plant stand count:*** Do as shown in Section 4.4.1.B.
- ***Plant height:*** Do as shown in Section 4.4.1.B.
- ***Maximum green leaf area:*** Do as shown in Section 4.4.1.B.
- ***Maximum leaf area index (LAI)*** (dimensionless): Do as shown in Section 4.4.1.B.

C. Root parameters

- ***Total root length, root dry matter, and root volume:*** Do as shown in Section 4.4.1.C.

D. Yield component parameters (based on IPGRI and NBPGR, 2004)

- ***Number of capsules per plant*** [number/plant] is recorded as the mean of five randomly selected plants at physiological maturity.
- ***Capsule/head weight*** [kg] is the mean of five randomly selected plants at physiological maturity.
- ***Seeds per capsule*** [number per capsule] is the mean of five randomly selected plants at physiological maturity.
- ***Grain moisture content*** [%]: Do as shown in Section 4.4.1.D.
- ***Thousand-seed weight*** [g]: Do as shown for pulse crops in Section 4.4.1.D.
- ***Lodging susceptibility*** [%]: Do as shown in Section 4.4.1.D.

E. Yield parameters

- ***Aboveground biomass*** [kg/ha]: Do as shown in Section 4.4.1.E.
- ***Grain yield*** [kg/ha]: Do as shown for pulse crops in Section 4.4.1.E.
- ***Straw yield*** [kg/ha]: Do as shown in Section 4.4.1.E.
- ***Harvest index:*** Do as shown in Section 4.4.1.E.
- ***Oil yield*** [liters]: Seed oil content is measured per treatment.

F. Plant tissue analysis data

- Do as shown in Section 4.4.1.F.
- Grain N [%] is measured at physiological maturity.
- ***Weed count:*** Do as shown in Section 4.4.1.F.

G. Nutrient-use efficiency

- Do as shown in Section 4.4.1.G.

H. Physiological parameters

- Do as shown in Section 4.4.1.H.

I. Quality parameters

- Do as shown in Section 4.4.1.I.
- ***Seed crude protein content*** [g/100 g DW].
- ***Amino acid composition*** [µg/g DW]: Estimate essential amino acids in seed samples (FAO, 1991).
- ***Oil content*** [% DW]: Briefly indicate the method used for the estimation with relevant references.
- ***Oil composition:*** Ratio of oleic/linoleic fatty acids.
- ***Oil stability*** [%]: Percentage of anti-oxidants (sesamin, sesamolin, lignans).

I. Disease score

- Do as shown in Section 4.4.1.J.

4.4.3 Vegetable crops (onion, tomato, pepper, potato)

A. Phenology

- ***Days to flowering*** is measured from transplanting until 50% of the plants have at least one open flower in a uniform growing environment.
- ***Days to physiological maturity*** is the number of days from seedling transplanting to a day on which at least 90% of the plants in a plot attained physiological maturity.

B. Shoot parameters

- ***Stand count:*** Plants that are successfully established in the central rows of the net plot area are counted at harvest and expressed as a percentage of the optimum expected number.
- ***Stand vigorosity*** is measured by the GreenSeeker. The Trimble GreenSeeker hand-held crop sensor is an easy-to-use measurement device that can be used to assess the health or vigor of a crop to make better nutrient management decisions on your farm. Normalized difference vegetation index (NDVI) readings can range from 0.00 to 0.99: the higher the reading, the healthier and more vigorous the plant.
- ***Plant height*** is measured from the ground to the shoot tip of the main plant from randomly selected plants at maturity. The number of samples must sufficiently represent the population depending on the area to be covered. Plot experiments require at least 10 plant samples.
- ***Stem diamete***r (tomato, potato, pepper) is measured in cm using a Vernier caliper 10 cm up from the root collar for 5 to 10 randomly selected plants from the middle rows.
- ***Shoot girth diameter*** (onion): The diameter of the base of the shoot at 2-3 cm from ground level is measured at full growth stage using a Vernier caliper for 5 to 10 randomly selected plants.
- ***Number of leaves per plant:*** The total number of leaves/compound leaves per plant is determined by counting from 5 to 10 randomly selected plants at maturity.
- ***Number of primary branches:*** The number of branches extended from the main stem are counted and recorded on 10 randomly selected plants in harvestable rows at flowering stage.
- ***Total leaf area*** [cm^2] is determined for five plants from a plot that is randomly selected/ pre-tagged by measuring the leaf length (LL) [cm] of the individual plants at flowering stage.

- ***Individual leaf area (LA)*** [cm^2]: For potato plants, this is estimated from individual leaf length following the formula developed by Firman and Allen (1989) using base ten logarithms from leaf length (L) measured in centimeters [cm].

$$\log_{10}(LA) = (2.06 * (\log_{10} L)) - 0.458$$

- ***Leaf area index (LAI)*** is determined by dividing the value of the leaf area by the area of the land occupied by the plant using the equation developed by Diwaker and Oswalt (1992):

$$\text{Leaf area index (LAI)} = \frac{LAm\ X\ N}{A}$$

where LAm = mean leaf area of the plant [cm^2], A = the area [cm^2] occupied by one plant in the cropping area, and N = the number of leaves on the plant.

