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TAKING THE PULSE OF OUR PLANET FROM SPACE

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Mapping surface conditions for crop residue assessment using PRISMA satellite imaging spectroscopy

Monica Pepe[1]; Loredana Pompilio[1], Luigi Ranghetti[1,2], Ramin Heidarian Dehkordi[1], Beniamino Gioli[3] and **Mirco Boschetti[1]**

1 National Research Council of Italy, Institute for Electromagnetic Sensing of the Environment, CNR-IREA, Italy;
2 IBF Servizi S.p.A., Italy;
3 National Research Council of Italy, Institute for Bioeconomy, CNR-IBE, Italy

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Background and motivation

Non-photosynthetic vegetation (NPV) is defined as vegetation that cannot convert solar energy into chemical energy (Asner, 1998) and it is **composed by plant litter, standing dead or dying vegetation (SDV)** and **crop residues (CR)**.

SDV & CR play a strategic role in the frameworks of sustainable agriculture (Hank, 2019) and more recently of carbon farming (Smith et al. 2020).

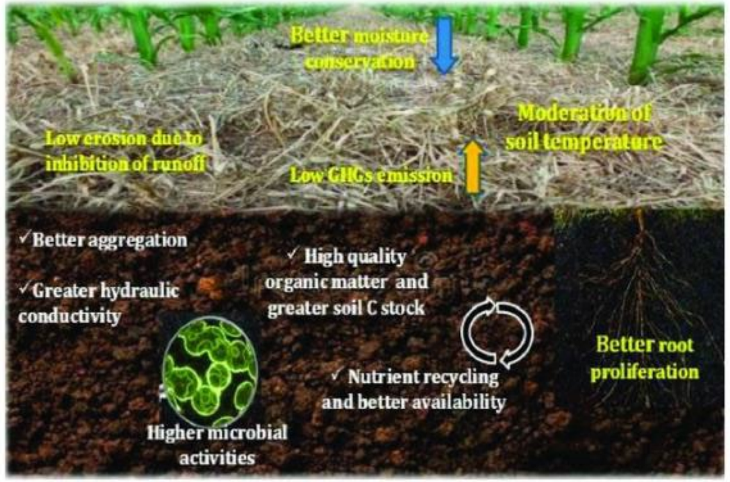
This importance is overall connected to their **role in the cycling of carbon**, **nutrients and water**, and in particular in conservation of soil.

Retention of CR on the fields provides

- **protection against erosion of wind and water** (Arsenault & Bonn, 2005), **controls temperature and moisture** evaporation,
- maintains **high levels of soil organic carbon** (Lal et al., 1999, Haddaway et al. 2017),
- **reduces soil compaction** due to agricultural machinery and improves the soil structure.

vegetation at late mature growth stages

plant senescent material left after harvesting (Daughtry et al., 2004),



Sustainability 2020(12):9808 DOI: 10.3390/su12239808

Background and motivation

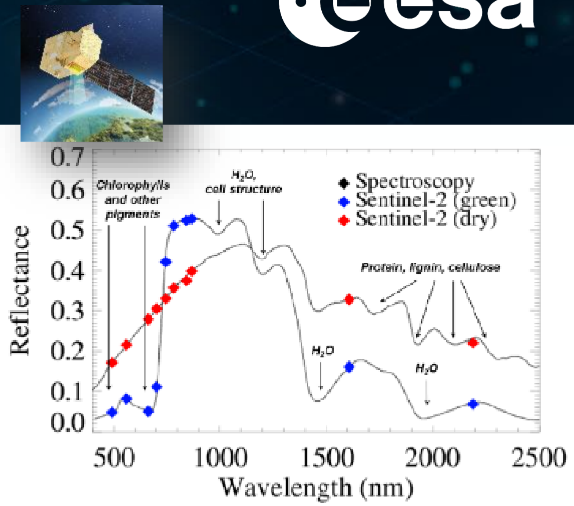
By means of **mapping presence and abundance of NPV**, remote sensing could contribute to monitor/control the implementation and rate of conservation practices in agriculture (European Commission, 2018), providing also information for eco-system services → **NPV become a priority variable in the design of satellite missions** (Hank, 2019, Berger, 2021; Hively et al., 2021).

PRISMA proved **suitable for distinguishing NPV from green vegetation (GV) and bare soil (BS)** and promising for quantification based on **absorption peaks of ligno-cellulose** (Pepe et al. 2020)

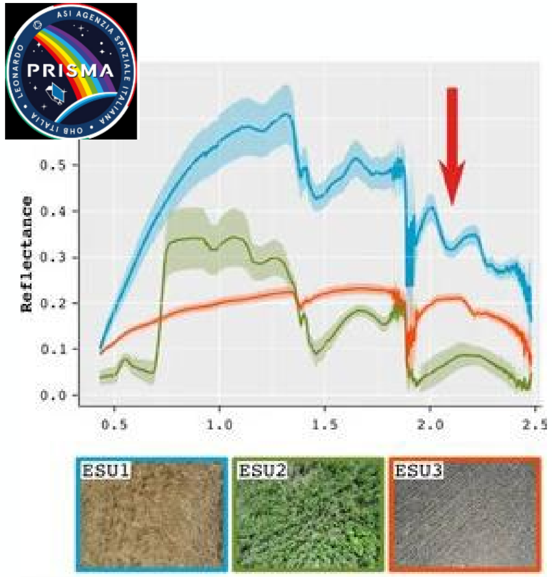
To obtain **accurate evaluation of NPV (presence and quantification)** it is important the knowledge of land use and **surface conditions changes as related to the timing of tillage or planting** (Daughtry et al. 2005; Zheng et al. 2012; Berger et al. 2022)

