
General guidelines for monitoring stress severity in drought screening trials



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Headquarters: College, Los Baños, 4031 Laguna, Philippines
Mailing address: IRRI, DAPO Box 7777, Metro Manila, Philippines
Phone: +63 (2) 580-5600
Fax: +63 (2) 580-5699
Email: info@irri.org
Web: irri.org

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Why environmental characterization is important for drought screening trials

Environmental characterization is important in drought screening trials because one scientist's definition of drought can be very different from another scientist's definition of drought. Also, labeling an experiment as a "drought treatment" does not ensure that the plants will experience a standard stress intensity or that the yield reduction will be due to drought alone. To overcome this uncertainty, quantitative measurements can be conducted to characterize the type of drought stress in screening trials.

The results of drought screening trials for crop breeding become much more valuable for scaling up to global estimates if the environmental conditions have been characterized. Although some of the most important drought-prone areas receive few resources for conducting key research studies, there are low-cost approaches that can be used to effectively characterize drought screening trials in these locations.

This booklet provides descriptions of simple, low-cost approaches for reliably characterizing the severity of drought stress in breeding trials. These methods have been used as drought screening protocols by a network of breeders at a range of sites in South Asia (Singh et al 2017). A list of suppliers is given at the end of this booklet. The methods described are based on our experience in rainfed lowland rice, but can also be adapted for use in other crops.



Conducting rainfall measurements

Background: The amount and timing of rainfall are the key determinant of drought stress during a crop growing season. Rainfall is measured by either a manually read rain gauge (for depth of rainfall per day) or a tipping bucket rain gauge with a datalogger (for rainfall depth and intensity).

Methods: Any open-topped container can be used as a rain gauge if the area of the opening is known and the user has a way to quantify the volume of rainfall collected.

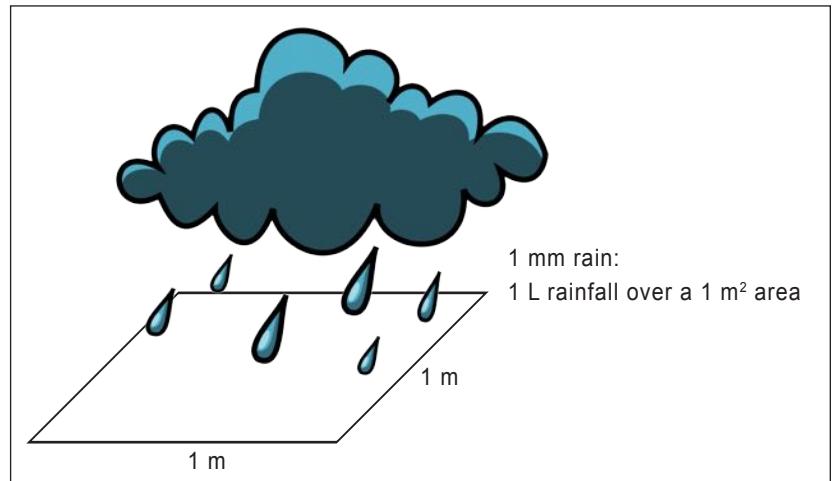
Data analysis: For circular containers:

Radius (r) of a container opening (cm) = diameter/2

$\pi = 3.14159$

Area of a container opening (cm²) = πr^2

Rainfall (mm) = $\frac{\text{volume of rainfall collected (mL)}}{10 \times \text{area of the container opening (cm}^2\text{)}}$



Manual rain gauge



Tipping bucket rain gauge

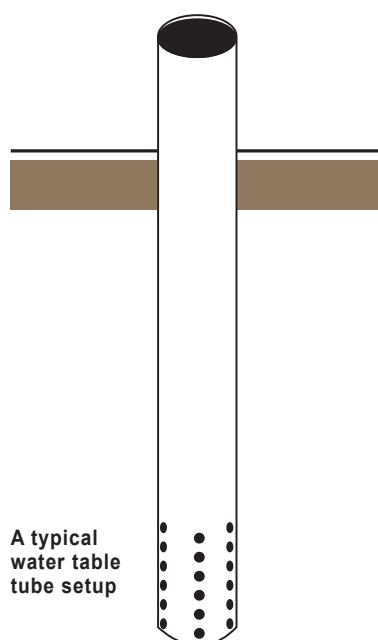
Water table depth measurements

Background: Water table depth can provide some indication of crop water availability, although this measurement may be most useful for rice experiments that typically experience high water tables. An observational well (also called a piezometer or water table tube) is used to monitor water table depth throughout the drydown period.

