Detection of organic matter content of arable soils with optical remote sensing data: the impact of soil surface state

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Changes in open soil surface under
the influence of atmospheric precipitation
during model experiment (Vindeker et al., 2018)

Agricultural practices → Soil surface ← Atmospheric precipitation

- moisture content
- surface roughness
- material composition

(organic matter, mineralogy, texture)

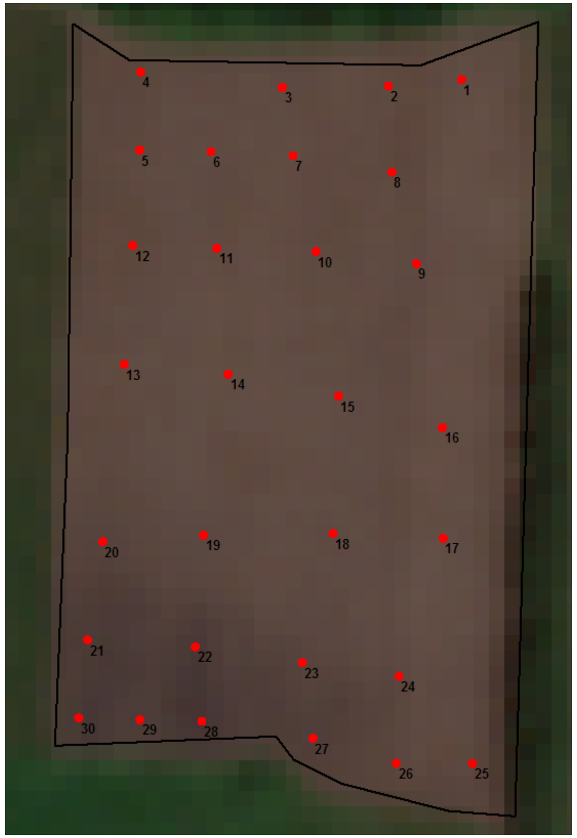
Spectral reflectance of the surface of arable soils in optical range contains the information only about the properties of very thin surface layer.

Difference in properties between soil surface layer and soil ploughed horizon affects the accuracy and reproducibility of the models predicting soil properties from optical remote sensing data.

