Impact of agricultural practices on soil organic carbon in Luxembourg

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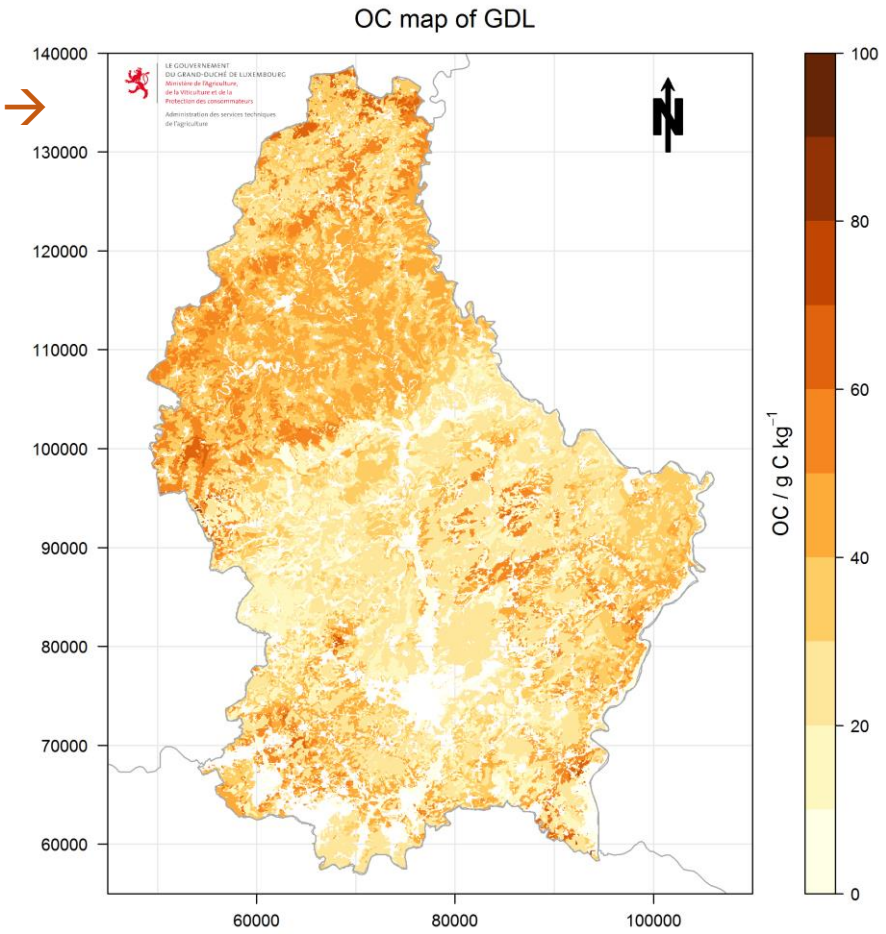
LE GOUVERNEMENT
DU GRAND-DUCHÉ DE LUXEMBOURG
Ministère de l'Agriculture, de la Viticulture et du Développement rural

Administration des services techniques de l'agriculture

SOC content and stocks maps for Luxembourg

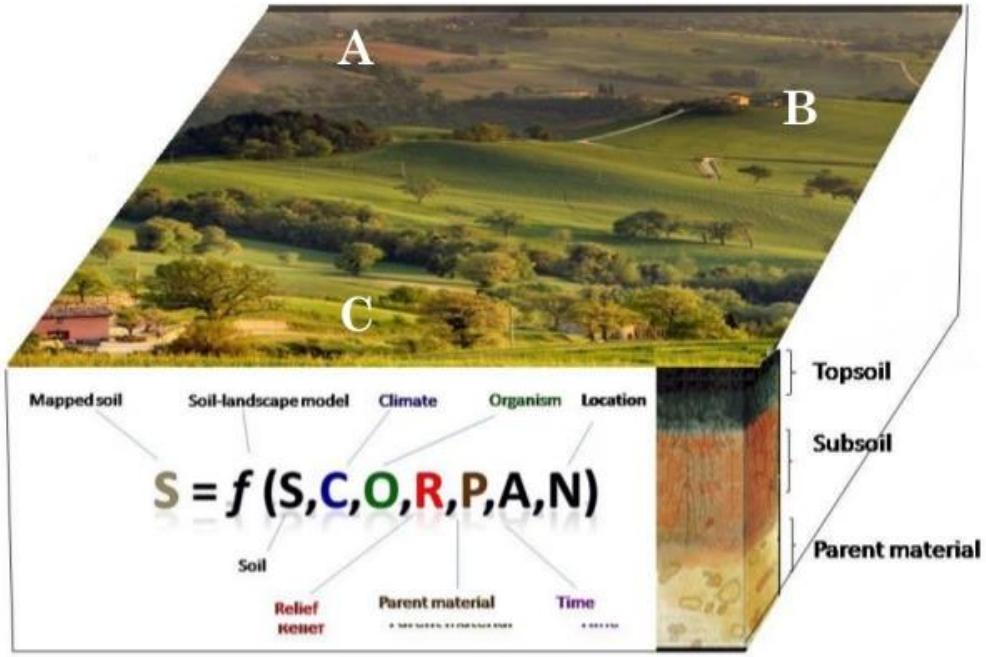
- SOC content and stock maps compiled in 2014
  - *forest, cropland, perm.grassland, vineyard*
- No Soil monitoring network exists
- Georeferenced soil data
  - SOC contents, BDAT routine soil testing
  - *Prime à l'entretien de l'Espace Naturel et de l'Environnement* - sols agricoles, viticoles (ASTA)
  - *Inventaire Forestier National* (Administration de la Nature et des Forêts) (1998-2001)

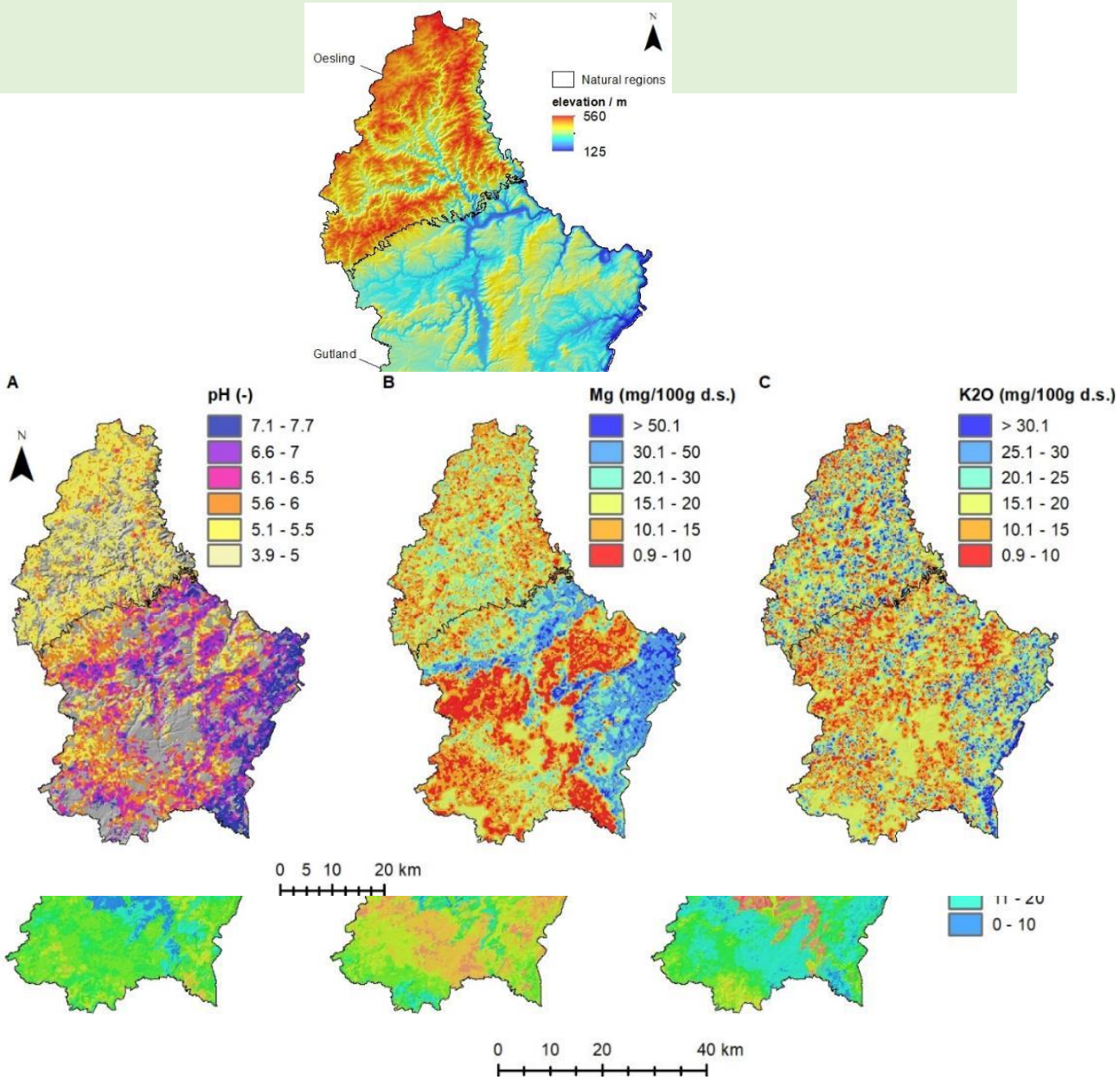
2012 – 2014 →



First SOC map; Stevens et al., 2014

Digital Soil Mapping





McBratney et al., 2003; Lagacherie, 2008

Available data for Luxembourg

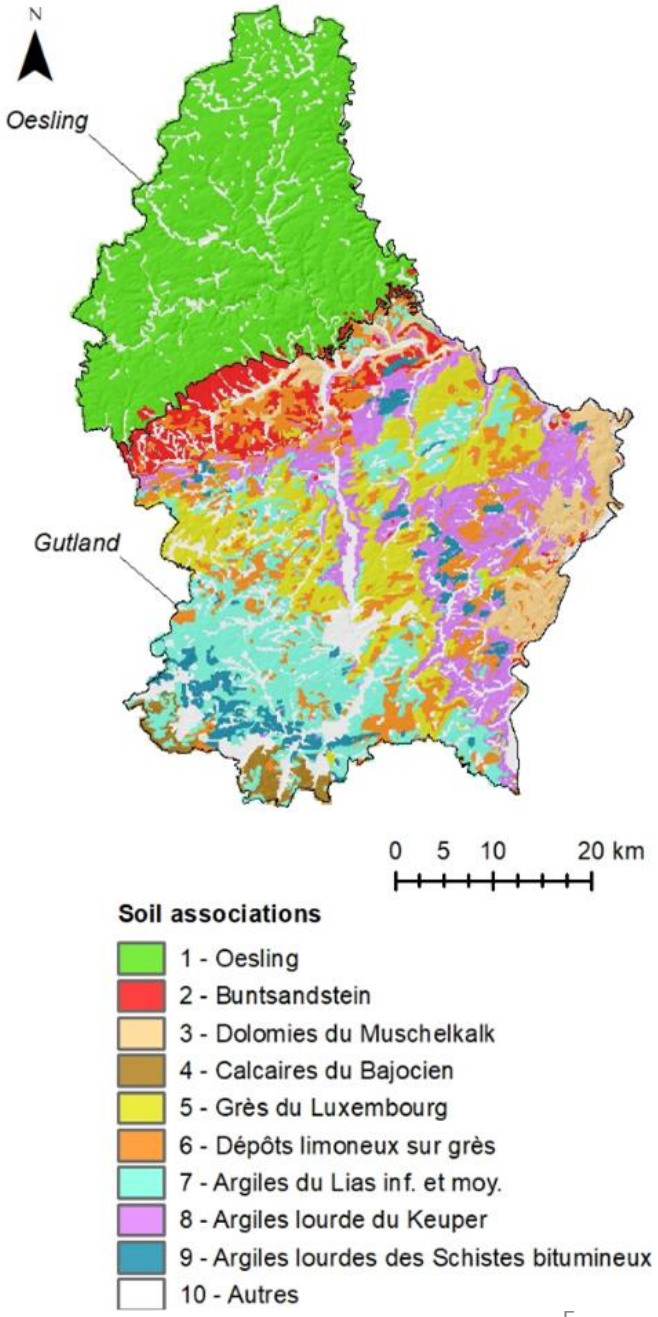
- BDAT historical (1900-1910): soil analyses on cropland (humic acid)
- BDSOL historical (1963-1974): soil profiles, soil augering horizons from soil survey (Walkley Black)
- BDSOL recent (2009 -) : soil profiles from soil survey (Dry Combustion)
- BDAT recent (2012 -) : soil analyses from agriculture/viticulture (Dry Combustion, composite sample)
- *Inventaire Forestier National (1998-2001): (Dry Combustion)*

- New and/or updated spatial covariates *(M. Steffen, 2019 - ASTA)*

Soils of Luxembourg

- 26 soil types in Luxembourg according to the major geological units *(1:100,000 soil map)*
  - Regrouped in 10 main soil associations based on mineralogy and texture

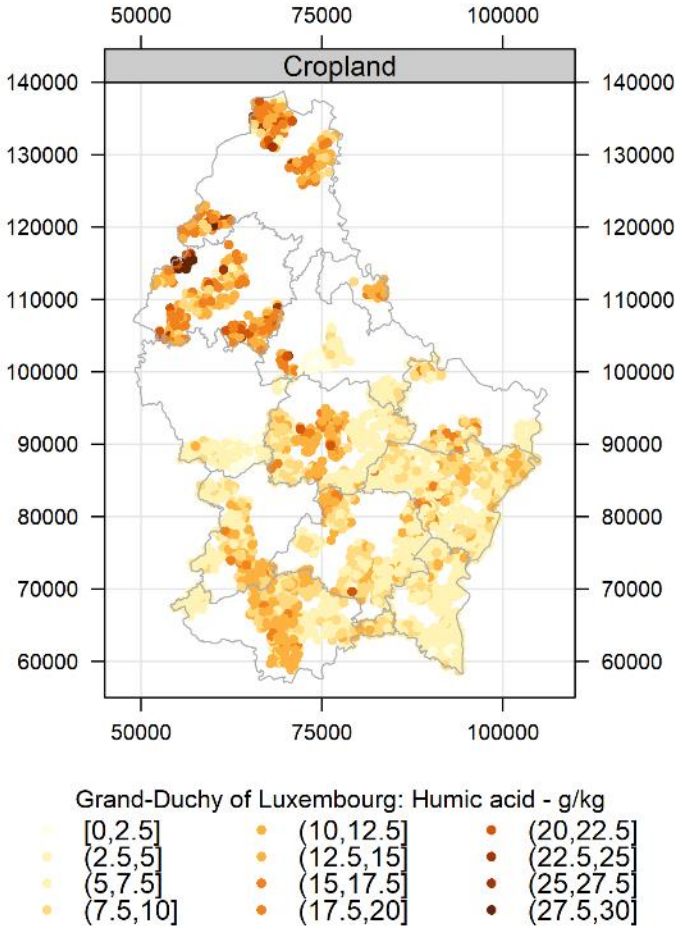
- 2 natural regions : Oesling and Gutland
  - Oesling → shallow stony silt loam soils *(skeletic dystric Cambisols)*
  - Gutland → clay loam - loam - silt loam soils, loamy sand and clay soils *(mainly Cambisols and Luvisols)*
  - 'Autres' → alluvium and colluvium