- ***Number of main stems per hill*** is determined by counting the stems that originated from the tubers from 10 randomly selected hills for each treatment, and taking the average at flowering stage.

C. Root parameters

- ***Total root length, root dry matter, and root volume:*** Do as shown in Section 4.4.1.C.

D. Yield component parameters

- ***Bulb diameter (horizontal and vertical; onion)*** [cm]: The mean bulb diameter of 10 sample bulbs for plot experiments or a sufficient number to represent the population is measured both vertically and horizontally using a Vernier caliper.
- ***Fruit length (tomato, pepper)*** [cm] is recorded from the stem end to the blossom end, to one decimal place, at maturity.
- ***Fruit width (tomato, pepper)*** [cm] is recorded at the largest diameter of cross-sectioned fruits, to one decimal place using a caliper, at maturity.
- ***Number of fruits per cluster, per branch, and per plant*** is recorded by counting the total number of fruits per cluster from 5 to 10 randomly selected plants at red ripening stage of the fruits.
- ***Total tuber number per hill (potato)*** is determined by adding up the number of marketable and unmarketable tubers. This parameter constitutes all tubers: small, medium, large, diseased, deformed, etc, that were produced by the plants.

E. Yield parameters

Onion

- ***Average bulb weight*** [g]: The average fresh weight of 10 randomly selected mature bulbs is measured by using a sensitive balance and is expressed in grams.
- ***Marketable bulb yield*** [Mg/ha]: This refers to the weight of healthy and marketable bulbs (20 to 160 g in weight). Bulbs below 20 g in weight are considered too small to be marketed, whereas those above 160 g are considered oversized according to Lemma and Shimeles (2003). This parameter is determined from the net plot at final harvest.
- ***Unmarketable bulb yield*** [Mg/ha]: The total weight of unmarketable bulbs that are undersized (<20 g), sprouted, diseased, and decayed and of bulbs from plants with physiological disorders such as a thick neck is measured from a net plot at final harvest.
- ***Total bulb yield*** [Mg/ha] is measured from the total harvest of a net plot as a sum weight of marketable and unmarketable yields per plot.

Tomato, pepper

- ***Marketable fruit yield*** [Mg/ha] is recorded by weighing all harvests of marketable fruits from the inner rows of each plot and is calculated in metric tons per hectare.
- ***Unmarketable fruit yield*** [Mg/ha] is recorded by weighing all harvests of unmarketable fruits from the inner rows of each plot and is calculated in metric tons per hectare.
- ***Total fruit yield (TFY)*** [Mg/ha] is recorded as the sum of the weight of marketable and unmarketable fruit yields and is converted to metric tons per hectare.
- ***Average fruit weight*** [g]: The average fresh weight of 10 randomly selected mature fruits is measured by using a sensitive balance and is expressed in grams.

Potato

- ***Tuber weight*** [g] is determined at harvest by dividing the weight of all tubers obtained from five randomly selected plants (hills) by the total number of tubers.
- ***Marketable tuber yield*** [kg/ha] is the weight of tubers that are free from diseases and insect pests, and are greater than or equal to 25 g in weight.
- ***Unmarketable tuber yield*** [kg/ha] is the weight of tubers that are diseased and/or rotted and small-sized (less than 25 g in weight).
- ***Total tuber yield*** [kg/ha] is the sum of marketable and unmarketable tuber yields.
- ***Harvest index*** [%] is expressed as the ratio of total bulb/tuber/fruit dry weight to total biomass dry weight and is expressed in percentage.

F. Plant tissue analysis data

- ***Root total N, P, K, and aboveground N, P, K.*** Do as shown in Section 4.4.1.F.
- ***Bulb/fruit/tuber N, P, K…*** [mg/g DM] are measured at physiological maturity.
- ***N, P, K… harvest index*** [ratio] is the ratio of bulb/fruit/tuber N, P, K… to aboveground N, P, K… at physiological maturity.

G. Quality parameters

- ***Neck thickness*** [cm]: The average neck widths of 10 randomly selected mature bulbs or a sufficient number of bulbs representing the population are measured by using a Vernier caliper and are expressed in centimeters after harvest.
- ***Total soluble solids (TSS)*** [°Brix] is determined at harvest time from 10 randomly selected bulbs for onion or from a sufficient number of fruits for tomato representing the population by a hand-held refractometer using the procedures described by Waskar et al. (1999) for onion and using the procedures as described by Acedo et al. (2008) for tomato fruits.
- ***Other quality parameters:*** Lycopene content (spectrophotometric method; Davis et al., 2003), total acidity, and pungency in pepper (capsaicin content; HPLC-method) (Popelka et al., 2017).

4.4.4 Fruit crops (banana, mango, and avocado)

Banana

Plant cycle under evaluation: cycle 1 (main plant), cycle 2 (ratoon crop).