Map such **surface conditions related to NPV** is **important**:

- it is **the first step before quantitively estimate** NPV
- **identification of dynamics** are valuable information **for monitoring conservation practices**



ESA CHIME MRD (2021)



NPV spectral features from PRISMA (Pepe et al. 2021)

Study objective & test site 1/2

Objective: Mapping **surface conditions related to NPV** exploiting spectroscopic features from spaceborne hyperspectral data and machine learning algorithm.

Rationale: 1) use of **physical based analysis** of spectra according to target properties to **define enhanced diagnostic features** and 2) **ML** to define a **mapping paradigm** flexible and transferable in time and space

Surface condition classes:

Bare soil **BS**


Emerging vegetation **EV**


Green vegetaion **GV**

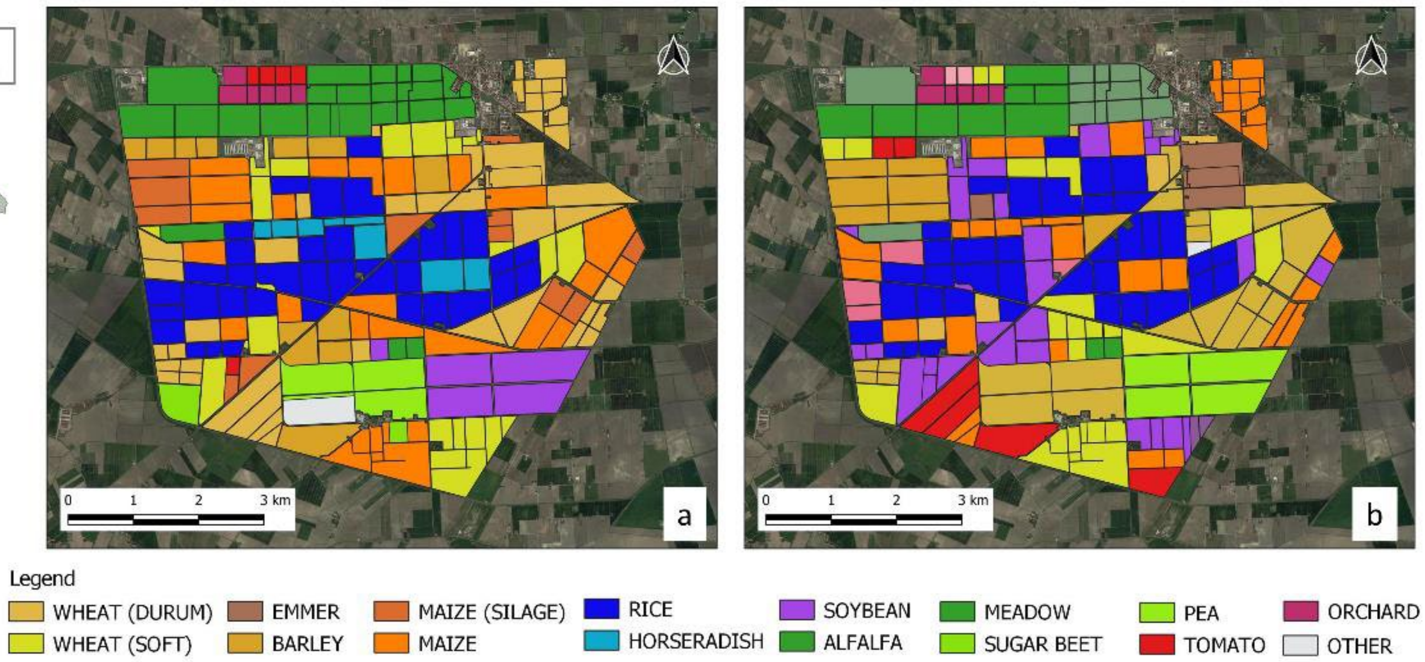

Standing dead vegetation **SDV**

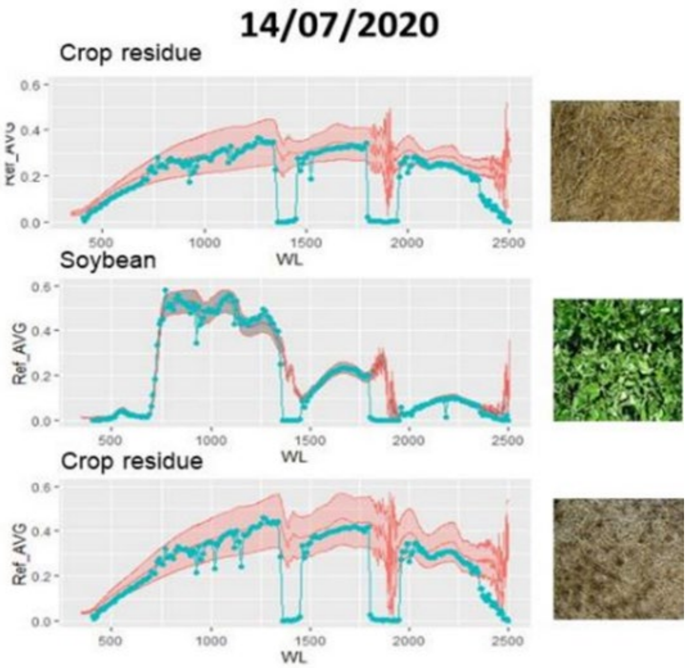

Crop residue **CR**


Mixed condition




Study objective & test site 2/2





- Bonifiche Ferraresi S.p.A. farm is located in the Po Plain (Emilia-Romagna; 44°53′N; 11°59′E)
