Potential for improving African smallholder cereal farming using Sentinel-2A spectral reflectance

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A paper from the Proceedings of the
16th International Conference on Precision Agriculture
21-24 July 2024
Manhattan, Kansas, United States

Abstract.

Cereal crops are critical for African smallholder farmers to improve regional food availability, yet many struggle with low productivity from non-optimal practices. This study evaluated the possibility of using Sentinel-2 MSI data to guide improved management techniques for African small-scale cereal systems. Maize, wheat, and rice plots were established in Togo, Tunisia, and Tanzania, respectively during 2021-2023 using improved varieties, planting, fertilization, and irrigation practices versus standard farmer practices. Spectral signatures were collected during the growing seasons from preprocessed 10-band Sentinel-2 MSI data for each plot, leveraging Python coding and ArcGIS Pro through the Digital Earth Africa Analysis Sandbox tool. Vegetation reflectance values were analyzed over crop growth cycles for spectral signatures of each cereal. The goal was to assess satellite remote sensing's potential for measuring variability and changes within 1-hectare plots, under different practices. Spectral reflectance curves highlighted distinct crop differences and consistent dissimilarities between practices, especially in the red-edge and near-infrared wavelengths. Comparing average rice plot reflectance, considerable differences occurred between practices in the near-infrared region. Similar patterns appeared for maize and wheat, with the improved treatments exhibiting higher near-infrared reflectance suggesting healthier, denser vegetation versus standard practices. Findings indicate that Sentinel-2 MSI spectral measurements could detect cereal crop variability between improved practices and standard smallholder farm management methods. However, analyzing spectral signatures through crop growth stages, combined with assessing detailed management practices, could provide a better understanding of the cereal crop reflectance responses.

Keywords. *Cereal Crops, Smallholder, Sentinel-2A, Spectral reflectance curve, Remote sensing, Precision agriculture.*

Introduction

Remote sensing from satellites and other aerial systems to collect reflectance measurements from crop canopies can provide insights into important agronomic parameters like leaf area, crop health, and yield. (Lobos et al., 2019). When the leaf receives radiation from the sun, part is transmitted to lower leaf layers, part is absorbed by the chlorophylls and other pigments, and the rest is reflected; the reflectance is, therefore, the ratio of the reflected and incident radiation.

The spectral reflectance profile is a graphical representation of the reflectance for each wavelength at specific bands and is closely associated with the absorption of certain wavelengths linked to specific characteristics or plant conditions (Garbulsky et al., 2011).

Plant spectral reflectance can thus be used for characterizing the effects of abiotic and biotic stresses (Garriga et al., 2014). For instance, in a healthy leaf, chlorophyll pigments absorb in the blue (400–500 nm) and red (600–700 nm) range, generating a higher reflection in the green wavelengths (500–600 nm); carotene also has a strong absorbance in the blue range. Most of the past research has concentrated on the measurement in the visible (VIS; ~400–770 nm) and near-infrared (NIR; ~770–1300 nm) spectrum, although new studies are also covering the UV (~300–400 nm) and the short wavelength infrared 1 (SWIR1; ~1300–1900 nm) and 2 (SWIR2; ~1900–2500 nm) (Hernandez et al., 2015).

Objectives

The goal of this study was to use spectral reflectance curves obtained from Sentinel-2 multispectral data to assess patterns of variability and practice differences in African smallholder cereal production on farms smaller than 2 ha.

Procedure

Forty-two African smallholder cereal farms producing maize, wheat, and rice were monitored respectively in Togo, Tunisia, and Tanzania. Two treatments were established on all farms with one-half of each farm managed using improved practices (IMP) and the other half being managed by farmers under their traditional practices (FP). Measurements collected during the growing seasons from 2021 to 2023 included yield and spectral reflectance values from Sentinel-2 MSI data.