Study area

Test field

Object and methods of research

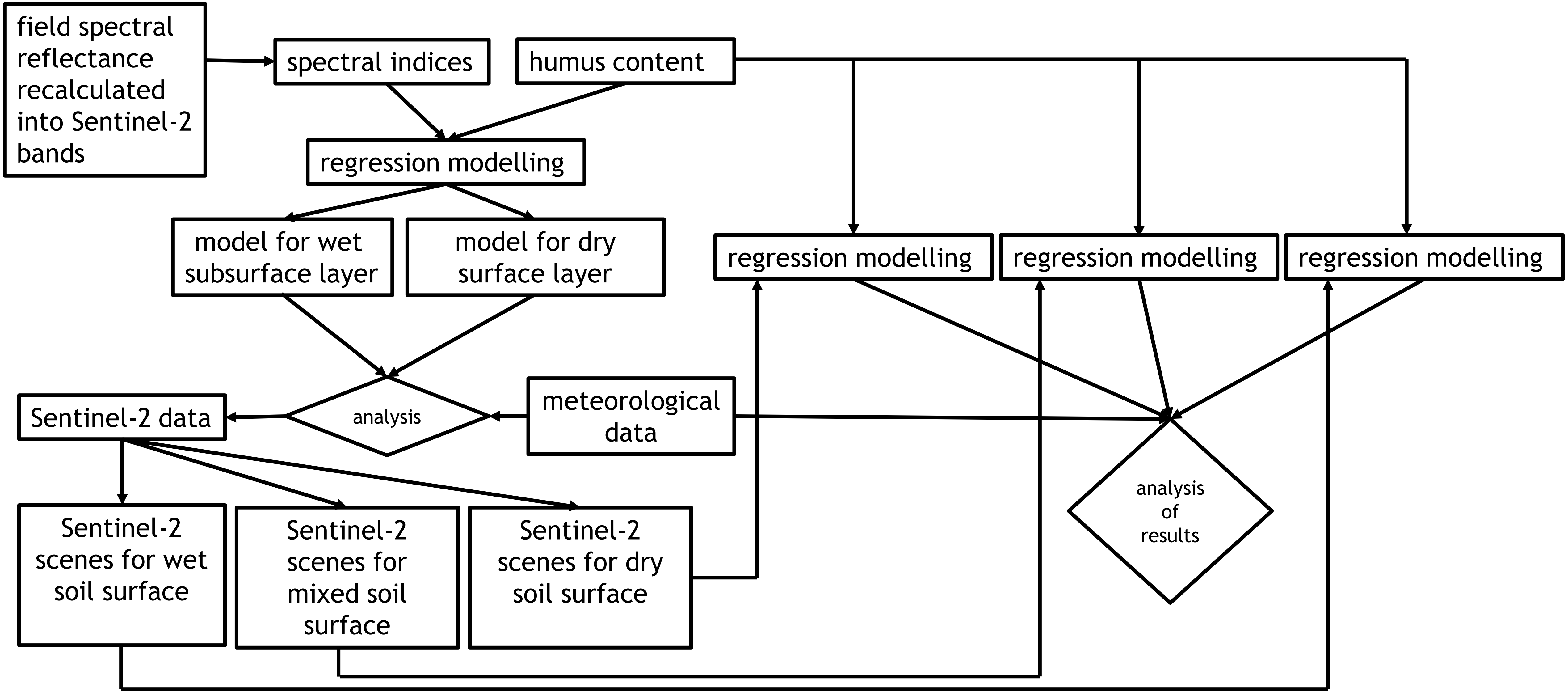


Sampling scheme

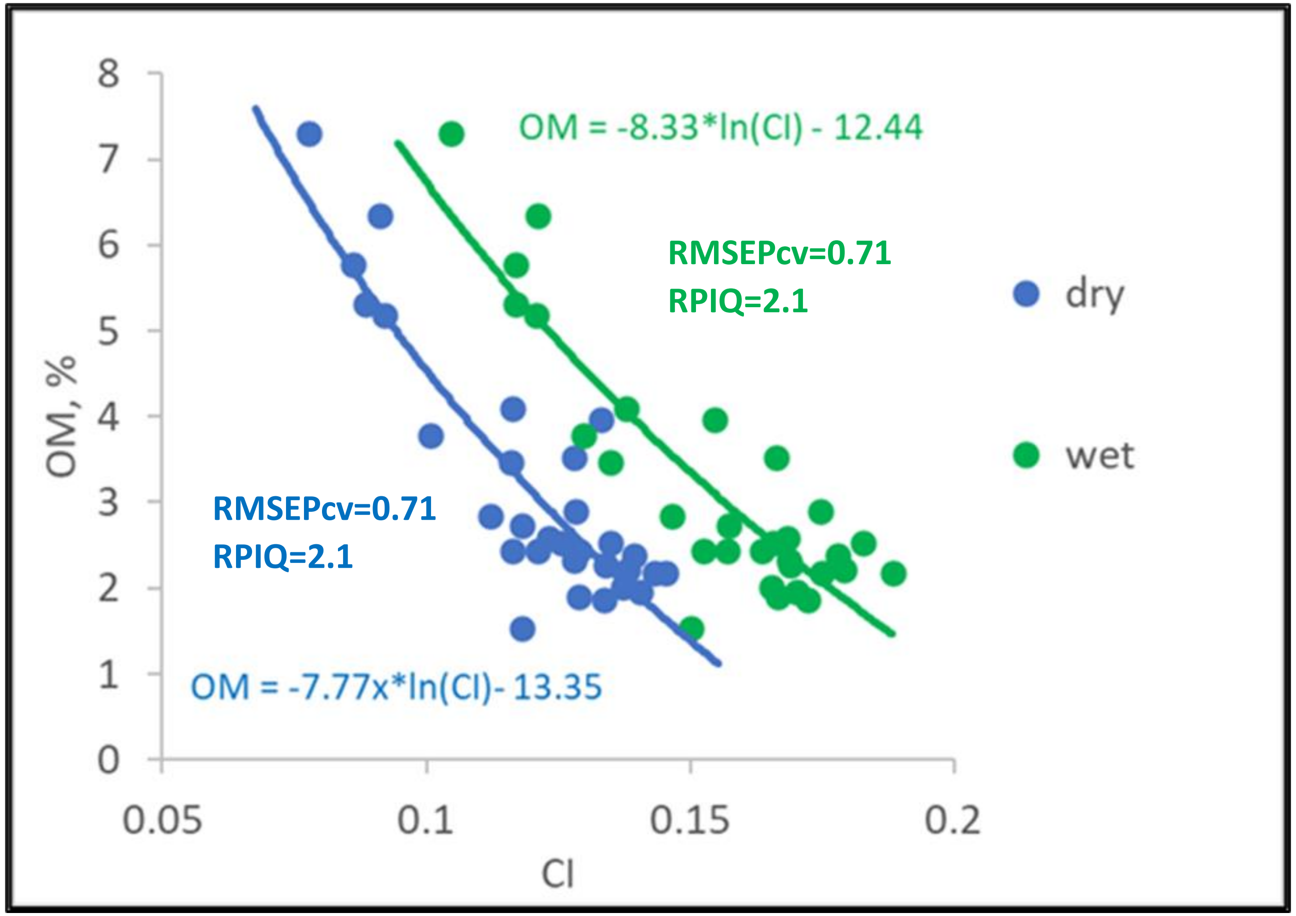
Object: arable grey forest soils on loess loam; test field was complete fallow in 2019.