- The estate is ~ 3800 ha wide with a diversified crop production and rotation from year to year
- The area is a **CAL/VAL site of ASI-CNR PRISCAV project** and it is regularly acquired by **PRISMA background mission**. Other research activities have been conducted in the framework of **ESA CHIME-RCS study** in 2020 and 2021 and **AVIRIS-NG Europe Campaigns**

Materials and method

Data

EO data: PRISMA L2D products

- 6 images per crop season from April to September for the 2020 – 2021 (12 in total)
- hyperspectral cube of i) 231 narrowbands from 400 to 2500 nm ~ 10 nm spectral resolution, ii) ground sampling distance (GSD) of 30 m

Ground truth and ancillary information:

- Observation on crop/field status (phenology, target conditions) @ PRISMA overpass
- Farm information on agricultural practices, types and dates (e.g. sowing, harvesting, soil preparation, etc.),

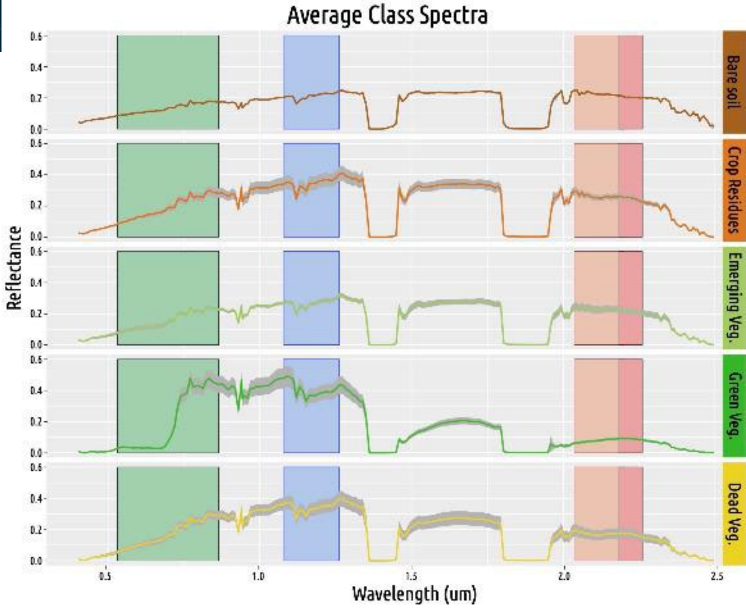
Processing

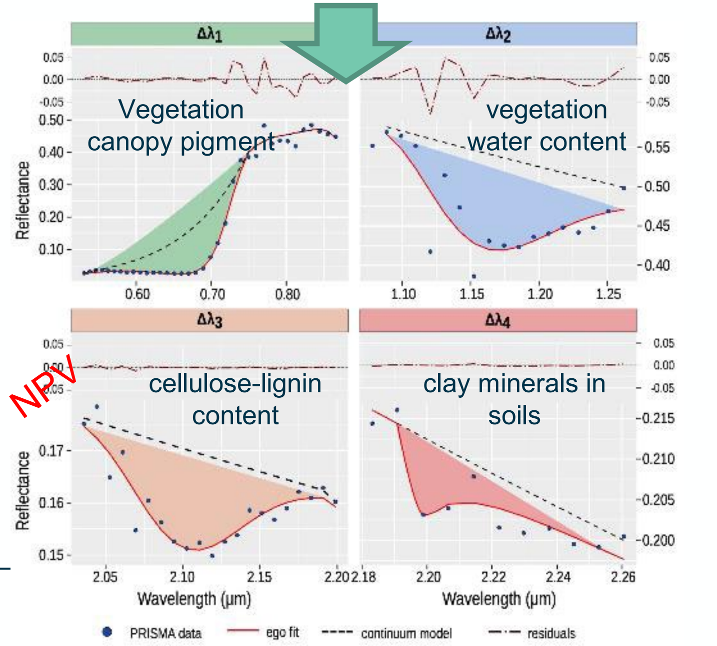
Spectroscopic modelling to derive input features:

- **Exponential Gaussian Optimization** (EGO) modelling of **4 known diagnostic intervals** ($\Delta\lambda 1 - \Delta\lambda 4$) to derive **4 spectral parameters** (band center **xc**, width **w**, depth **s** and asymmetry **k**)
- **Creation of a reduced feature space of 16 input** (4 regions x 4 parameters) for image classification

Mapping approach:

- **ML** → Decision Tree (R rpart package) → efficient and transparent to interpret decision rules
- **Input** → EGO Spectroscopic features computed from random selection of PRISMA spectra from ground truth information at field level for **BS**, **EV**, **GV**, **SDV**, **CR** (24/04 and 21/06/21 image)
  - Training 150 pixels sample per class (tot 750)
  - Testing 300 pixels sample per class (tot 1500)





Results: descriptive statistics

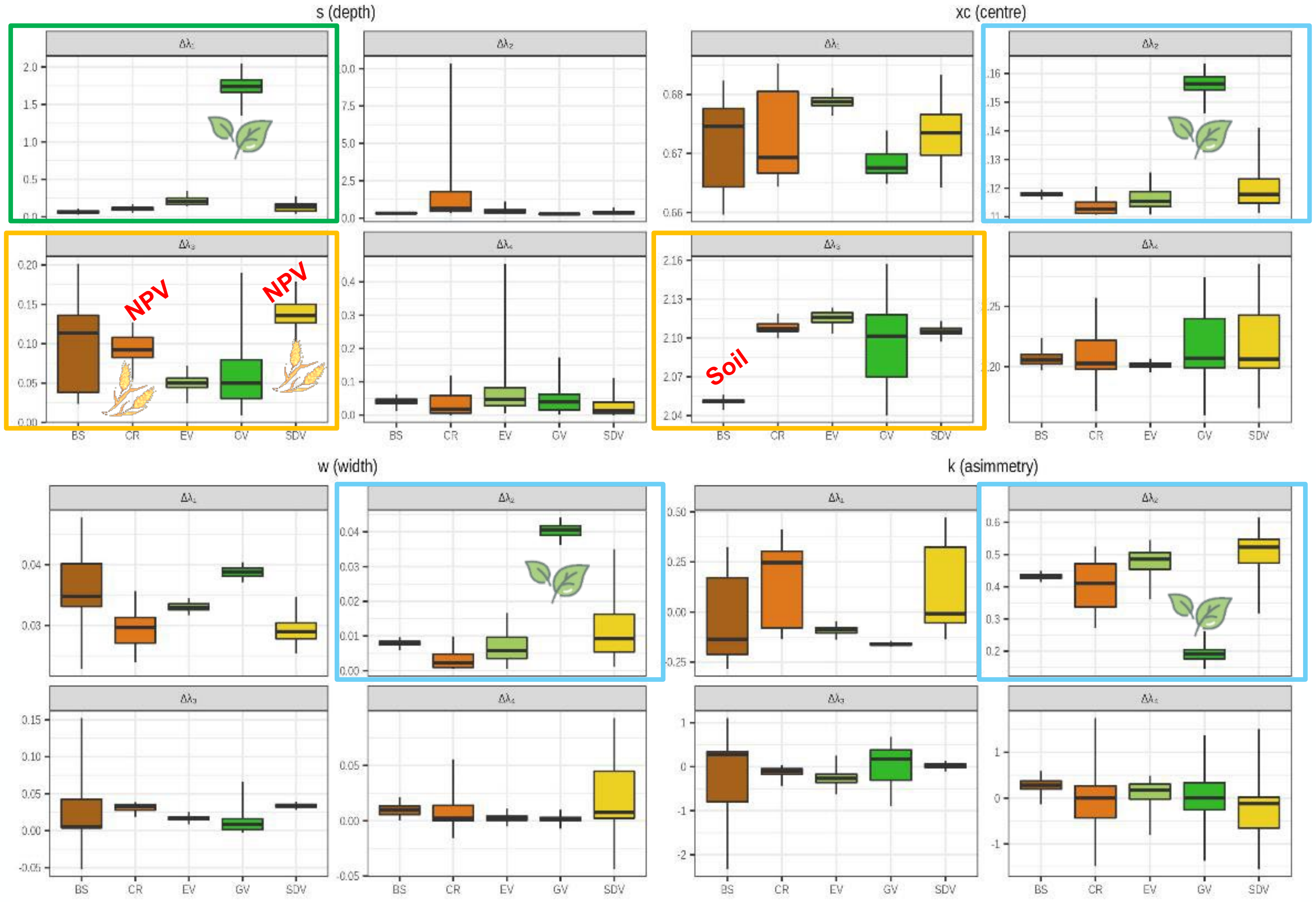
Diagnostic features analysis

$\Delta\lambda_1$ (canopy pigments' absorption) **band depth (*s*)** significantly diagnostic vegetation (**GV** and **EV**).

$\Delta\lambda_2$ (canopy water absorption) in green vegetation **band center (*xc*)** @ 1160 nm, largest **band width (*w*)**, less skewed **band asymmetry (*k*)**

$\Delta\lambda_3$ (cellulose-lignin absorption peak) **band depth (*s*)** and **width (*w*)** show generally higher values for **SDV** and **CR**. **BC center position (xc)** is shifted.