Methods: For perched water table depth measurements, an observation well can be made from a 1.2-meter-long × 2-inch-diameter PVC pipe with small perforations in the bottom portion of the pipe. The perforations (small holes or slits) can be made with a drill or hacksaw. Alternatively, a type of PVC called “filter pipe” can be purchased, which has perforations built into the wall of the pipe. The bottom of the tubes can be wrapped with hardware cloth so as not to clog the perforations. Water table tubes are typically manufactured locally. Automated sensors are also available.

It is very important to prevent filling of the tubes with mud – keep the perforations small and cover them with hardware cloth if needed. Tubes are installed to a depth of 1 meter, with the extra 20 cm protruding above the soil surface. The water table depth is monitored using a measuring stick or with a measuring tape with a foam stopper attached at the 0-cm point to detect when the surface of the water is reached. The measuring stick should not be immersed into the water because it will displace the water, resulting in erroneous readings.

Data analysis: After measuring the distance from the top of the PVC tube to the top of the water table, the length of tube protruding above the soil surface (e.g., 20 cm) is subtracted, and the water table depth is recorded as the distance from the soil surface. For example, if the tube contains only 10 cm of water at the bottom of a 1.2-m tube with 20 cm protruding above the soil surface, the water table depth is recorded as 90 cm.



Gravimetric and volumetric soil moisture measurements



Soil sampling to determine gravimetric soil moisture



Device for monitoring volumetric soil moisture

Background: A simple way to determine the soil moisture level in a field is to collect a soil sample and weigh it; then dry and weigh it again. This approach is termed “gravimetric soil moisture measurement.” Sampling for gravimetric soil moisture measurements can be repeated during the drought stress treatment, although this results in many holes in a field. Gravimetric soil moisture measurements can also be converted into volumetric soil moisture measurements by considering the soil bulk density. Devices such as TDR, theta probes, etc., monitor volumetric soil moisture through reflection of electric signals. The major disadvantage of gravimetric and volumetric soil moisture measurements is that they cannot indicate water availability/stress from one soil type to another. That is, a gravimetric soil moisture level of 40% at a depth of 25–30 cm in a clay soil results in more severe stress than a level of 40% in a clay soil.

Methods: Soil moisture levels typically vary with depth. Therefore, for all soil moisture measurements, it is necessary to define the depth of the measurement/sampling. For rainfed lowland rice, we typically take gravimetric soil moisture measurements from depths of 5–10 cm and 25–30 cm.

Because of soil heterogeneity, it is recommended to conduct this measurement at multiple locations or in a transect in an experimental field. The number of samples will depend on the size of the experiment. It is generally suggested to take at least one measurement per replicate or at least per 100–200-m² area. The soil sample weight can range from 20 to 500 grams depending on the depth increments targeted and the number of subsamples bulked together (if any).

Standard drying conditions are 105 °C for 24 hours, but lower temperatures can be used for longer times. The sample can be considered dry once the weight is stable.

