Schweizerische Eidgenossenschaft
Confédération suisse
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Federal Department of Economic Affairs,
Education and Research EAER
Agroscope

M3-Machine learning on hyperspectral data - wheat trial

Nicolas Vuille-dit-Bille

Agroscope: swiss federal institute for agricultural research

Group:
- Cultivation Techniques and Varieties in Arable Farming

Team:
- 35 People

Domains of research:
- Agronomy
- Crop science

Main areas of work:
- Characterization of genotypes of field crops
- Improvement of management practices of field crops

Crop species:
- Winter cereals (**wheat**, barley, oat, …)
- Maize
- Potato and Sugar beet
- Oil crops and grain legumes
- Minor crops (e.g. Quinoa, Amaranth)

Variety trial context

- Winter wheat varieties are tested on different experimental fields across Switzerland with different modality (low vs high inputs)
- Each year, winter wheat varieties performance are reported and recommended to farmers according to a list
- Challenge: not easy to estimate and understand accurately specific varieties response to specific environment linked to abiotic and biotic stresses (uncontrolled factors on the field)

Blé d'automne — Variétés

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swiss granum

Liste recommandée des variétés de blé d'automne pour la récolte 2023

Variété	TOP										
	RUNAL	TITLIS	CH CLARO	CH NARA	PIZNAIR	AXEN[£]	DIAVEL*	MONTALBANO[£]	BONAVAU[£]	BARETTA	CADLIMO
Année d'inscription	1995	1996	2009 (dern. année)	2010	2020	2022 (prov.)	2020	2018	2022 (prov.)	2018	2020
Rendement (Extenso)[1]	-	-	-	+	+	+++	+	++	++	+(+)	++
Rendement (PER)[2]	--	--	+	-(-)	Ø	+(+)	+	+	Ø	+	+
Précocité à l'épiaison[1]	mt	t	mp	mt	mt	tp	tp	t	mt	t	t
Hauteur des plantes[1]	m	ml	mc	tc	m	l	tl	m	c	ml	m
Verse[1, 2]	++(+)	++	+++	+++	+	++	++(+)	+++	+++	++	+
Résistance: Oïdium[1]	+(+)	Ø	+	+(+)	+(+)	Ø	+(+)	++	+	+(+)	+(+)
Résistance: Rouille jaune[1]	+	++	-	+++	++	Ø	++(+)	+++	+	+++	++
Résistance: Rouille brune[1]	-	-	Ø	Ø	+	++	+++	++	Ø	+(+)	+(+)
Résistance: *Septoria nodorum* feuilles[1, 3]	-	Ø	--	+	-	Ø	Ø	Ø	Ø	Ø	Ø
Résistance: *Septoria nodorum* épi[1, 3]	Ø	Ø	-	Ø	+	++	Ø	++	+	++	+
Résistance: *Septoria tritici* feuilles[1, 3]	-	Ø	--	+	Ø	+	++	+	++	+	++
Résistance: Fusariose épi[1, 3]	Ø	+	-	--	Ø	Ø	Ø	++	Ø	+	Ø
Résistance: Germination sur pied[1]	+(+)	+	-	+	+	+	Ø	+	Ø	-	Ø
Teneur en protéines[1]	+++	++(+)	+++	+++	+++	+++	++(+)	+++	+++	++(+)	++(+)
Zélény[1]	+(+)	++	++	+++	++(+)	++	++(+)	++	++(+)	++	++(+)
Poids à l'hectolitre[1]	++	++	Ø	+++	+(+)	++	++	+	++	Ø	+(+)
Poids de mille grains[1]	moyen	grand	petit	petit	petit	moyen	petit	grand	moyen	petit	très petit

Variété	I						II				Fourrager				Biscuit
	ARINA	FOREL	SIMANO[£]	ALPVAL	HANSWIN	CAMPANILE	POSMEDA	LUDWIG	LEVIS	SPONTAN	PONCIONE	CAMPESINO	SAILOR	MULAN	DILAGO
Année d'inscription	1981	2008	2012 (dern. année)	2022 (prov.)	2015	2021	2019	2004	1997	2017	2019	2022 (prov.)	2015	2007 (dern. année)	2019
Rendement (Extenso)[1]	Ø	Ø	+	++	++	+++	+++	+++	+	++++	++++	++++	++++	+++(+)	++++
Rendement (PER)[2]	-	+	Ø	+(+)	+(+)	+(+)	++(+)	++	+(+)	+++(+)	++++	++++	++++	+++	+++(+)
Précocité à l'épiaison[1]	t	mp	tp	t	mp	mt	mp	mt	mt	mt	t	mt	t	t	t
Hauteur des plantes[1]	tl	m	c	m	m	m	tl	tl	c	m	l	c	ml	m	ml
Verse[1, 2]	Ø	++	+++	+++	++(+)	++	+	+	+++	+++	+	+++	++(+)	++(+)	++
Résistance: Oïdium[1]	Ø	+	+	+(+)	Ø	+	+	+	Ø	+(+)	+(+)	++	++	+	Ø
Résistance: Rouille jaune[1]	Ø	Ø	+	++	+	++	Ø	+	+	Ø	++	+++	+	-	+
Résistance: Rouille brune[1]	--(-)	--(-)	+	Ø	Ø	++	Ø	-	-	Ø	Ø	++	Ø	-(-)	Ø
Résistance: *Septoria nodorum* feuilles[1, 3]	-	-	Ø	+	Ø	Ø	++	Ø	Ø	++	++	++	Ø	+	++
Résistance: *Septoria nodorum* épi[1, 3]	++	Ø	-	+	+	Ø	++	++	-	++	++	++	++	+	++
Résistance: *Septoria tritici* feuilles[1, 3]	Ø	--	-	++	+	++	++	+	Ø	++	++	Ø	+	-	Ø
Résistance: Fusariose épi[1, 3]	++	-	Ø	Ø	-	Ø	-	Ø	-	++	-	+	Ø	Ø	+
Résistance: Germination sur pied[1]	Ø	+	+	+	+	+	+	Ø	Ø	Ø	+	+	Ø	--	Ø
Teneur en protéines[1]	++(+)	+(+)	++(+)	++(+)	+(+)	++	Ø	Ø	++	Ø	Ø	-	-(-)	-(-)	Qualité biscuit
Zélény[1]	Ø	++	++	++	+	++	Ø	Ø	++	-	Qualité fourragère				
Poids à l'hectolitre[1]	+++	+++	+(+)	++	+++	+++	+(+)	+(+)	++	+(+)	+(+)	+	++(+)	-	+++
Poids de mille grains[1]	moyen	très petit	moyen	grand	grand	moyen	très grand	très grand	moyen	moyen	très grand	petit	très grand	moyen	grand

[1,2]Cette description variétale a été établie sur la base des résultats moyens de deux (trois) ans obtenus dans le réseau d'essais d'Agroscope et DSP[1], complétés par ceux du réseau d'essais culturaux swiss granum pour le rendement en mode PER[2] et quelques autres appréciations. Ces informations peuvent toutefois varier en fonction du lieu et des conditions climatiques de l'année.

L'appréciation du rendement s'entend entre variétés au sein d'un même type de production (lecture horizontale!). La description ci-dessus ne permet donc pas une comparaison entre types de production (Extenso ou PER)

[3]Échelle d'appréciation à cinq niveaux (++, +, Ø, - et --).

[£]Variété à épis barbus.

[*]Variété pouvant être semée au printemps, la qualité étant légèrement supérieure.

Toutes les variétés qui sont actuellement inscrites ou l'ont été dans le passé sur la liste recommandée de swiss granum peuvent être commercialisée sous Suisse Garantie.

Légende:
+++ = très bon
++ = bon
\+ = moyen à bon
Ø = moyen
\- = faible à moyen
\- - = faible
\- - - = très faible
case vide = aucune information

Précocité:
tp = très précoce
p = précoce
mp = mi-précoce
mt = mi-tardive
t = tardive

Hauteur des plantes:
tc = très courte
c = courte
mc = moyenne à courte
m = moyenne
ml = moyenne à longue
l = longue
tl = très longue

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agridea

Juin 2022

Case study: winter wheat trial with 2 treatments over 2 years on 3 sites

- 5 winter wheat varieties

- 2 years: 2021 to 2022

- 3 sites: Changins, Goumoens and Reckenholz

- Case study context: study variety response to different N treatment

➢ Find variety that are performing well also under limited available N in order to reduce N fertilization (economic and environmental cost)

- 3 main treatments: none, reduced and conventional

- Measurement to estimate varieties performance:

➢ Grain yield
➢ Straw yield
➢ Grain protein
➢ Other physiological parameters (harvest index, leaf area index, chlorophyll content, canopy cover…)

