Chapter 2
In Situ Destructive Sampling

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2.1 The Concept of Representivity

When designing experiments, environmental scientists face the challenge of how to accurately represent nature. The idea of sampling patterns and strategies truly reflecting research variables is intrinsic to scientific pursuits. This is particularly true in environmental science due to the complex heterogeneity present in nature. It is vitally important in most studies for researchers to account for natural variations in soil, air, water, and vegetation that can change in space and time. Many strategies focus on the use of strategically placed transects or plot-based sampling campaigns designed to include as many aspects of a particular variable as possible within a study area. Determining how many samples must be taken, whether they are of soil, plant matter, water, etc., depends entirely on the balance of time, effort, and cost while in the field. As a rule of thumb, the more samples that can be gathered correctly, the more trustworthy eventual results will be. Unfortunately, environmental sampling can be time-consuming and expensive depending on its location or the procedures for its procurement. This is one of the reasons why the use of satellite-based remote sensing, computer modeling, and proximal sensing has gained popularity within the scientific community in recent decades. However, the heterogeneity and scale of the environment again make large spatial-scale research difficult and often require in situ validation campaigns to

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A. Wahbi et al., *Cosmic Ray Neutron Sensing: Estimation of Agricultural Crop Biomass Water Equivalent*, https://doi.org/10.1007/978-3-319-69539-6_2

ensure data quality. This is one of the main advantages of the use of the CRNS, due to the significant spatial and temporal variations soil moisture can exhibit.

2.2 Plant Sampling Pattern and Design

The calibration process for the CRNS technique has been extensively detailed and is a prime example of controlling for heterogeneity within agricultural environments [1–6]. The CRNS calibration function first proposed by Desilets et al. [1] is designed primarily around a sampling structure within the circular footprint of the instrument (circle of radius ~ 250 m). Specifically, 18 sampling sites are distributed on six transects located every 60° within the circle. Along each transect three sampling sites are located at 25, 75, and 200 m from the center point (usually where the CRNS is located; see Fig. 2.1).

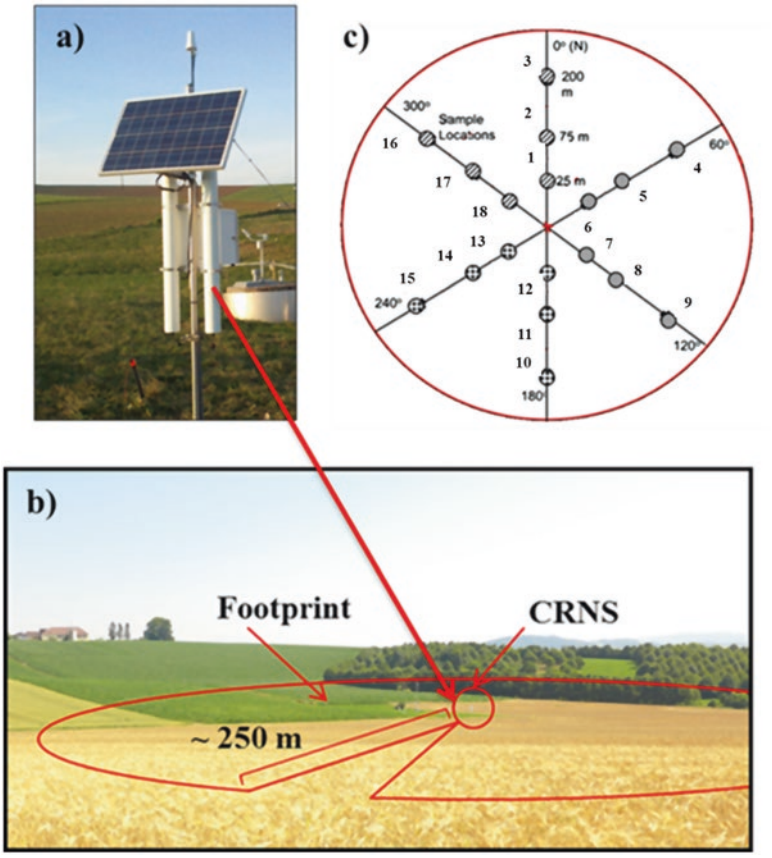

Fig. 2.1 Depiction of a stationary CRNS (**a**), its footprint on the landscape (**b**), and calibration sampling pattern (**c**)

2.2.1 *Sampling Instructions*

Along with soil samples, plant samples are taken at each of the 18 sampling sites. The following is a step by step guide for proper in situ destructive sampling:

Step One: Randomly select one to three individual plants (depending on crop size, large plants such as fully grown maize may be impractical to remove three individuals) spaced apart from each other, and pull them from the ground as to preserve as much root structure as possible.

Step Two: Shake any loose soil from the bottom of the plant so only the plant itself remains.

Step Three: Place the entire plant into a brown paper bag (or other containers) labeled appropriately (i.e., plants 1–3, point numbers 1–18; see Fig. 2.1); be careful to minimize folding or breaking of the plant cellular structure during removal and placement into the bag as to minimize any water loss.

Step Four: Fill back each hole left by the removed plants and repeat process at each of the 18 sampling locations collecting one to three plants at each site.

2.3 Biomass Water Equivalent

Fundamentally, the CRNS detects all environmental hydrogen within its footprint including hydrogen in soil moisture water molecules (see Fig. 2.2). As such, the primary component of crop biomass that introduces error to the CRNS signal is cellular water.