Methods:

1) Field survey (15.08.2019):
30 mixed soil samples of upper soil horizon;
measurement of spectral reflectance of surface and subsurface layer at sample points with field spectroradiometer HendHeld-2 (325-1075 nm);
2) Laboratory analysis: humus content(Turin's method) was used as indicator of organic matter content in collected soil samples.
3) Preprocessing of field spectral data:
removement of noisy regions (before 350 nm and after 900 nm);
averaging and smoothing with Savitzky-Golay function (R, package *prospectr*);
recalculation into Sentinel-2 bands using Gaussian function (R, package *hsdar*);
4) Preprocessing of Sentinel-2 data:
selection of satellite data for the test region for 2019;
atmospheric correction (Sen2Cor, SNAP);
extraction of spectral reflectance for pixels where we have collected spectral data and soil samples in the field (ILWIS Academic 3.3);

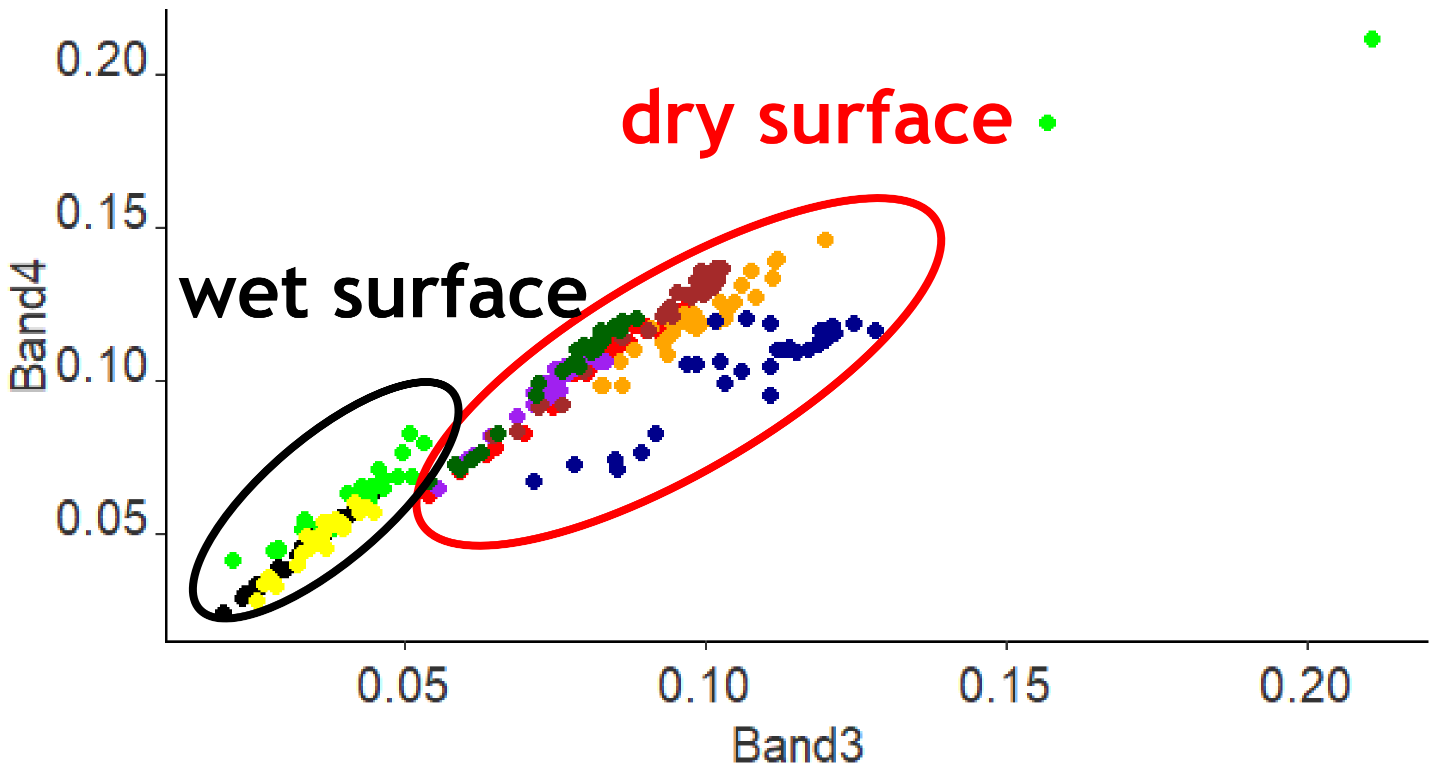

field spectral reflectance recalculated into Sentinel-2 bands
spectral indices
humus content
regression modelling