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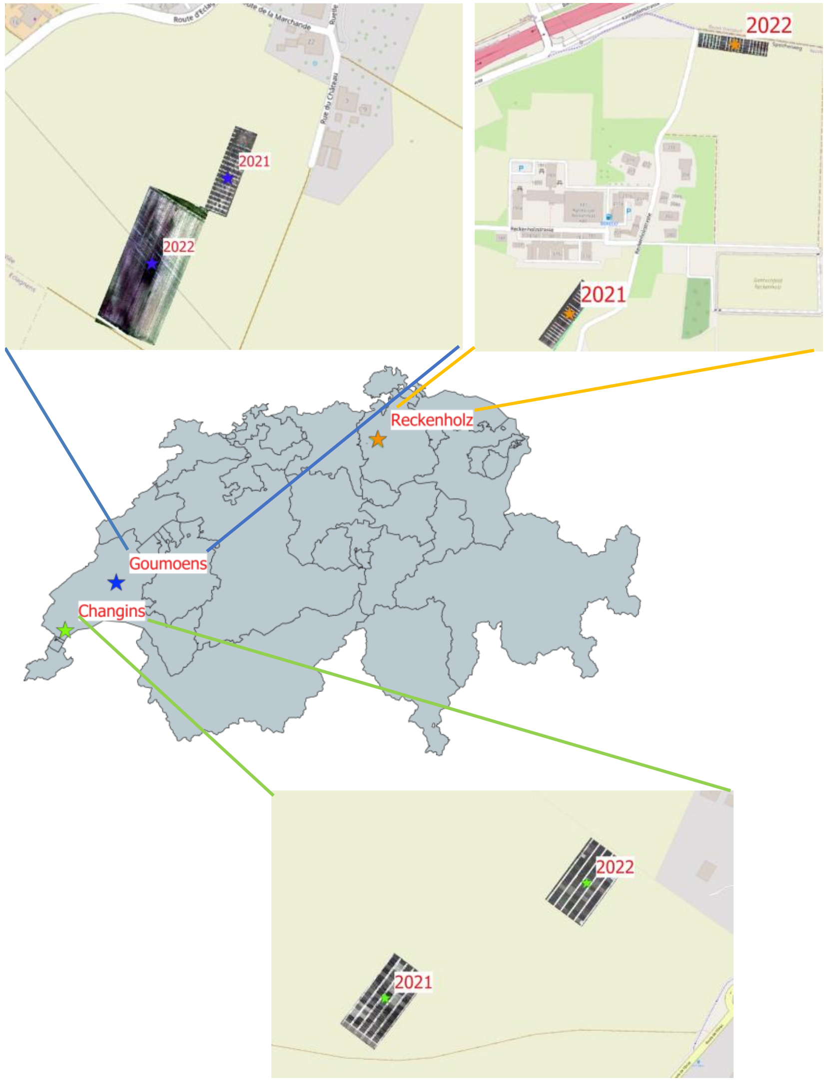
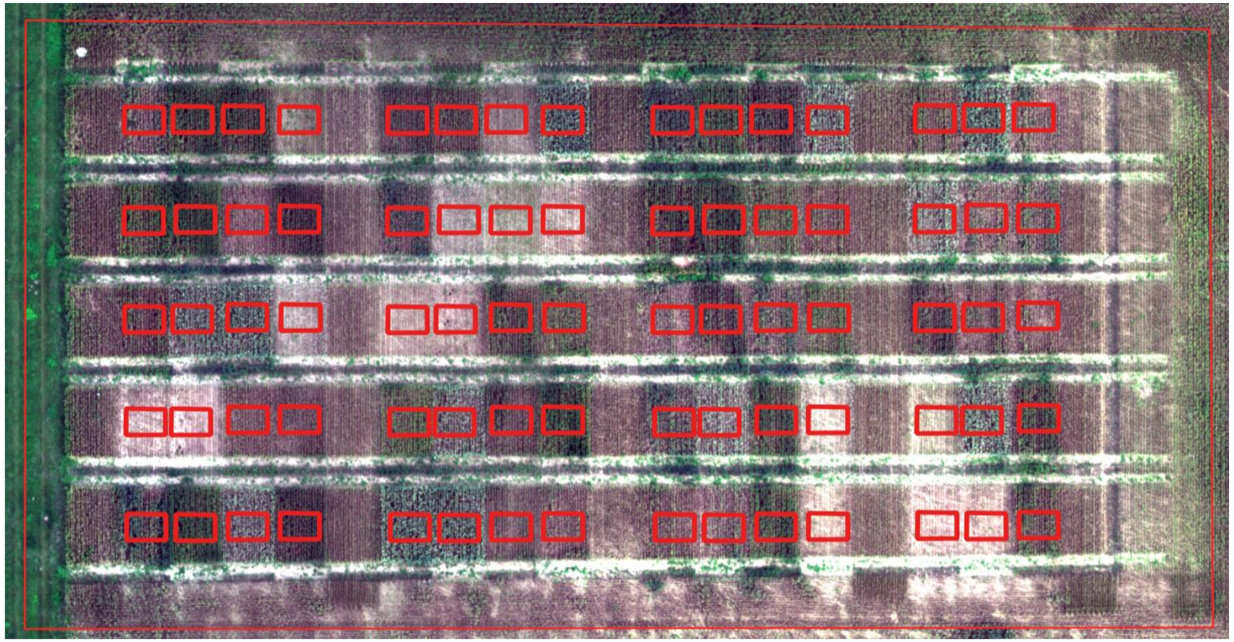
Case study: field experimental design



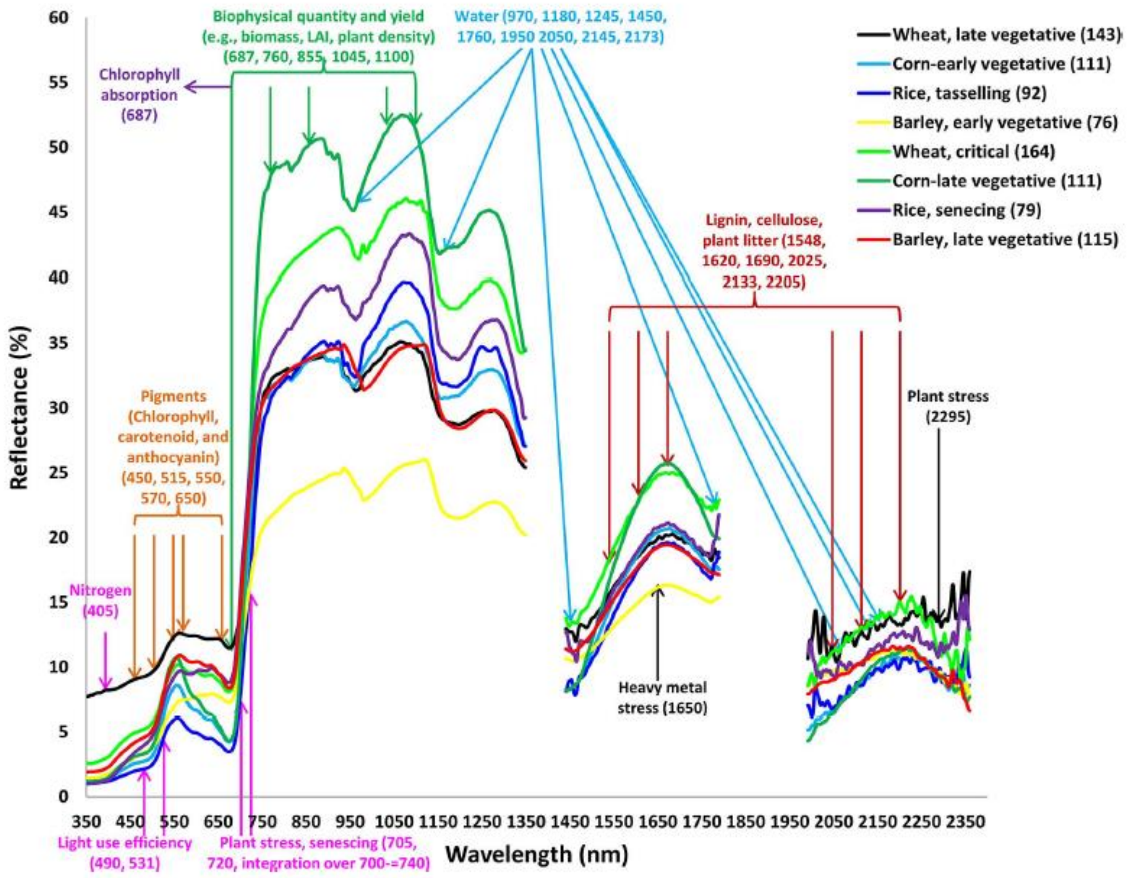


Case study: variety x N treatments

Treatment ID	Variety	N treatment	Total N applied	N rate
1	CH Claro	N0	0 kgN/ha-1	0-0-0
2	CH Claro	N1	80 kgN/ha-1	20-40-20
3	CH Claro	N2	80 kgN/ha-1	20-60-0
4	CH Claro	N3	160 kgN/ha-1	40-80-40
5	CH Claro	N4	160 kgN/ha-1	40-120-0
6	CH Nara	N0	0 kgN/ha-1	0-0-0
7	CH Nara	N1	80 kgN/ha-1	20-40-20
8	CH Nara	N2	80 kgN/ha-1	20-60-0
9	CH Nara	N3	160 kgN/ha-1	40-80-40
10	CH Nara	N4	160 kgN/ha-1	40-120-0
11	CH Camedo	N0	0 kgN/ha-1	0-0-0
12	CH Camedo	N1	80 kgN/ha-1	20-40-20
13	CH Camedo	N2	80 kgN/ha-1	20-60-0
14	CH Camedo	N3	160 kgN/ha-1	40-80-40
15	CH Camedo	N4	160 kgN/ha-1	40-120-0
16	Montalbano	N0	0 kgN/ha-1	0-0-0
17	Montalbano	N1	80 kgN/ha-1	20-40-20
18	Montalbano	N2	80 kgN/ha-1	20-60-0
19	Montalbano	N3	160 kgN/ha-1	40-80-40
20	Montalbano	N4	160 kgN/ha-1	40-120-0
21	Runal	N0	0 kgN/ha-1	0-0-0
22	Runal	N1	80 kgN/ha-1	20-40-20
23	Runal	N2	80 kgN/ha-1	20-60-0
24	Runal	N3	160 kgN/ha-1	40-80-40
25	Runal	N4	160 kgN/ha-1	40-120-0

Repetition 1						Repetition 2						Repetition 3					
7	25	24	16		2	23	1	15		10	17	4	13		22	14	8
N2	N5	N4	N0		N2	N3	N0	N5		N5	N2	N4	N3		N2	N4	N3
17	19	8	5		9	11	16	21		25	20	18	23		12	7	10
N2	N4	N3	N5		N4	N0	N0	N0		N5	N5	N3	N3		N2	N2	N5
22	12	14	11		21	6	24	18		8	4	9	17		5	2	3
N2	N2	N4	N0		N0	N0	N4	N3		N3	N4	N4	N2		N5	N2	N3
1	6	23	3		18	13	5	19		9	12	20	11		16	15	24
N0	N0	N3	N3		N3	N3	N5	N4		N4	N2	N5	N0		N0	N5	N4
10	20	13	4		15	14	2	3		22	7	19	21		6	1	25
N5	N5	N3	N4		N5	N4	N2	N3		N2	N2	N4	N0		N0	N0	N5

Hyperspectral data: theory



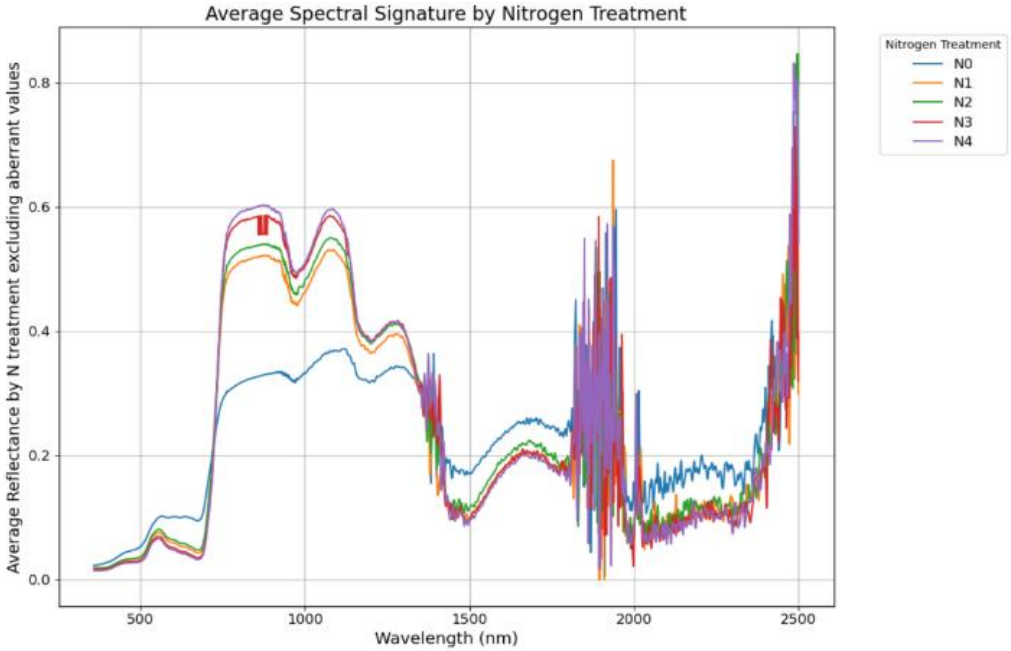
Thenkabail, P. S., Mariotto, I., Gumma, M. K., Middleton, E. M., Landis, D. R., & Huemmrich, K. F. (2013). Selection of hyperspectral narrowbands (HNBs) and composition of hyperspectral twoband vegetation indices (HVIs) for biophysical characterization and discrimination of crop types using field reflectance and Hyperion/EO-1 data. IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing, 6(2), 427-439. https://doi.org/10.1109/JSTARS.2013.2252601

Hyperspectral data collection

	ID	CropStage	rflt_359	rflt_360	rflt_361	rflt_362	rflt_363	rflt_364	rflt_365	rflt_366	...
450	1	Heading	0.018496	0.018435	0.018400	0.018405	0.018403	0.018397	0.018387	0.018440	...
451	2	Heading	0.020588	0.020687	0.020785	0.020865	0.020946	0.021021	0.021073	0.021132	...
452	3	Heading	0.011134	0.011124	0.011104	0.011091	0.011060	0.011027	0.011021	0.011047	...
453	4	Heading	0.014384	0.014365	0.014328	0.014269	0.014220	0.014181	0.014157	0.014164	...
454	5	Heading	0.031535	0.031565	0.031607	0.031671	0.031738	0.031801	0.031855	0.031862	...