A. Phenology (based on IBPGR, 1984)

- ***Flowering date*** [dd/mm/yyyy] refers to the date on which more than 50% (expert suggestion) of the plants in a plot have emerged bunches/started flowering during the first season.
- ***Maturity date*** [dd/mm/yyyy] refers to the date when at least 50% (expert suggestion) of the plants in a plot during the first season showed maturity.
- ***Days to flowering*** [days]: Record the number of days from planting to bunch emergence.
- ***Days to maturity/plant crop cycle*** [days]: Record the number of days from planting to the date on which 90% (expert suggestion) of the plants in a plot have matured.
- ***Plant cycle for ratoon crops*** [days] is the number of days between two successive harvests.

B. Shoot parameters (based on IBPGR, 1984)

- ***Plant height*** [m] at first flowering is the mean height of 10 randomly selected plants at flowering measured from the ground to the curve of the bunch stalk using a measuring stick.
- ***Pseudostem height*** [m] is the mean height of 10 randomly selected main plants measured from the base of the pseudostem to emerging points of the peduncle or to the curve of the bunch stalk using a measuring stick.
- ***Pseudostem girth*** [cm] is the mean of 10 randomly selected plants measured at 1 m above the ground at first flowering using a tape measure.
- ***Canopy spread (diameter)*** [cm] is the mean diameter of 10 randomly selected plants measured at first flowering.
- ***Leaf number at flowering*** [number per plant] is the mean count of green leaves from 10 randomly selected plants per plot at flowering.
- ***Leaf length*** [cm] is the mean of fully expanded leaf length measured from the

leaf blade base to the tip of the leaf from 10 randomly selected plants at flowering using a tape measure.

- ***Leaf width*** [cm] is the mean of fully extended leaf width measured at the point where the maximum breadth exists in the leaf at the time of flowering from 10 randomly selected plants using a tape measure.
- ***Total leaf area*** [m^2]: LA estimation in banana is quite laborious because of the enormous leaf size, even with the help of an electronic area meter. Attempts can be made to estimate non-destructively by multiplying the product of the length and breadth of the third leaf by the constant factor (0.8) and number of leaves and this is expressed as m^2/plant for some cultivars (Potdar and Pawar, 1991; Karuna and Rao, 2013). The constant value (factor) developed for the cultivar/variety or canopy class in consideration will be used.
- ***Leaf area index (LAI)*** is calculated as the total leaf area [m^2] of the given canopy at flowering emergence and then divided by the total plot area of the canopy [m^2]. LAI can range from 0 (bare ground) to more than 10 (dense conifer forests). Specify whether other indirect non-destructive estimation methods are used.

C. Yield and yield component parameters (based on IBPGR, 1984)

- ***Bunch weight*** [kg]: Cut the bunch stalk (peduncle) above the first hand at the level of the last scar and immediately below the last hand and then measure the weight.
- ***Marketable fruit yield*** [Mg/ha] refers to the weight of healthy and marketable fruits. This parameter is determined from the harvested net plot.
- ***Unmarketable fruit yield*** [Mg/ha]: The total weight of unmarketable fruits that are undersized, sprouted, diseased, and decayed and of fruits from plants with physiological disorders is measured from a net plot.
- ***Total fruit yield*** [Mg/ha]: The total fruit yield is measured from the total harvest of a net plot as a sum weight of marketable and unmarketable yields that is measured in kg per plot and finally converted into kg per ha.
- ***Average fruit/finger weight*** [g]: Divide the collective weight of the hands (cut from the peduncle) by the number of fruits.
- ***Fruit length*** [cm] is measured as the internal arc of the central external fruit of the middle hand without a pedicel.
- ***Fruit diameter*** [mm] is measured from the central external fruit of the middle hand using a caliper.

D. Crop physiological parameters: measured at selected growth stages for perennials

- Do as shown in Section 4.4.1.H.

E. Quality parameters (based on IBPGR, 1984)

- ***Fruit shape:*** Record as straight, curved, elongated, S-shaped, etc.
- ***Proportion of pulp and peel:*** Fruits, after maturating (ripe but not overripe), are weighed to determine the weight of the pulp and peel relative to the total weight of each fruit. Use 10 randomly selected mature fruits.
- ***Pulp total soluble solids*** [°Brix] is determined from the juice of matured fruits (not overripe) of five randomly selected or sufficiently representative fruit samples using refractometer readings of the refractive index at 20 °C in three replications. Temperature correction must be made by using the method described by the manufacturer's manual.
- ***Fruit K*** [mg/100g] is measured by laboratory analysis.
- ***Fruit P*** [mg/100g] is measured by laboratory analysis.
- Specify any additional information recorded.

F. Disease score

- Record damage caused by diseases using a disease severity score. Rate the damage in each plot. If possible, give both the local and scientific name of the disease pathogen. Indicate the reference followed for scaling or rating.

Mango and avocado

Tree type: Record as seedling, grafted, or clonal.

Rootstock-scion type: Record the rootstock and scion type.

A. Phenology (based on IPGRI, 1995, 2006)

Record data from 75% of the trees in the experimental plot or from sufficiently representative tree samples

- ***Tree age*** [years]
- ***Years to flowering*** [years]: Number of years from planting to first flowering.
- ***Flowering duration:*** Record the dates for first flowering and end of flowering [dd/mm/yyyy].
- ***Years to fruiting*** [years] represents the number of years from planting to first fruiting.
- ***Days from flowering to fruit maturity*** [days] is the average of observations from 5 to 10 tagged fruit samples.

