GHENT
UNIVERSITY

PRECISION AGRICULTURE: BIOFERTILIZATION

29 JUNE, LISBON, PORTUGAL

Dr. Ir. Muhammad A. Munnaf
Postdoctoral researcher
Precision SCORing group
Department of Environment

GHENT UNIVERSITY

Precision SCORing
For maximizing farm productivity at minimized environmental impacts

fwo

European Commission

SOILdarity

COVERAGE

Precision agriculture

Goal

Cycle

Sensing

Proximal soil and crop sensors

Remote sensing

Modeling & mapping

Predictive modeling

Data fusion approaches

Mapping within-field variation

Control applications

A case study: Precision biofertilization

GHENT UNIVERSITY

PRECISION AGRICULTURE

PRECISION AGRICULTURE

- PA is a management strategy that gathers, processes and analyzes temporal, spatial and individual data and combines it with other information to support management decisions according to estimated variability for improved resource use efficiency, productivity, quality, profitability and sustainability of agricultural production [Jan 2021]

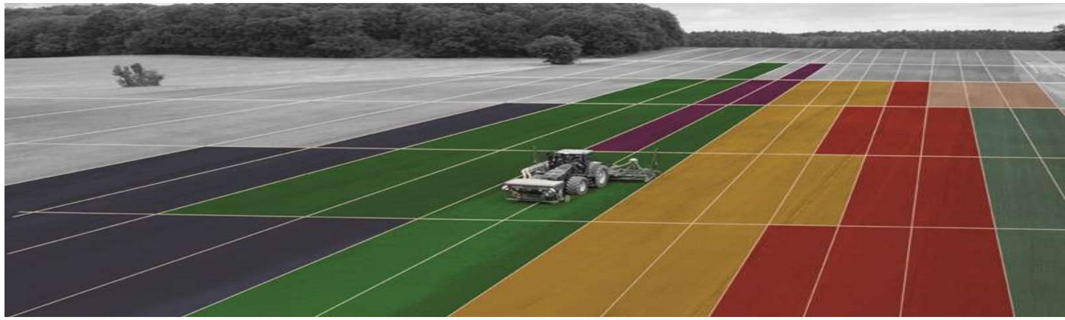


Image from John Deere/Land-Data Eurosoft;
Dana and Stuart, (2023)

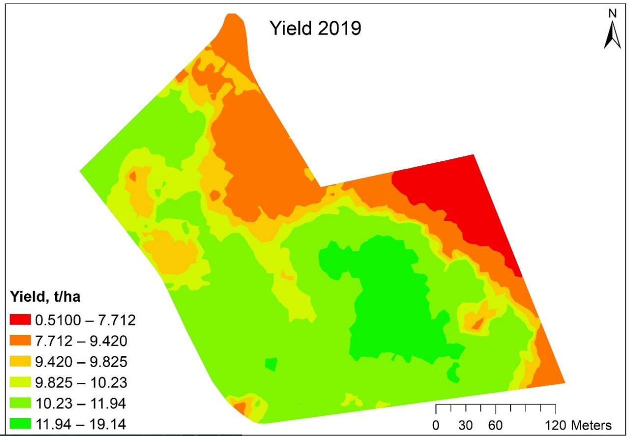
GHENT UNIVERSITY

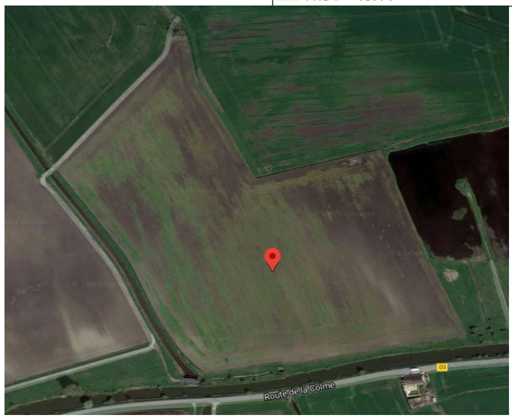
WHY PA?