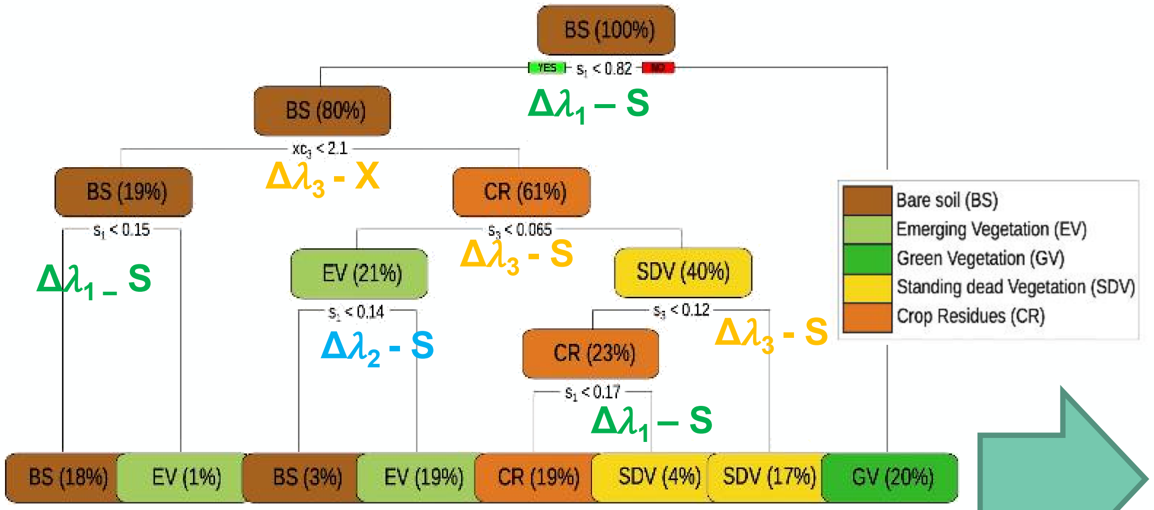
$\Delta\lambda_4$ (clay minerals absorption) analysis does not provide evidences of any diagnostic features for the considered classes *'**



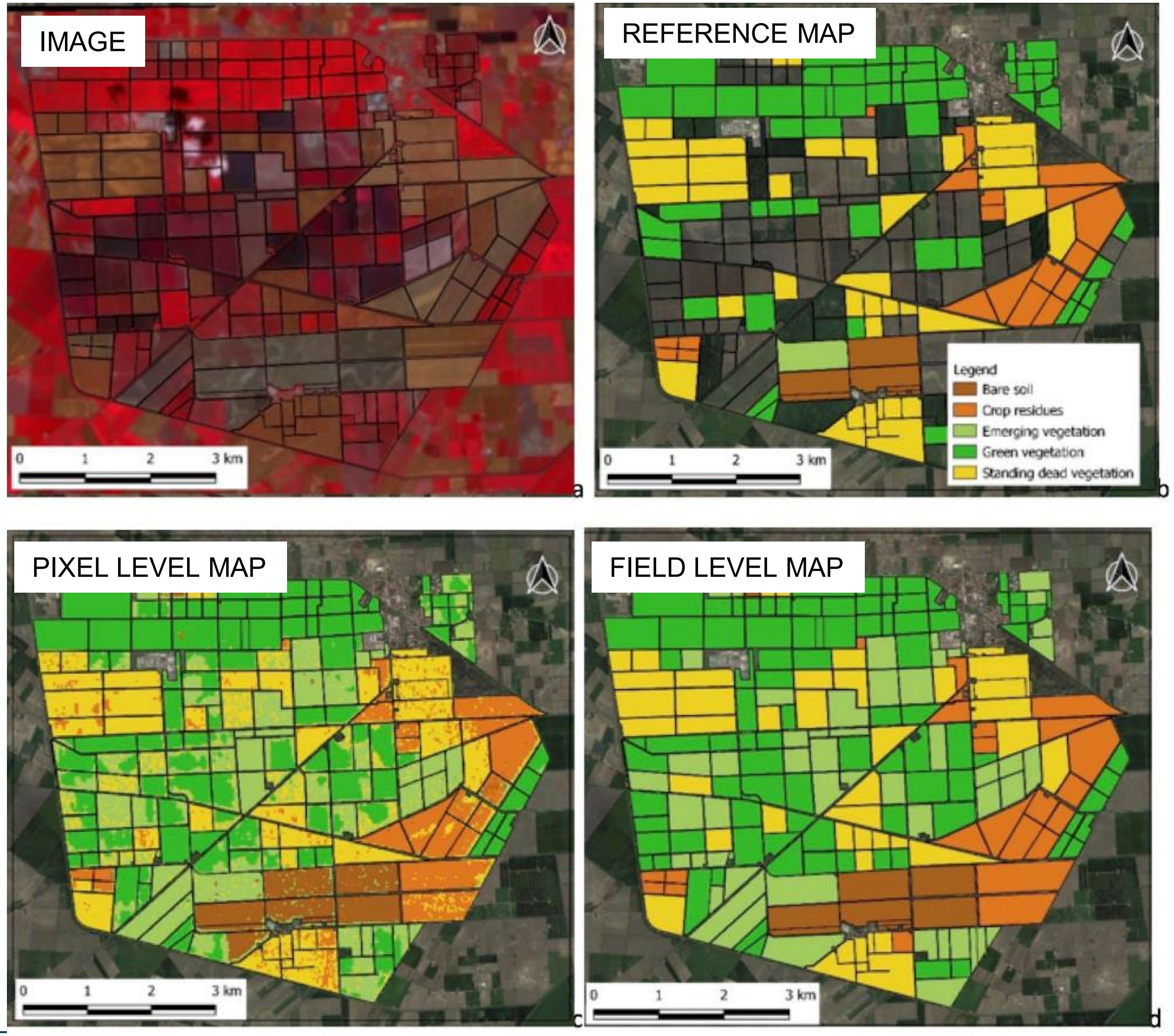
*considered interval is quite narrow ; **known drop in radiance in this part of the SWIR PRISMA signal (Cogliati et al., 2021)