B. Shoot parameters (based on IPGRI, 1995 and 2006)

- ***Tree height*** [m]: Measure from ground level to the top of the tree. If grafted, record also the height of the graft union and rootstock name. This is relevant only for unpruned trees.
- ***Plant height*** [cm] is measured at transplanting and at different growth stages depending on the objective of the study.
- ***Tree spread*** [m] is measured as the mean diameter using two perpendicular directions. This is applicable for growth stages before pruning.
- ***Girth of the main stem*** [cm] is recorded at 30 cm above ground level or above and below the graft union depending on the objective of the study.
- ***Total leaf area per plant*** and mean area of individual leaves (measured by a leaf area meter or using length × width × a constant value (K) developed for the variety or canopy class) at desired meaningful critical growth stages.

C. Yield and yield component parameters (based on IPGRI, 1995 and 2006)

For yield and yield component parameters, sampling should take place from a representative number of branches belonging to the middle canopy and distributed across the four directions of the tree.

- ***Number of total and fruit-bearing branches per tree*** is quantified from 5 to 10 randomly selected fruit trees depending on availability or on sufficiently representative tree samples, and is then averaged over the number of harvested trees.
- ***Number of fruits per tree*** is quantified from 5 to 10 randomly selected fruit trees depending on availability or on sufficiently representative tree samples in the harvested net plot, and is then averaged over the number of harvested trees.
- ***Yield per tree*** [kg/tree] is measured using a weighing balance on fruits harvested from 5 to 10 randomly selected fruit trees depending on availability or on sufficiently representative tree samples in the harvested net plot, and is then averaged over the number of harvested trees.
- ***Productivity*** [kg/m^2]: Yield relative to tree canopy size is calculated from the length and width of fruits harvested from 5 to 10 randomly selected fruit trees depending on availability or on sufficiently representative tree samples in the harvested net plot.
- ***Fruit length*** [cm] is measured using a caliper on 10 randomly selected fruits or from sufficiently representative fruit samples harvested in a net plot and then averaged over the number of selected fruit samples.
- ***Fruit diameter*** [cm] is measured at the broadest part using a caliper. The average obtained from 10 randomly selected fruits or from sufficiently representative fruit samples harvested in a net plot and then averaged over the number of selected fruit samples.
- ***Fruit weight*** [g] is measured using a weighing balance (two decimal points) on 10 randomly selected fruits or from sufficiently representative fruit samples harvested in a net plot and then averaged over the number of selected fruit samples.
- ***Marketable fruit yield weight*** [Mg/ha] refers to the weight of healthy and marketable fruits. This parameter is determined from the harvested net plot and is measured in kg per plot and then converted into kg per hectare.

- ***Unmarketable fruit yield weight*** [Mg/ha] is the total weight of unmarketable fruits that are undersized, sprouted, diseased, decayed, and physiologically disordered from a net plot and is expressed in metric tons per hectare. Record the reasons for unmarketable fruits (underweight, diseases/insects, cracks, etc.).
- ***Total fruit yield*** [Mg/ha] is measured from the total harvest of a net plot as a sum weight of marketable and unmarketable yields that is measured in kg per plot and finally converted into kg per hectare.
- ***Yield behavior*** (if possible) is suggested to be observed from the average of 75% of the trees per plot (as continuous, alternate, erratic).

D. Plant tissue sampling

- Leaf sampling (fully expanded, mature, and photosynthetically active leaves from the middle canopy branches).

E. Crop physiological parameters: measured at selected growth stages for perennials (based on IPGRI, 1995 and 2006)

- Do as shown in Section 4.4.1.H.

F. Quality parameters (based on IPGRI, 1995 and 2006)

- ***Proportion of pulp, peel, and seed*** [%]: Fruits, after maturing (indicated by their soft consistency), are weighed to determine the weight of the pulp, peel, and seed relative to the total weight of each fruit. Take samples from 10 randomly selected mature fruits.
- ***Flesh/pulp oil*** [%] for avocado: Take samples from 10 randomly selected mature fruits (not ripe). Indicate the method of estimation.
- ***Oil composition:*** Different standard methods are used (Flores et al., 2019). When oil compositions are quantified, indicate the method used.
- ***Pulp total soluble solids*** [°Brix] is determined from the juice of matured fruits of five randomly selected or sufficiently representative fruit samples using refractometer readings of the refractive index at 20 °C in three replications. Temperature correction must be made by using the method described by the manufacturer's manual.
- ***Juice volume*** [mL]: Measure the juice volume from five randomly selected or sufficiently representative fruit samples in three replications.
- Specify any additional information recorded.

G. Disease score

Record damage caused by diseases using a disease severity score. Rate the damage in each plot. If possible, give both the local and scientific name of the disease pathogen. Indicate the reference followed for scaling or rating.