In-field soil heterogeneity affects crop productivity, nutrients use & environment

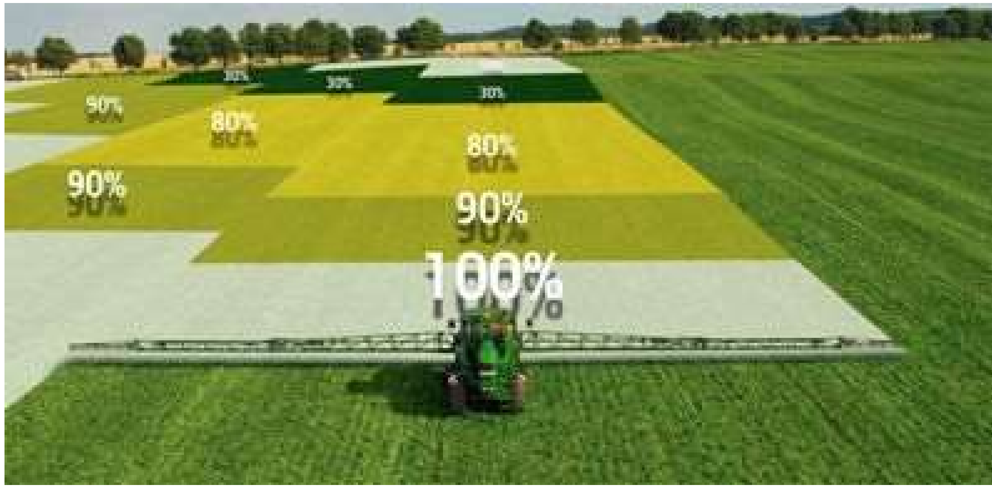
Heterogeneity should be managed accordingly i.e., variable rate N, P, K, ...