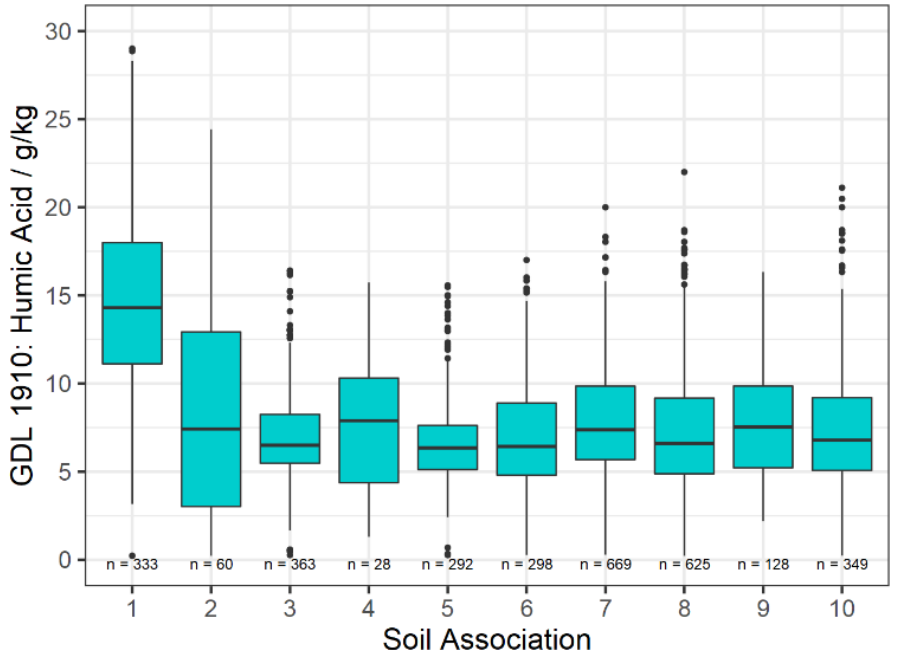


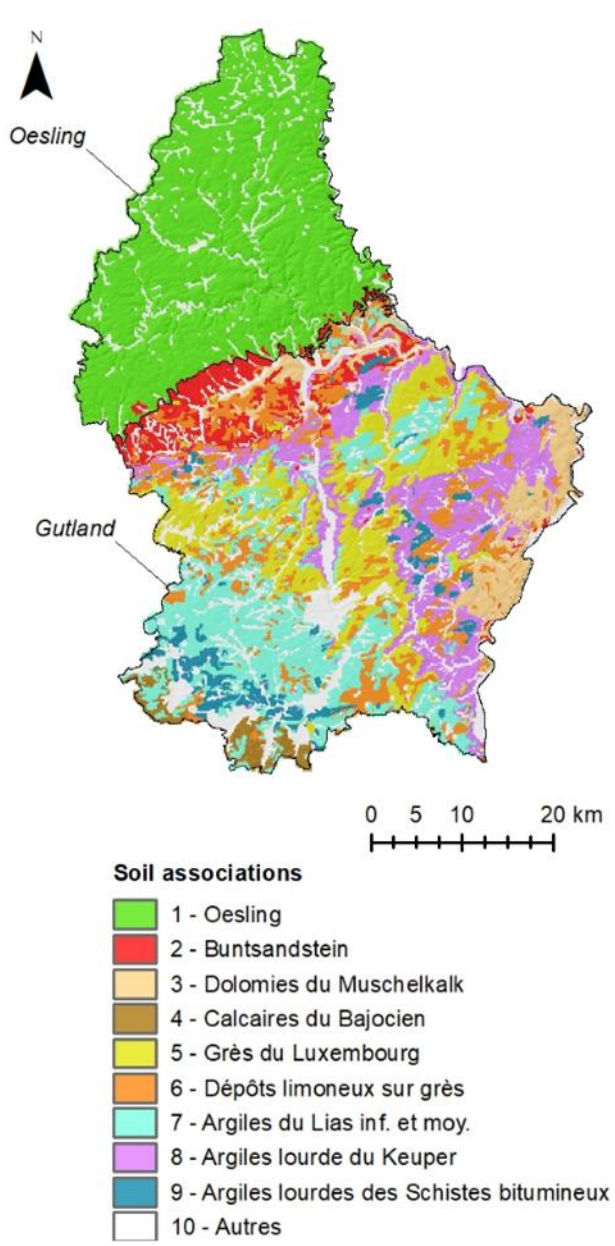
HISTORICAL SOC trends

Comparing historical and recent soil organic status

- **1900-1910: Humic acid content in croplands (in g/kg)**



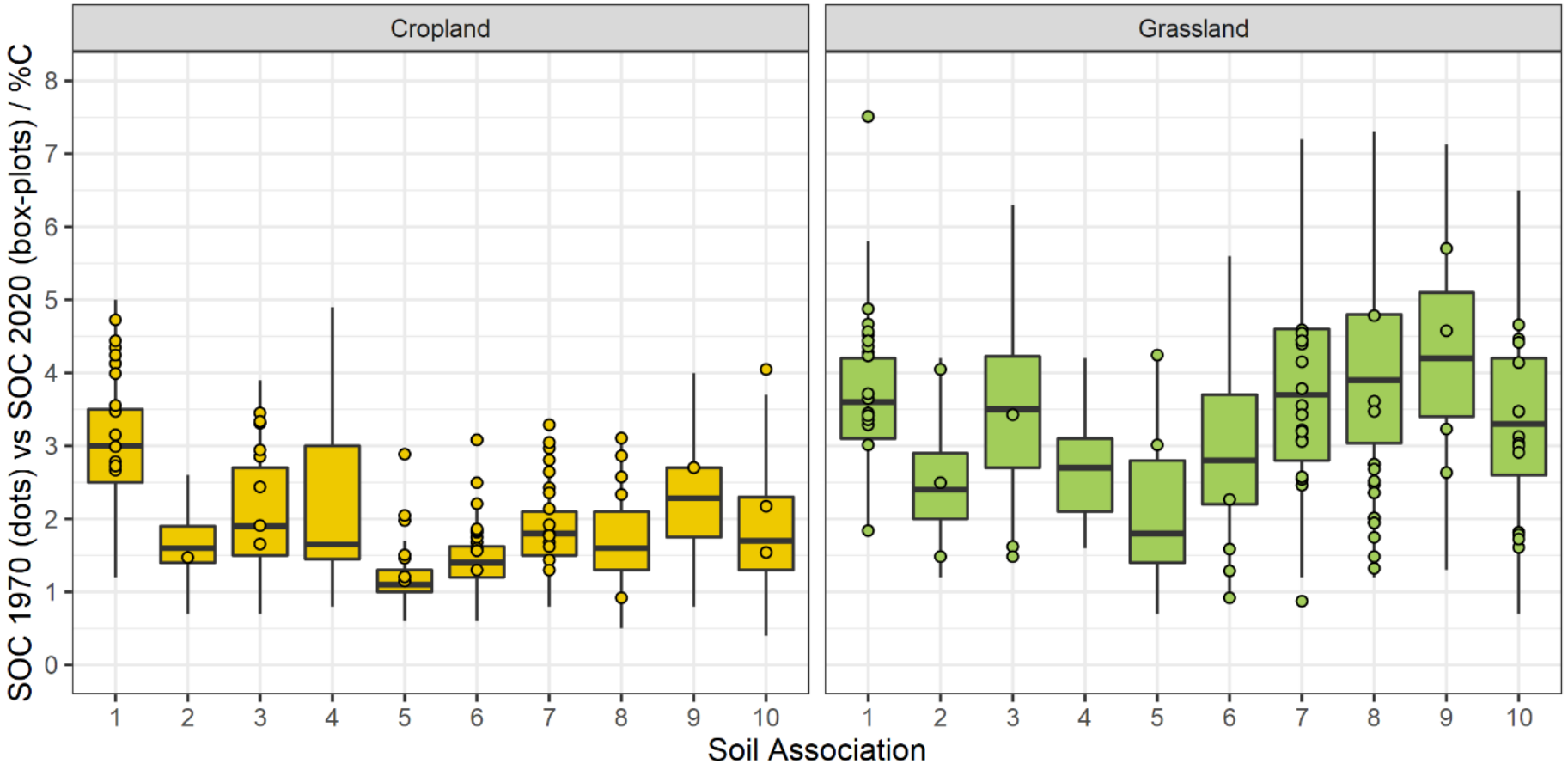


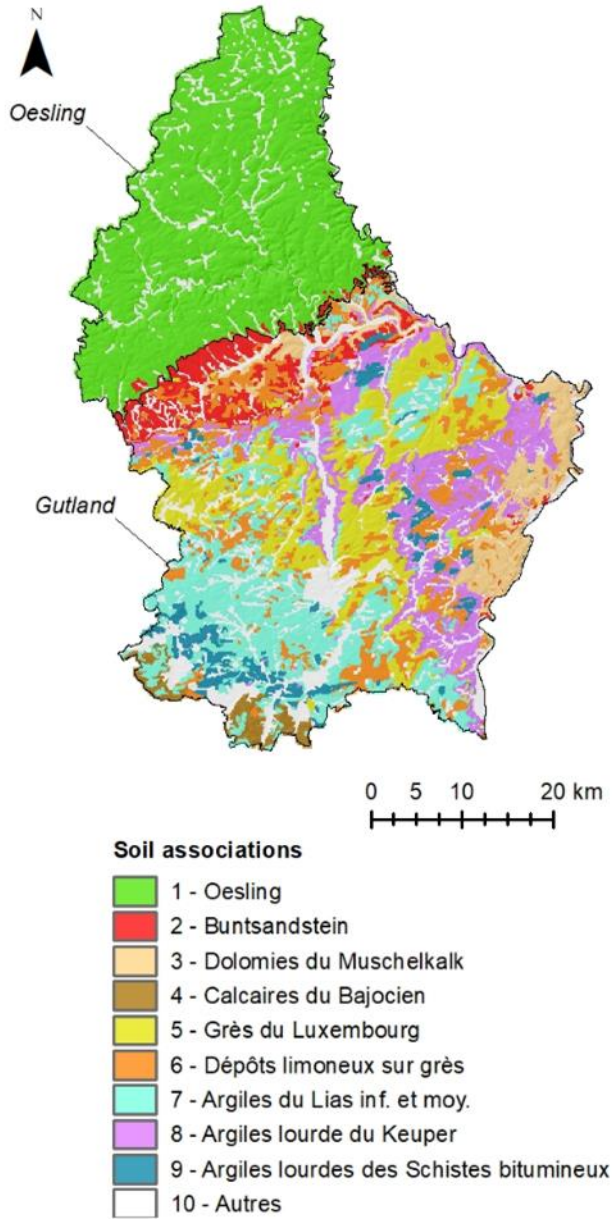


HISTORICAL SOC trends

Comparing historical and recent soil organic status

- **1963-1974: SOC in %C** **Points = 1963-1974; box-plots = 2012-2019**



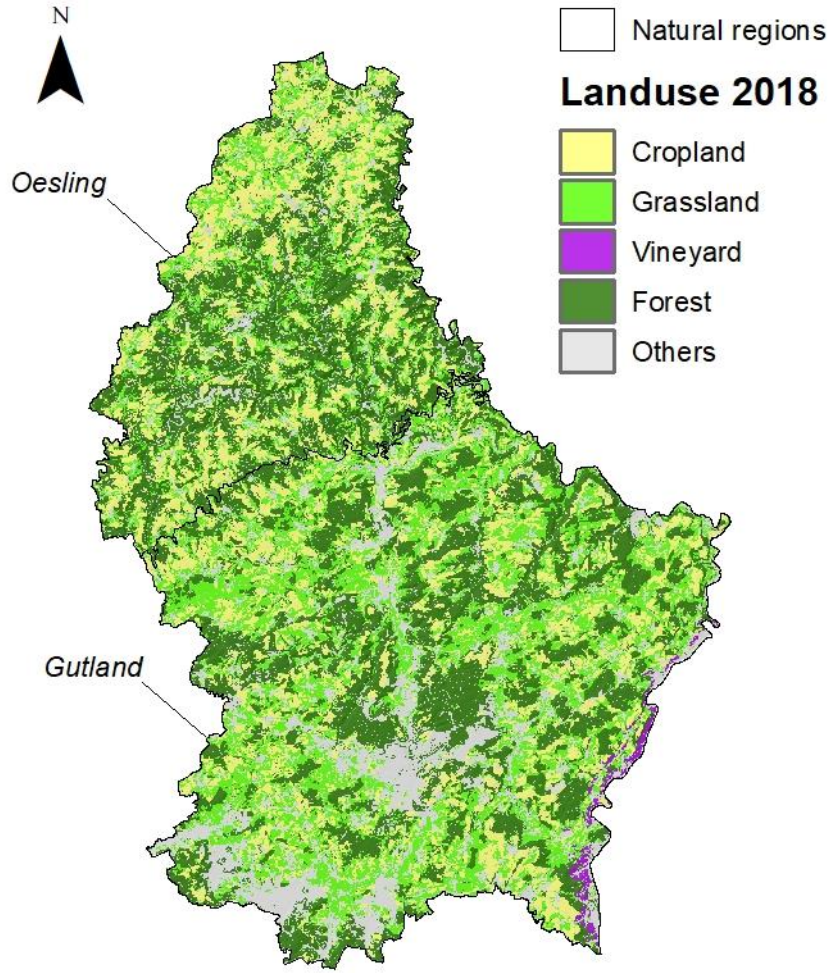


Not enough historical data for statistical analysis

Recent soil data available at ASTA

2012-2015 → 2016-2019

- Agricultural soils in cropland, permanent grassland , **vineyards**
- Forest soils: no recent inventory
- Improved data analysis compared to 2014



D'après Chartin et al., 2019

Sampling and analysis of SOC

Sampling:

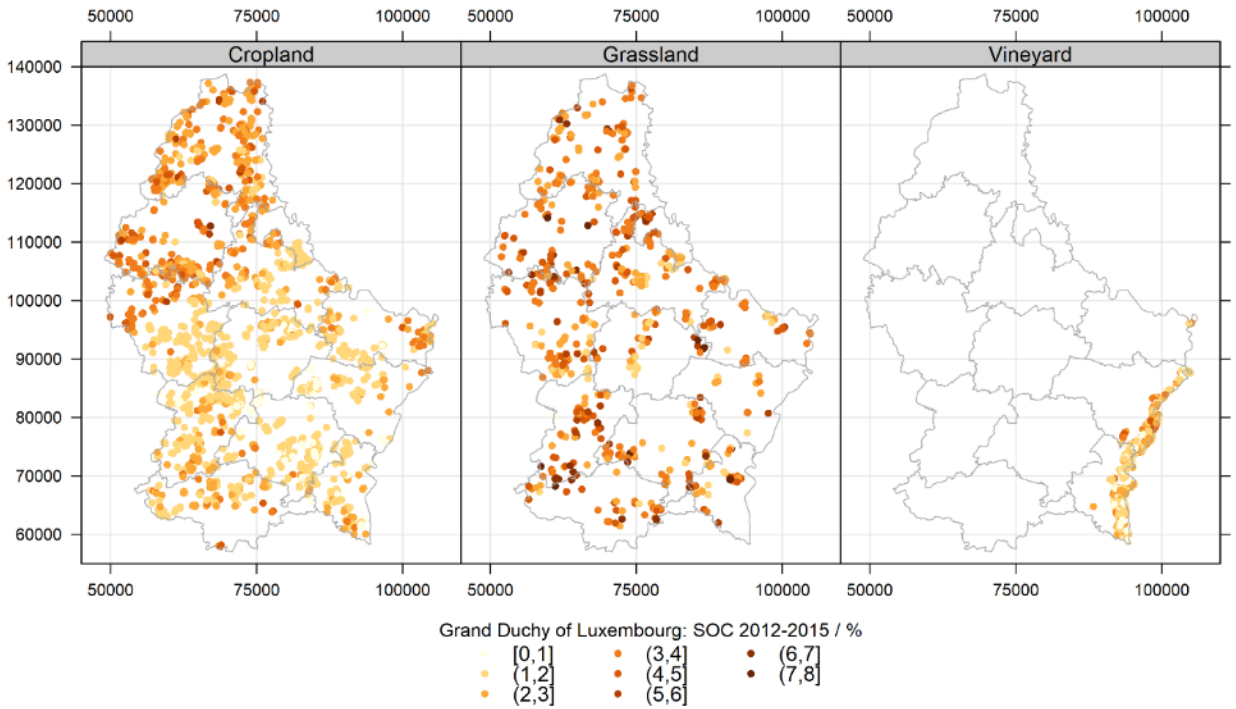
- Composite sample per field *(mean field size 1.85ha in 2019)*
- Sampling depth:
  - Croplands: 0-25cm
  - Permanent grassland: 0-15 cm
  - Vineyards: 0-30 cm

Laboratory:

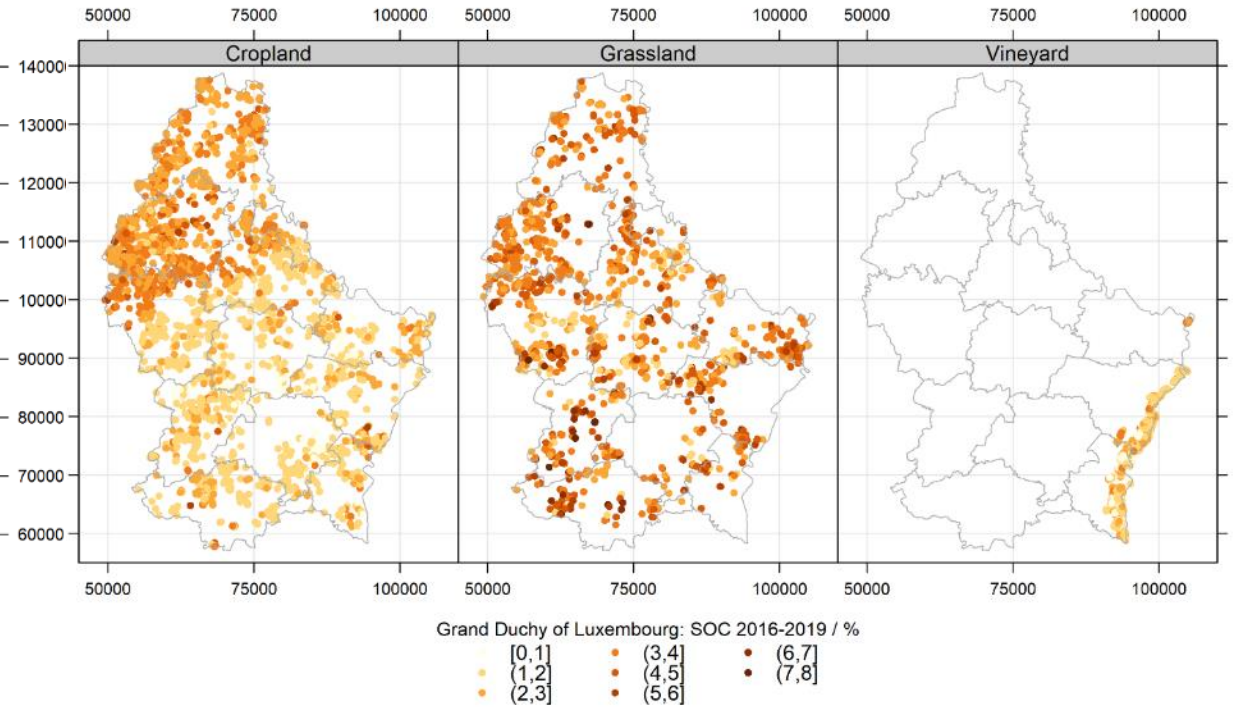
- Drying at < 40°C and sieving at 2mm *(ISO 11464)*
- SOC = CT – IC *(ISO 10694)*
  - CT : total C by dry combustion
  - IC: inorganic C acidification (H_3PO_4; 20%) + Infrared spectrometry of CO_2
  - ISO/IEC 17025

Recent SOC data

2012-2015



2016-2019



Chartin et al., 2022

Recent SOC trends : Digital Soil Mapping

- Generalized Additive Models

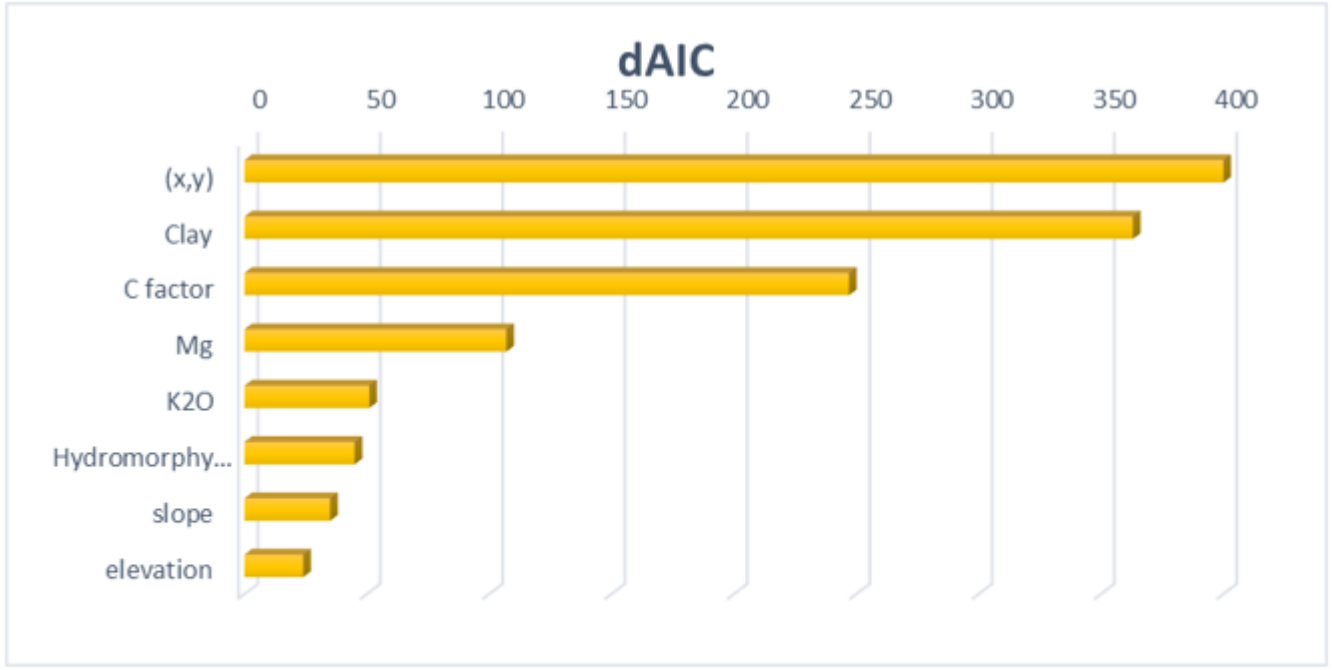
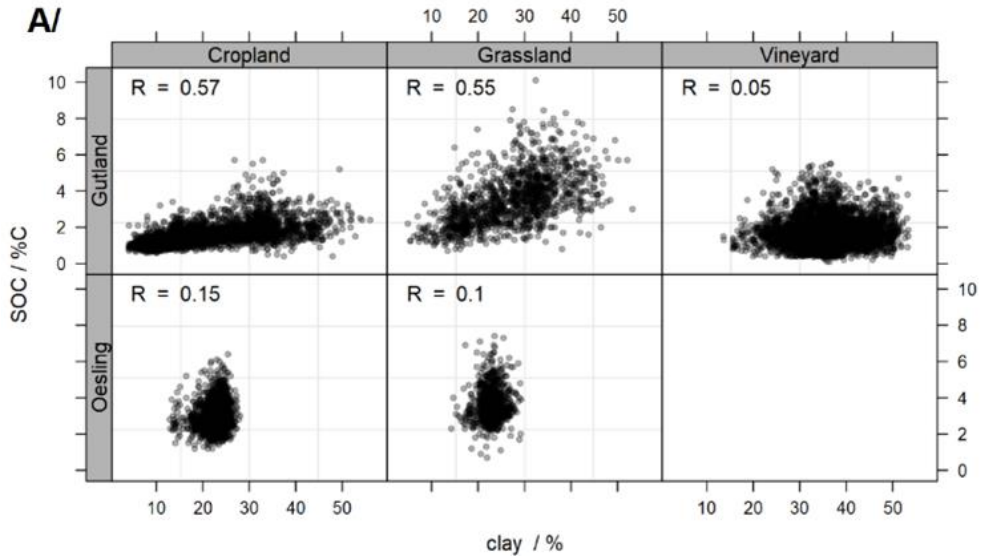


*Figure 4.19: Implication of covariates in the GAM fitted on topsoil SOC (%C for the 0-25cm depth) in **croplands** of Grand-Duchy of Luxembourg. dAIC represents the difference of AIC to the final model (Akaike Information Criterion; Akaike, 1974). Only the covariates showing a p-value < 0.05 in the final GAM model were kept in this Figure.*