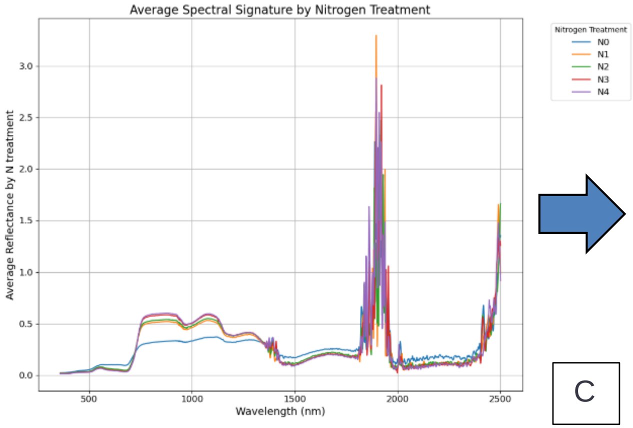
5 rows × 2285 columns

1) Time series data corresponding to key crop growth stage
- 2 years: 2021-2022
- 3 sites: Changins, Goumoens and Reckenholz

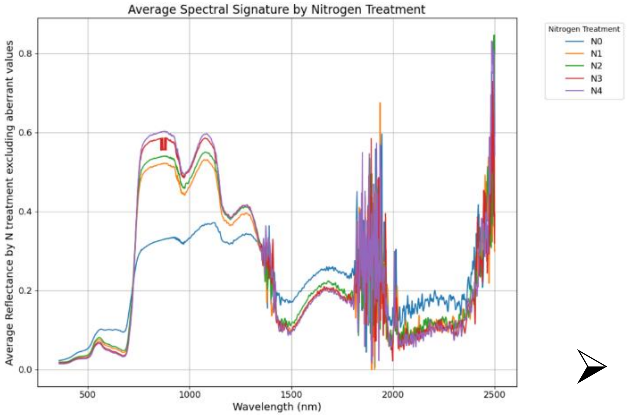


Hyperspectral data cleaning

A



B



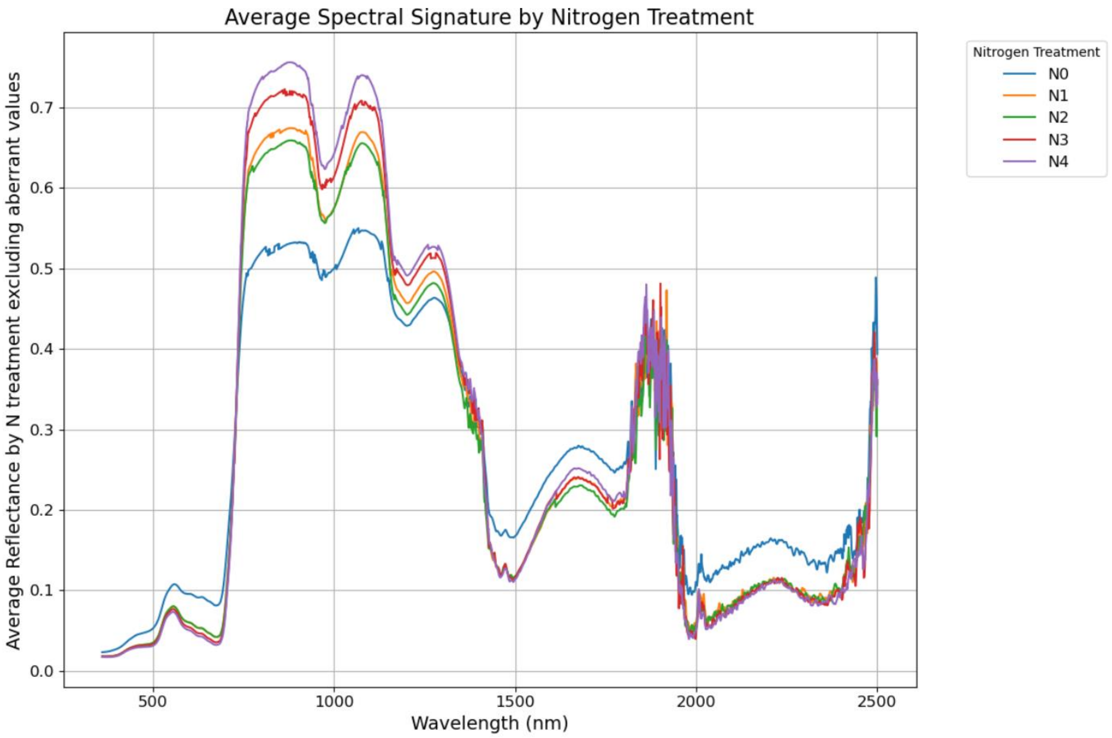
C

rflt_1897	rflt_1898	rflt_1899	rflt_1900	rflt_1901	rflt_1902	rflt_1903	rflt_1904	rflt_1905	rflt_1906	rflt_1907	rflt_1908	rflt_1909	rflt_1910	rflt_1911	rflt_1912	rflt_1913	rflt_1914	rflt_1915
3.65109	1.57072	0.11207	0	0	0.49875	3.40531	6.31836	6.93534	5.42574	3.44232	2.08599	0.8421	0.0401	0.09552	0.68635	0.99688	0.70513	0.22659
0	0	0	0	0	0.20351	1.30842	2.54547	3.29907	3.65119	3.90309	4.32029	4.82436	5.0141	4.6142	3.82203	2.90764	1.75334	0.56256
5.4275	2.55384	0.48193	0	0	0	0	0	0.32878	1.30063	2.57771	4.41397	6.88327	8.03605	6.11016	2.43515	0	0	0
0	0	0	0	0	0.04905	0.22445	0.6276	1.59903	3.30271	4.76955	5.17186	4.84432	4.08858	2.79168	1.08563	0	0	0.01463
5.37194	2.27108	0.0801	0	0	0.3443	2.32134	4.40049	5.14362	4.61088	4.00978	4.28905	5.07373	5.92674	6.98027	8.06941	7.88266	5.33062	1.95038
0.81859	2.04315	2.59596	1.91616	0.76257	0.07337	0	0	0.27699	1.21087	1.94526	1.68752	0.6835	0.00747	0.48706	1.51293	1.99315	1.3634	0.38286
1.93819	0.74591	0	0	0	0.12372	0.73757	1.55642	2.52785	3.81587	4.84425	5.10155	4.79747	4.08797	2.79606	1.09488	0	0	0
3.27589	1.56713	0.33642	0.07524	0.17031	0.17755	0.0956	0.02367	0	0	0	0	0	0	0	0	0.0064	0.0616	0.18455
1.14922	0.42958	0	0	0	0.20863	1.36616	2.60572	3.19384	3.23986	3.05809	2.77345	2.2949	2.00312	2.3005	2.87672	2.96343	2.00092	0.77056
6.31177	2.53065	0	0	0	0.3682	2.50787	4.58384	4.73626	2.9105	1.17578	1.2578	2.49347	3.88858	5.28418	6.71098	6.92894	4.96177	2.18082
0	0	0.29913	1.14134	2.11909	2.53421	2.28112	1.75126	1.24262	0.62538	0.09923	0	0	0	0	0	0.02468	0.46145	0.99958
0.78897	0.31633	0	0	0	0.18593	1.27455	2.31343	2.34271	1.37021	0.32577	0	0	0	0.8807	2.24004	3.02623	2.84011	2.19731
0.54719	0.00091	0.05426	1.35364	2.97649	3.44338	2.39589	0.97024	0.25355	0.05448	0.01941	0	0	0	0.89127	2.24505	3.02574	2.80263	2.14106
1.8161	1.2263	0.71446	0.38403	0.12306	0	0	0	0.006	0	0.4497	2.78224	6.7009	8.98935	7.06027	2.82781	0	0	0
5.44003	3.69178	2.44344	2.3637	2.59375	2.32541	1.35329	0.31996	0	0	0	1.03008	2.87957	3.99043	3.14675	1.24665	0	0	0.10897
3.01297	1.19763	0	0	0	0.2584	1.76293	3.21643	3.25489	1.74557	0.56125	1.42127	3.72405	5.85795	7.24715	8.21736	7.8752	5.18782	1.64394
5.28126	3.29602	1.94438	1.96428	2.41014	2.42069	1.89147	1.24672	0.75402	0.21031	0.12636	1.3102	3.59699	4.9896	3.93647	1.57768	0	0	0
0	0	0.02033	0.41413	0.86717	0.97242	0.60299	0.13592	0	0.02957	0.13389	0.12389	0.05917	0.00291	0	0	0.03497	0.67788	1.44723
3.82576	1.52524	0	0	0	0	0	0	0	0	0	0.83589	2.60319	3.93772	4.10994	3.62621	2.92847	1.86369	0.70435
1.51907	0.54738	0	0.12876	0.60934	1.19642	2.14235	2.92237	2.73378	1.50242	0.31528	0	0.11688	0.88174	2.99495	5.83466	6.96641	4.94827	1.75135
9.26216	8.25811	6.86398	4.98083	2.85051	1.44894	0.91119	0.71853	0.45186	0.20684	0.03585	0	0	0	0	0	0.03759	0.59401	1.38275
0.78021	0.29783	0	0.01707	0.17226	0.26313	0.27788	0.28465	0.29655	0.24524	0.37956	1.02185	2.09111	2.95082	3.18501	3.08764	3	3	3
4.01407	10.0492	13.0255	10.5126	5.76396	2.60768	1.12044	0.29945	0	0	0	1.4921	4.64609	6.91176	6.81081	5.38885	3.86886	2.12624	0.461
0.52924	1.41811	2.03425	2.22447	2.16642	1.88139	1.22152	0.51891	0.21235	0.26766	0.37709	0.30411	0.14125	0.00744	0	0	0.09983	1.93012	4.12489
0.95261	2.37456	2.99046	2.10132	0.65867	0	0	0.23182	0.24433	0	0	0.89976	2.5685	3.92348	4.39194	4.35785	3.93777	2.66389	1.25786
1.74158	2.69089	2.97404	2.04297	0.65633	0	0	0	0	0	0	0	0	0	3.49292	8.70671	10.9645	7.66269	2.35185
2.36691	0.94899	0	0	0	0.04842	0.31588	0.60499	0.75857	0.81762	0.78215	0.60118	0.27782	0.01482	0	0	0.04005	0.78142	1.66402
0	0	0.00998	0.19301	0.41249	0.50578	0.42347	0.31326	0.33885	0.50708	0.62806	0.5209	0.24479	0.01253	0	0	0.04067	0.82827	1.73434
0.49318	1.42973	2.02426	2.03145	1.75393	1.37434	0.78361	0.19059	0	0	0	0.65621	2.0429	2.97404	2.6921	1.74414	0.94708	0.4879	0.15627
4.94584	5.88809	5.93987	4.42599	2.30051	1.0106	0.70185	0.72965	0.62906	0.51624	0.41081	0.22911	0	0	0.46711	1.27388	2.07387	2.97309	3.78122