Heterogeneity





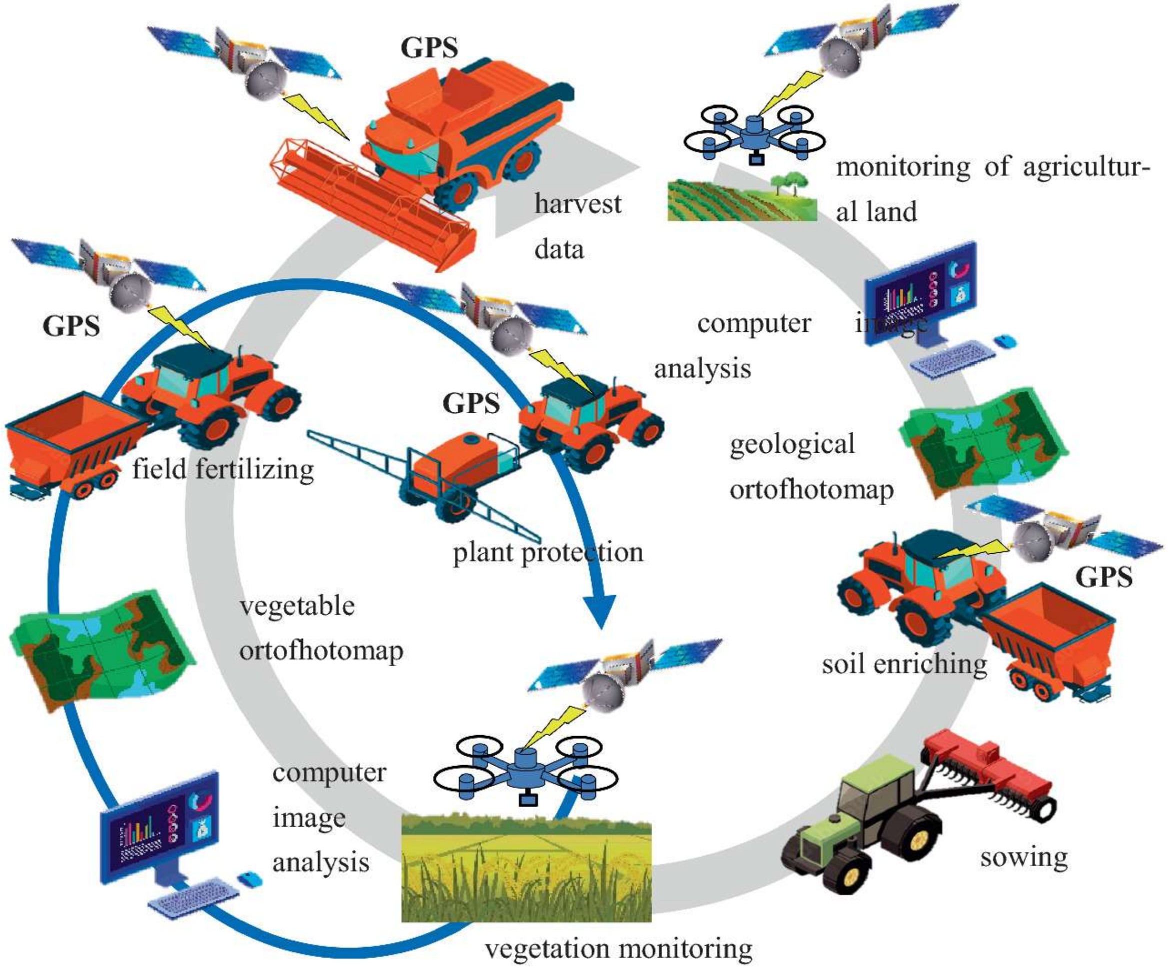
Variable inputs



GHENT UNIVERSITY

BNF, biological nitrogen fixation; N, nitrogen.

PA CYCLE



Wiecha et al., (2022)

PA PILLARS

Sensing

Proximal
On-line
Remote

Modelling

Data driven
Fusion
Geo-statistical
Mechanistic

Control Application

Tillage
Seeding
Fertilization
Pesticide
Herbicide
Irrigation
Selective harvest
…….

GHENT UNIVERSITY

python R jupyter Visual Studio Code

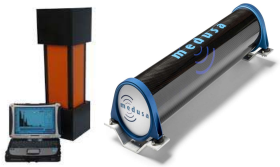
SENSING

❑ Proximal

Vis-NIRS

MIR

XRF



Gamma

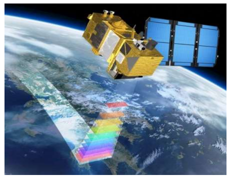
EMI sensor

FDR sensor

ISE sensor

Draft sensor

❑ Remote

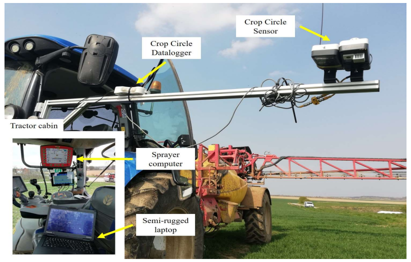


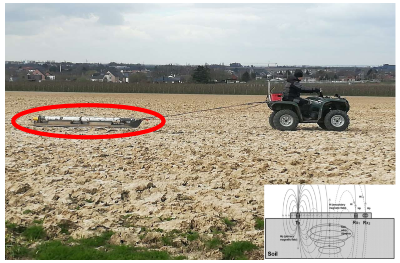
Sentinel 2

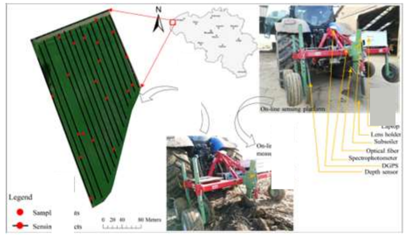
LandSat 8

DJI Mavic 2

❑ On-line







GHENT UNIVERSITY

MODELING

Predictive

Machine learning

- RF
- SVM
- PLSR
- Xgb
- …..