model for wet subsurface layer
model for dry surface layer
regression modelling
regression modelling
regression modelling
Sentinel-2 data
analysis
meteorological data
analysis of results
Sentinel-2 scenes for wet soil surface
Sentinel-2 scenes for mixed soil surface
Sentinel-2 scenes for dry soil surface

Relationship between spectral reflectance of dry surface and wet subsurface layer measured in the field and soil humus content



CI= (red-green)/(red+green). In Sentinel-2 bands: CI= (Band4-band3)/(Band4+Band3)

Spectral reflectance for sample points measured with HandHeld-2 field spectroradiometer and registered by Senteniel-2 data in Band3-Band4 spectral space



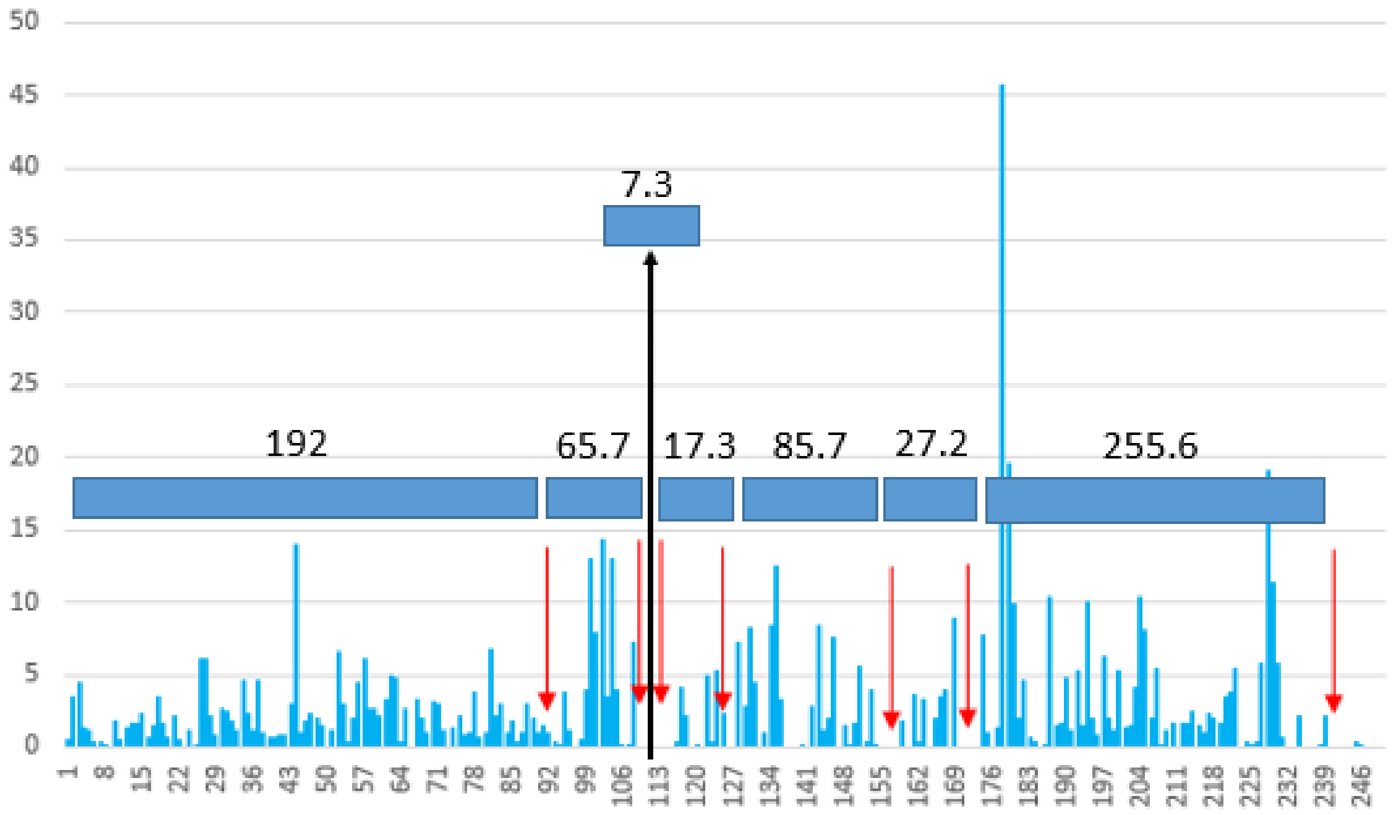
dry soil surface layer – red points;
wet subsurface layer – black points;
2/04/2019 - green points;
17/04/2019 – yellow points;
20/04/2019 – orange points;
5/05/2019 – purple points;
6/06/2019 – brown points;
19/06/2019 – dark-green points;
28/08/2019 – dark-blue points.
Red oval delineates points with dry soil surface, black oval – with wet soil surface.