Summary of Results

Analysis of Sentinel-2 MSI signatures across different treatments and cereal crops facilitated a comprehensive physiological profiling underlying the observed productivity differentials (Figure 1Figure 1). Notably, the divergence in rice reflectance was most prominent in the red-edge and near-infrared plateau from 703.9 to 864.8 nm, indicating disparities in canopy density and leaf area between management approaches, consistent with established remote sensing principles (Segarra et al., 2020). This reaffirms the superior vigor of improved rice cultivation, as evidenced by the heightened green peak around 560 nm. In the case of Tunisian wheat (Figure 2), a distinction over all ten bands is observed with IMP having higher reflectance values. That suggests potential delays in growth stages or intermittent stressors associated with conventional farmer practices (Segarra et al., 2020). Differences between maize plot reflectance curves (Figure 3) from Togo were like those for rice in Tanzania (Figure 4), with higher reflectance in the red band (664.5 nm) for FP crops compared to IMP crops.

In summary, our findings demonstrate the potential of remote sensing technologies to help understand agricultural practices, guide enhanced productivity, and foster sustainability in smallholder cereal farming systems. Through continued research and technological advancements, we can harness the full potential of satellite spectral data for precision agriculture and informed decision-making in agricultural management.

Acknowledgments

This study was funded by the African Plant Nutrition Institute (APNI).