4.4.5 Coffee

A. Vegetative parameters (IBPGR. 1980)

Sample three to six trees per plot depending on plot size or the number of trees per plot.

- ***Population density*** (spacing between plants and rows) (consider the whole plot).
- ***Plant height*** (from base to tip) at transplanting, early field establishment (before crop bearing), and potential bearing stages (third to eighth crop) depending on the objective of the study.
- ***Total number of bearing heads***/suckers per tree.
- ***Number of potential bearing heads*** per tree each year at crop-bearing stages.
- ***Mean internode length*** of the main stem at transplanting, early field establishment, and potential bearing stages.
- ***Number of main stem nodes*** at transplanting, early field establishment, and potential bearing stages.
- ***Plant height*** up to the first primary branch at transplanting, early field establishment, and potential bearing stages.
- ***Mean length of primary branches*** (sample three pairs of branches from the top, middle, and bottom parts of the canopy for representative trees and take the mean value).
- ***Canopy diameter*** (measured from one end/tip of the longest pair of primary branches to the other end in east-west and north-south directions, and taking the mean value). Canopy diameter/volume is measured

at early stages and in subsequent growth stages in the field (measured once a year).

- ***Main stem girth*** at the base (at 5 cm height) at transplanting, early field establishment, and potential bearing stages.
- ***Total leaf area per plant*** and mean area of individual leaves (measured by a leaf area meter or length × width × a constant value (K) developed for the variety or canopy class) at transplanting, early field establishment, and potential bearing stages.
- ***Branching angle for primary branches*** (sample three pairs of branches from the top, middle, and bottom parts of the canopy for representative trees; measure the angle at the branch insertion point before the trees start bearing crops, and take the mean value).
- ***Total number of primary branches per tree*** at transplanting, early field establishment, and potential bearing stages.
- ***Total number of secondary branches*** per tree at early field establishment and at potential bearing stages.
- ***Mean number of secondary branches*** per primary branch at early field establishment and at potential bearing stages.
- ***Number of crop-bearing and non-bearing primary branches per tree*** (crop-bearing branches with at least two clusters of fruits, otherwise non-bearing at potential bearing stage).
- ***Number of crop-bearing trees per plot*** (trees with at least 80 fruits, otherwise non-bearing at potential bearing stage).

B. For nursery/greenhouse-grown/potted plants/seedlings

- Taproot length (measured from root collar to tip of the taproot).
- Number of lateral roots emerging from the taproot.
- Number of secondary laterals emerging from the primary laterals.
- Number of feeder roots.
- Total length of lateral roots.
- Total length of feeder roots.
- Root volume (determined by displacement method).
- Plant height (from the base to the tip of the main stem).
- Number of nodes of the main stem.
- Internode length.
- Total number of primary branches per plant.
- Mean length of primary branches.
- Total number of leaves per plant.
- Total leaf area per plant and mean area of individual leaves (measured by a leaf area meter or length × width × a constant value (K) developed for the variety or canopy class) or total leaf area (mean area of individual leaves × total number of leaves).
- Total dry matter yield (DMY) (oven-drying root parts, stem, leaves, and branches separately at 70 ^{o}C until a constant weight) and total leaf dry weight to calculate specific leaf area (leaf area to leaf weight ratio, which is the inverse of leaf thickness).
- Dry matter partitioning (to leaves, stem, branches, and root parts in % of the total DMY, and root to shoot ratio).

C. Yield and yield components

- Number of flowers per cluster and per branch.
- Number of clusters per branch.
- Number of fruits per branch and per cluster.
- Crop to leaf ratio (visual assessment on a 1-5 scale, where 1 represents low-bearing and 5 represents high- or over-bearing, as a normal ratio is assumed to be 4-6 berries per leaf).
- Mean number of bearing nodes per branch.
- Number of bearing branches per tree.
- Number of bearing trees per plot.
- Fresh cherry yield per tree and per plot.
- Clean coffee yield per tree and per unit area.
- Harvesting/picking frequency.
- Harvesting method (selective picking or stripping) (Fig. 2).

Fig. 2. Selective picking of coffee cherries from clusters/bearing nodes of primary branches at red full-ripening stage.
Source: Coffee and Tea Development Authority, Bunachin Magazine (1990)

D. Quality parameters (Table 4)

- Bean screen size, shape and make, color, and odor (raw quality) [40%].
- Cup (organoleptic) or liquor quality (acidity, body, flavor, aromatic intensity, bitterness, cup cleanness, etc.) [60%].
- Overall quality (raw + cup quality) [100%].
- Biochemical quality attributes (trigonelline, caffeine, chlorogenic acid, sucrose, crude fat, crude protein, dry matter, ash, moisture content).