Results: mapping accuracy

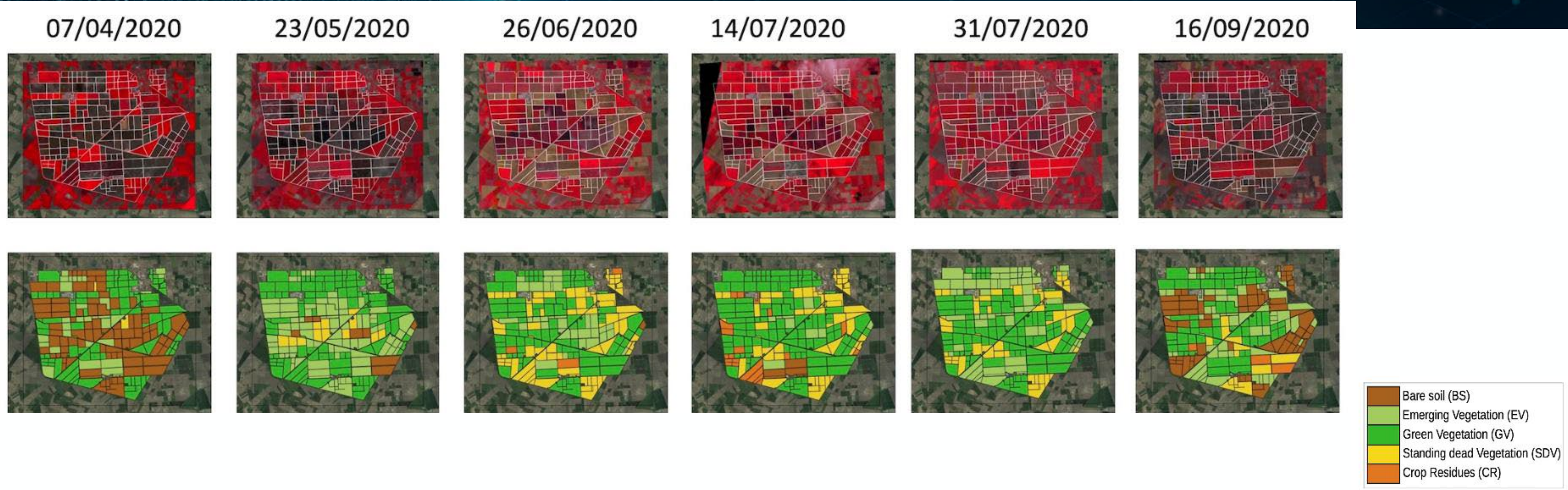
Decision Tree and accuracy



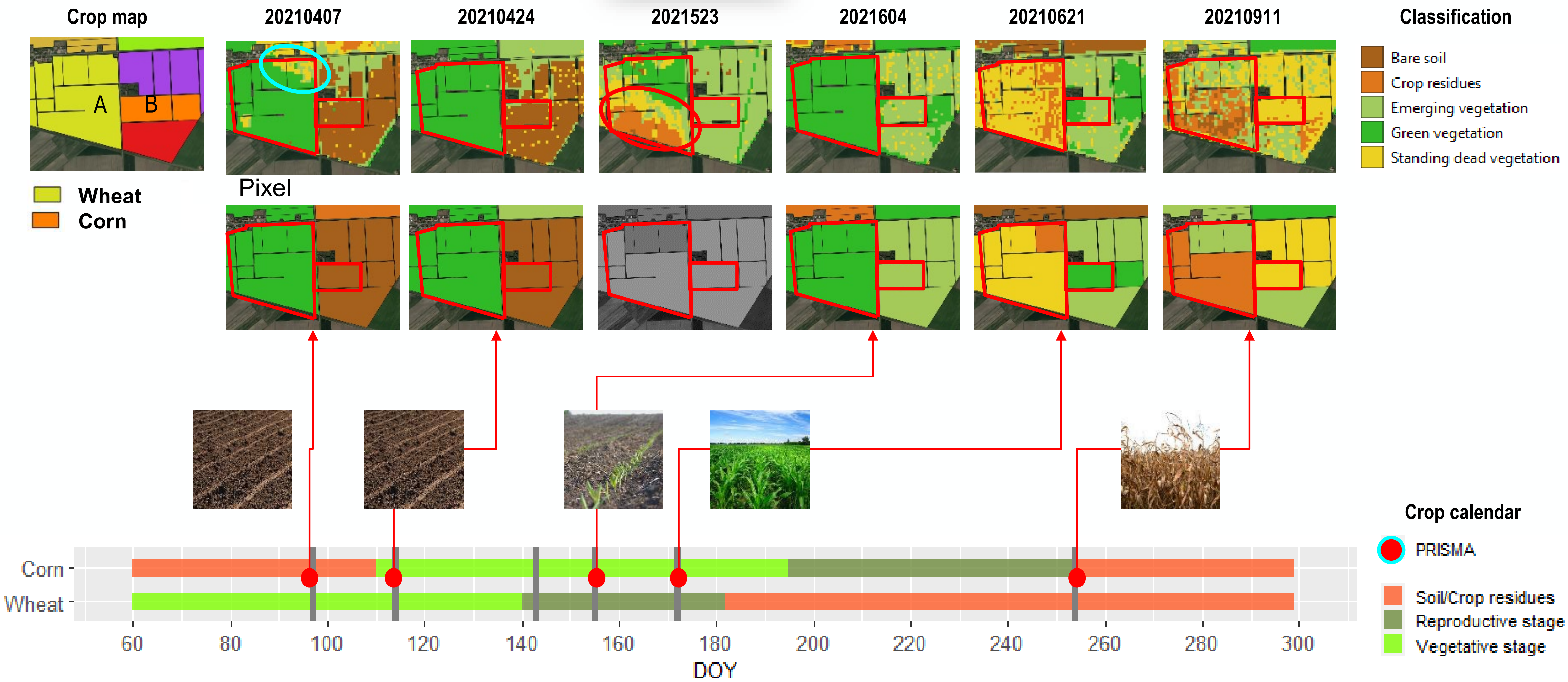
		Reference				
		BS	CR	EV	GV	DVS
Prediction	BS	269	3	6	0	0
	CR	0	273	1	0	28
	EV	11	2	277	0	2
	GV	0	0	0	298	0
	DVS	2	21	16	0	270
Sensitivity		0.9539	0.913	0.9233	1	0.9
Specificity		0.9925	0.9754	0.9873	1	0.9669
Overall Acc.	0.9378					
K coeff.	0.9222					



Results: mapping generation



Results: information conte ysis



Conclusion

Test of a **two-steps classification approach** for **mapping crop conditions as related to NPV** and soil conservation practices from **spaceborne imaging spectroscopy PRISMA data**.

1) **EGO modelling** applied to four diagnostic spectral intervals → hyperspectral space reduced features

2) **Decision Tree** trained at pixel level →decision rules for the classification –> **BS**, **EV**, **GV**, **SDV**, **CR**