Spiking

- LW-PLSR
- EW-PLSR

Deep learning

- CNN
- BPNN
- RNN
- AE-NN

Transfer learning

- EPO
- OSC
- DS
- PDS
- CWT

Feature engineering

Variables selection

- VIF
- VIP
- SR
- PCA
- PLSR

Fusion

Multivariate

- PLSR-BPNN
- PLSR-CNN
- PCA-CNN
- Ensemble
- Concatenation

Geostatistical

- Cokriging
- Clustering

Mechanistic

Simulation

- EuroRotateN
- AquaCrop
- APSIM
- InfoCrop
- Wofost

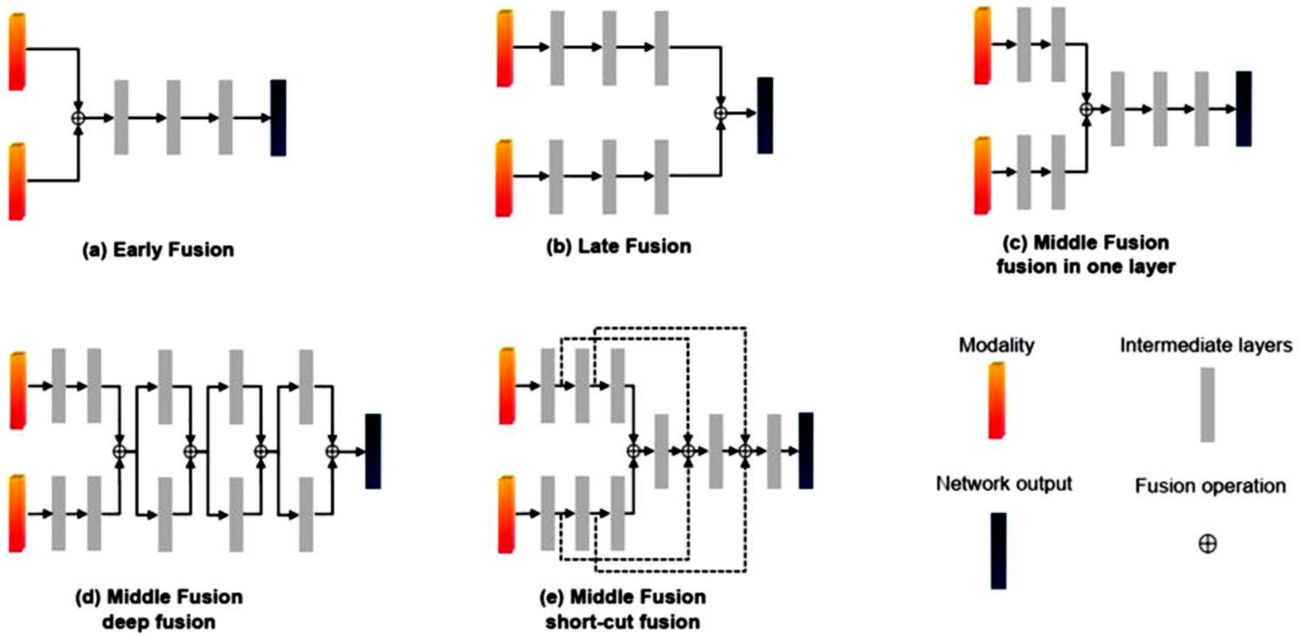
python MATLAB R jupyter Visual Studio Code

GHENT UNIVERSITY

DATA FUSION

Single sensor complements information to multiple sensors

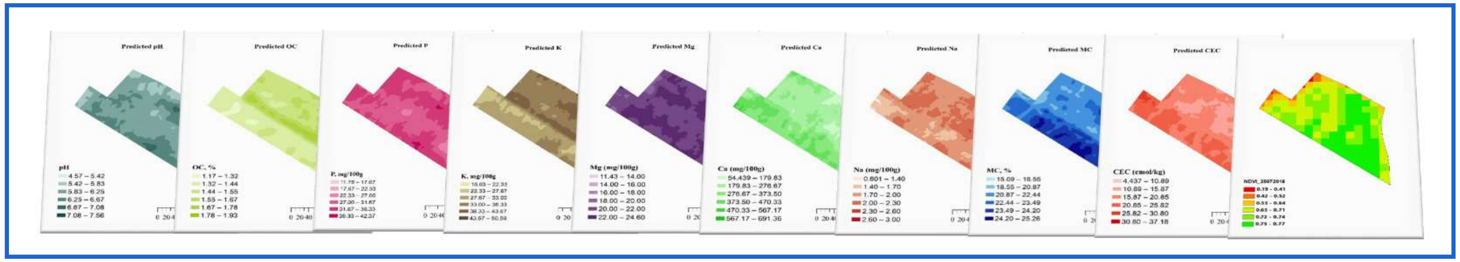
A big challenge in synchronizing data structures and sampling supports