Variations in RMSEP of humus content modelling due the to difference in soil surface state

Acquisition date of Sentinel-2 images	RMSEP when using regression model for dry soil surface	RMSEP when using regression model for wet subsurface layer	Soil surface class
2/04/2019	6.11	3.72	wet
17/04/2019	2.37	1.33	wet
20/04/2019	1.93	3.39	dry
5/05/2019	1.19	1.43	dry
6/06/2019	1.23	1.57	dry
19/06/2019	1.88	0.86	dry
28/08/2019	1.13	1.99	dry

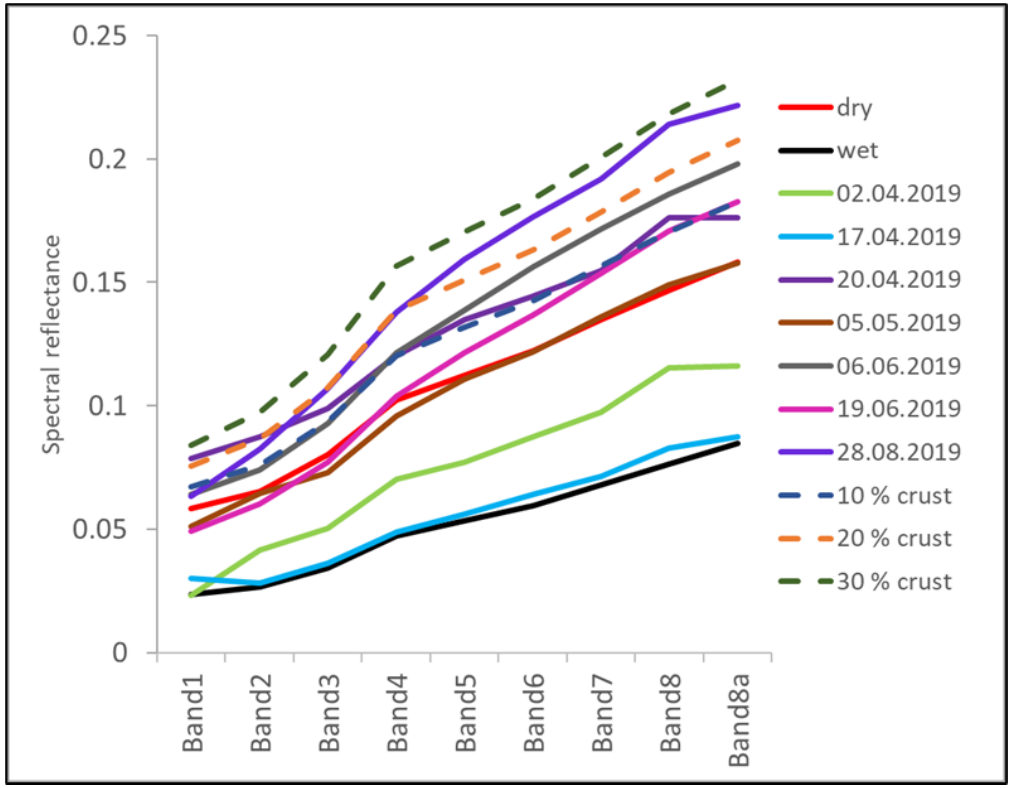
Rainfall patterns for the year 2019 for the test field