DT is successfully (OA and K > 0.9) **applied on a PRISMA hyperspectral image time series** on the test site **field condition maps at parcel level** over the two crop seasons (2020 -2021)

Analysis of trajectories proved that classification **results are consistent with independent data**, and confirm that the **approach is accurate for field condition mapping**.

Future work will consider the following tasks:

1) exploitation of **spectral libraries** regarding NPV fractions (Hively et al., 2021) to **move ahead to a quantitative estimation** of abundance (NPV-related, green vegetation and soil).

2) **Exploit RTM** (PROSPECT-PRO; Feret et al., 2021) to **simulate spectral signature at different CBC** and in relation to **changing plant/soil moisture content** to assess detection limits and/or develop transferable solution (hybrid-approaches)

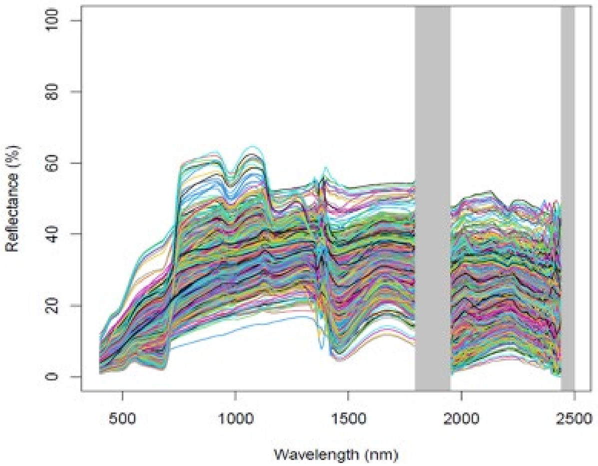
Pepe et al (2022) Mapping spatial distribution of crop residues using PRISMA satellite imaging spectroscopy. European Journal of Remote Sensing under revision