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Annexes

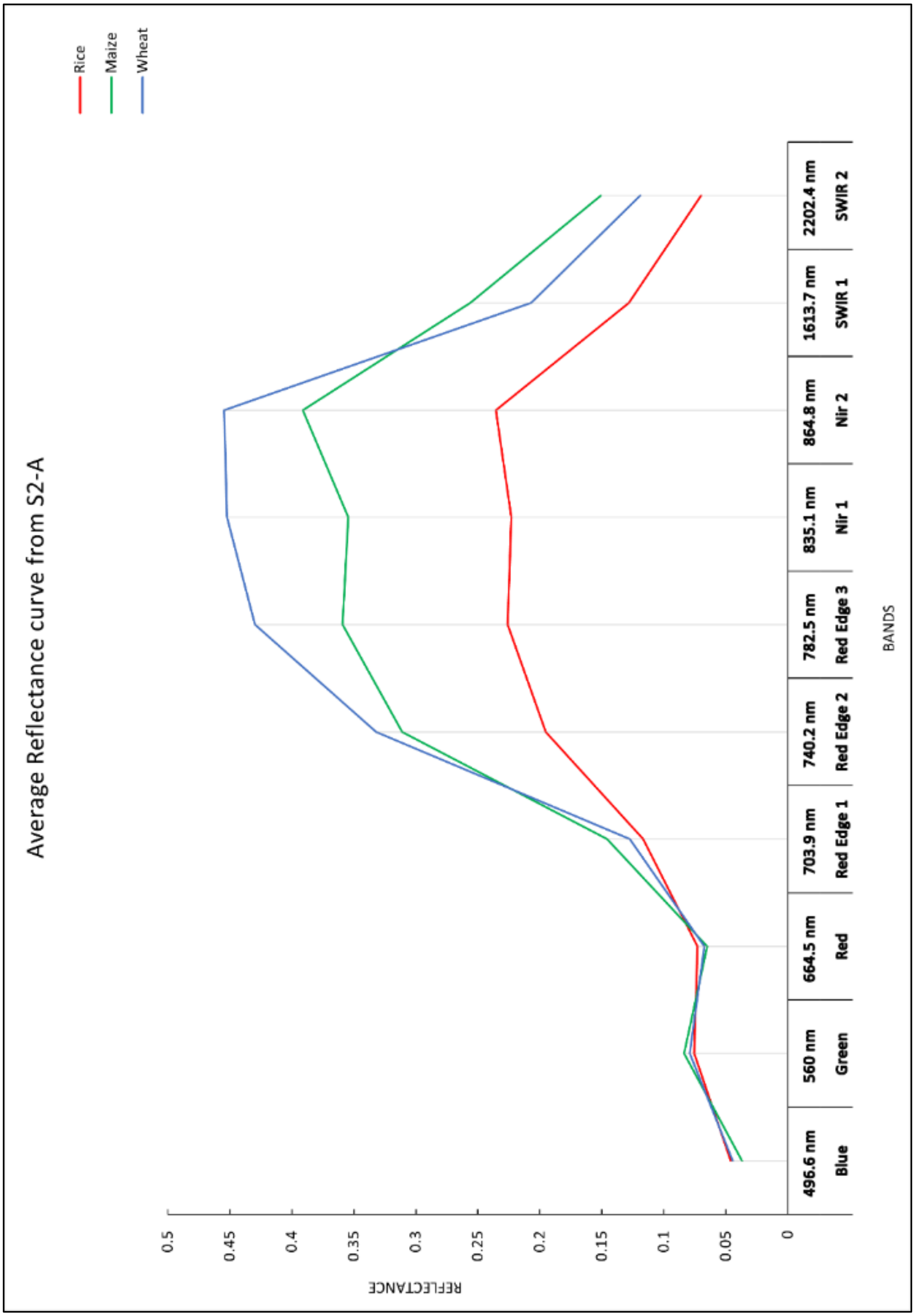

Figure 1 Average reflectance