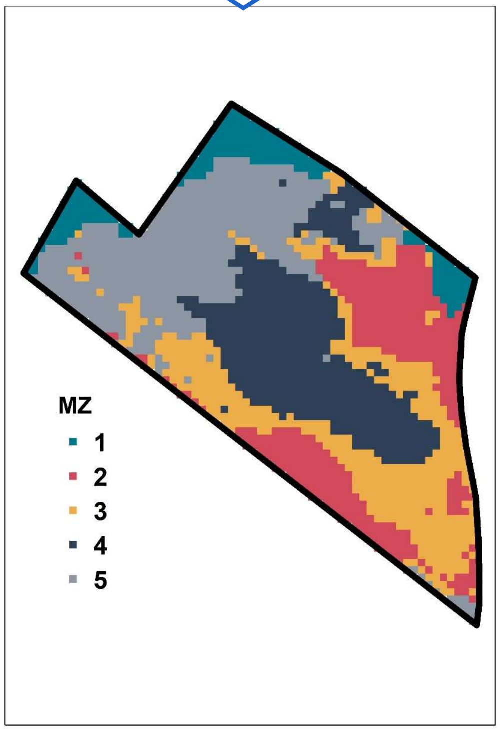


(Feng et al., 2020)

FUSION FOR MZ

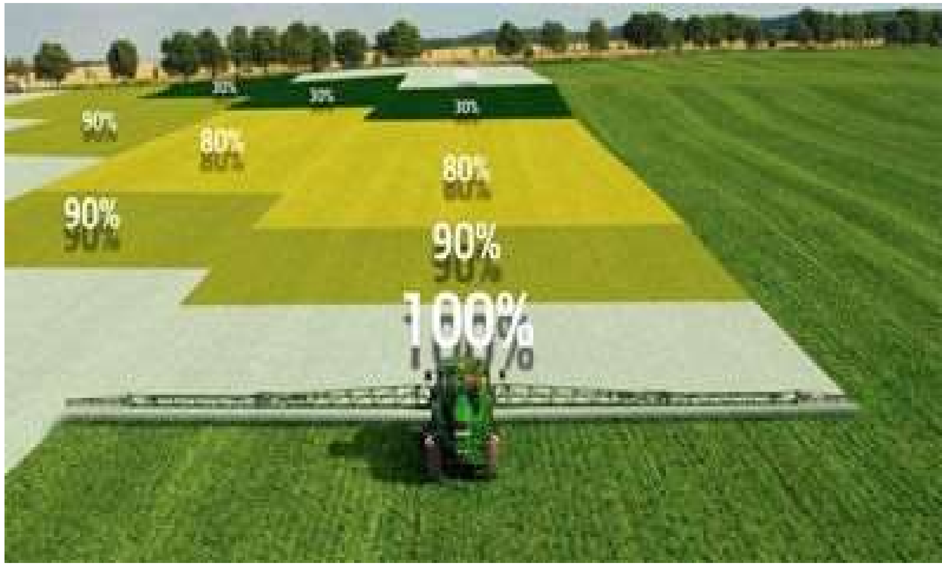
Information layers





VARIABLE DOSES

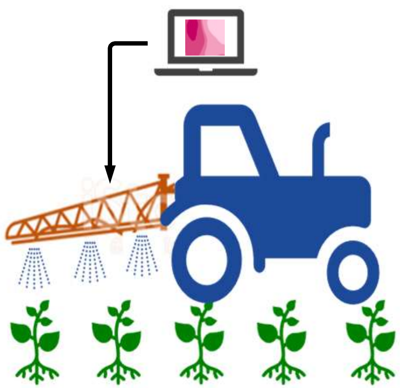
Kings	• Feeding the rich
Robin Hood	• Feeding the poor
Marginal Robin Hood	• Feeding the poor marginally
Sufficiency index	• Need based