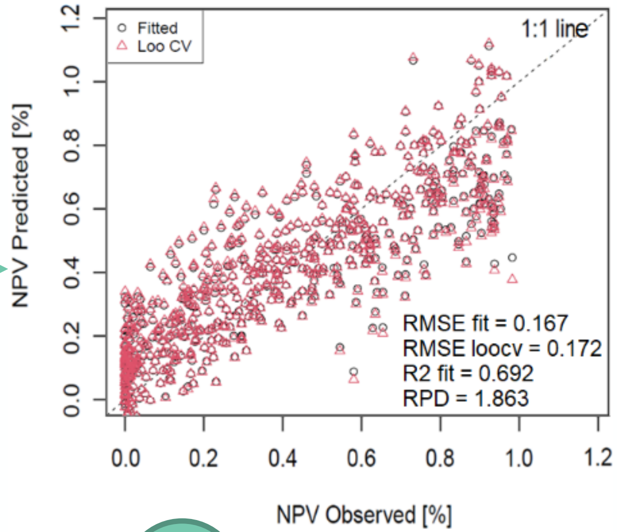
Pepe.m@irea.cnr.it

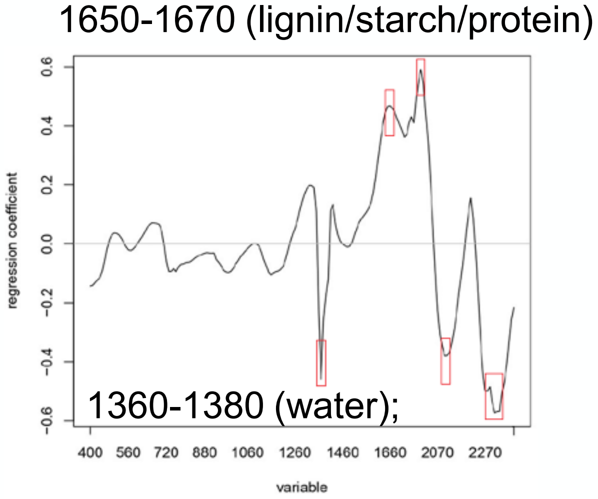
Ongoing activities: CR abundance

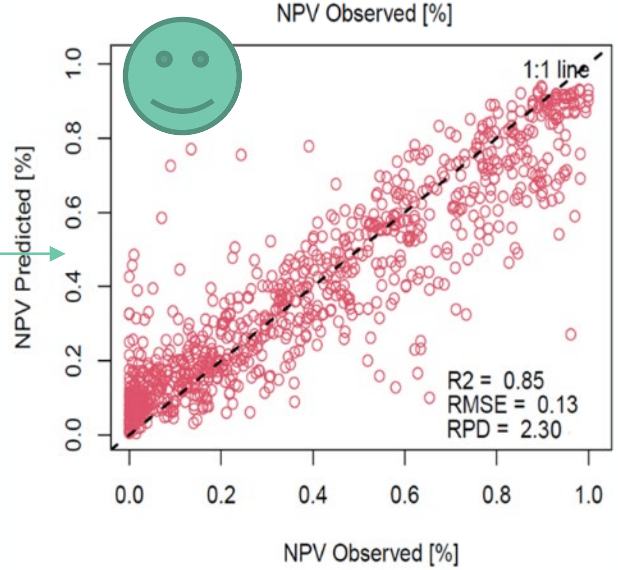
Machine Learning approaches: full spectra vs spectroscopic features enhancement

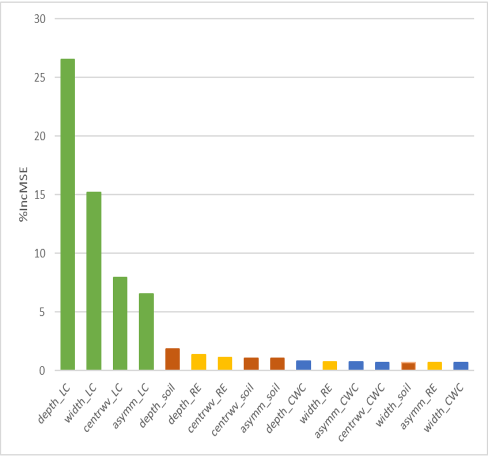
- Data: USGS spectral library 916 samples with different abundaces of CR, GV and S (Hively et al., 2021)











- **Test 1**: Input: full spectra information (excluding atmospheric absorption bands); MLRA: PLSR
- **Test 2**: Input: 16 spectroscopic features (4 region x 4 parameters); MLRA: Random Forest + 10-fold cross validation & 5 times iteration

Ongoing activities: CR abundance

22 June 2022 - Spec_VegTraits-1: Quantifying priority vegetation traits from spaceborne imaging spectroscopy data

Pepe et al . Quantifying Crop Residue Cover by Spectroscopy Techniques Exploiting In-situ, Aerial and Simulated Spaceborne Hyperspectral Data for PRISMA Mapping Applications

Agenzia Spaziale Italiana

PRIS4VEG

Development of algorithms for the estimation of functional parameters of terrestrial vegetation from PRISMA data in the agro-forestry sector

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UNIVERSITÀ DEGLI STUDI DI MILANO BICOCCA

UNIVERSITÀ DEGLI STUDI DELLA Tuscia

ITC

istituto per il rilevamento elettromagnetico dell'ambiente