Data analysis:

Gravimetric soil moisture (%) measurement, dry weight basis

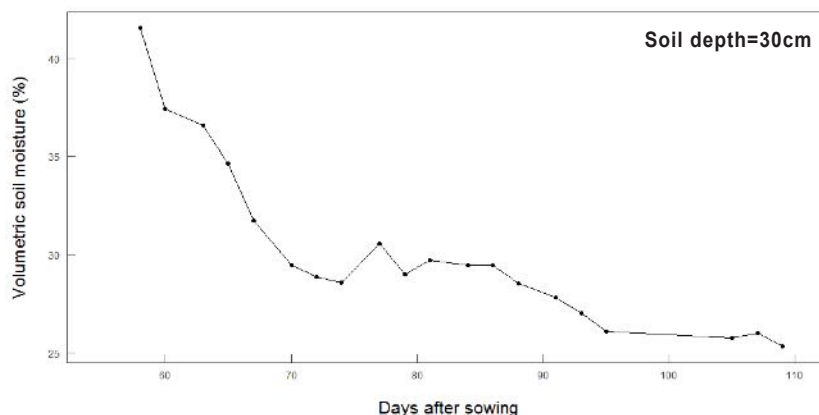
$$\theta_m = \frac{\text{mass of soil water}}{\text{mass of dry soil}} = \frac{(\text{weight of freshly collected soil} - \text{weight of dry soil})}{\text{weight of dry soil}} \times 100$$

Volumetric soil moisture (%)

$$\theta_v = \theta_m \times \rho_b$$

Bulk density (g cm⁻³)

$$\rho_b = \frac{\text{mass of dry soil}}{\text{volume of soil}}$$

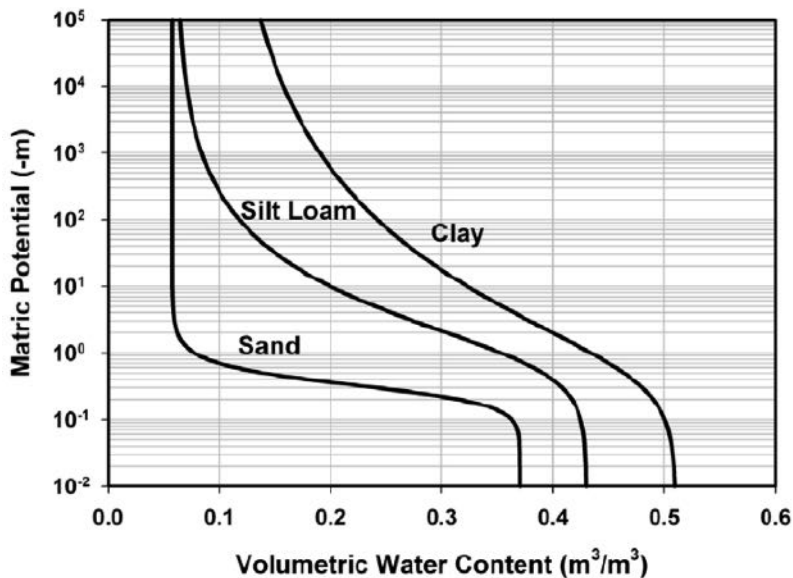


Tensiometers for characterizing drought screening trials:

Background: A tensiometer is an instrument that measures soil water potential using a water-filled tube with a porous cup at the end. The soil water potential reflects the energy with which water is held in the soil and can therefore be used to compare one soil type to another as an indicator of drought stress. The instrument is installed at a known depth in the soil. The tensiometer operates by developing a vacuum inside the tube as water moves out through the porous cup into drying soil. Most tensiometers provide readings through a gauge, although digital vacuum sensors and other datalogging soil water potential sensors are available.

The suction of the vacuum is measured as a negative pressure in kilopascals (kPa). As such, drier soils show lower (or more negative) soil water potentials. The porous cup must remain in close contact with the soil to function properly, and the tensiometer range is typically limited to values of less than 100 kPa. However, the accuracy is higher between 0 and 70 kPa. Therefore, crop systems in which severe drought stress is expected should install the tensiometers deeper to ensure continuity of measurements.

The needle on the gauge goes up as water moves out of the porous cup. This indicates more negative soil water potential.



The relationship between soil water potential (matric potential) and volumetric water content changes in different soil types. Source: Tuller and Or, 2003.

← Wet soil: water moves into cup
 → Dry soil: water moves out of cup

Methods

Tensiometer setup

Assembly: All threaded parts (the porous cup, gauge, and cap) can be wrapped with teflon tape to maintain a good seal, and the parts should be screwed on tightly. Be sure to keep the rubber O-rings in place. These steps help prevent leaks when a vacuum develops inside the tensiometer as the soil dries.