Table 4: Standard parameters and their respective values used for coffee quality evaluation.*

RAW VALUE [40%]					
SHAPE AND MAKE	POINTS	COLOR	POINTS	ODOR	POINTS
Very good	15	Bluish	15	Clean	10
Good	12	Grayish	12	Trace	8
Fair/average	8	Greenish	8	Light	5
Mixed	5	Faded	5	Moderate	2
Small	2	Brownish	2	Strong	1

LIQUOR VALUE [60%]					
ACIDITY	POINTS	BODY	POINTS	FLAVOR/CHARACTER	POINTS
Pointed	20	Full	20	Very good	20
Medium/P	15	Medium/F	15	Good	15
Medium	10	Medium	10	Average	10
Light	5	Light	5	Fair	7
Lacking	2	Thin	2		

**In addition, refer to JARC and ECX coffee quality manuals.*

E. Plant tissue sampling

- Leaf sampling (fully expanded, mature, and photosynthetically active leaves from the middle canopy, at third or fourth node from the tip of branches or main stem).
- At least 12 trees should be maintained per net plot for agronomic data for tree crops, including coffee.

F. Crop physiological parameters: measured at selected growth stages for perennials

- Do as shown in Section 4.4.1.H (see also Fig. 3).

Fig. 3. An example of scoring arabica coffee seedlings for drought stress development and the corresponding 1-5 scale for stress score values. *Source: Tesfaye (2005).*

(The degree of leaf folding or wilting is scored using a 1 to 5 scale, where 1 = all leaves are green and turgid, 2 = most leaves are still turgid, except the youngest, which show leaf folding, 3 = all leaves wilt and/or show leaf folding (symptoms of senescence evident), 4 = leaves (especially the older ones) turning pale green and showing severe wilting or folding, and 5 = leaves turning brown and dry, mostly drooping.)

5. References

AACC (American Association of Cereal Chemists). 2000. Approved methods of the American Association of Cereal Chemists. 10th edition. St. Paul, Minnesota, USA.

Acedo, A.; Thanh, C.; Borarin. 2008. Technological development for fresh and processed tomato and chilli. In: Asia Vegetable Research and Development Center (AVRDC) (ed.) Training manual on postharvest research and technology development for tomato and chilli. RETA countries. p. 75-87.

Bache, B.W. 1974. Soluble aluminium and calcium-aluminium exchange in relation to the pH of dilute calcium chloride suspensions of acid soils. *European Journal of Soil Science*. DOI: 10.1111/j.1365-2389.1974.tb01128.x

Baligar, V.C.; Fageria, N. K.; He, Z. L. 2001. Nutrient use efficiency in plants. *Communications in Soil Science and Plant Analysis* 32: 921–950.

Balota, M.; Payne, W.A.; Evett, S.R.; Peters, T.R. 2008. Morphological and physiological traits associated with canopy temperature depression in three closely related wheat lines. *Crop Science* 48(5): 1897–1910.

Berry, P.M.; Spink, J. 2012. Predicting yield losses caused by lodging in wheat. *Field Crops Research* 137: 19–26

Blake, G.R.; Hartge, K.H. 1986b. Particle density. In: Klute, A. (ed.), Methods of Soil Analysis. Part 1. Physical and Mineralogical Methods. Agronomy Monograph 9. Soil Science Society of America, Madison, Wis., USA. p. 377-382.

Blake, G.R.; Hartge, K.H. 1986a. Bulk density. In: Klute, A. (ed.), Methods of Soil Analysis. Part 1. Physical and Mineralogical Methods. Agronomy Monograph 9. Soil Science Society of America, Madison, Wis., USA. p. 363-375.

Bouyoucos, G.J. 1962. Hydrometer method improved for making particle size analyses of soils. *Agronomy Journal* 54:464–465.

Caldicott, .J.B.; Nuttall, A.M. 1979. A method for the assessment of lodging in cereal crops. *J. Natl. Inst. Agric. Bot.* 15: 88–91.

Cassel, D.K.; Nielsen, D.R. 1986. Field capacity and available water capacity. In: Klute, A. (ed.), Methods of Soil Analysis. Part 1. Physical and Mineralogical Methods. Agronomy Monograph 9. Soil Science Society of America, Madison, Wis., USA. p. 901-926.

Davis A.R.; Fish, W.W.; Perkins-Veazie, P. 2003. A rapid spectrophotometric method for analyzing lycopene content in tomato and tomato products. *Postharvest Biology and Technology* 28:425-430.

Diwaker, B.; Oswalt, D.L. 1992. Research planning and data handling. International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Andhra Pradesh, India. 89 p.

Dobermann, A.R. 2005. Nitrogen Use Efficiency – State of the Art. Agronomy & Horticulture. Faculty Publications 316. University of Nebraska-Lincoln. https://digitalcommons.unl.edu/agronomyfacpub/316.

Eagle, A.J.; Christianson, L.E.; Cook, R.L.; Harmel, R.D.; Miguez, F.E.; Qian, S.S.; Ruiz Diaz, D.A. 2017. Meta-analysis constrained by data: recommendations to improve relevance of nutrient management research. *Agronomy Journal* 109(6):2441-2449.

EIAR (Ethiopian Institute of Agricultural Research). 2011. Coordination of National Agricultural Research System, Ethiopia. English and Amharic Version. EIAR, Addis Ababa.

Fageria, N.K.; Baligar, V.C. 2003. Improving nutrient use efficiency of annual crops in Brazilian acid soils for sustainable crop production. *Communications in Soil Science and Plant Analysis* 32(7):1303-1319.