The term biomass water equivalent (BWE, mm of H_2O) is used in the CRNS calibration functions to describe the equivalent amount of water that would be required to introduce the same amount of water as a particular type of living crop biomass. It is defined as follows (Eq. 2.1) where *SWB* and *SDB* stand for standing wet and dry biomass, respectively, (kg/m^2) and f_{WE} = 0.494 which is the stoichiometric ratio of H_2O to organic carbon molecules in the plant (assuming this is mostly cellulose $C_6H_{10}O_5$) [4, 5]. Note: the units in the following equation are mass per unit area which is equivalent to a depth of water. During destructive sampling between one and three plants are removed. As such, an average plant density must be known to calculate into kg/m^2 or mm H_2O (i.e., by dividing by the density of water = 1000 kg/m^3 and multiplying by 1000 to convert m to mm). The plant density can be estimated by laying down a quadrat (i.e., a square of dimensions 50×50 cm, 1×1 m, etc. made of PVC) and counting the number of plants inside the encompassed area.

$$\mathrm{BWE}=SWB-SDB+SDB*f_{WE} \tag{2.1}$$

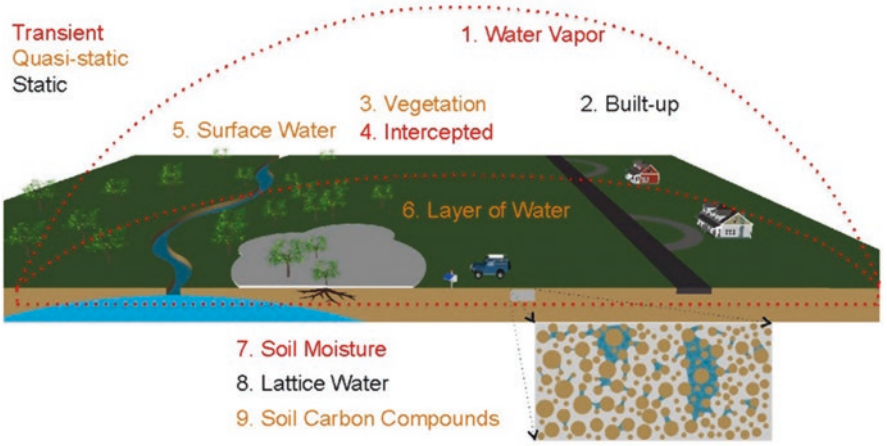

Fig. 2.2 Depiction of environmental hydrogen sources including those that change and do not change in time

2.3.1 Processing Instructions

After initial in situ collection, time becomes a highly relevant factor due to the water loss freshly harvested biomass samples experience immediately upon removal from the field. The following is a step by step guide on the proper weighing and oven-drying protocols for the determination of BWE:

Step One: Weigh biomass samples while they are still full of water as soon as possible from the time of their removal from the soil. This should be done with the plants in a container placed on the scale after zeroing. This can be difficult with fully grown maize plants but can be done if the plant is folded or cut within the container until it fits and then promptly weighed.

Step Two: Dry the plants in a standard convection drying oven at 70 ° C for 120 h (can check mass at 96 h and 120 h to make sure it is not changing by more than 1% between time intervals; otherwise, continue for an additional 24 h).

Step Three: Remove dried plants and weigh them once more.

2.4 Conclusions

The calibration process for the CRNS technique involves in situ sampling of biomass designed to quantify the hydrogen in its cellular structure and the water within. Traditional destructive biomass sampling is employed in a radial sampling pattern controlling for spatial variability of soil, water, and vegetation characteristics. This section provides detailed descriptions of biomass sampling procedures and the

determination of BWE. The main limitation of this form of sampling is its time-consuming nature and therefore is limited to a few fields at a time. This works well for stationary CRNS locations where the BWE must be calculated for one singular field but becomes difficult when mobile versions of the CRNS technique are employed in which the BWE must be determined for many fields (see Franz et al. (2015) and Avery et al. (2016) for more details on the mobile aspects of this technology [4, 5]).

References

1. Desilets D, Zreda M, Ferré TPA (2010) Nature's neutron sensor: land surface hydrology at an elusive scale with cosmic rays. Water Resour. Res. 46:W11505
2. Zreda M, Schuttleworth WJ, Zeng X, Zweck C, Desilets D, Franz T, Rosolem R (2012) COSMOS: the cosmic ray soil moisture observing system. Hydrol Earth Syst Sci 16:4079
3. Franz TE, Zreda M, Ferre PA, Rosolem R, Zweck C, Stillman S, Zeng X, Shutt WJ (2012) Measurement depth of the cosmic ray soil moisture probe affected by hydrogen from various sources. Water Resour Res 48:W08515
4. Franz TE, Wang T, Avery W, Finkenbiner C, Brocca L (2015) Combined analysis of soil moisture measurements from roving and fixed cosmic ray neutron probes for multiscale real-time monitoring. Geophys Res Lett 42:3389
5. Avery WA, Finkenbiner C, Franz TE, Wang T, Nguy-Robertson AL, Suyker A, Arkebauer T, Munoz-Arriola F (2016) Incorporation of globally available datasets into the roving cosmic ray neutron probe method for estimating field-scale soil water content. Hydrol Earth Syst Sci 20:3859
6. Franz TE, Wahbi A, Vreugdehil M, Weltin G, Heng L, Oismueller M, Strauss P, Dercon G, Desilets D (2016) Using cosmic ray neutron probes to monitor landscape scale soil water content in mixed land use agricultural ecosystems. Appl Environ Soil Sci 2016:11