Variance explained by the spatial models

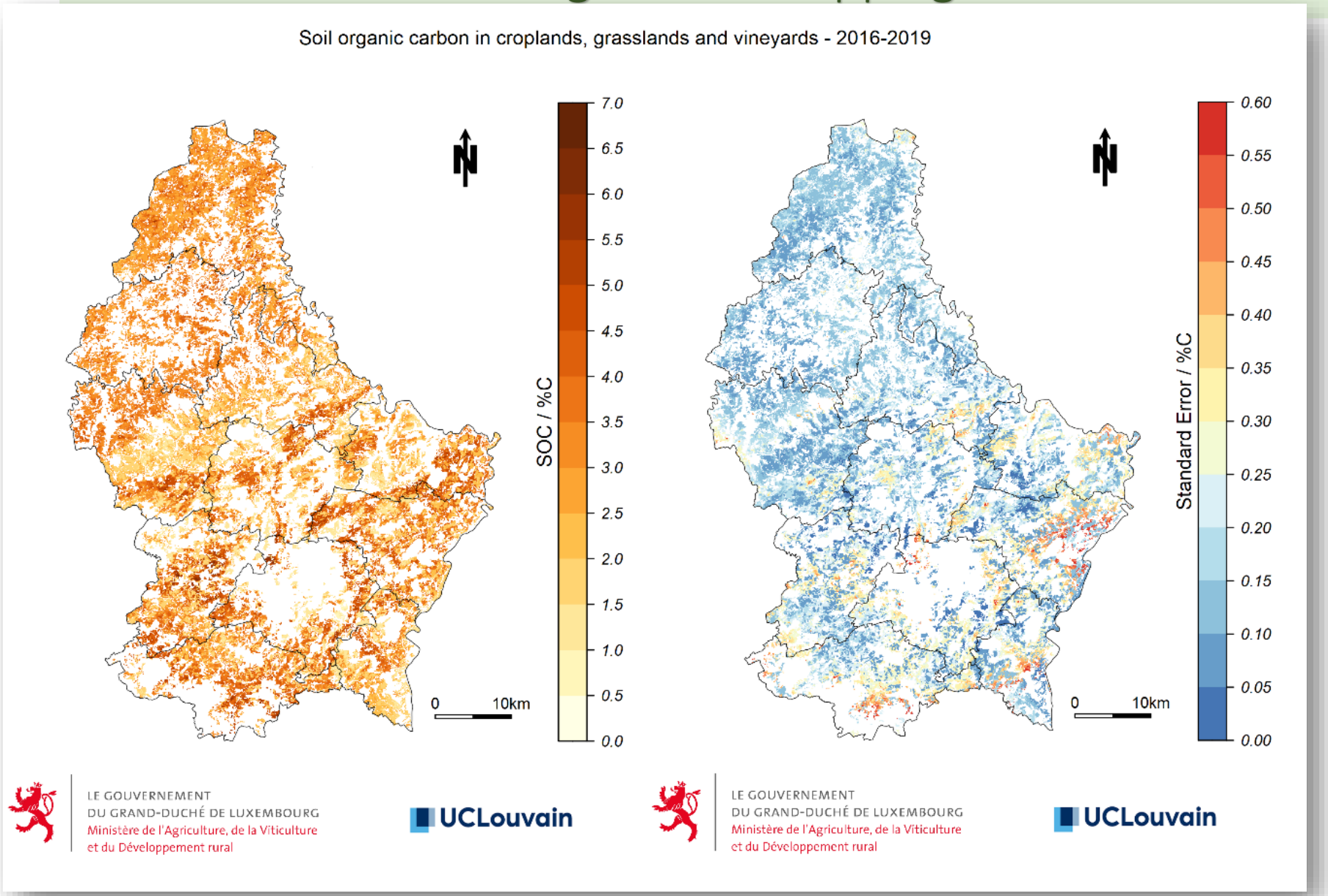
Cropland: ~75%

Grassland: ~40%

Vineyards: ~15%

Chartin et al., 2022

Recent SOC trends : Digital Soil Mapping



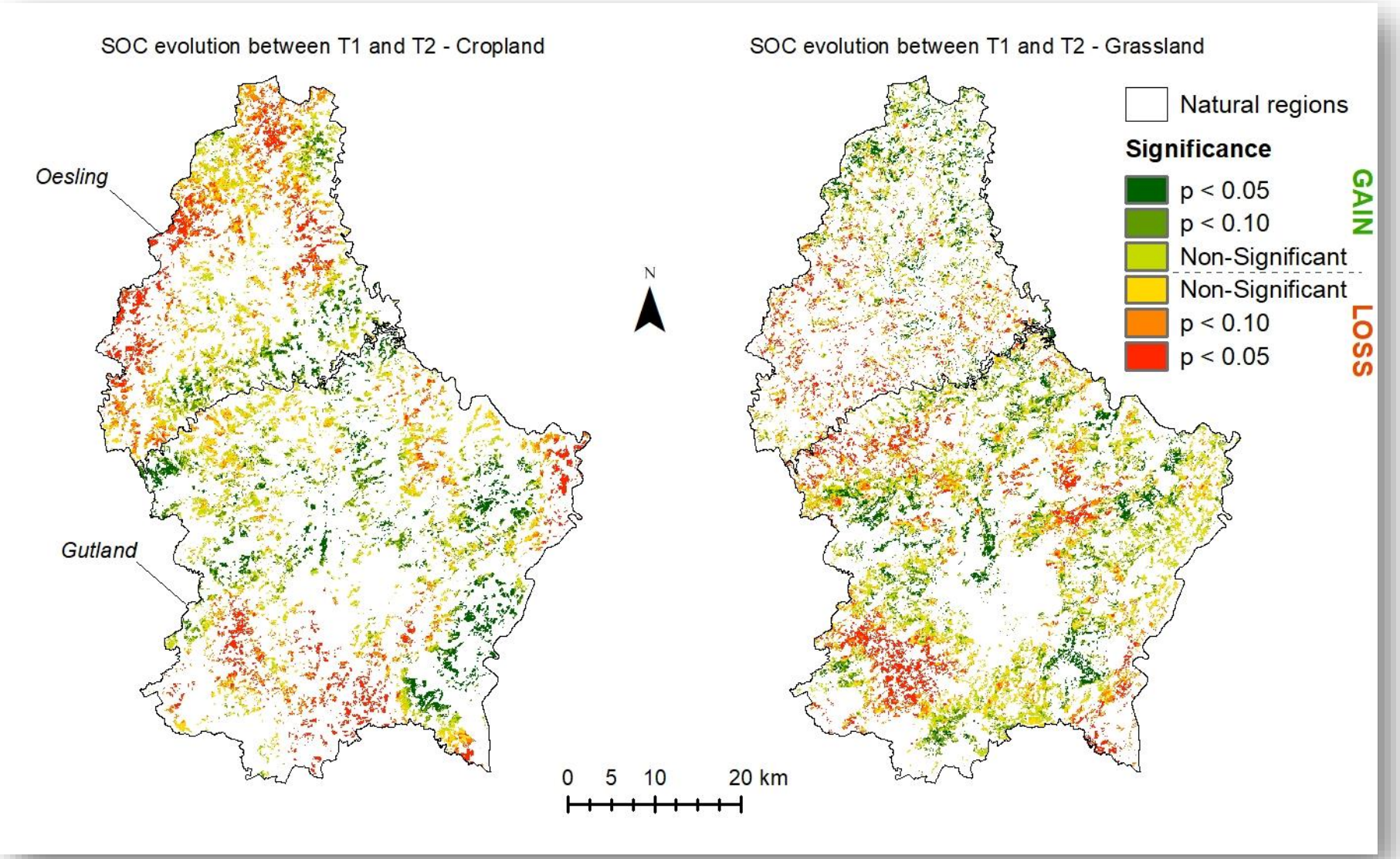
SOC- Mean (SE)

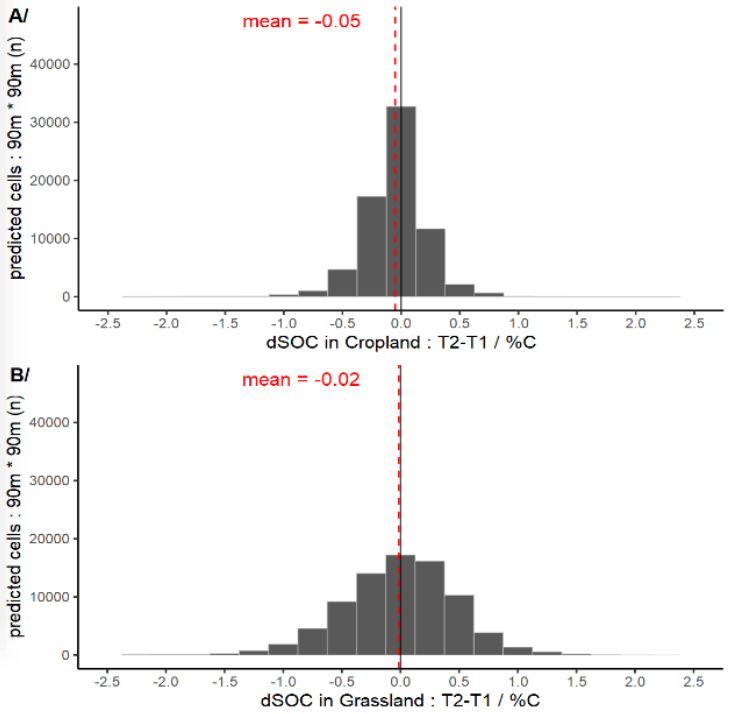
Cropland: 2.25(0.74)%C

Grassland: 3.57(0.76)%C

Vineyards: 1.74(0.31)%C

Recent SOC trends : Digital Soil Mapping





Shifting to SOC stocks

Improving SOC stock assessment compared to the method applied in 2014

Computing on the first 0-30 cm – *required by the IPCC*

$$SOCst.30 = SOC.30 \times d \times (1 - RM) \times BD$$

With:

- SOCst.30 = SOC stocks at 0-30 cm depth (Mg C.ha^{-1})
- SOC.30 = SOC content of Fine Earth at 0-30 cm (%C = g of SOC for 100 g of FE)
- D = depth (cm; here, 30)
- RM = Rock fragment content by Mass (g.g^{-1})
- BD = Bulk Density (g.cm^{-3})

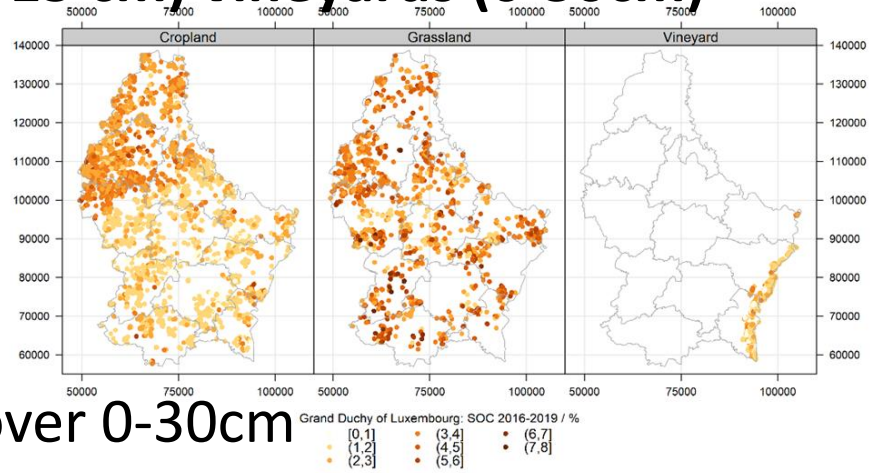
(Ellert and Bettany, 1995; Mikha et al., 2013; Orgill et al., 2013; Hobley et al., 2018)

SOC stocks workflow

$$SOCst.30 = SOC.30 \times d \times (1 - RM) \times BD$$

SOC content croplands (0-25cm) ; grasslands (0-15 cm) vineyards (0-30cm)

For all sampling points in BDAT



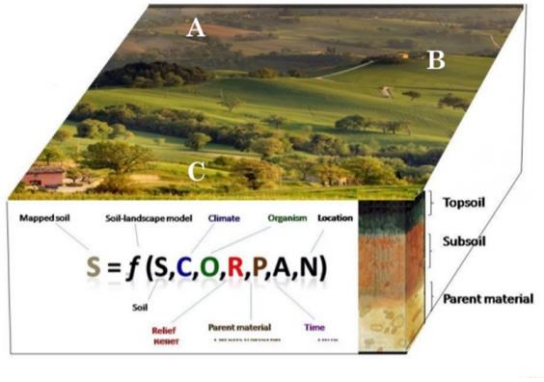
1: Standardization SOC contents by integration over 0-30cm