Tensiometers should be filled with either distilled water or rainwater, in order to prevent algae growth and clogging of the porous cup with salts. Because the filling hole is very small, it is difficult to pour water directly into it. A wash bottle can be used to fill the tensiometer quickly.

After assembling the tensiometers, saturate the porous cups by soaking them in a bucket filled with distilled water or rainwater overnight.

Tensiometers can be checked after soaking. Fill the tensiometers with water and hang them in the air overnight. The next day, there should be a reading (generally 30–50 kPa depending on the conditions). Having no water in the tensiometer tubes after hanging overnight indicates a leak, either at the joint of the porous cup or due to the cap not being tightly closed.

After soaking and while the tensiometer is still immersed in water, the screw on the front of the gauge can be adjusted to zero if needed.



Installing tensiometers in the field and taking measurements

The tensiometers should be installed so that the center of the porous cup is at the nominated depth below the soil surface. In rainfed lowland rice, we generally target a depth of 30 cm. As the porous cup is typically ~5 cm long, this means making a hole 32.5 cm deep for a tensiometer installed at 30 cm. The tensiometer tube can be marked to indicate where the tube should reach the soil surface.

Try to use tensiometers of similar length in an experiment, since the length of the tensiometer tube affects the readings.

Tensiometers can be installed early in the season, but in rice it is recommended to wait until the soil has dried enough that it is solid and can be walked on.

Use an auger or pipe that is a similar diameter to that of the tensiometer to make the appropriate-sized hole in the soil. A tight fit between the tensiometer and the soil will help maintain good contact.

If available, install at least one unit per replicate or per 100–200 m². It is better to install multiple tensiometers so that a defective tensiometer can be easily identified based on the readings from the others. It is preferable to install the tensiometers within planted plots rather than in the alley-way in order to obtain measurements that better reflect the growing environment.

Avoid damaging the plant shoots or roots when installing the tensiometer, and avoid making deep footprints near the tensiometer to maintain conditions representative of your experiment.

As the soil dries, the water level in the tensiometer will go down and it will be necessary to refill the tensiometer occasionally. If the tensiometer becomes empty, the gauge will show zero or unusually low readings even when the soil is dry. Always record the date of refilling for each tensiometer, when it rained, and when irrigation was applied. These notes will help explain sudden changes in readings.

After refilling, the tensiometer will need some time to re-equilibrate with the soil. It's normally good to wait overnight until resuming readings after refilling.



Use an auger or pipe that is similar diameter to the tensiometer

Maintenance of tensiometers

Since oils can clog the porous cup, it's good to minimize handling of the porous cup with a bare hand.

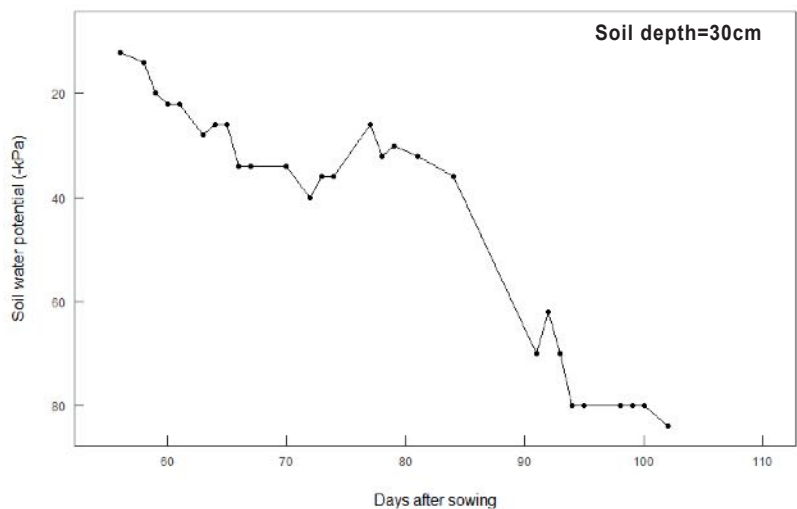
After the end of an experiment, the tensiometers can be pulled out of the soil. Clean the exterior thoroughly with water, soak the porous cups overnight to clean them, and air-dry the tensiometers before storing them.