profiles of Maize, Rice, and Wheat

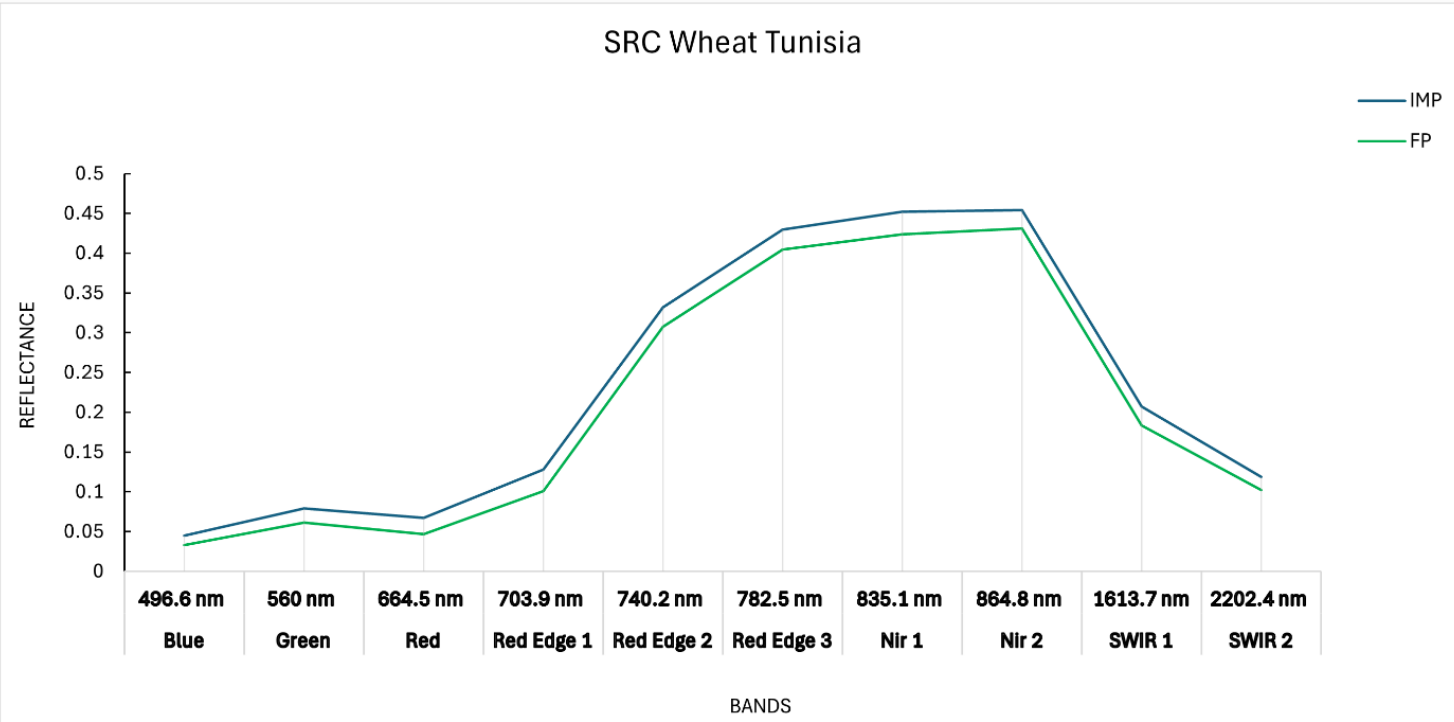

Figure 2 IMP VS FP in Tunisia

