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# RGB-BASED SOIL WATER CONTENT PREDICTION ENHANCED BY HYPERSPECTRAL CALIBRATION

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## ABSTRACT

While hyperspectral imaging (HSI) cameras demonstrate high accuracy for detecting soil water content (SWC)-related spectral variations, their field deployment remains constrained by prohibitive costs and operational complexity. This study investigates utilizing low-cost RGB cameras through HSI-guided calibration for SWC estimation. 210 paired HSI-RGB measurements were acquired across five soil texture classes (0-40% fine particles), fourteen moisture levels (0-39% SWC), and three illumination conditions (halogen, LED, mixed). Excluding saturated conditions (SWC>22%) and erroneous measurements, 122 samples were retained for analysis. The RGB model incorporates illumination-invariant features, HSI-supervised teacher networks utilizing spectral indices (NDWI970, continuum depth at 970 nm, VIS/NIR slopes), dual domain-adversarial networks for lighting and texture invariance, and self-supervised chromaticity learning. Spectral sensitivity analysis (Δreflectance/Δmoisture) revealed illumination-dependent channel rankings: halogen and mixed illumination exhibited |Red|>|Green|>|Blue| sensitivity with pronounced NIR response, whereas LED illumination demonstrated |Green|>|Red|>|Blue| sensitivity with negligible response, consistent with limited LED emission in the NIR range. Experimental results achieved low single-digit percentage-point errors with improved explained variance relative to baselines. Optimal performance (~2% error) was observed under halogen and mixed illumination, while LED conditions yielded elevated errors. Cross-illumination validation showed generalization for halogen and mixed conditions with moderate LED performance. Cross-texture evaluation maintained accuracy irrespective of composition. These findings establish the viability of RGB-based systems for cost-effective soil water content estimation in precision agriculture applications, supported by HSI-RGB integration framework and calibration.

**Keywords:** Soil Water Content, RGB Camera, Hyperspectral Imaging, Color Correction, Precision Agriculture.

## INTRODUCTION

Soil water content (SWC) is a key variable for irrigation management and yield optimization. While HSI can capture SWC-sensitive absorption features, it is costly and complex for field use. RGB cameras are inexpensive and portable but susceptible to lighting and texture variations. This study quantifies how far RGB can go toward HSI-grade SWC estimation using a controlled HSI–RGB paired dataset and a learning framework for illumination robustness. We evaluate RGB-only SWC prediction under multiple illuminations and textures, benchmark against settings, and identify approaches to close the gap to HSI.

## MATERIALS AND METHODS

### Dataset and Preprocessing

Five textures (0,10,20,30,40% fines) × fourteen SWC levels (0–39%, step 3%) × three lights (halogen 3200 K, LED 5600 K, mixed 4400 K) yielded 210 paired HSI–RGB samples. We filtered to SWC≤22%. Final N=132 with per-light counts 44/44/44 (halogen/LED/mixed).

### Model Architecture and Features

HSI-derived teacher targets were NDWI970, continuum depth at 970 nm, and mean spectral slopes (VIS/NIR). Model: a shared MLP encoder feeds (i) an SWC regressor, (ii) a teacher head for HSI targets, (iii) two domain heads (lighting, texture) via a gradient reversal layer, and (iv) a self-supervised head to recover r/g/b chromaticity.

## RESULTS & DISCUSSION

In the Random 80/20 the model attained an error around ~2%, indicating single-digit percentage-point performance without relying on calibration. Holdout illumination tests, halogen and mixed conditions exhibited small errors, whereas LED remained higher, consistent with the illumination-dependent sensitivity in HSI (strong Red/NIR under halogen/mixed; Green-centric with negligible NIR under LED). To consolidate robustness for field deployment, we will emphasize illumination-aware relight augmentation and teacher-target standardization, with imbalance-aware weighting across lighting–texture strata. Addition, we plan to extend the analysis to incorporate organic matter and key chemical properties, and to validate a practical calibration protocol using reference tiles and routine recalibration so that the RGB pipeline remains reliable under operational variability.

## CONCLUSIONS

For SWC≤22%, the RGB-only approach with illumination-invariant features and domain-adversarial training achieved low single-digit errors, with ~2% under favorable illumination, and is well-positioned for field use as chemical factors are incorporated.

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