2: Estimate for BD

3: Estimate for RM

4: Calculate SOCst.30 with confidence limits for each sampling point

Digital soil mapping



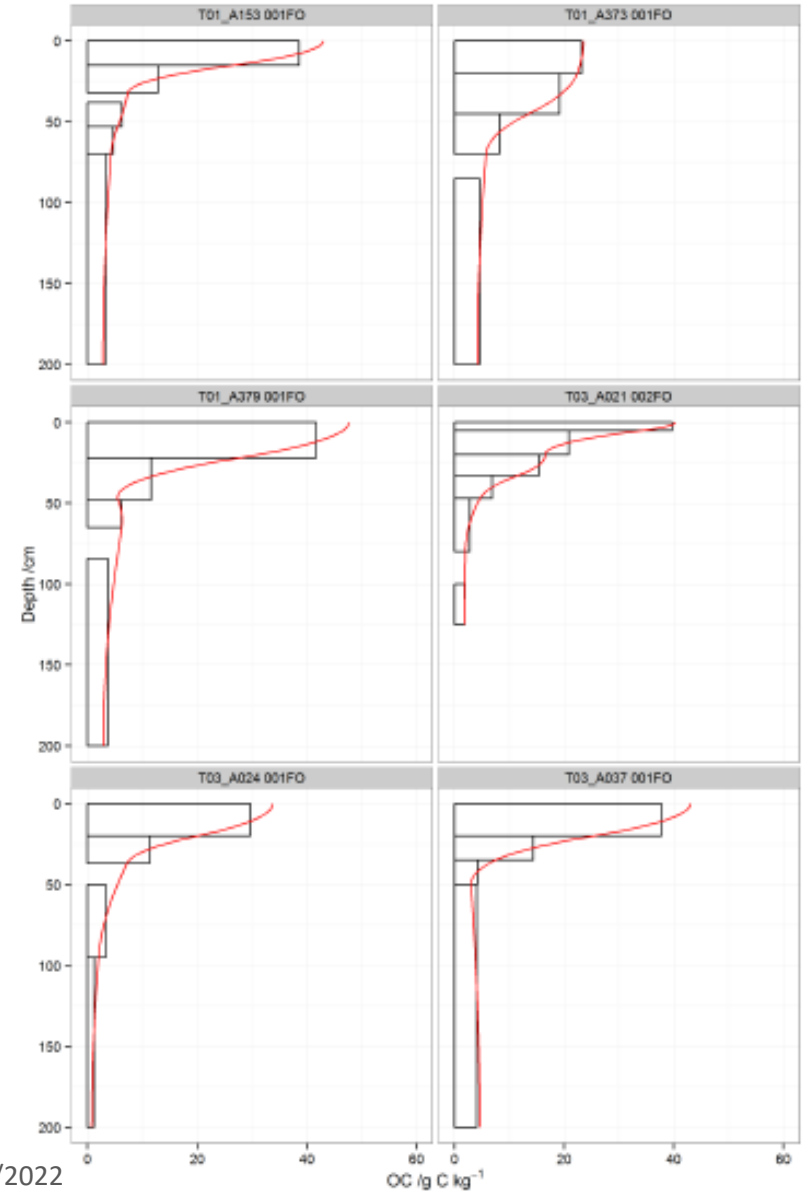
5: Spatial analysis on SOC stocks

1 SOC stocks integration over 0-30 cm

SOC.30 estimation

- Data:
  - BDSOL historical_1964-1973
  - BDSOL recent_2009-2019

- Mass Preserving Spline on SOC profiles and integration to 0-30cm



Bulk Density

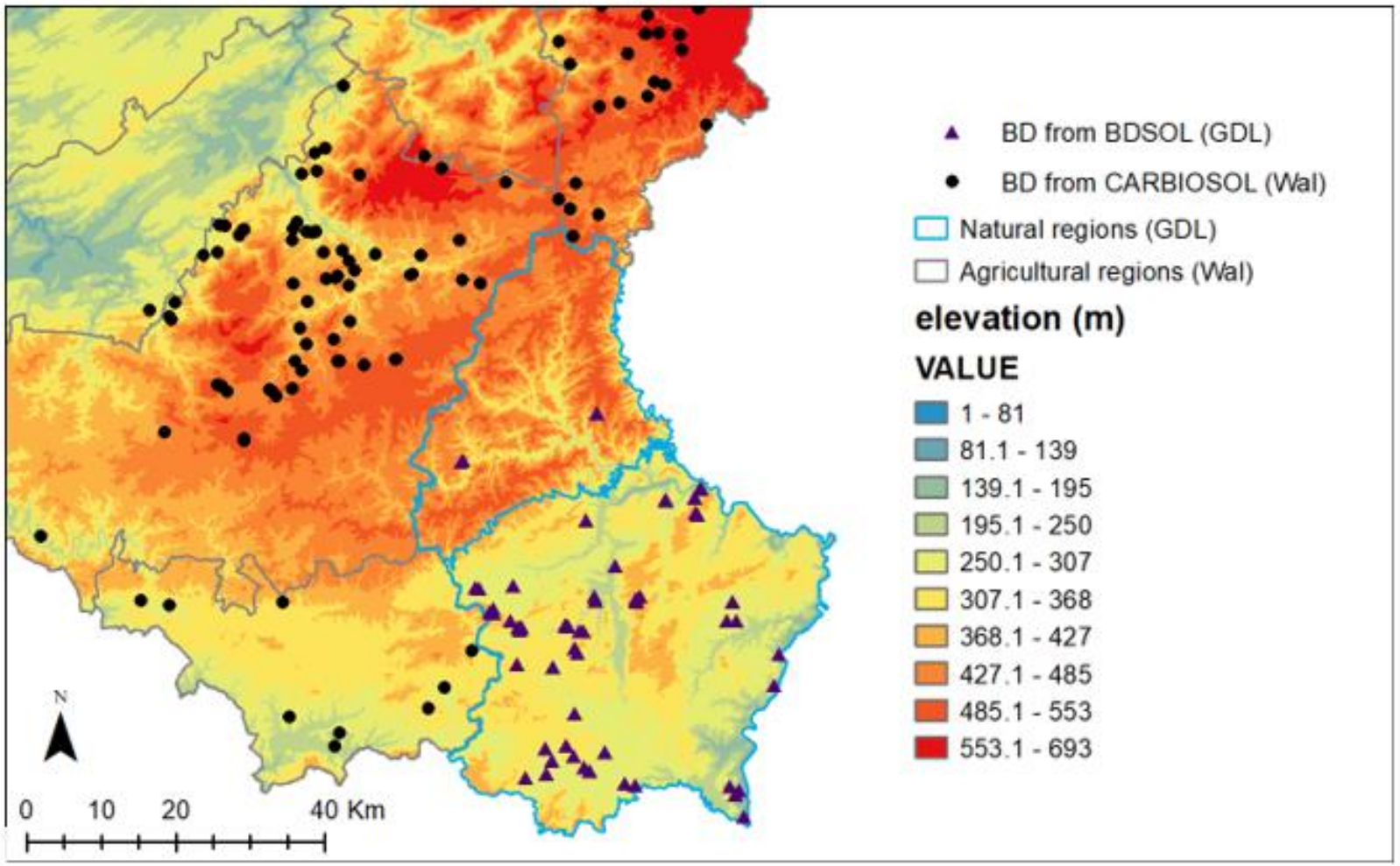
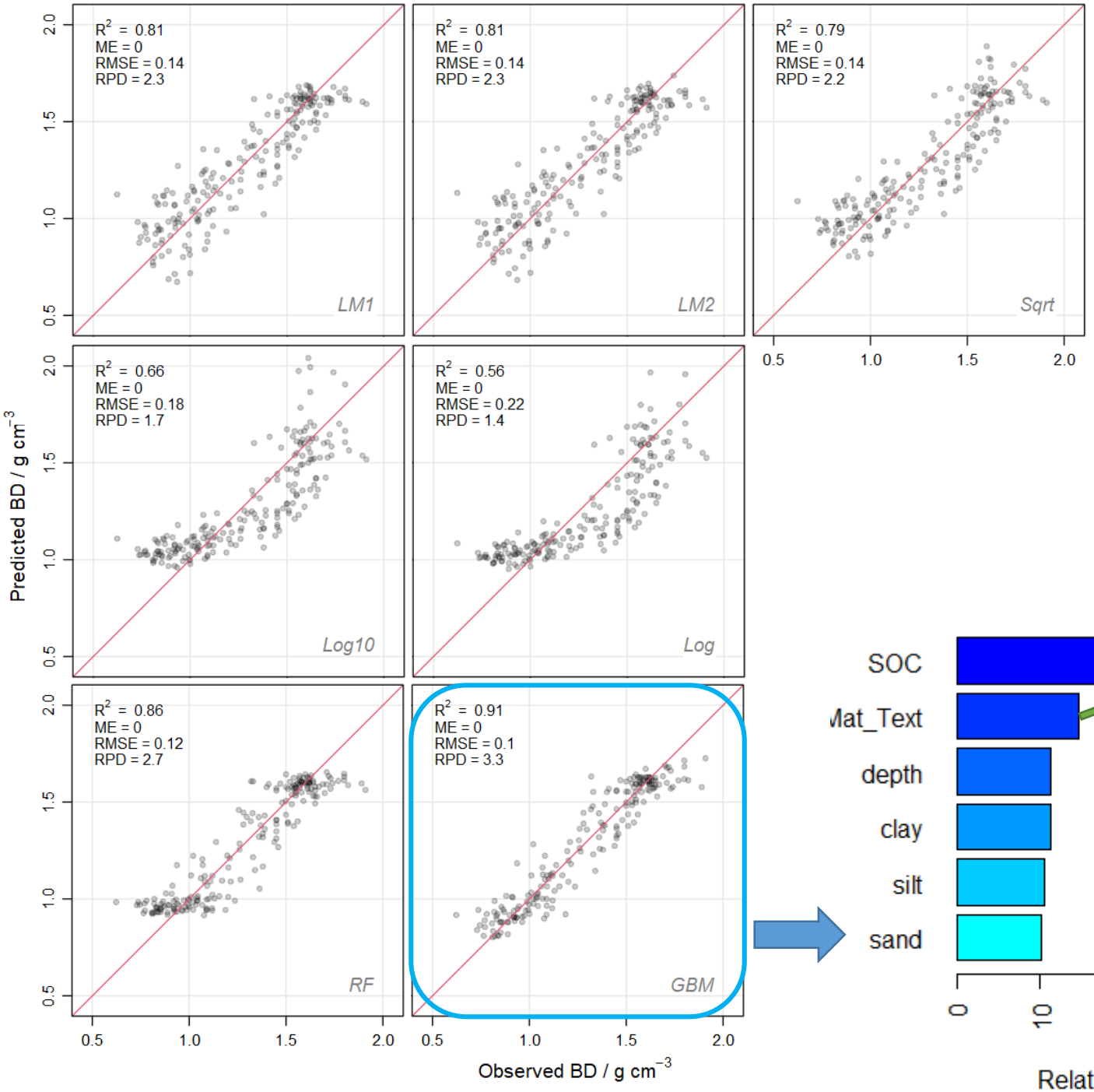
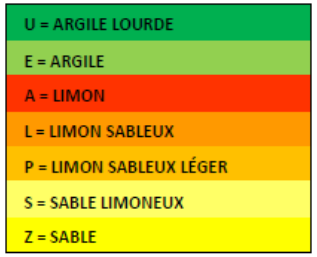


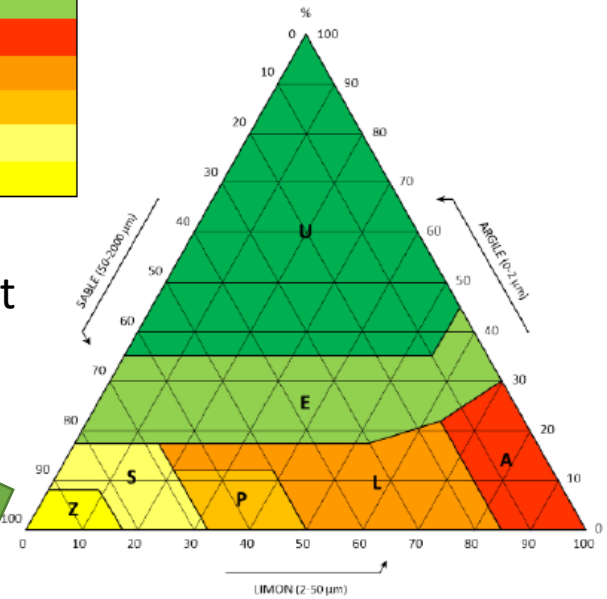
Figure 5.3: Location of Bulk Density (BD) data in Grand-Duchy of Luxembourg (GDL) from BDSOL_2009-2019 and Wallonia (Wal) from CARBIOSOL dataset (Chartin et al., 2017).

Bulk Density: Pedo-Transfer Functions





Mat_Text



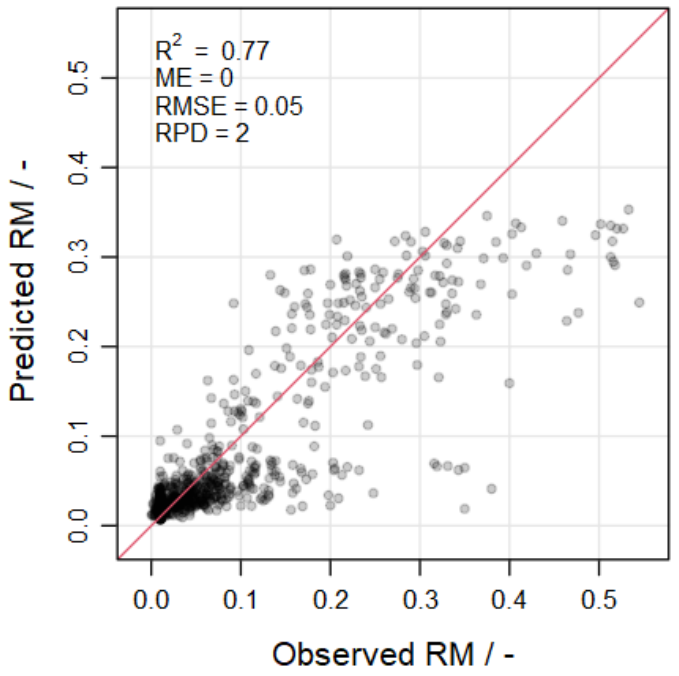
l: Texture triangle designed for soils of Belgium and Grand-Duchy of Luxembourg.

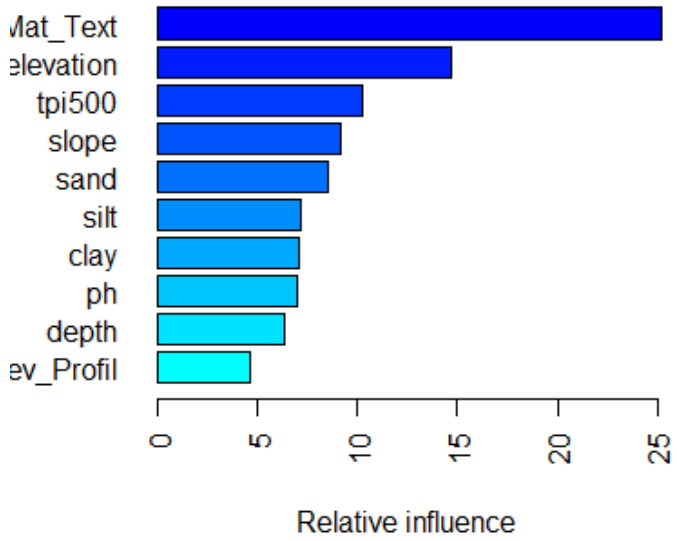
Rock fragment content by Mass : PTF

Data:

- Historical profiles
- BDSOL_2009-2019
- BDSOL_1964-1973

Modelled by GBM





Under-estimation of high RM values

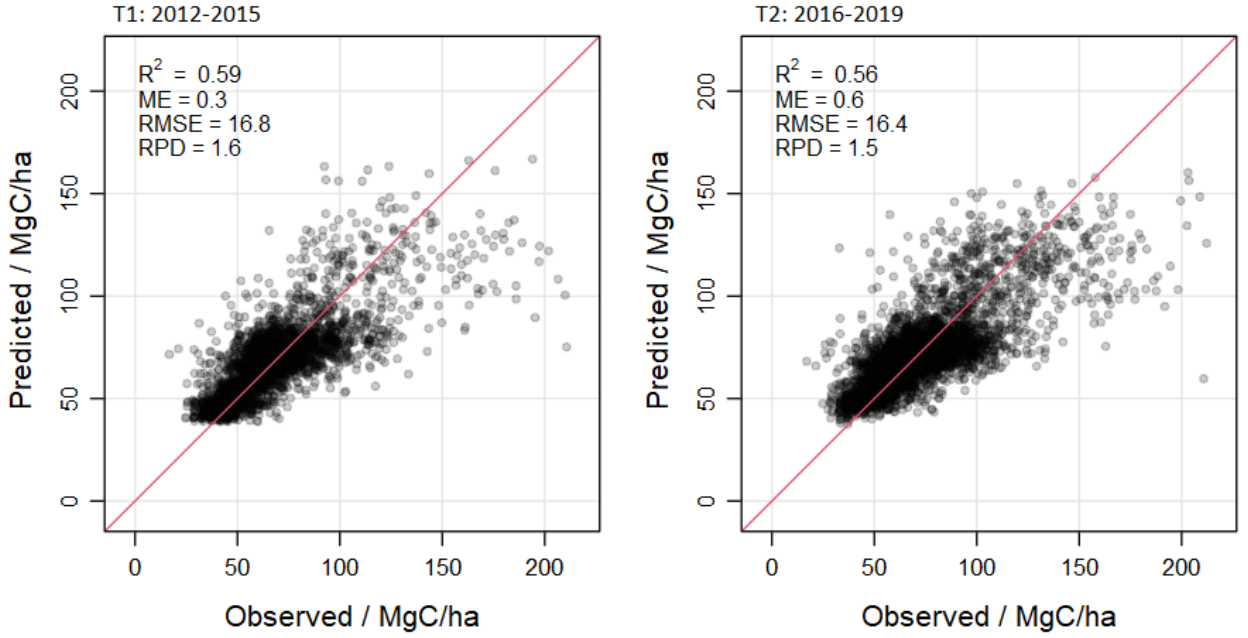
Computation of SOCst.30 and associated uncertainties

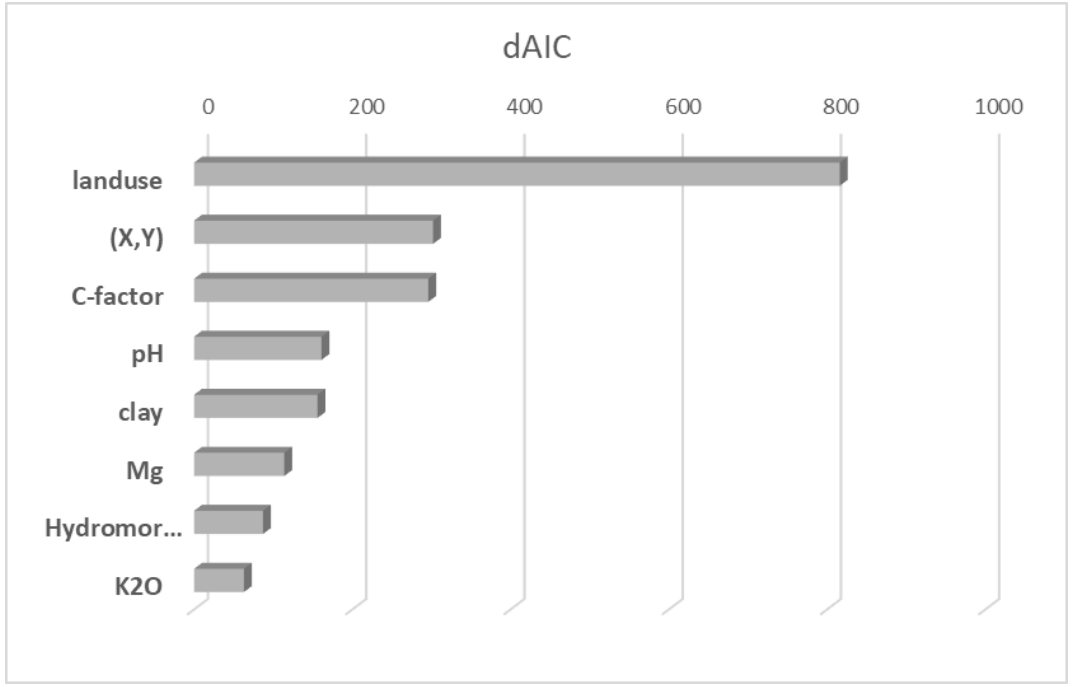
- Estimation errors (model uncertainty) for each component (SOC.30, BD et RM) at each observation in the ASTA database
- Ensemble Uncertainty Propagation
  - Monte-Carlo simulations (500 runs)
  - Normal distribution of uncertainties assumed
- Calculate mean SOCst.30 and Confidence Interval (CI) for 500 runs

Soil Asso.*	SOC.30		BD		RM		SOCst.30	
	CI (%C)	Rel. CI (%)	CI (g/cm³)	Rel. CI (%)	CI (-)	Rel. CI (%)	CI (MgC/ha)	Rel. CI (%)
1	0.02	0.72	0.22	19.28	0.18	67.60	20.44	28.17
2	0.01	1.00	0.20	14.42	0.11	149.07	10.77	18.37
3	0.02	0.92	0.20	15.40	0.08	121.56	12.53	16.56
4	0.02	1.02	0.24	18.66	0.11	129.93	15.39	21.52
5	0.02	1.79	0.24	15.78	0.04	218.22	6.30	13.32
6	0.02	1.29	0.23	15.86	0.06	186.79	8.54	15.00
7	0.01	0.90	0.22	15.42	0.05	157.20	10.70	15.13
8	0.02	1.06	0.21	14.65	0.05	163.35	9.66	14.02
9	0.02	0.85	0.23	16.63	0.05	187.71	14.14	15.88
10	0.02	1.13	0.22	16.18	0.07	186.60	10.94	16.90