Tensiometer data presentation

Zero readings: If the tensiometer reading is 0 due to wet soil, this measurement should be recorded. If there were no data on a certain day due to loss of all water from the tensiometer or another problem, this measurement should be noted as missing.

The drier the soil, the more prone the tensiometer measurements are to errors. If a particular reading is suspected to be erroneous, it can be removed. For example, if there are three tensiometers in an experiment with two tensiometers showing readings of -50 kPa and one showing a reading of 0, it is likely that there is a problem with the tensiometer reading 0 and this point can be removed. Likewise, if a tensiometer showing consistent readings over several days suddenly shows measurements close to zero with no obvious change in soil moisture status, the measurement can be removed and the instrument should be checked for potential problems.

Average tensiometer readings can be graphed over time in reference to days after sowing.



Common problems with using tensiometers

Problem	Possible solutions
Loss of contact between the porous cup and the soil due to cracking or soil shrinkage. This can be visually observed or suspected due to a sudden change in readings without obvious changes in soil moisture status.	If the soil is not too dry, it may be possible to resume function by changing the location of the tensiometer. However, augering a new hole is not likely to be successful in regaining tensiometer function once the soil becomes very dry and hard.
	Another strategy that can provide a temporary solution to loss of contact is to remove the tensiometer, add a soil slurry (mud or soil from the experimental field) to the hole, and put the tensiometer back in the same hole.
The needle appears to be stuck at 0.	Apply suction to the gauge stem to see if the needle is free to move.
	If the needle does not move, the screw on the face of the gauge may be too tight. It can be loosened with a screwdriver.
	If the needle does move and the soil appears to be drying, try checking for leaks. The gauge and tube cap can be re-wrapped with teflon tape, the O-rings can be checked, and the parts can be tightened.
	If the soil is not very dry, it might just take a few more days until more negative readings start to appear. This is especially the case as the tensiometer is installed at deeper depths. The soil surface can appear to be very dry while the soil at depth is still very wet.
Tensiometer readings are decreasing as the soil dries but not to the extent expected.	Check for leaks.
	Check for loss of contact with the soil.
	Older porous cups can be rejuvenated by acid wash: Fill the tensiometers with 0.1 N solution of HCl, put them in a bucket, and leave them overnight. Don't screw the cap on, and allow the acid solution to drain through the porous cup. Wash the tensiometers with distilled water by draining water through the cup into a bucket overnight.
Theft/damage	Individual parts of the tensiometer are available as replacement parts.
	Theft can be deterred by hiding the tensiometers in the planted plots. Shorter tensiometers don't stick up above the plant canopy as much as longer tensiometers do. A stake installed near the tensiometers can help the reader to quickly locate them.

Summary

- Environmental characterization is a key component to scaling up and comparing regional data, especially from drought screening trials
- Daily rainfall and soil moisture readings are recommended as minimum parameters to characterize drought screening trials
- Remember that all soil moisture readings must indicate the depth of measurement

References

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- Torres R, Henry A, Kumar A. 2012. Methodologies for managed drought stress experiments in the field. *In*: Shashidhar HE, Henry A, Hardy B, eds. *Methodologies for root drought studies in rice*. Los Baños (Philippines): International Rice Research Institute. 65 p. <http://irri.org/resources/publications/books/methodologies-for-root-drought-studies-in-rice>
- Tuller M and Or D. 2003. Water retention and characteristic curve. *In* book: *Encyclopedia of Soils in the Environment*, Publisher: Elsevier Ltd., Oxford, U.K., Editors: D. Hillel, pp.278-289

List of Suppliers

Instruments that have been used for characterizing drought screening trials are listed below. When purchasing equipment to be used in drought screening trials, it is always recommended to contact the supplier for a quote and any clarification about the specifications of the instrument. This is especially important for purchasing equipment that will be shipped internationally.