GHENT UNIVERSITY

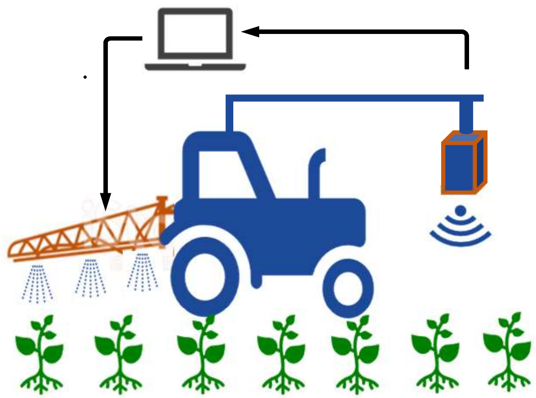
PRECISION CONTROLS

Map-based technology is ready to implement, rest requires improvements



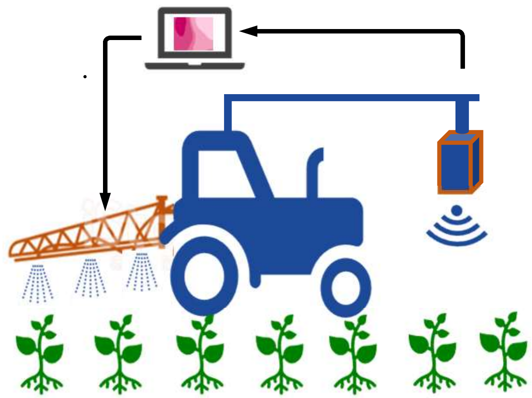
MAP-based

Limited to soil fertility data



Sensor-based

Limited to crop vegetation index

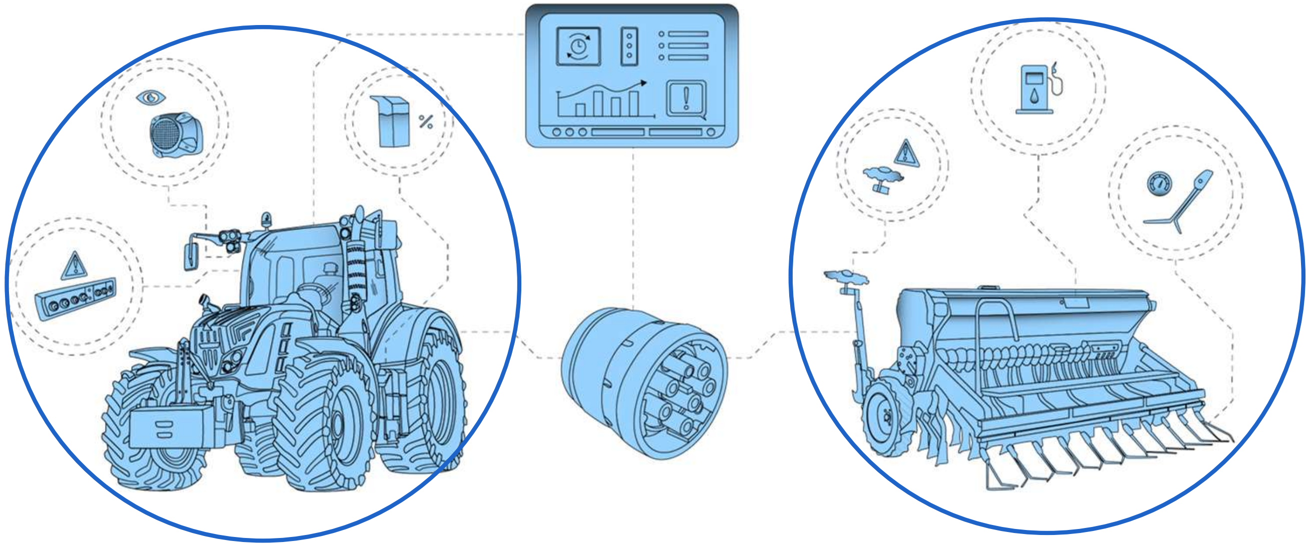


Map-sensor-based

GHENT UNIVERSITY

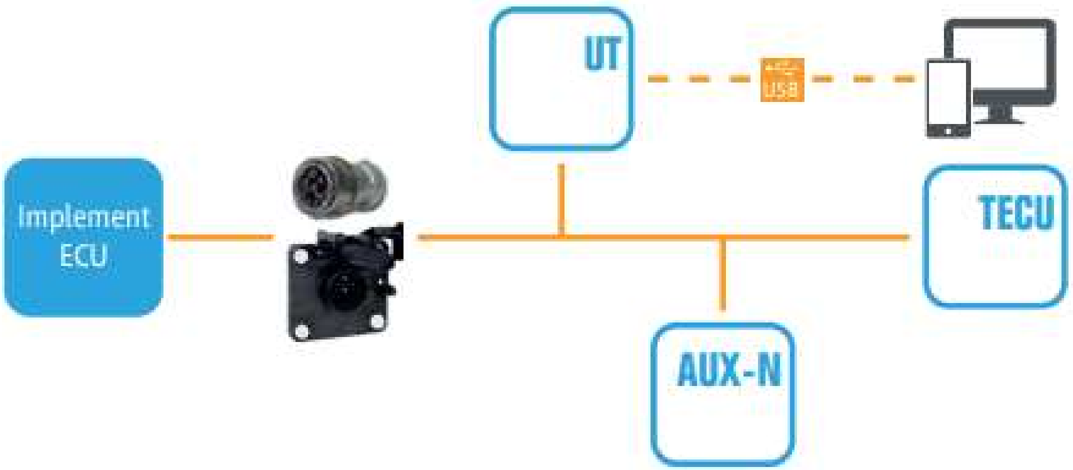
CONTROL PROTOCOL

ISOBUS ISO 11783 is a SAE J1939 based communication protocol for the agricultural equipment. Also recognizable as “Tractors and machinery for agriculture and forestry – Serial control and communications data network”. On-board computer allows tractor’s and implements interacting with one another. ISO 11783 protocol was originally released in 2001.



FUNCTIONALITY

AEF Certified ISOBUS UT TECU AUX-N TC-BAS TC-GEO TC-SC
www.aef-isobus-database.org