5 SOC stocks: Digital soil mapping

- GAM model on SOCst.30 (cropland and grassland together)
  - Calibration on T1 + T2 : variance explained of 63%
  - Validation on T1 and T2 separately – 10-fold cross-validation (stratified by soil association)





T1: n = 2884; 10-fold CV

T2: n = 4571; 10-fold CV

For Wallonia (SMN):
R^2 = 0.65; RMSE = 16

5: Maps and statistics of SOCst.30 for soil associations or entire GDL

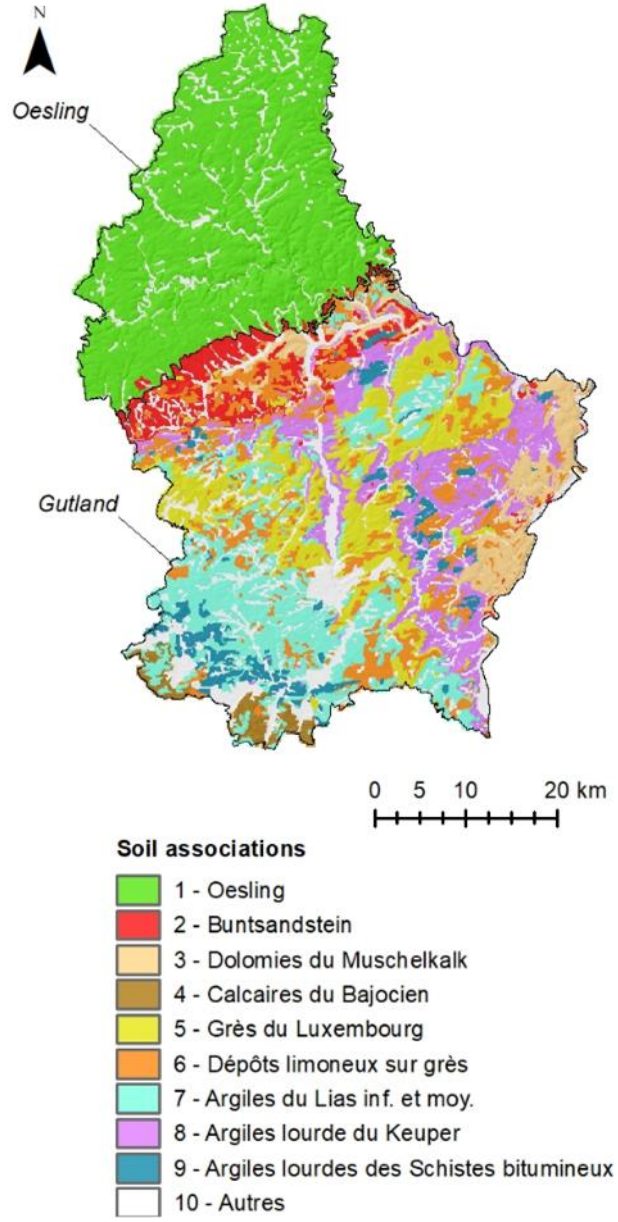
$$SOCst.30 = SOC.30 \times d \times (1 - RM) \times BD$$

- Monte-Carlo MC1 simulation (x100) on stock equation components (SOC.30, BD, RM)
- Monte-Carlo MC2 Simulation (x100) on the GAM (spatial model) parameters

= 10,000 model runs

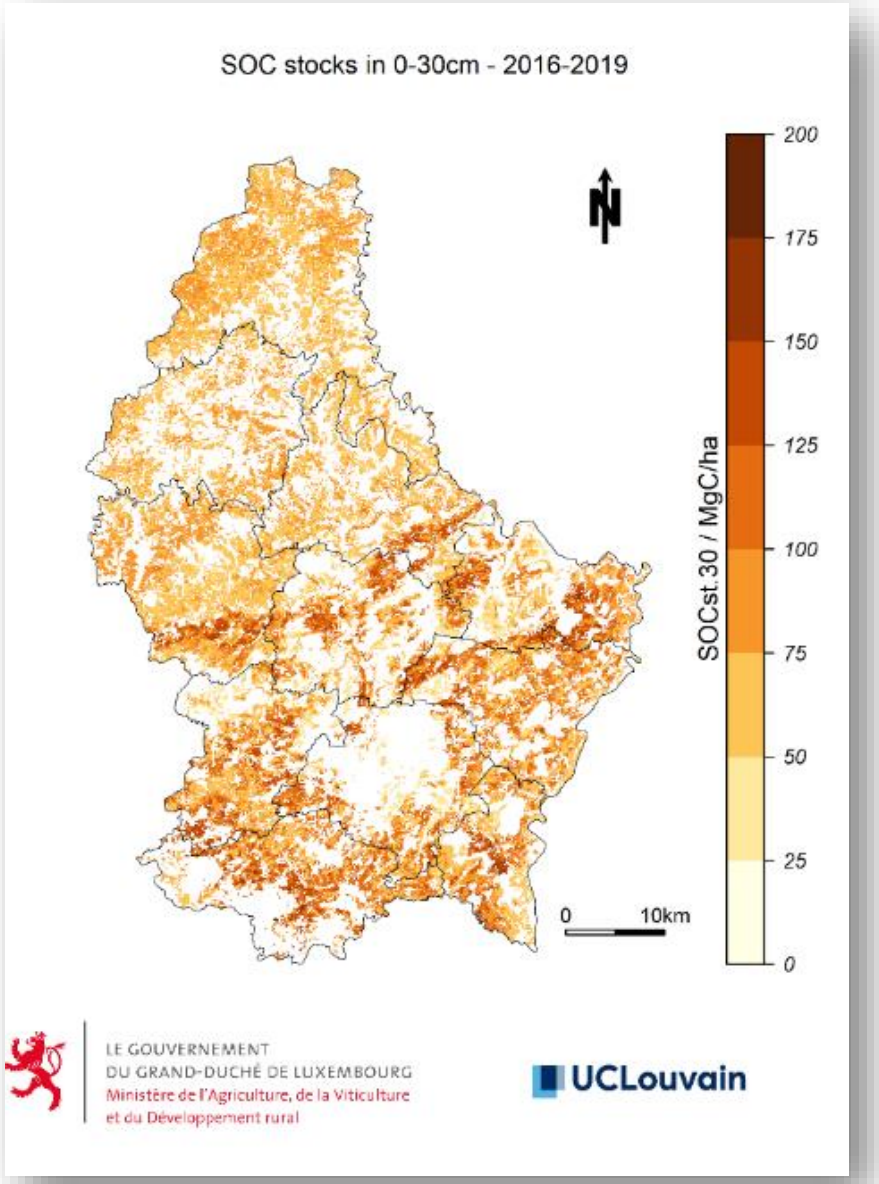
Cropland

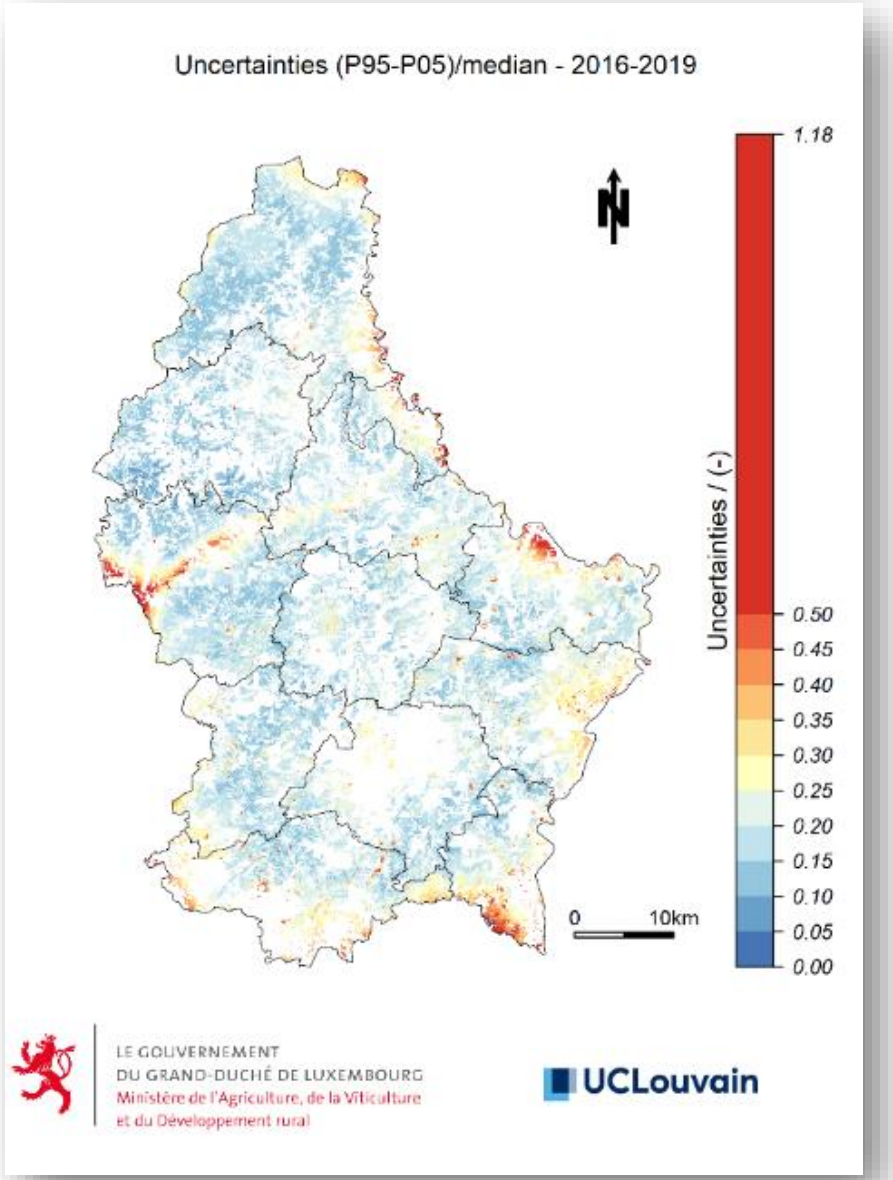
		T1: 2012-2015				T2: 2016-2019			
Assoc.	n cells	P05	median	mean	P95	P05	median	mean	P95
1	27603	63.1	73.0	74.2	89.1	63.3	72.0	72.6	83.9
2	4610	47.8	59.1	61.0	80.5	48.2	57.2	58.6	74.8
3	3784	52.3	72.1	73.4	99.1	54.9	71.5	71.4	86.0
4	330	46.8	66.9	68.2	95.6	50.9	73.4	73.7	108.1
5	5909	39.2	48.0	49.4	63.1	40.6	48.2	50.1	65.5
6	7796	43.4	57.7	59.3	79.8	45.0	57.7	59.3	77.5
7	10169	52.0	70.4	71.1	92.0	54.7	69.7	70.3	86.8
8	4898	50.1	71.6	71.1	90.0	52.2	75.1	75.8	100.0
9	1492	51.0	76.5	77.4	100.1	53.6	74.9	75.0	92.3
10	4299	46.7	67.5	66.7	87.5	47.9	67.2	66.5	85.8



5: Maps and statistics of SOCst.30 for entire GDL

Uncertainty: (P95-P05)/median



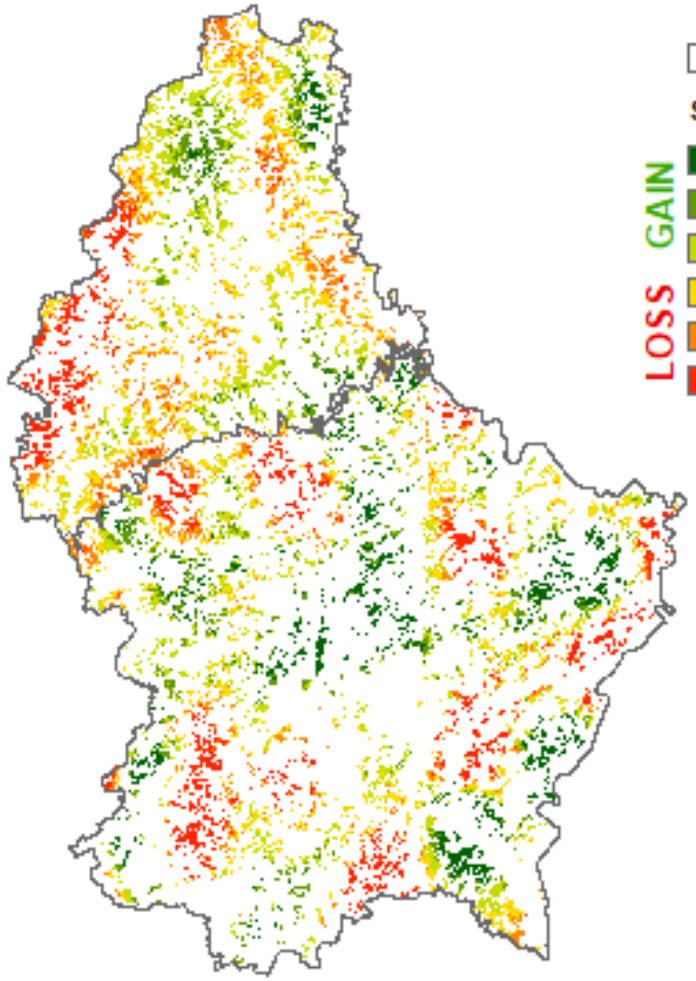


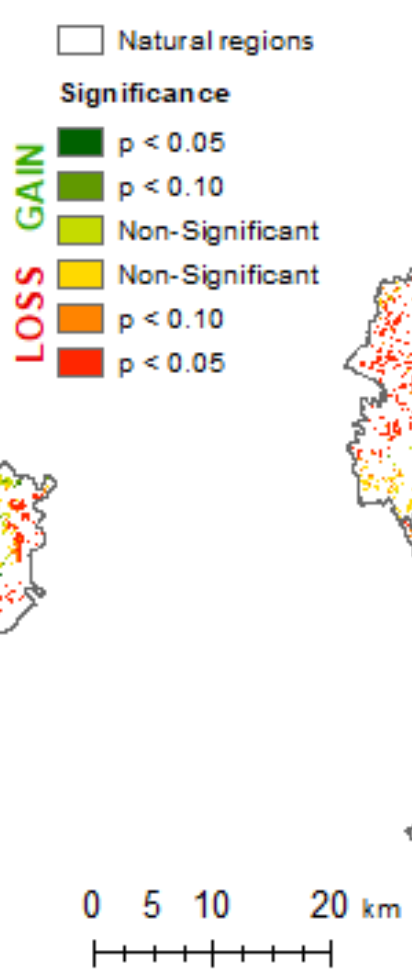
5: Maps and statistics of SOCst.30 for entire GDL