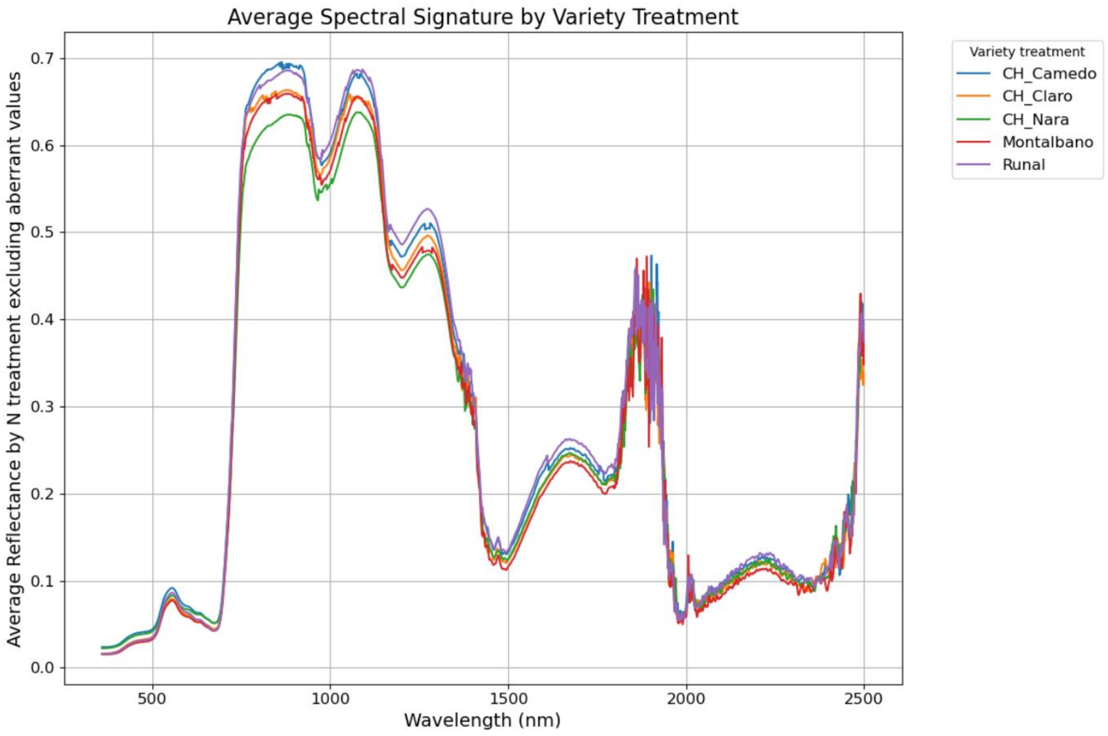
- Remove bands with aberrant values : <0 or >1
- Remove bands with 0 value