UT — ISOBUS Universal Terminal can render numerous implement-specific displays superfluous.

TECU — Tractor Electronic Control Unit provides tractor data to other ISOBUS devices, such as forward speed or PTO speed or rear hitch position. In this way, for example, an implement can apply fertilizer depending on the driving speed provided by TECU.

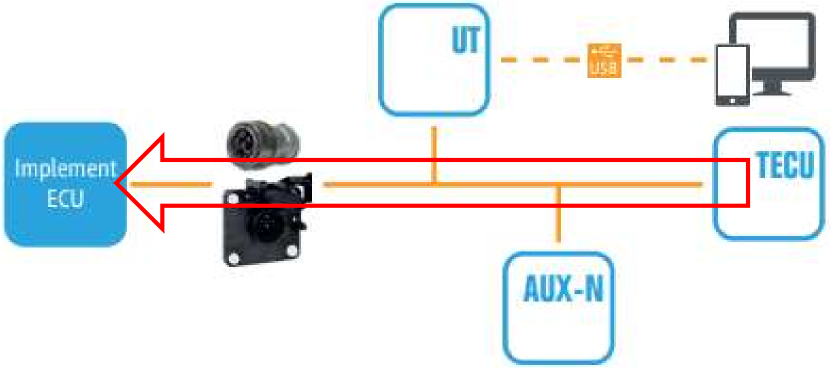
ECU — ECU rests on the implement that makes the implement smart. It stores all settings defined through UT. It generally contains the control layers and electronics needed to control certain components such as boom valve.

AUX-N — To connect additional elements, such as a joystick or switchbox to the ISOBUS. Once connected, implement can be operated by the AUX device instead of ISOBUS Universal Terminal.

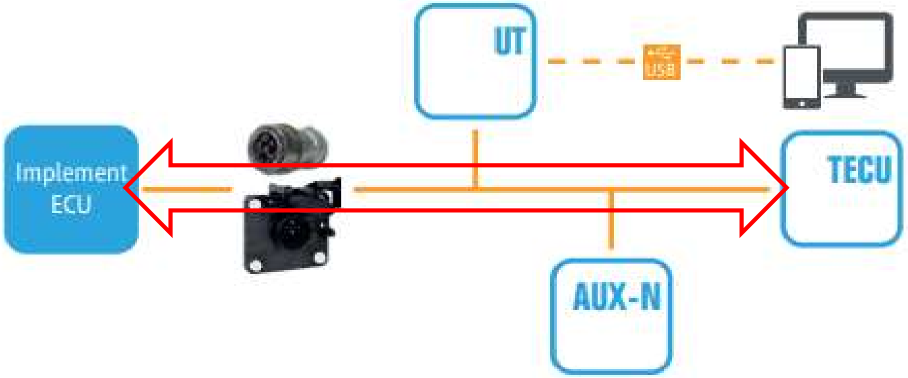
GHENT UNIVERSITY

ISOBUS CLASSES

Class 2 is to control implements.