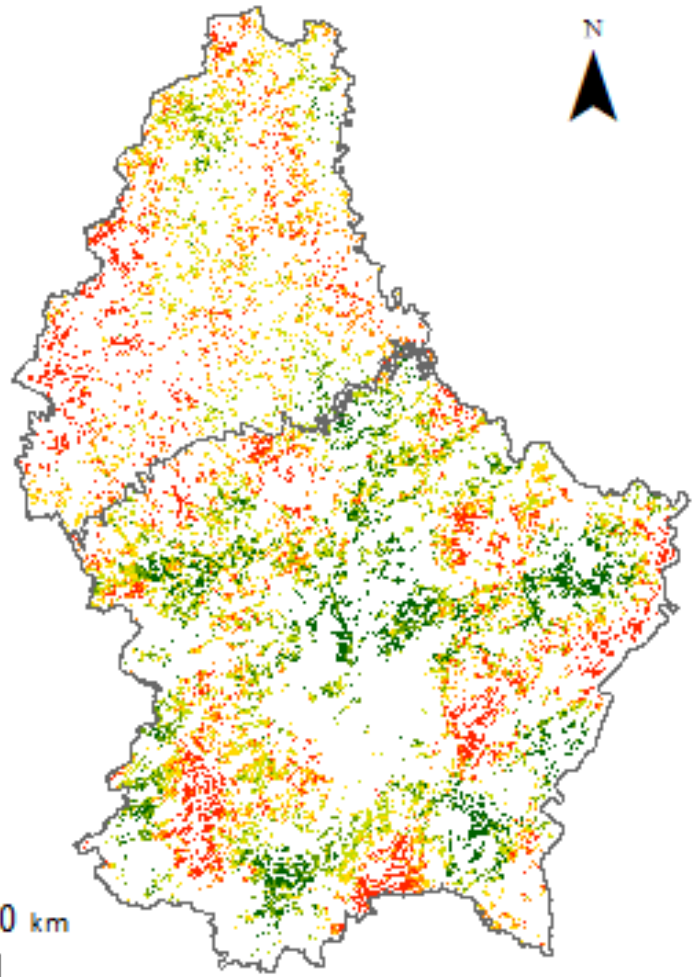
Uncertainty: (P95-P05)/median

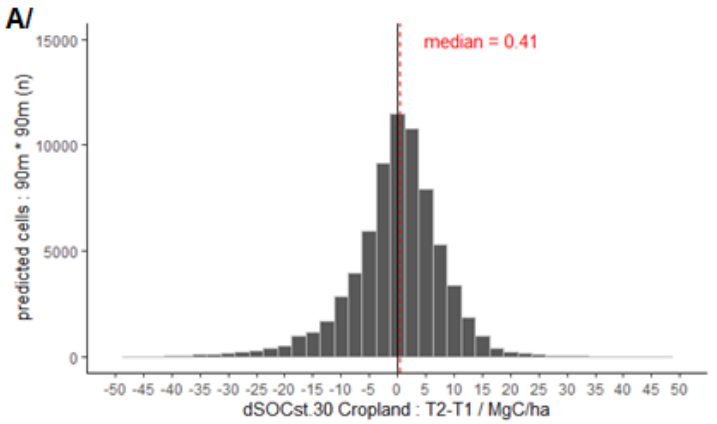
Potential SOCst.30 evolution between T1 and T2 - Cropland

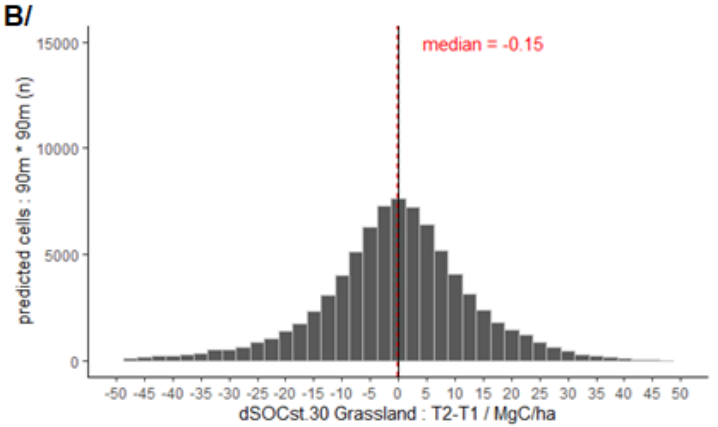
Potential SOCst.30 evolution between T1 and T2 - Grassland











Implication of GAP on recent short-term SOC dynamics

- **GAP = Good Agricultural Practices**

EU asked to monitor the effects of environmentally-friendly farming techniques
(as in Mesures Agro Environnementales– MAE)

3 GAP studied - applied in cropland ONLY

Reduced Tillage (RT): MAE 262-362-462

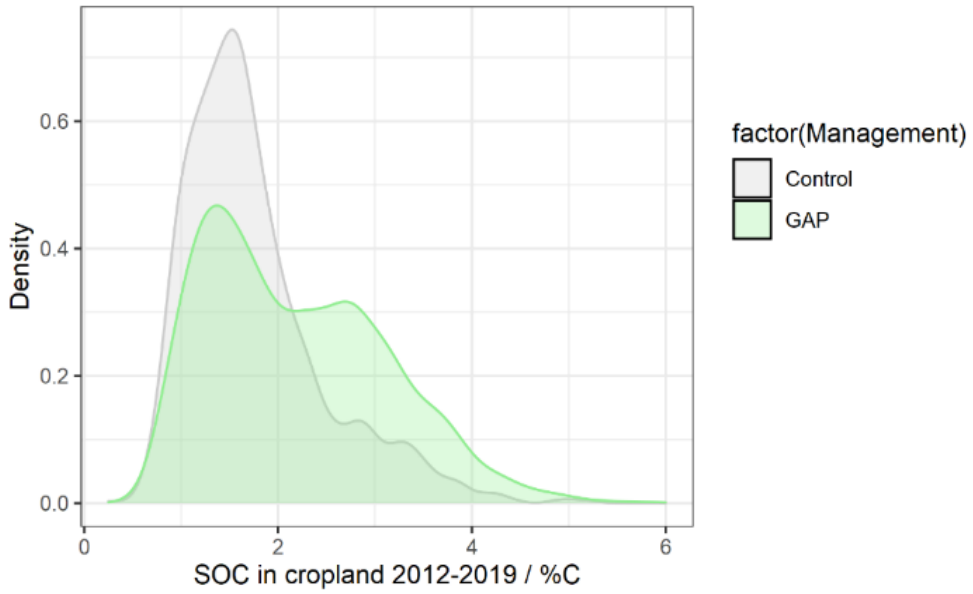
Cover Crops (CC): MAE 262-362-462 + Greening Initiative

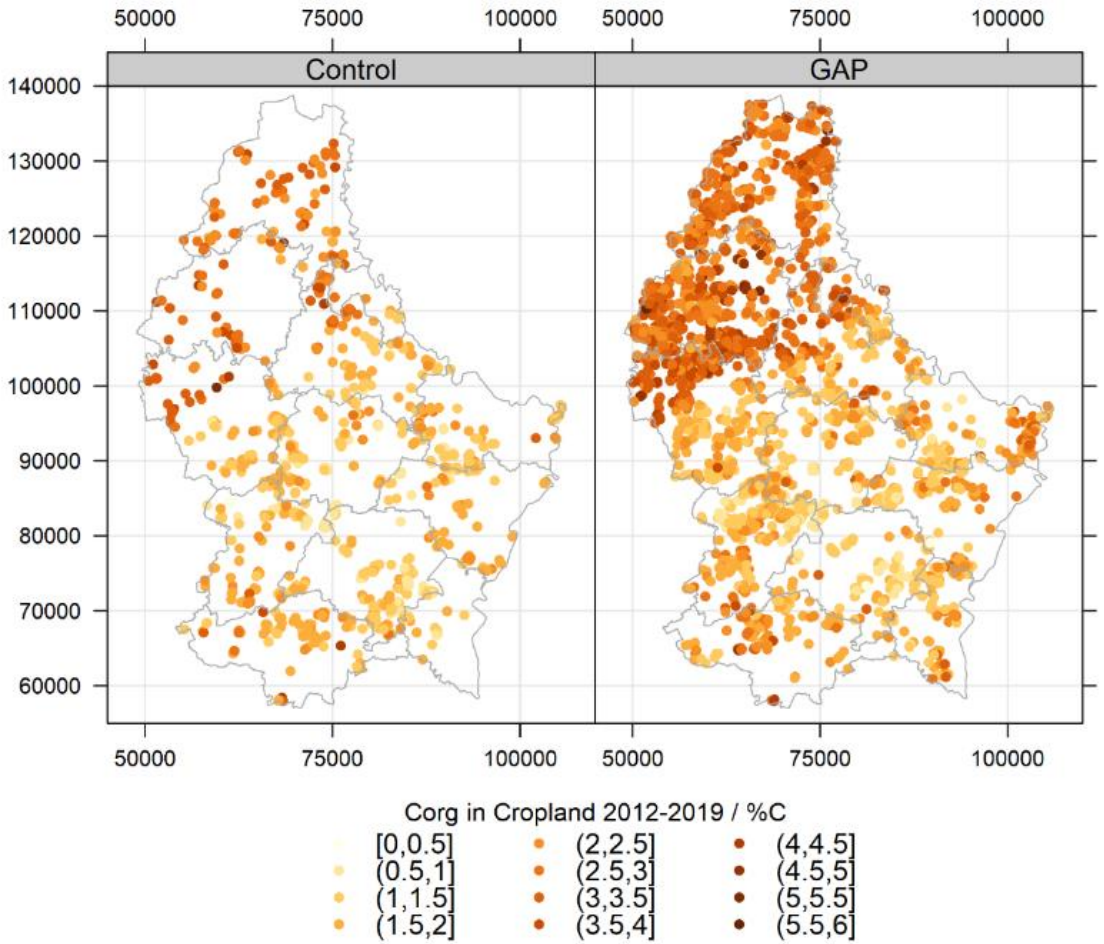
Temporary Grassland (TG): less than or equal to 5 consecutive crop years without ploughing
(categorized as arable land – cropland)

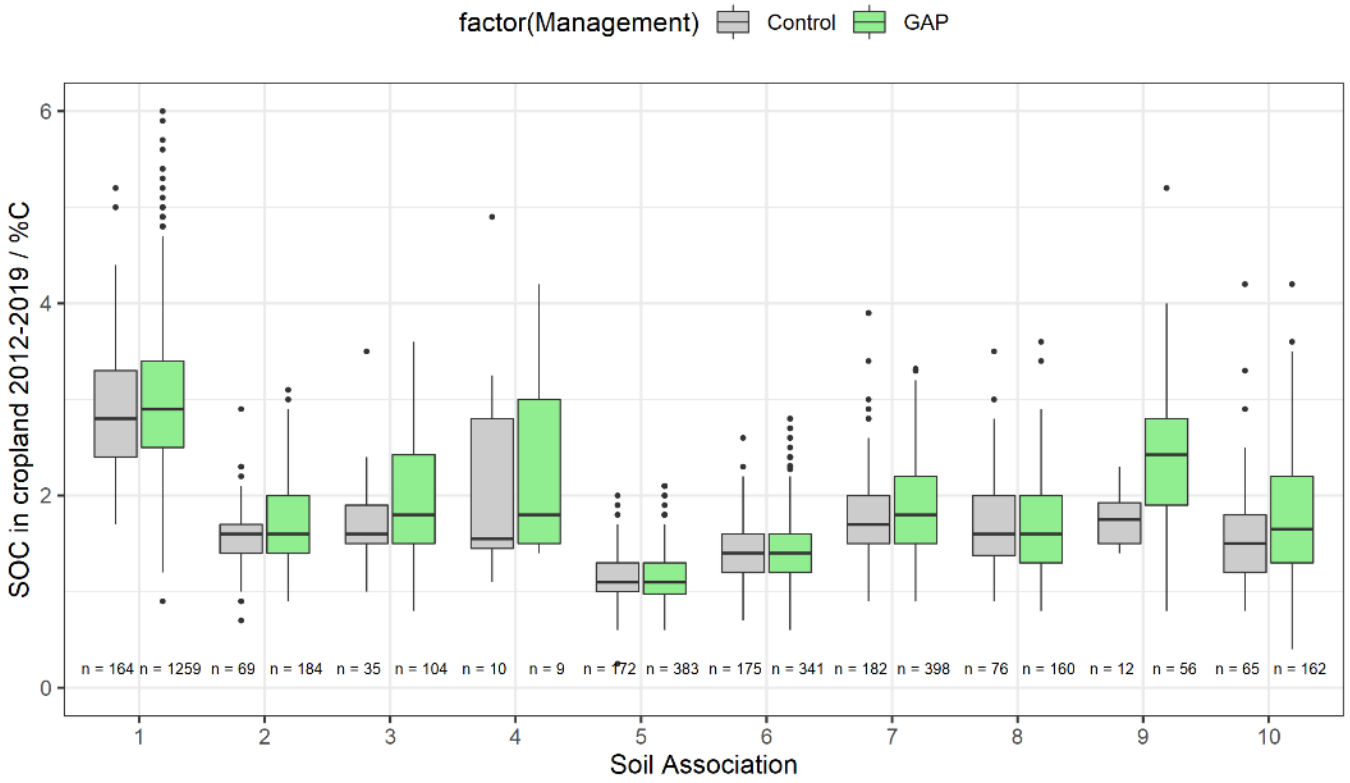
Implication of GAP on recent short-term SOC dynamics

- **Data**

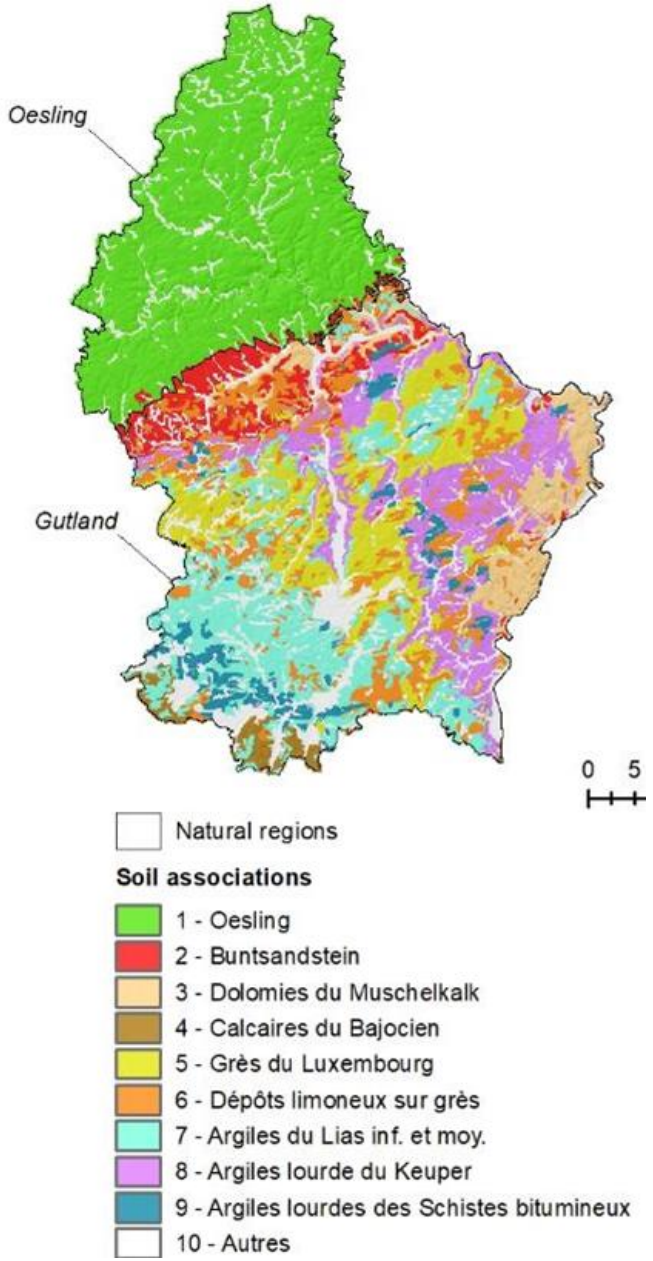
Soil routine analysis for farmers (ASTA; 2012-2019)
LPIS (Land Parcel Information System)