Average of spectral signature by treatments at heading

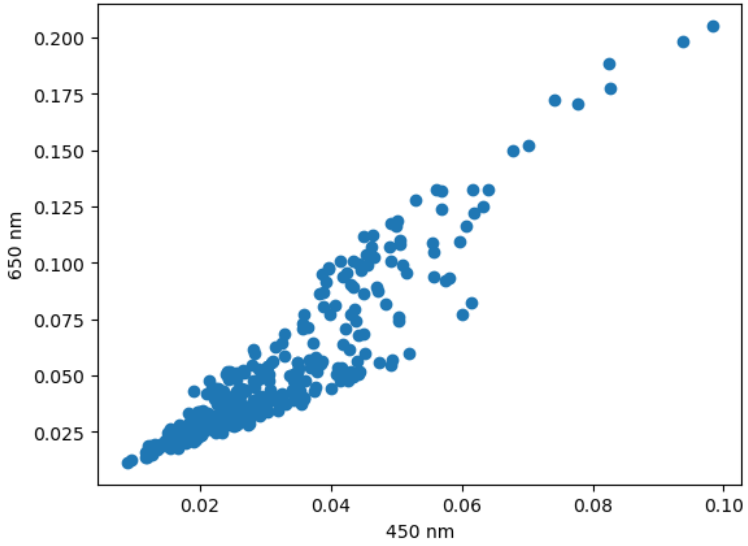
Nitrogen treatment

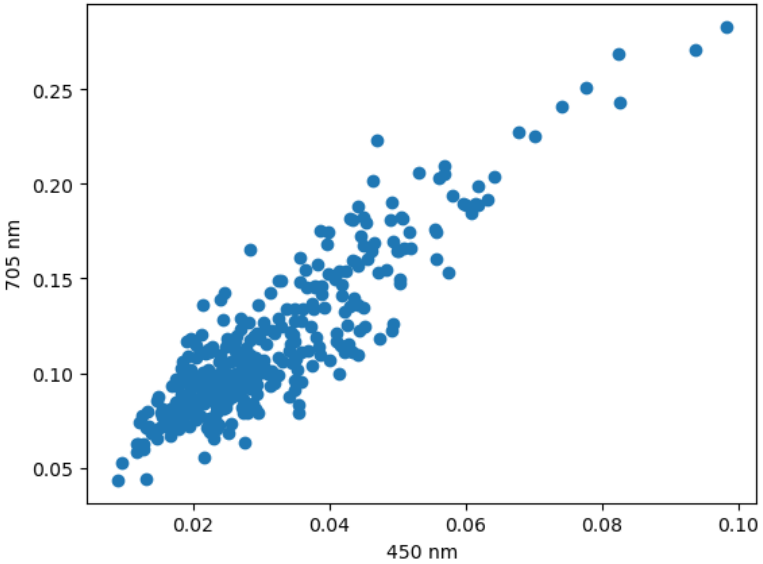


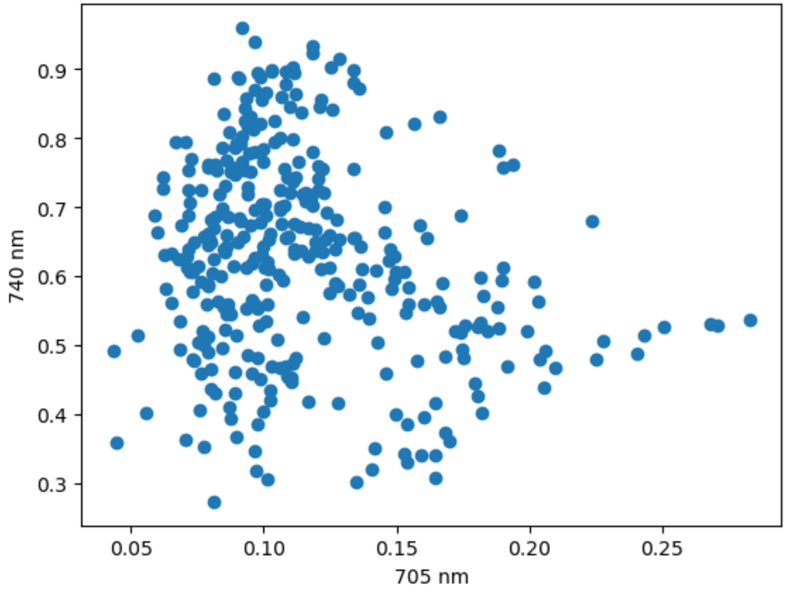
Variety treatment

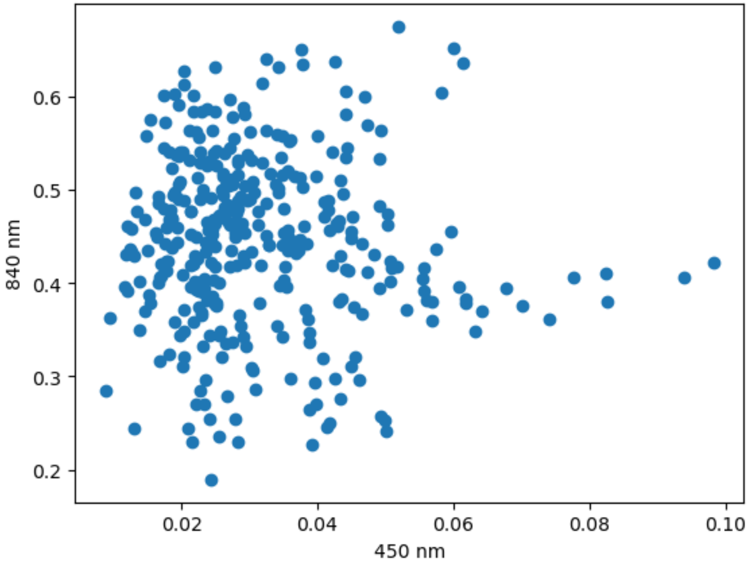


Hyperspectral: highly intercorrelated





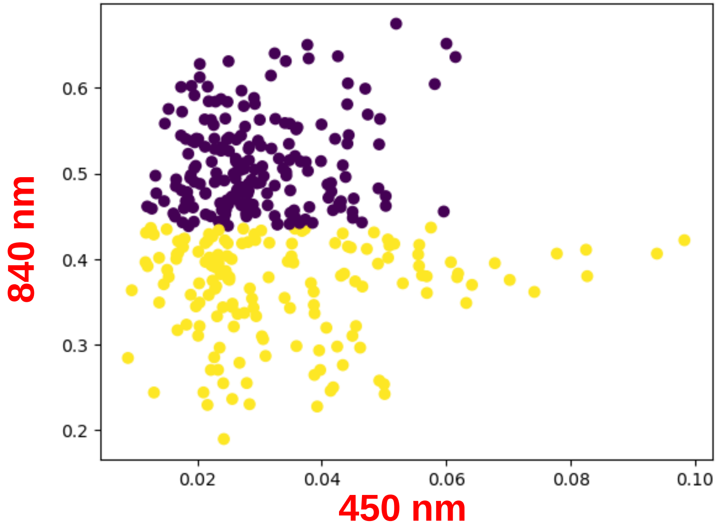


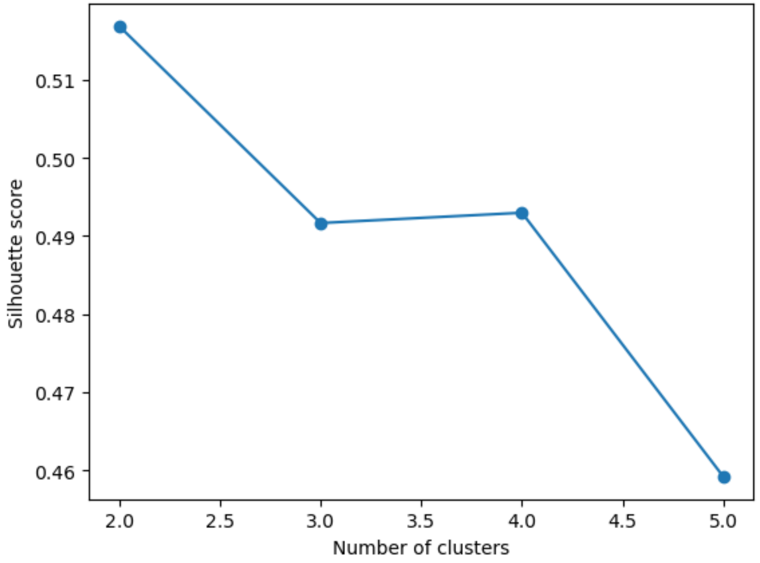


Agroscope

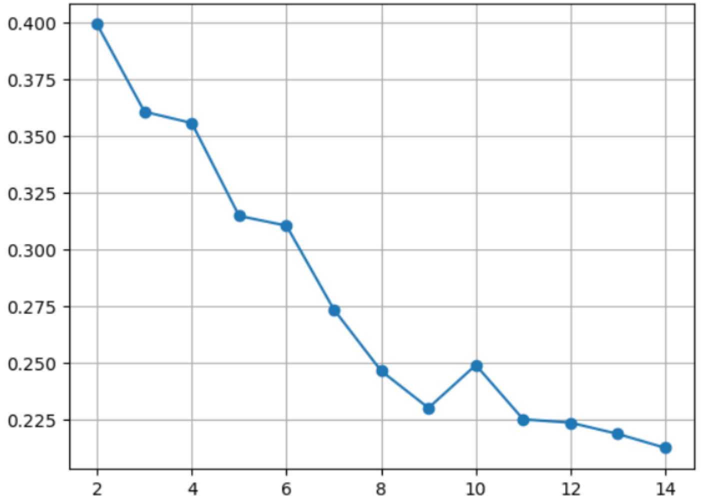
Data exploration: clustering (K-means) and umap

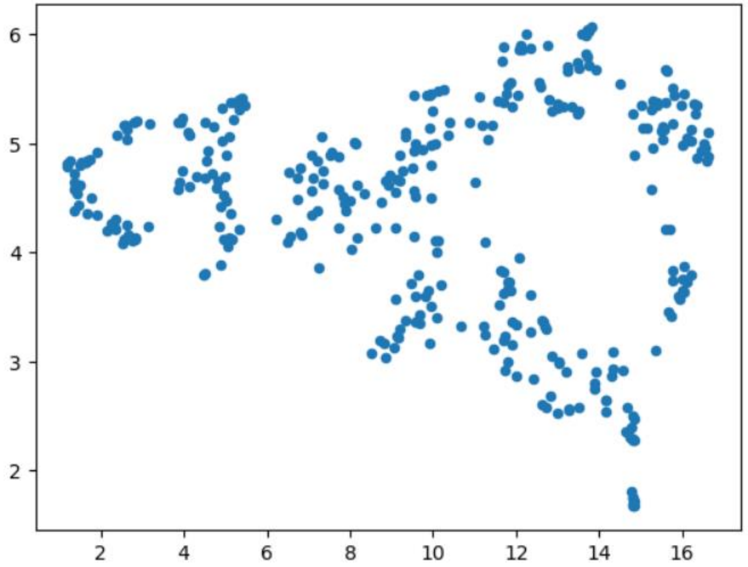
2D





High dimensional

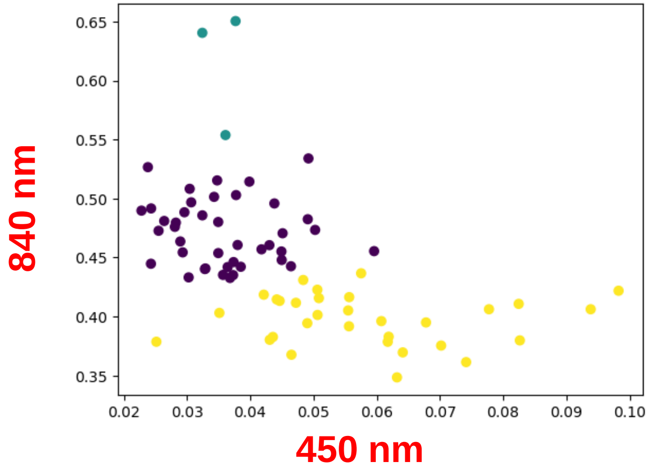


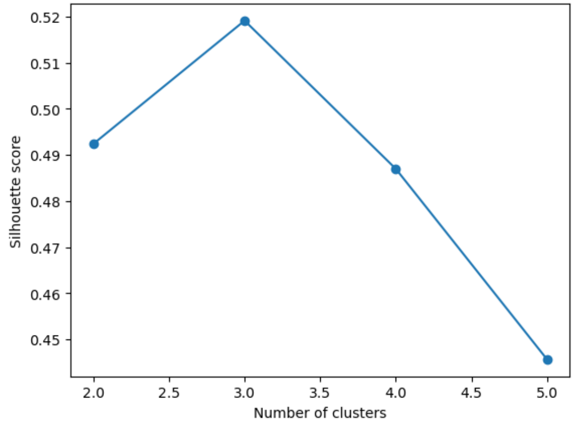


tés

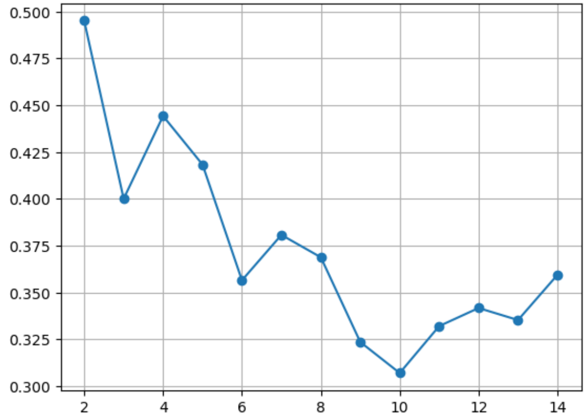
Data exploration: clustering (K-means) and umap – Focusing on Changins in 2022

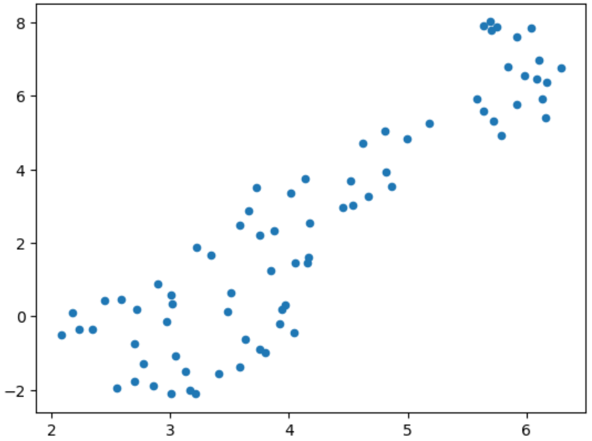
2D





High dimensional





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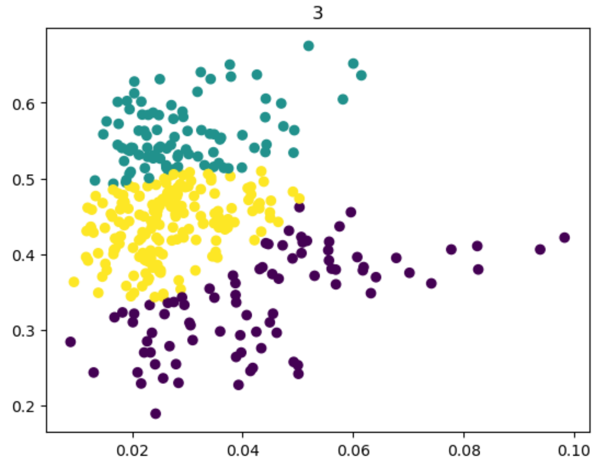
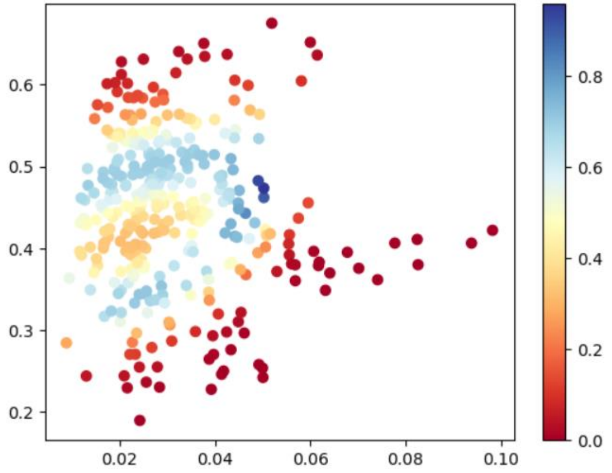
Data exploration: Gaussian mixtures (soft clustering)

