


# Chapter 10

## A Non-Invasive Revolution in Soil and Root Water Content Monitoring by Integrating Deep Learning and GPR

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### ABSTRACT

*This chapter introduces a technique that combines simulations using Ground Penetrating Radar (GPR), advanced processing of signals and deep learning to determine water content in plant roots as well as nearby soil. Using dielectric mixing models, computer programs were used to create synthetic radargrams of root-soil interactions under various moisture levels. Radargrams were improved by using methods such as Singular Value Decomposition and Inverse Amplitude Decay. Convolutional Neural Networks (CNNs), including InceptionV3, MobileNetV2 and ResNet50V2, were adapted for using in classifying both root and soil water content. InceptionV3 got the top results among tested models for estimating plant*

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*roots. For easier soil moisture classification, MobileNetV2 was able to run quickly and efficiently. ResNet50V2 managed to perform with similar accuracy and level of stability for both types of tasks.*

## **INTRODUCTION**

Water supply and management for agriculture are essential for maintaining food security, ecosystem service sustainability, and economic stability. It is becoming more critical that accurate tools for the determination of soil and root zone water become available due to climate change with the lengthening and increasing intensification of drought, together with changing patterns in rainfall. Global freshwater scarcity is projected to intensify, with agriculture accounting for nearly 70% of withdrawals, making efficient water management increasingly urgent (Ingrao et al., 2023). The ability to accurately monitor subsurface moisture is a critical component of the ability to drive irrigation optimization, improve water use efficiency, and maintain crop health in water limited or inefficiently distributed areas around the world, particularly arid and semi-arid regions. Moreover, agricultural policies and water management regulations in many countries now mandate precision irrigation practices, creating added pressure to adopt reliable soil moisture monitoring technologies.

One of the central difficulties is to estimate the water content in the root zone, controlling plant water uptake and thus determining growth and yield. Common approaches, which include soil sampling and point sensors, are often not spatially resolved, disturb the soil-root interface and only offer localized information. Such limitations highlight the need for non-intrusive, scalable methods that can provide spatially distributed and time-lapsed information on soil moisture.

Ground Penetrating Radar (GPR) poses as a promising geophysical tool for this task, working by taking advantage of the differences in the dielectric properties between soil and roots, affected by water content, allowing subsurface structures to be unveiled. Nonetheless, GPR data interpretation is challenging due to signal noise, heterogeneous soil, and environmental variability. While signal processing methodologies such as SVD, IAD and, more recently, deep learning methods (such as CNNs) have been investigated to identify informative characteristics in radar-gram data, a lack of labeled data, model generalizability issues, and the need for explainability continue to hinder practical deployment.

To address these critical limitations and advance the field beyond current capabilities, this chapter introduces a novel and comprehensive framework that integrates three key innovations: (1) extensive synthetic GPR data generation using electromagnetic modeling to overcome data scarcity, (2) sophisticated signal processing combining Singular Value Decomposition (SVD) and Inverse Amplitude

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