FAO (Food and Agriculture Organization of the United Nations). 2006. Guidelines for Soil Description. 4th edition. Rome, Italy.

FAO. 1977. Soil and plant testing and analysis. FAO Soil Bulletin 38/1. Rome, Italy.

FAO. 1990. Guidelines for Soil Profile Description, 3rd edition (revised). Food and Agriculture Organization of the United Nations, International Soil Reference Information Centre, Land and Water Development Division. Rome, Italy.

FAO. 1991. FAO/WHO Food and nutrient paper. Protein quality evaluation. Report of joint FAO/WHO expert consultation. FAO. 651:1-66, Bethesda, Md., USA.

FAO. 1998. Crop Evapotranspiration: Guidelines for computing crop water requirements. Irrigation and Drainage Paper No. 56. Rome, Italy.

Firman, D.M.; Allen, E.J. 1989. Estimating individual leaf area of potato from leaf length. *Journal of Agricultural Science* 112:425-426.

Fischer, R.A.; Stapper, M.1987. Lodging Effects on High-yielding Crops of Irrigated Semidwarf Wheat. *Field Crops Research*, 17: 245-258

Flores, M.; Saravia, C.; Vergara, C.E.; Avila, F.; Valdés, H.; Ortiz-Viedma, J. 2019. Avocado Oil: Characteristics, Properties, and Applications. *Molecules* 24:2172. DOI:10.3390/molecules24112172

Flynn, R.; Ball, S.T.; Baker, R.D. 1999. Sampling for Plant Tissue Analysis. Guide A-123. College of Agricultural, Consumer and Environmental Sciences, New Mexico State University.

Fuchs, M. 1990. Infrared measurement of canopy temperature and detection of plant water stress. *Theoretical and Applied Climatology* 42(4):253–261.

IBPGR (International Board for Plant Genetic Resources). 1991. Descriptors for Maize. International Maize and Wheat Improvement Center, Mexico City/ International Board for Plant Genetic Resources, Rome, Italy.

IBPGR. 1980. Descriptors for Coffee (Coffea spp. and Psilanthus spp.). International Board for Plant Genetic Resources Report. IBPGR, Rome, Italy.

IBPGR. 1984. Descriptors for Banana (*Musa* spp.). International Board for Plant Genetic Resources Report. IBPGR, Rome, Italy.

IPGRI and ICRISAT. 1993. Descriptors for Sorghum (*Sorghum bicolor* [L.] Moench). International Plant Genetic Resources Institute, Rome, Italy; and International Crops Research Institute for the Semi-Arid Tropics, Patancheru, India.

IPGRI and NBPGR. 2004. Descriptors for Sesame (*Sesamum* spp.). International Plant Genetic Resources Institute, Rome, Italy; and National Bureau of Plant Genetic Resources, New Delhi, India.

IPGRI (International Plant Genetic Resources Institute). 1982. Descriptors for *Phaseolus vulgaris*. IPGRI, Rome, Italy.

IPGRI. 1994. Descriptors for Barley (*Hordeum vulgare* L.). IPGRI, Rome, Italy.

IPGRI. 1994. Descriptors for Wheat (*Triticum* spp.). IPGRI, Rome, Italy.

IPGRI. 1995. Descriptors for Avocado (*Persea* spp.). IPGRI, Rome, Italy.

IPGRI. 2006. Descriptors for Mango (*Mangifera indica* L.). IPGRI, Rome, Italy.

Judd, L.A.; Jackson, B.E.; Fonteno, W.C. 2015. Advancements in root growth measurement technologies and observation capabilities for container-grown plants. *Plants* 4:369-392. DOI: 10.3390/plants4030369

Karuna, Y.; Rao, K.K. 2016. Studies on phenological characters of different banana cultivars (*Musa*) in Visakhapatnam, Andhra Pradesh. International *Journal of Science and Research* 5(5): 1689-1693.

Kladivko, E.J.; Helmers, M.J.; Abendroth, L.J.; Herzmann, D.; Lal, R.; Castellano, ...Villamil, M.B. 2014. Standardized research protocols enable transdisciplinary research of climate variation impacts in corn production systems. *Journal of Soil and Water Conservation* 69(6):532-542. DOI: 10.2489/jswc.69.6.532

Lemma, D.; Shimeles, A. 2003. Research Experience in Onion Production. Research Report Number 55. EARO, Addis Ababa, Ethiopia.

Mariotti, F.; Tomé, D.; Mirand, P.P. 2008. Converting nitrogen into protein—beyond 6.25 and Jones' factors. *Critical Reviews in Food Science and Nutrition* 48(2):177–184.

McCauley, A.; Jones, C.; Olson-Rutz, K. 2017. Soil pH and Organic Matter. Nutrient Management Module No. 8. http://landresources.montana.edu/nm

Minasny, B.; McBratney, A.B.; Brough, D.M.; Jacquier, D. 2011. Models relating soil pH measurements in water and calcium chloride that incorporate electrolyte concentration. *European Journal of Soil Science*. DOI: 10.1111/j.1365-2389.2011.01386.x

MoA (Ministry of Agriculture). 1998. Agro-ecological zones of Ethiopia. Natural Resources Management & Regulatory Department. With support from the German Agency for Technical Cooperation (GTZ). Addis Ababa, Ethiopia.