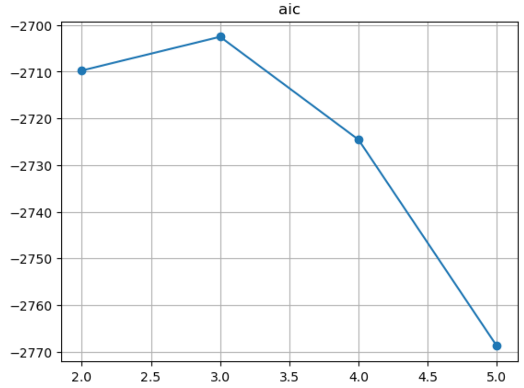


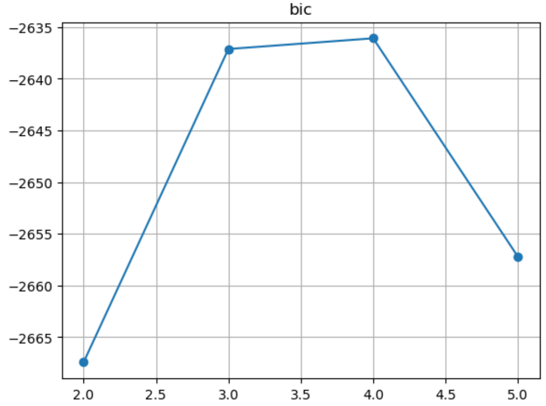
840 nm

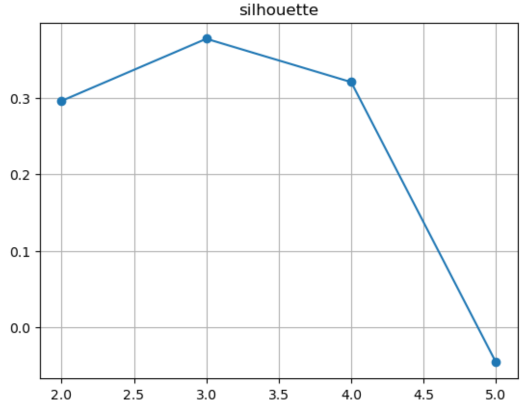
450 nm



Cluster uncertainty







- **Take into account more complex cluster shapes than circular (K-means)**

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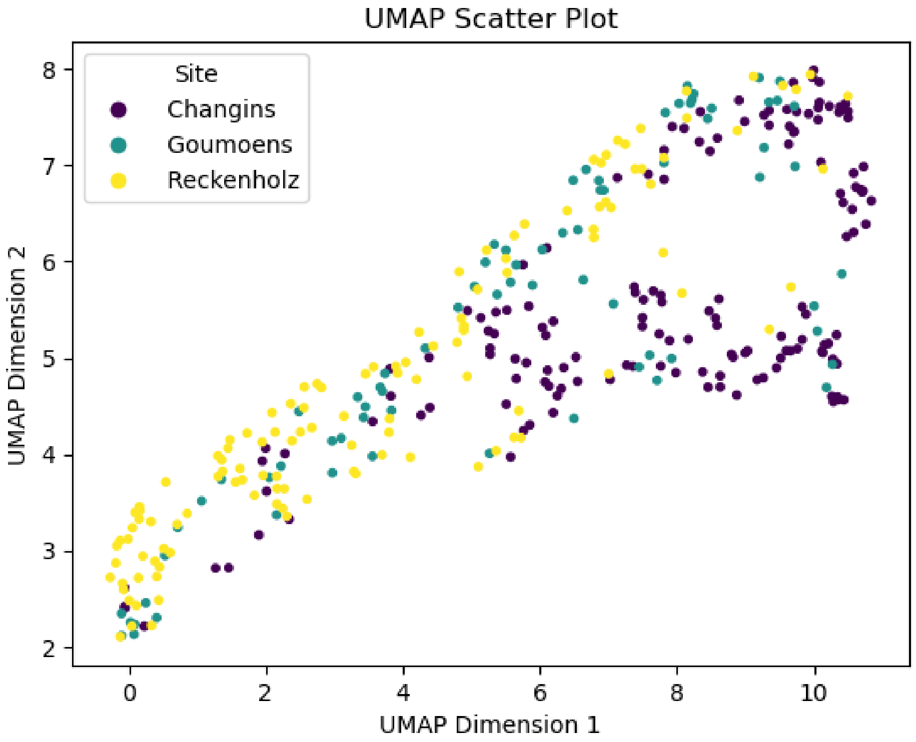
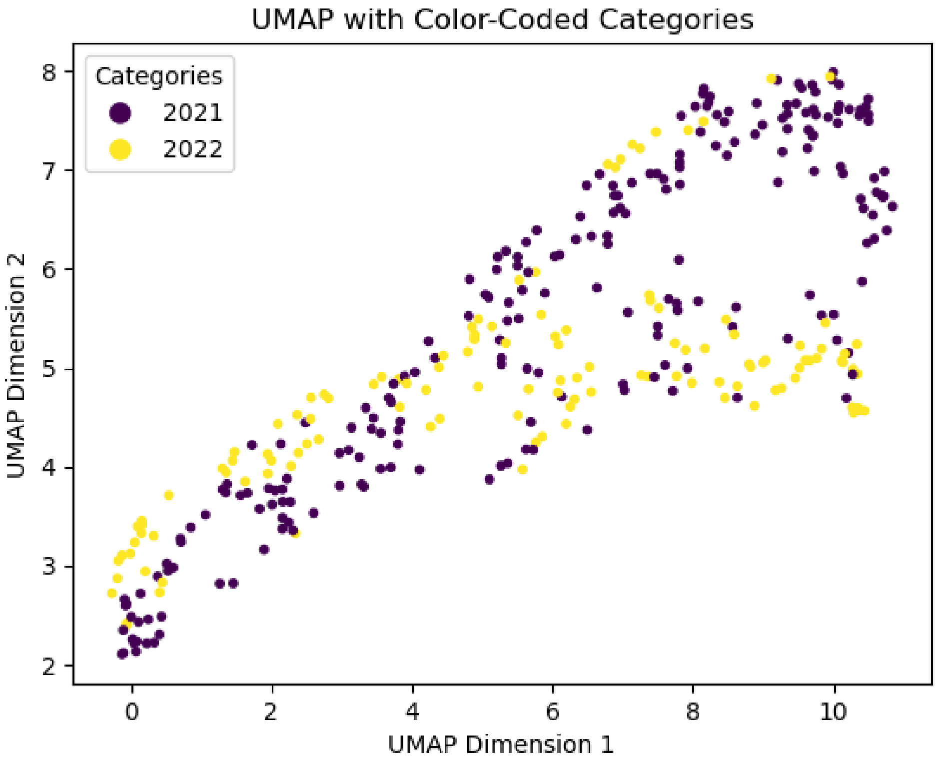
Data exploration: umap





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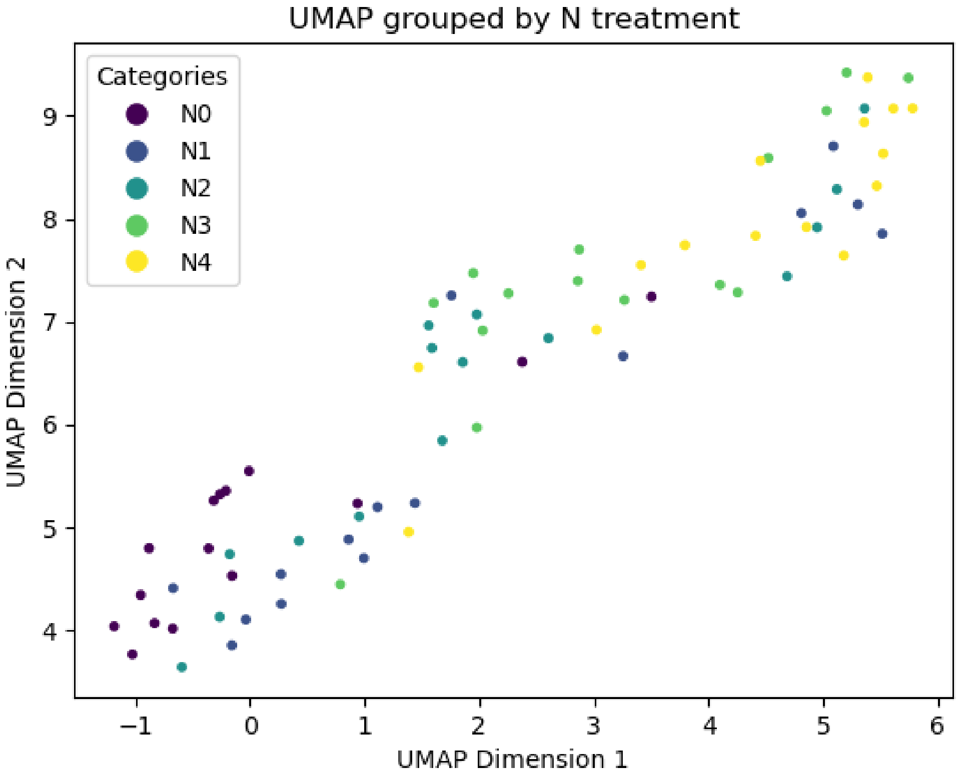
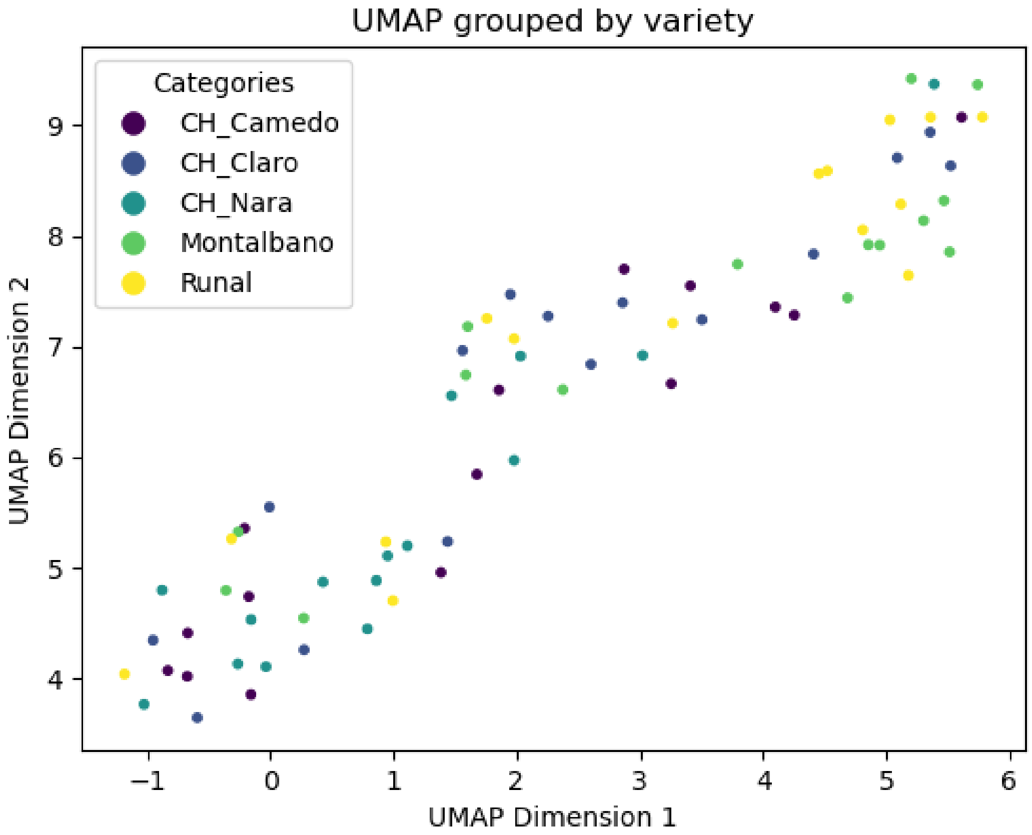
Data exploration: umap-focus on Changins 2022





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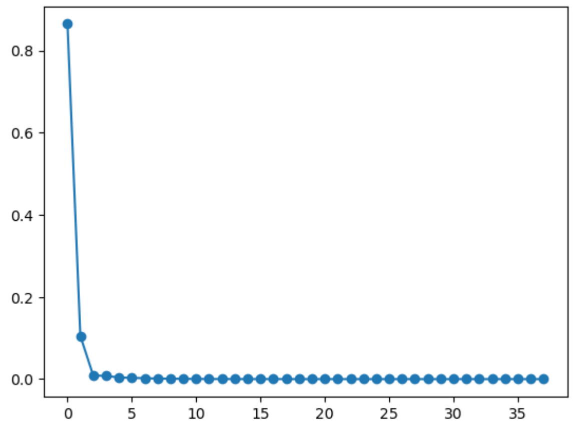
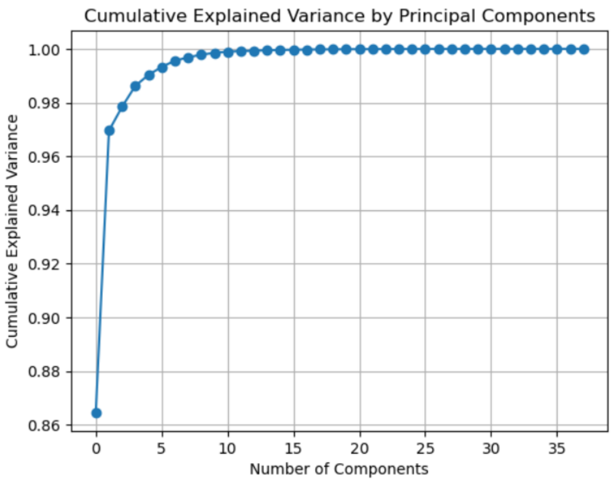
Data exploration: PCA