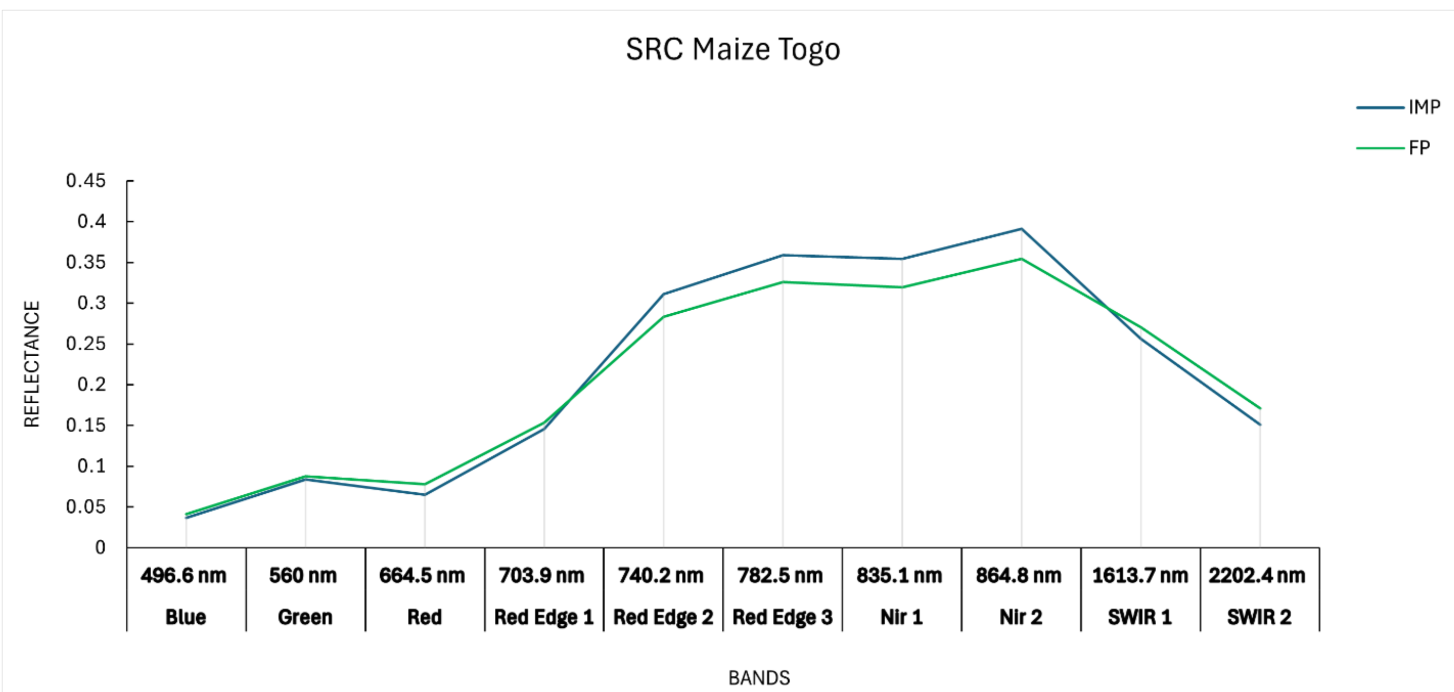

Figure 3 IMP VS FP in Togo

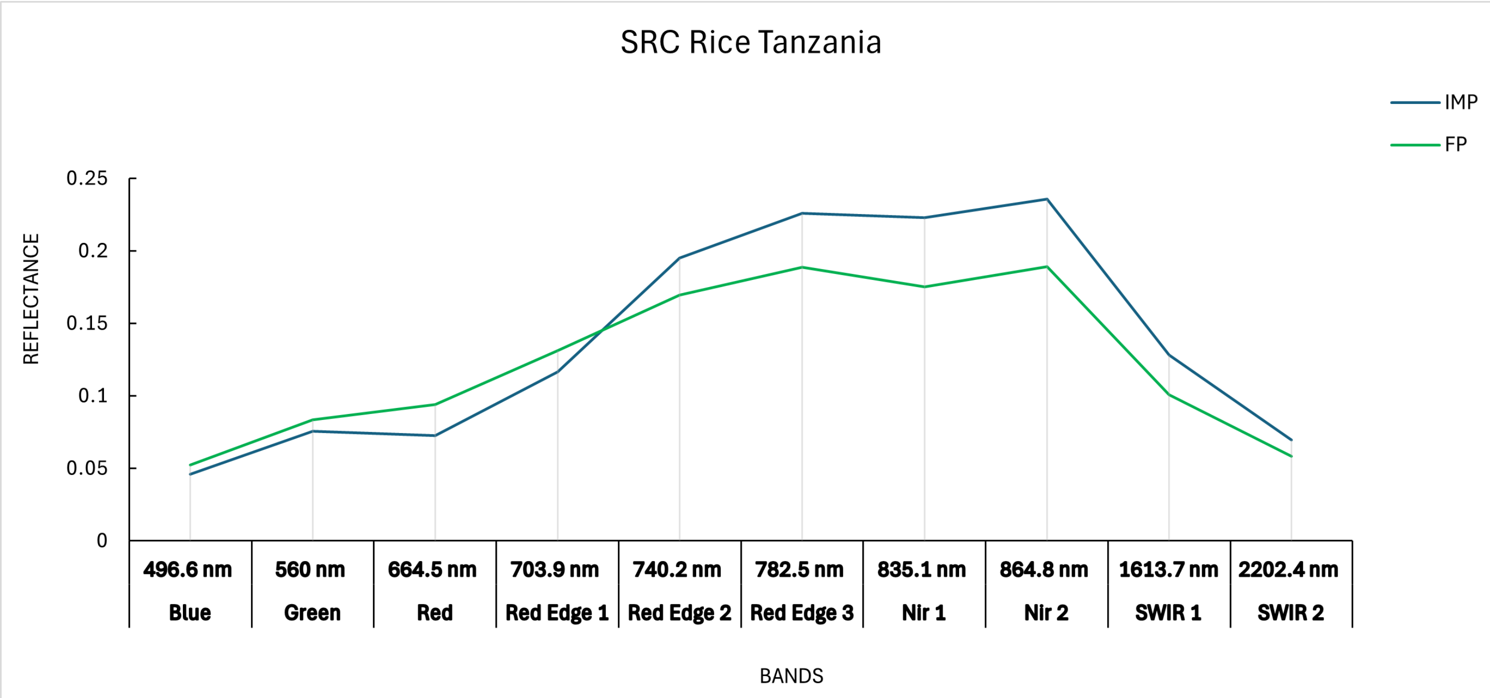

Figure 4 IMP VS FP in Tanzania