Moll, R.H.; Kamprath, E.J.; Jackson, W.A. 1982. Analysis and interpretation of factors which contribute to efficiency of nitrogen utilization. *Agronomy Journal* 74:562–564.

Newman, E.I. 1966. A method of estimating the total length of root in a sample. *Journal of Applied Ecology* 3(1):139-145. DOI: 10.2307/240167

Popelka, P.; Jevinová, P.; Karel, S.; Roba, P. 2017. Determination of capsaicin content and pungency level of different fresh and dried chilli peppers *Folia Veterinaria* 61(2):11-16.

Potdar, M.V.; Pawar, K.R. 1991. Non-destructive leaf area estimation in banana, *Scientia Horticulturae* 45:251–254.

Richards, L.A. 1954. Diagnosis and Improvement of Saline and Alkali Soils. United States Department of Agriculture (USDA). Agriculture Handbook No. 60, Washington, D.C., USA.

Rowell, D.L. 1994. Soil Science: Methods and Applications. Addison Wesley Longman Limited, England.

Sanchez, F.J.; Manazanares, M.; de Andres, E.F.; Tenorio, J.L.; Ayerbe, L. 1998. Turgor maintenance, osmotic adjustment and soluble sugar and proline accumulation in 49 pea cultivars in response to water stress. *Field Crops Research* 59:225-235.

Spectrum Analytic Inc. 2009. Illustrated Guide to Sampling for Plant Analysis. Washington.

Tennant, D. 1975. A test of a modified line intersect method of estimating root length. *Journal of Ecology* 63(3):995-1001. DOI: 10.2307/2258617

Tesfaye, S.G. 2005. Growth, water relations, yield and crop quality of Arabica coffee in response to water stress and deficit irrigation. PhD Dissertation, University Putra Malaysia (UPM), Malaysia.

Waskar, D.P.; Khedkar, R.M.; Garande, V.K. 1999. Effect of post-harvest treatments on shelf life and quality of pomegranate in evaporative cool chamber and ambient conditions. *Journal of Food Science Technology* 36(2):114-117.

Weih, M.; Asplund, L.; Bergkvist, G. 2011. Assessment of nutrient use in annual and perennial crops: a functional concept for analyzing nitrogen use efficiency. *Plant Soil* 339:513-520.

WMO (World Meteorological Organization). 2006. Guide to meteorological instruments and methods of observation. Preliminary seventh edition. WMO-No. 8. Geneva, Switzerland.

6. Appendices

Appendix Table 1: Sampling field crops for tissue analysis.* *(FAO Soil Bulletin, 1977; Spectrum Analytic Inc. 2009)*

STAGE OF GROWTH	PLANT PART TO SAMPLE	NUMBER OF PLANTS TO SAMPLE
Maize		
• Seedling stage (less than 30 cm) or	All aerial portions	20-30
• Prior to tasseling or	The entire fully developed leaf below the whorl	15-25
• From tasseling and shooting to silk initiation and brown silk stage	The entire leaf at the ear-node (ear leaf)	15-25
• Sampling after silking occurs is not recommended		
Sorghum Prior to or at heading	Second leaf from top of plant	15-25
Small grains (wheat and barley)		
• Seedling stage (less than 30 cm)/Feekes stages 3 through 9 or	All aerial portions	50-100
• Prior to heading/Feekes stage 10	The four uppermost mature leaves/flag leaves	50-100
• Sampling after heading is not recommended		
Legumes (beans and soybeans)		
• Seedling stage (less than 30 cm) or	All the aerial portion	20-30
• Prior to or during initial flowering	Two or three fully developed leaves at the top of the plant	20-30
• Sampling after pods begin to set is not recommended		
Onion		
• Seedling stage	Entire aboveground portion of plant	30-50 plants
• At the middle of the growth period before root or bulb enlargement	Central recently mature leaves	25-30 plants
Tomato	Entire aboveground portion of plant	20-25 plants
• Seedling stage	Youngest fully developed upper (third to fourth) leaves from growing tip on main stem	25-30 leaves
• Vegetative, bloom, fruiting		
Potato	Entire aboveground portion of plant	20-25 plants
• Seedling stage	Youngest fully developed (third to sixth) leaves from growing tip on main stem	25-30 leaves
• Vegetative to full bloom stage		
Pepper		
• At the middle of the growth period	Recently fully developed leaves	25-35 leaves

** In problem fields where the growth or appearance of one area differs from the rest of the field, plant analysis can often determine the cause of these differences and indicate the best method for correcting the problem. In such cases, triplicate soil and plant samples in both normal and problem fields are required.*

Partners:


german
cooperation
DEUTSCHE ZUSAMMENARBEIT


giz


CABI


Alliance
Bioversity
International
CIAT
International Center for Tropical Agriculture
Since 1967 Science to cultivate change


CGIAR
RESEARCH
PROGRAM ON
Water, Land and
Ecosystems