	V_1	V_2	V_3	V_4	V_5	V_6	V_7	V_8	V_9	V_10	...	V_29	V_30	V_31	V_32
rflt_400	0.002937	0.035984	-0.002985	0.036265	-0.066545	-0.077143	0.047143	0.018090	0.027047	-0.030372	...	-0.314811	0.013153	0.370203	-0.570470
rflt_450	0.004546	0.057737	0.008797	0.048449	-0.083053	-0.093928	0.058513	0.031172	0.033828	-0.038866	...	-0.097061	0.031067	-0.051995	0.439703
rflt_500	0.007968	0.075280	0.011633	0.057094	-0.102647	-0.111227	0.070736	0.038209	0.045630	-0.059384	...	0.001776	0.045085	-0.137613	0.450820
rflt_550	0.004938	0.118608	0.100272	0.041700	-0.076588	-0.132578	0.133371	0.025159	0.008326	-0.070819	...	0.464148	-0.161390	-0.025780	-0.243287
rflt_600	0.018468	0.136195	0.055064	0.063748	-0.126743	-0.139727	0.104721	0.041003	0.076547	-0.104400	...	0.177287	-0.002736	-0.130536	-0.221454
rflt_650	0.024707	0.141009	0.020273	0.078288	-0.151596	-0.132552	0.071822	0.055425	0.113306	-0.113475	...	-0.030904	0.120243	-0.309854	-0.225976
rflt_700	0.022719	0.176140	0.104292	0.057160	-0.127722	-0.154214	0.136993	0.031696	0.086213	-0.128917	...	-0.135049	-0.047044	0.202034	0.128728
rflt_710	0.005987	0.192111	0.219704	0.011086	-0.058324	-0.144916	0.194052	-0.000885	0.026911	-0.131047	...	-0.078937	-0.051935	0.400239	0.239990
rflt_720	-0.023342	0.190195	0.329054	-0.035184	0.022756	-0.115419	0.246817	-0.045449	-0.020716	-0.097410	...	-0.127544	-0.031272	-0.026472	0.001404
rflt_730	-0.077068	0.152240	0.411113	-0.068129	0.120301	-0.045753	0.256434	-0.071563	-0.090646	-0.021463	...	-0.054480	0.214311	-0.510202	-0.139891
rflt_740	-0.152834	0.071806	0.380125	-0.038900	0.173887	0.054169	0.161227	-0.040682	-0.175539	0.090713	...	0.178868	-0.147663	0.331254	0.042661
rflt_750	-0.222108	-0.014992	0.241446	0.043583	0.144238	0.120612	-0.003116	0.014278	-0.249012	0.255482	...	-0.165143	0.008243	0.025910	0.019577
rflt_760	-0.259550	-0.056748	0.115213	0.092566	0.044302	0.060705	-0.063564	0.019648	-0.047796	0.043965	...	0.085799	0.072182	0.095962	0.029375
rflt_770	-0.278402	-0.076261	0.073083	0.133530	0.008369	0.075799	-0.126264	0.056414	-0.127857	0.132030	...	0.083548	0.064112	-0.139257	0.047678
rflt_780	-0.284698	-0.080844	0.051317	0.147931	-0.025486	0.047185	-0.127509	0.068652	-0.105174	0.070686	...	0.183179	0.033072	0.105926	-0.091678
rflt_790	-0.288159	-0.080257	0.037642	0.151115	-0.061858	0.003719	-0.104245	0.053524	-0.021094	-0.036496	...	-0.215291	-0.330882	-0.070489	-0.058744
rflt_800	-0.291212	-0.080241	0.033173	0.157454	-0.080462	-0.012503	-0.093401	0.051798	-0.008328	-0.066501	...	-0.274390	-0.159398	-0.253548	0.038784
rflt_850	-0.296626	-0.073656	0.020933	0.160679	-0.134902	-0.071902	-0.069440	0.053835	0.047964	-0.159894	...	0.080215	0.707552	0.197408	0.016602
rflt_900	-0.296011	-0.058551	0.011742	0.145246	-0.168055	-0.097280	-0.043212	-0.042513	0.242654	-0.185614	...	0.148816	-0.454504	-0.026414	0.022098
rflt_950	-0.249193	0.007015	0.095887	0.063978	-0.050155	0.033271	-0.047558	-0.215876	0.580823	0.068516	...	-0.024967	0.096911	0.030991	-0.013949
rflt_1000	-0.221344	0.052433	-0.220139	-0.169310	0.070945	-0.052127	0.170324	0.011850	-0.180992	-0.034090	...	-0.045098	0.002954	0.015247	-0.014242
rflt_1050	-0.258284	0.012576	-0.313951	-0.141051	-0.033743	-0.144897	0.224923	0.084717	-0.242277	-0.161996	...	0.012214	0.006920	-0.014762	0.018567
rflt_1100	-0.261066	0.015344	-0.341905	-0.131394	-0.048759	-0.162334	0.248113	0.035208	-0.147742	-0.133742	...	-0.004369	0.022071	0.022281	-0.015644
rflt_1150	-0.182186	0.125109	-0.177318	-0.205285	0.048684	0.042876	0.155912	-0.196696	0.381576	0.250415	...	0.039289	0.045725	0.026331	0.011381
rflt_1200	-0.134697	0.167963	-0.061158	-0.194213	0.145048	0.106900	0.001842	-0.009889	0.045947	0.031876	...	-0.164195	0.045232	-0.026473	-0.007882
rflt_1250	-0.144183	0.167683	-0.070284	-0.202348	0.144352	0.106196	0.008684	0.024206	-0.016463	-0.010005	...	0.433927	-0.070000	-0.027036	0.039075
rflt_1300	-0.137737	0.181770	-0.067180	-0.201547	0.131538	0.103304	0.011670	-0.011545	0.046018	0.005243	...	-0.329916	-0.080701	-0.022178	-0.038984
rflt_1350	-0.081059	0.223784	-0.060618	-0.151056	0.067630	0.086480	-0.000640	-0.083112	0.208114	0.205121	...	0.029125	0.006407	-0.002334	0.015347
rflt_1450	0.011202	0.227878	-0.103072	0.166558	-0.268382	-0.401319	0.014654	0.149950	-0.105201	0.733861	...	-0.001113	-0.017803	-0.011077	-0.002601
rflt_1500	0.016259	0.241944	-0.042922	0.086942	-0.118142	-0.025608	-0.123851	0.219955	0.020149	-0.118426	...	-0.014608	-0.007850	0.035438	0.014579
rflt_1550	0.001391	0.256196	-0.003615	0.008483	-0.061399	0.037940	-0.191749	0.202485	-0.008351	-0.131753	...	-0.052260	0.047501	-0.000355	-0.024791
rflt_1600	-0.013472	0.261232	0.004638	-0.027502	0.010186	0.088423	-0.193448	0.185481	-0.010470	-0.086758	...	-0.029999	-0.034136	0.015457	-0.008421
rflt 1650	-0.024138	0.265059	0.012019	-0.051561	0.037006	0.103989	-0.215153	0.144908	-0.025571	-0.065104	...	0.013342	0.004593	0.012563	0.004921

- ➢ **Most of the variance is explained by the first principal components**

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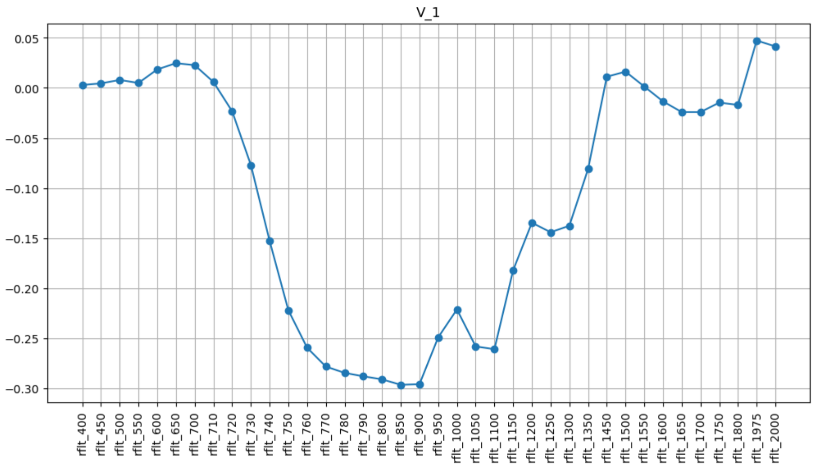
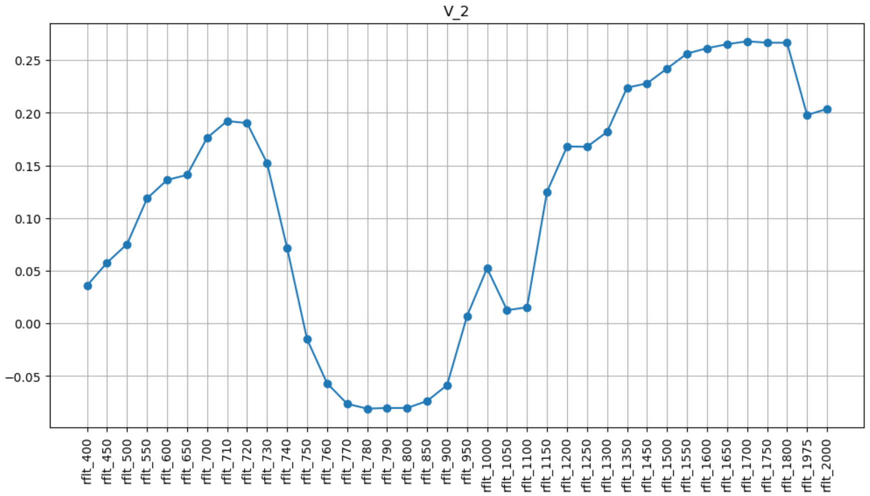
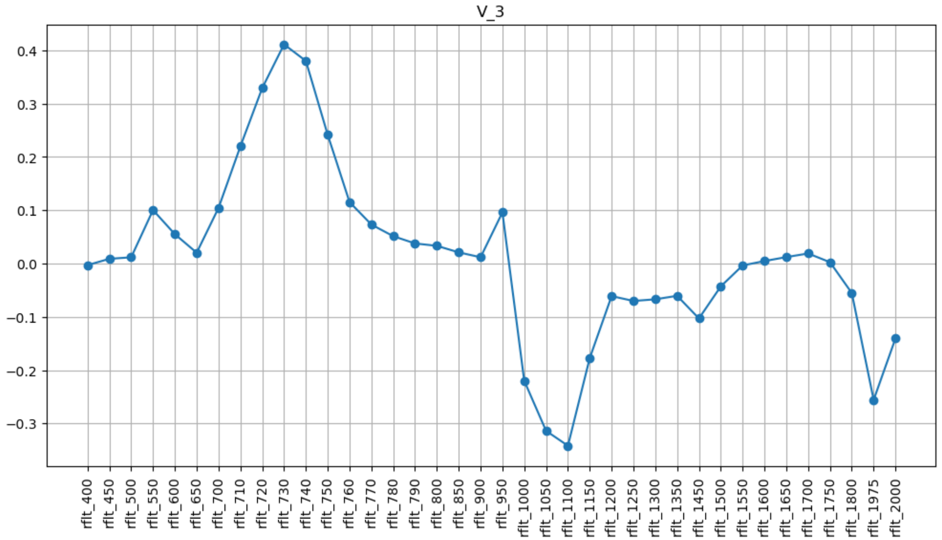
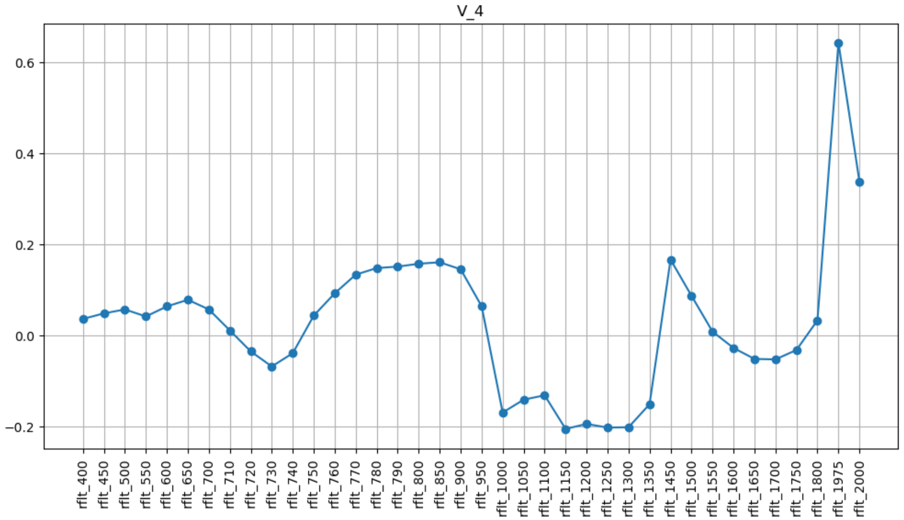
Data exploration: PCA