Rain gauges

Manually measured rain gauges:



Manually measured rain gauges are available from a range of suppliers, including the following:

<https://www.coleparmer.com/i/cole-parmer-clear-rain-gauges-0-to-25-2-cm/0331910>

<https://www.scientificsales.com/6331-Clear-View-Metric-Rain-Gauge-p/6331.htm>

<http://www.ictinternational.com/products/srg0/stainless-steel-rain-gauge/>

Tipping bucket rain gauges:

Since these rain gauges are operated with a datalogger, it is recommended to use them as part of a weather station package that can also monitor standard environmental parameters including temperature, relative humidity, and solar radiation. Please contact each supplier about its weather station packages.

These tipping bucket rain gauges offer the simplest setup:

<http://www.onsetcomp.com/products/sensors/s-rga-m002>

<https://www.davisnet.com/solution/vantage-pro2/>

This rain gauge has a more technical setup and involves datalogger programming but provides high-quality measurements:

<https://www.campbellsci.com/precipitation>





Soil augers

Augers for installing water table tubes and soil sampling for gravimetric soil moisture measurements:

This auger is recommended as a one-piece auger that functions well in a range of soil types:

One-piece Edelman auger

<https://www.ams-samplers.com/2-3-4-one-pc-edelman-auger-combination.html>

Auger for installing tensiometers:

These types of soil samplers remove soil cores, leaving a hole that is of similar size as the tensiometer. Please see the specifications or contact the supplier to match the length and diameter to your tensiometer.



<https://www.ams-samplers.com/7-8-x-21-soil-probe-w-handle.html>

<http://www.soilmoisture.com/ONE-PIECE-SOIL-SAMPLER-3-FT.-LENGTH-STAINLESS-STEEL/>

SSTAUGER (t-bar screw auger): www.soilspec.com.au

<http://www.ictinternational.com/products/0225/0225-lord-soil-sampler/?from=/products/soils/soil-augers-samplers/page/2/>



Water table depth sensor

PVC tubes are locally sourced. Although water table depth is typically measured manually, automated water level sensors are available, such as:

Water level data loggers

<http://www.onsetcomp.com/products/data-loggers/water-level>



Gravimetric and volumetric soil moisture measurements

Instruments for single-depth volumetric soil moisture measurements from the soil surface (when used in connection with a hand-held meter):

FieldScout TDR

<https://www.specmeters.com/soil-and-water/soil-moisture/fieldscout-tdr-meters/fieldscout-tdr-350-soil-moisture-meter-with-case/>



ThetaProbe Soil Moisture Sensor
<https://www.delta-t.co.uk/product/ml3/>



EC-5 Small Soil Moisture Sensor
<https://www.decagon.com/en/soils/volumetric-water-content-sensors/ec-5-lowest-cost-vwc/>



Instruments for multiple measurements with depth along the soil profile:

PR2 Soil Moisture Profile Probe
<https://www.delta-t.co.uk/product/pr2/>



MPkit-406
<http://www.ictinternational.com/products/mpkit-406/mpkit-406/?from=/products/soils/moisture-portable/>



Diviner 2000
<http://www.sentek.com.au/products/portable.asp>

Tensiometers for characterizing drought screening trials

Tensiometers:

Although many tensiometers are available, including from some local suppliers, note that some tensiometers are research-grade and others are targeted for producers/irrigation management. The following tensiometers have been used in drought screening trials:

2710L Standard Tensiometer Series

<http://www.soilmoisture.com/2710L-STANDARD-TENSIOMETER-SERIES/>
Model 2710ARL24-L 24", 1/2 BAR GAUGE is used in many rainfed rice screening trials.

A version of this tensiometer is also available with a refilling reservoir.



Irrrometer tensiometer

<http://www.irrometer.com/sensors.html#irro>



Soilspec Tensiometer

www.soilspec.com.au

This model uses only a water-filled tube and porous cup at each monitoring location. The tube is capped by a septum that is connected to a single gauge for each measurement (either a standard gauge or a computer gauge for datalogging)