Acquisition date of Sentinel-2 images	Day of the year	Average precipitation during the period per day
02.04.2019	92	2.08
17.04.2019	107	4.38
20.04.2019	110	2.43
05.05.2019	125	1.15
06.06.2019	157	2.7
19.06.2019	170	2.09
28.08.2019	240	3.7



Values above colored blocks show atmospheric precipitation accumulated between studied dates

Averaged spectral curves of bare soil surface and spectral mix curves with different soil crust fraction



Spectral curves obtained in the field for dry surface layer ("dry") and wet subsurface layer ("wet") are used as reference curves.

Variations in model parameters and accuracy when modelling humus content of soil surface layer with Sentinel-2 data (only for the dates with dry soil surface)

Acquisition date of Sentinel-2 images	R^2adjcv	RMSEPcv	RPIQ	Intercept		ln(CI)	
				value	St. error	value	St. error
reference model	0.75	0.71	2.1	-13.35	1.65	-7.77	0.77
20.04.2019	0.32	1.24	1.2	-10.43	3.23	-5.84	1.38
05.05.2019	0.64	0.77	1.9	-12.25	1.73	-7.62	0.85
06.06.2019	0.62	1.03	1.4	-17.44	3	-10.18	1.48
19.06.2019	0.81	0.72	2.1	-11.45	1.49	-7.54	0.77
28.08.2019	0.43	1.17	1.3	-13.07	3.32	-7.8	1.59

Temporal variations in rainfall intensity, spectral reflectance of soil surface and model accuracy

- **05/05/2019 and 19/06/2019**
  - average spectral curves – the closest to the reference spectral curve of dry soil surface
  - regression models had the highest accuracy and the lowest standard errors of model parameters
  - average precipitation was the lowest
- **28/08/2019**
  - average spectral reflectance differed the most from reference spectral reflectance of dry surface
  - average spectral reflectance in Band 3 and Band 4 was close to spectral mix with 20 % of soil crust
  - standard errors for model parameters were 2 times higher and model accuracy was almost two times lower compared to the reference model
  - average and accumulated precipitation were the highest
- **20/04/2019 and 06/06/2019**
  - average spectral curves were close to spectral mix with 10 % and 20 % of soil crust.
  - high standard errors of model parameters
  - regression model for 20/04/2019 had the lowest accuracy
  - R^2ajcv for 06/06/2019 was 0.62, but RPIQ was only 1.4

Discussion

- Both humus content and its composition affect soil spectral reflectance. At the same time atmospheric precipitation alters soil surface properties including humus.
- CI obtained from proximal and satellite remote sensing data was related to the content and composition of humus of ploughed soil horizon of the test field.
- The differences between humus content and composition of soil surface and humus of ploughed soil horizon at the time of satellite data acquisition caused the movement of average spectral curves from the reference spectral curve to spectral mixes with different fractions of soil crust. The degree of deviation increased with growth of precipitation sum.
- The discrepancy between soil surface layer and ploughed soil horizon explains the exception occurred for 19/06/2019. Regression model developed for 19/06/2019 from Sentinel-2 data had higher accuracy compared to the reference model developed with proximal sensing data due to the fact that humus of soil surface layer on this date was more similar to humus of ploughed soil horizon than on the date of field survey. That lead to the situation when the application of the model developed for dry surface layer to the image with dry soil surface resulted in higher RMSEP than application of model developed for wet subsurface layer.

Conclusion

- The impact of atmospheric precipitation on soil surface of the test field resulted in the difference in humus between soil surface layer and ploughed soil horizon and mainly led to the decrease in accuracy and quality of the models developed to predict humus content of ploughed soil horizon from optical remote sensing data.
- Accounting for the rainfall-induced changes of soil surface layer is necessary to ensure reproducibility of developed models and correct assessment of organic matter of soil ploughed layer, based on optical RS data.

Thank you for your attention!