38 features at the beginning → 17 features selected





V1:
- 900 nm
- 850 nm
- 800 nm
- 790 nm
- 780 nm
- 770 nm

V2:
- 700 nm
- 710 nm
- 720 nm
- 1800 nm
- 1550 nm

V3:
- 730 nm
- 740 nm
- 1050 nm
- 1100 nm

V4:
- 1975 nm
- 2000 nm

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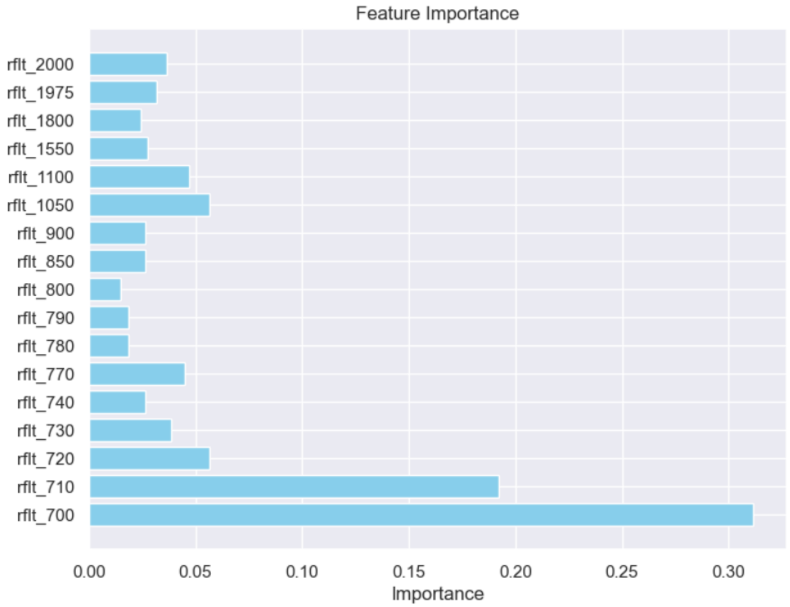
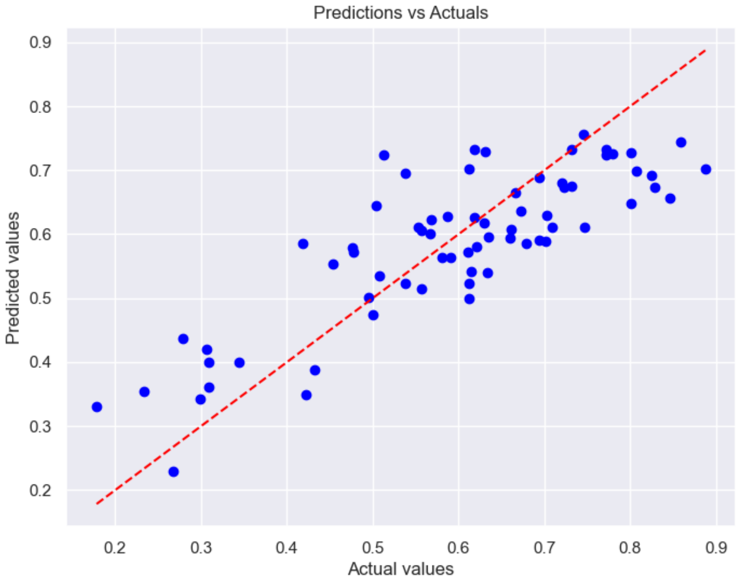
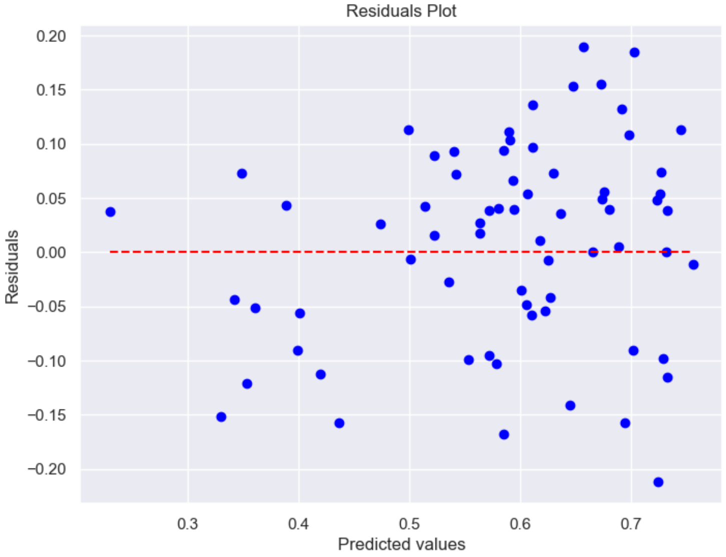
Random forest model with selected features





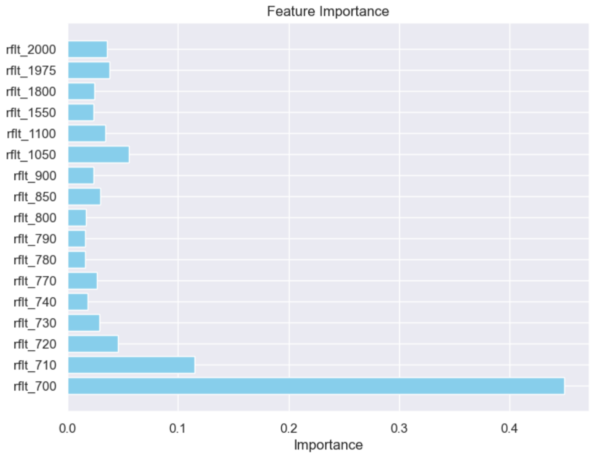



```
Training R-squared: 0.955
Test R-squared: 0.685
```

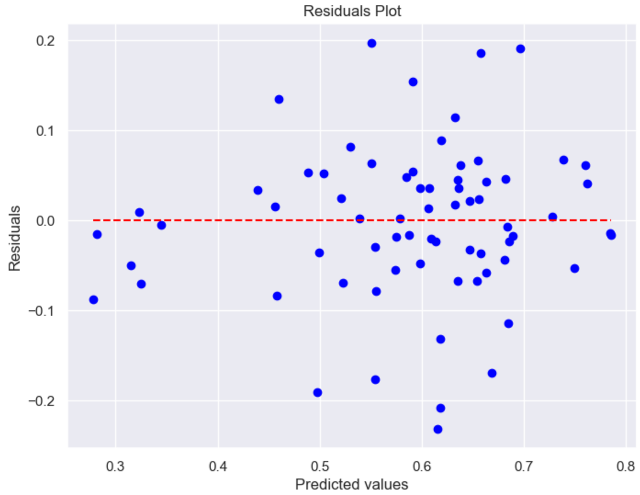
Random forest model with selected features: improvement tests

- Splitting train and test sets according to years or sites
- Reducing the tree depth (max_depth) and increasing the number of trees (n_estimators)

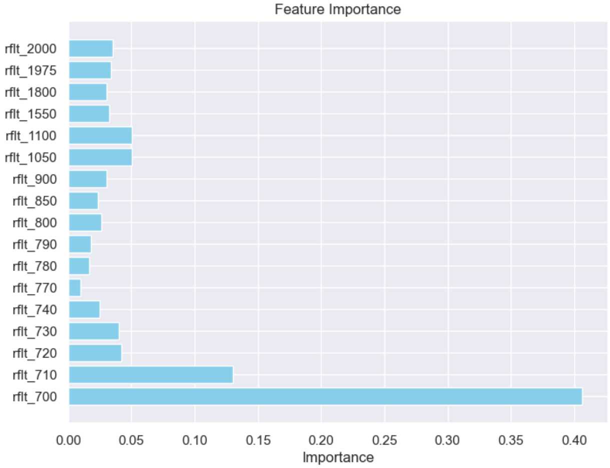
Sites




```
Training R-squared: 0.954
Test R-squared: 0.676
```



Years




```
Training R-squared: 0.950
Test R-squared: 0.706
```

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Conclusion

- **Field data can be noisy:**
  - Hyperspectral data is highly sensitive to weather conditions

- **Promising results in data exploration (PCA):**
  - Highlighted the importance of red-edge bands between 700 to 800 nm to be able to characterize winter wheat performance

- **Promising results in random forest:**
  - Highlighted the 700-710 nm part of the spectrum to explain grain yield differences
  - It was expected because in theory it is linked to Nitrogen (N) chlorophyll content which is in this context (different levels of N treatments) an important indicator of grain yield

- **Low performance in the test set compared to the training set:**
  - Overfitting?

- **Other agronomic parameter could be analysed to link to hyperspectral data**
  - Straw yield (positively correlated with grain yield)
  - Harvest index (indicates the ratio of grain on total plant weight (grain + straw)
  - Protein in grain (negatively correlated with grain yield)
  - Plant height (positively correlated with grain and straw yield; lodging effect)
  - Disease (can explain unexpected low yield)

Thank you for your attention

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