	Control							Good Agricultural Practices							Difference	
Assoc.	n	min	Q1	median	mean	Q3	max	n	min	Q1	median	mean	Q3	max	mean	p-value
ALL	960	0.3	1.2	1.6	1.8	2.0	5.2	3056	0.4	1.4	2.1	2.2	2.8	6.0		
1	164	1.70	2.40	2.80	2.86	3.30	5.20	1259	0.90	2.50	2.90	3.02	3.40	6.00	**0.16**	**< 0.01**
2	69	0.70	1.40	1.60	1.58	1.70	2.90	184	0.90	1.40	1.60	1.71	2.00	3.10	0.14	NS
3	35	1.00	1.50	1.60	1.74	1.90	3.50	104	0.80	1.50	1.80	2.03	2.43	3.60	**0.29**	**< 0.05**
4	10	1.10	1.45	1.55	2.16	2.80	4.90	9	1.40	1.50	1.80	2.44	3.00	4.20	0.29	NS
5	172	0.25	1.00	1.10	1.15	1.30	2.00	383	0.60	0.98	1.10	1.15	1.30	2.10	0	NS
6	175	0.70	1.20	1.40	1.39	1.60	2.60	341	0.60	1.20	1.40	1.43	1.60	2.80	0.04	NS
7	182	0.90	1.50	1.70	1.79	2.00	3.90	398	0.90	1.50	1.80	1.85	2.20	3.32	0.05	NS
8	76	0.90	1.38	1.60	1.70	2.00	3.50	160	0.80	1.30	1.60	1.69	2.00	3.60	-0.01	NS
9	12	1.40	1.50	1.75	1.77	1.93	2.30	56	0.80	1.90	2.43	2.41	2.80	5.20	**0.65**	**< 0.01**
10	65	0.80	1.20	1.50	1.61	1.80	4.20	162	0.40	1.30	1.65	1.80	2.20	4.20	**0.18**	**NS**



Temp. Grassland (++)

	Control							Temporary Grassland							Difference	
Assoc.	n	min	Q1	median	mean	Q3	max	n	min	Q1	median	mean	Q3	max	mean	p-value
ALL	960	0.3	1.2	1.6	1.8	2.0	5.2	599	0.5	2.0	2.7	2.7	3.3	6.0		
1	164	1.70	2.40	2.80	2.86	3.30	5.20	388	1.40	2.60	3.00	3.14	3.66	6.00	0.28	**< 0.001**
2	69	0.70	1.40	1.60	1.58	1.70	2.90	22	1.10	1.43	1.70	1.69	1.88	2.70	0.11	NS
3	35	1.00	1.50	1.60	1.74	1.90	3.50	15	1.60	2.00	2.60	2.59	3.15	3.60	0.86	**< 0.01**
4	10	1.10	1.45	1.55	2.16	2.80	4.90	1	1.70	1.70	1.70	1.70	1.70	1.70	-0.46	NS
5	172	0.25	1.00	1.10	1.15	1.30	2.00	44	0.60	1.10	1.30	1.30	1.43	2.10	0.16	**< 0.01**
6	175	0.70	1.20	1.40	1.39	1.60	2.60	26	1.10	1.40	1.60	1.64	1.78	2.50	0.26	**< 0.02**
7	182	0.90	1.50	1.70	1.79	2.00	3.90	35	0.90	1.40	1.70	1.84	2.20	3.20	0.04	NS
8	76	0.90	1.38	1.60	1.70	2.00	3.50	23	1.10	1.50	1.90	1.93	2.40	3.40	0.23	NS
9	12	1.40	1.50	1.75	1.77	1.93	2.30	10	1.60	2.18	2.53	2.68	3.40	3.70	0.91	**< 0.01**
10	65	0.80	1.20	1.50	1.61	1.80	4.20	35	0.50	1.45	2.10	2.15	2.70	3.60	0.53	**< 0.01**

Reduced Tillage (+)

	Control							Reduced Tillage							Difference	
Assoc.	n	min	Q1	median	mean	Q3	max	n	min	Q1	median	mean	Q3	max	mean	p-value
ALL	960	0.3	1.2	1.6	1.8	2.0	5.2	396	0.8	1.4	1.8	2.0	2.5	5.2		
1	164	1.70	2.40	2.80	2.86	3.30	5.20	94	1.40	2.50	3.05	3.01	3.40	5.00	0.15	NS
2	69	0.70	1.40	1.60	1.58	1.70	2.90	11	0.90	1.35	1.60	1.71	2.10	2.70	0.13	NS
3	35	1.00	1.50	1.60	1.74	1.90	3.50	15	1.10	1.50	1.70	1.87	2.00	3.30	0.13	NS
4	10	1.10	1.45	1.55	2.16	2.80	4.90	1	3.00	3.00	3.00	3.00	3.00	3.00	0.84	NS
5	172	0.25	1.00	1.10	1.15	1.30	2.00	46	0.80	1.00	1.10	1.14	1.34	1.80	-0.01	NS
6	175	0.70	1.20	1.40	1.39	1.60	2.60	50	0.80	1.20	1.40	1.46	1.68	2.80	0.07	NS
7	182	0.90	1.50	1.70	1.79	2.00	3.90	127	0.90	1.45	1.80	1.79	2.10	2.90	0	NS
8	76	0.90	1.38	1.60	1.70	2.00	3.50	24	1.00	1.30	1.45	1.55	1.71	2.40	-0.15	NS
9	12	1.40	1.50	1.75	1.77	1.93	2.30	18	1.50	1.93	2.55	2.52	2.78	5.20	**0.76**	**< 0.01**
10	65	0.80	1.20	1.50	1.61	1.80	4.20	10	0.90	1.40	1.50	1.63	1.88	3.00	0.02	NS

CC: mainly applied right before silage maize!

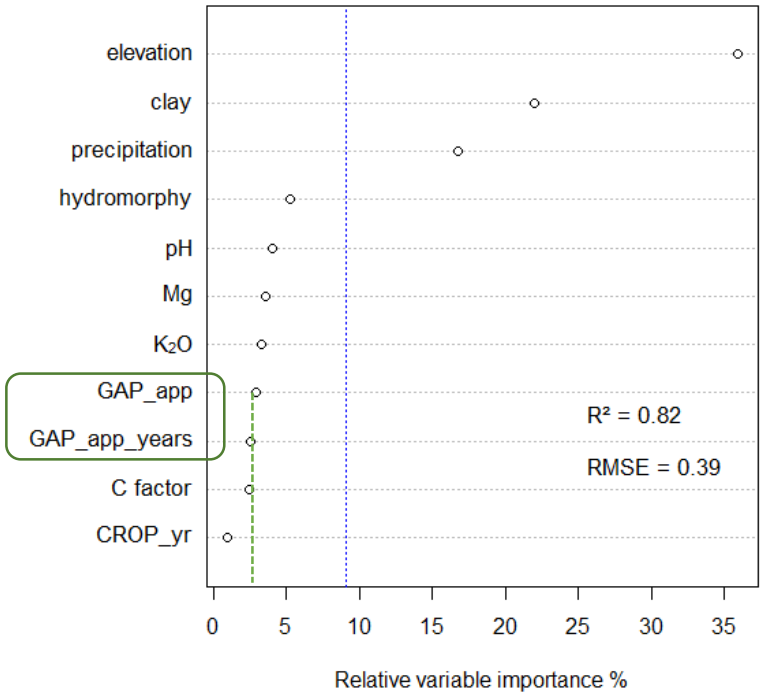
Cover-crops (0 / -)

	Control							Cover Crops							Difference	
Assoc.	n	min	Q1	median	mean	Q3	max	n	min	Q1	median	mean	Q3	max	mean	p-value
ALL	960	0.3	1.2	1.6	1.8	2.0	5.2	533	0.6	1.2	1.5	1.7	2.0	5.4		
1	164	1.70	2.40	2.80	2.86	3.30	5.20	85	1.50	2.20	2.70	2.71	3.10	5.40	-0.15	NS
2	69	0.70	1.40	1.60	1.58	1.70	2.90	53	0.90	1.20	1.50	1.55	1.80	2.60	-0.02	NS
3	35	1.00	1.50	1.60	1.74	1.90	3.50	16	1.10	1.40	1.65	1.94	2.13	3.60	0.21	NS
4	10	1.10	1.45	1.55	2.16	2.80	4.90	2	1.50	1.58	1.65	1.65	1.73	1.80	-0.51	NS
5	172	0.25	1.00	1.10	1.15	1.30	2.00	116	0.60	0.90	1.05	1.10	1.23	2.10	-0.05	NS
6	175	0.70	1.20	1.40	1.39	1.60	2.60	98	0.60	1.13	1.30	1.34	1.50	2.40	-0.05	NS
7	182	0.90	1.50	1.70	1.79	2.00	3.90	92	1.00	1.50	1.80	1.90	2.20	3.30	0.1	NS
8	76	0.90	1.38	1.60	1.70	2.00	3.50	38	0.90	1.20	1.40	1.59	1.80	3.60	-0.1	NS
9	12	1.40	1.50	1.75	1.77	1.93	2.30	3	1.10	1.40	1.70	1.53	1.75	1.80	-0.23	NS
10	65	0.80	1.20	1.50	1.61	1.80	4.20	30	0.80	1.10	1.35	1.48	1.80	3.00	-0.13	NS

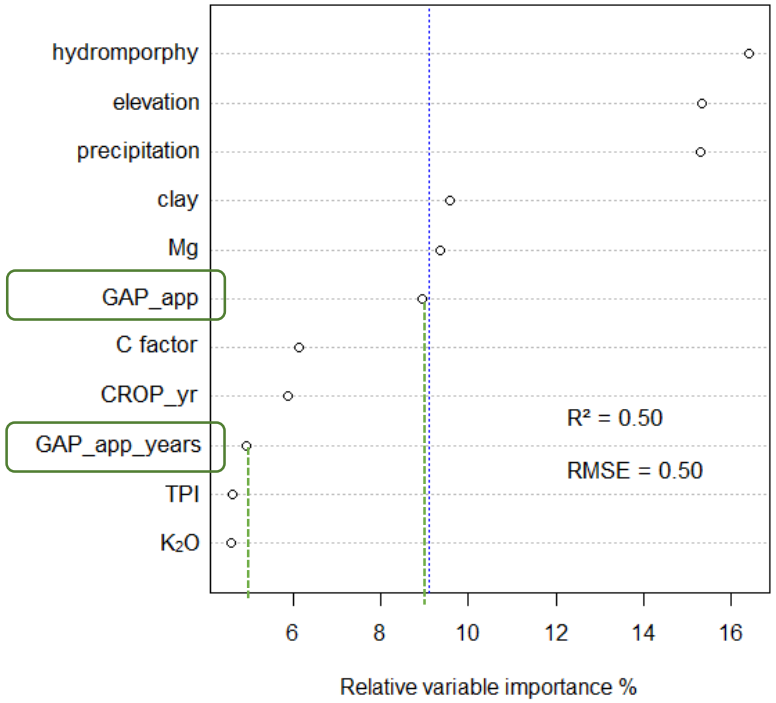
Implication of GAP on short-term SOC dynamics

- Conditional inference trees *(non-spatial models)*

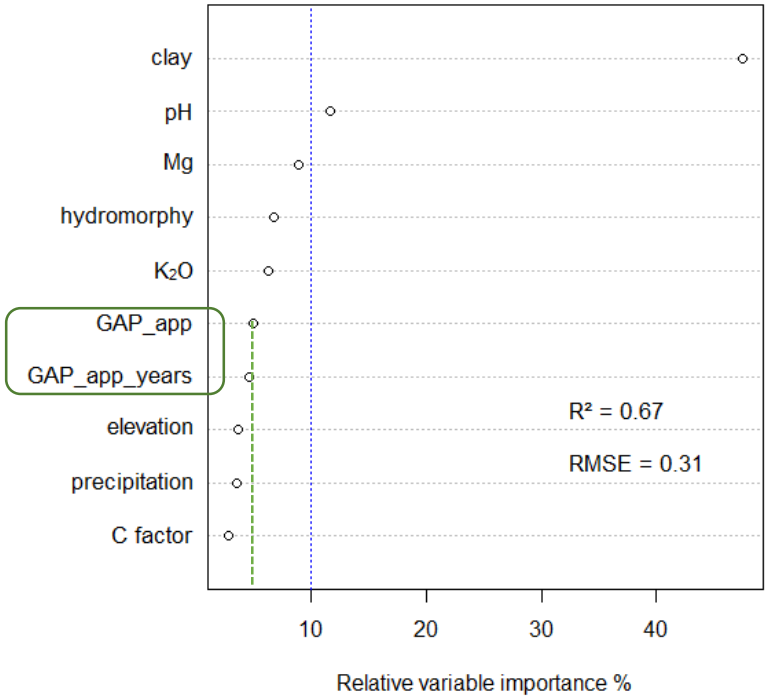
ALL GDL



Oesling



Gutland



GAP_app = GAP or combination of GAP applied
GAP_app_years = duration of application

CONCLUSIONS

- ASTA compiled extensive geo-referenced soil data bases for trends in SOC status
- SOC contents driven by N-S gradient (climate, altitude), clay content and crop cover
- Significant recent changes in SOC content and stock (2012-1019) are limited
- Effects of 3 Good Agricultural Practices on SOC
  - Temporary Grassland > reduced Tillage > Cover Crop *(impact of silage maize?)*
  - ‘Narrow window’ for improving SOC
- Additional data for bulk density, vertical C profiles and Rock fragment content are required for improving SOC stock assessment

Thank you for your attention

- The SOC research project was financially supported by the Ministry of Agriculture, Viticulture and Rural development
- Available reports on

https://agriculture.public.lu/de/pflanzen-boden/boden/thematische-karten-fachbereich-boden.html

https://agriculture.public.lu/de/beihilfen/beihilfen-bis-2022/innovation-forschung/forschungsprojekte-boden-wasser-biodiversitaet/c-organique.html