Class 3 is to control implement and tractor by each other.



GHENT UNIVERSITY

UNIVERSAL TERMINAL

TOUCH800 terminal

Terminal ports

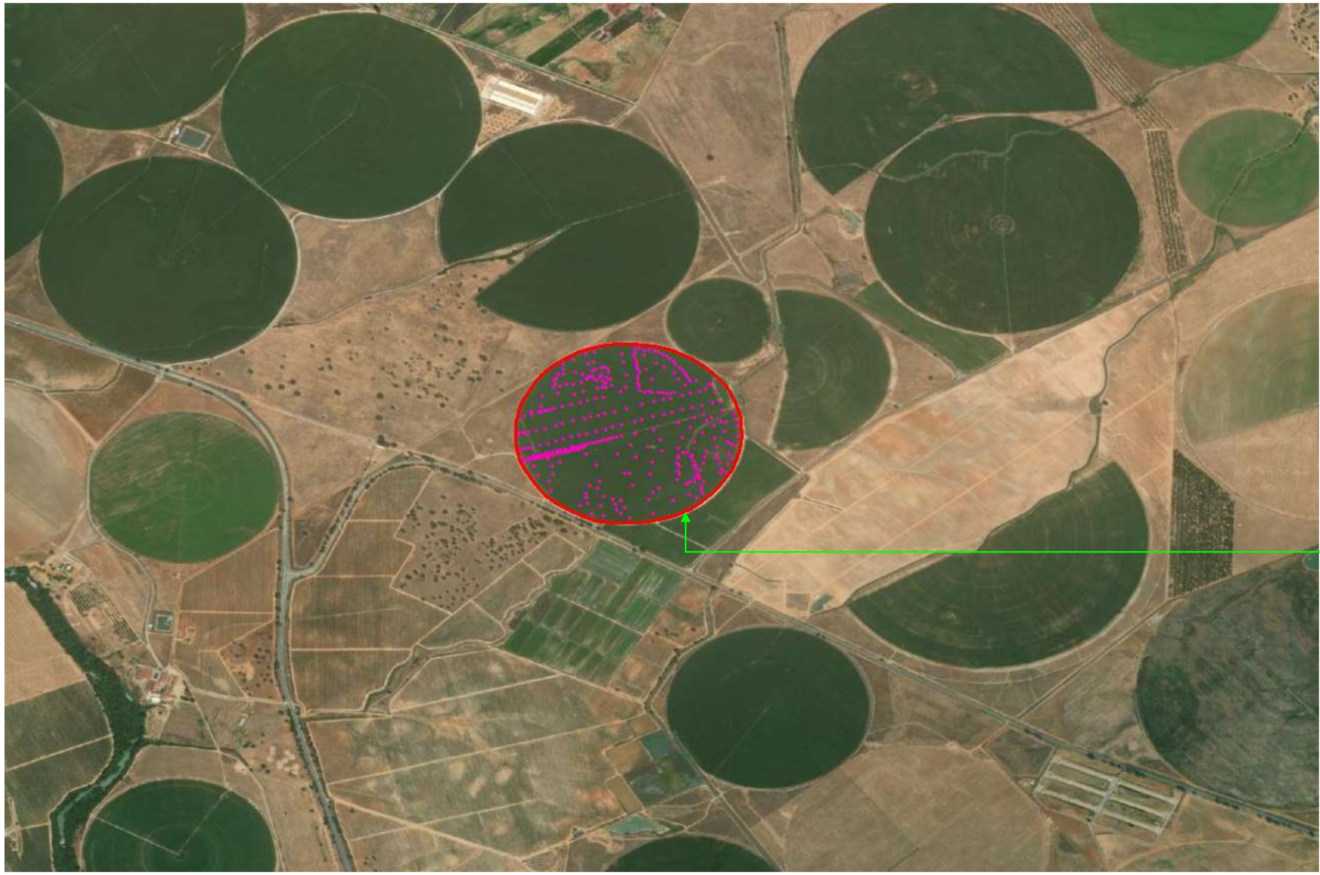
Terminal ports

Connector to ISOBUS

A CASE STUDY

GHENT UNIVERSITY

FIELD

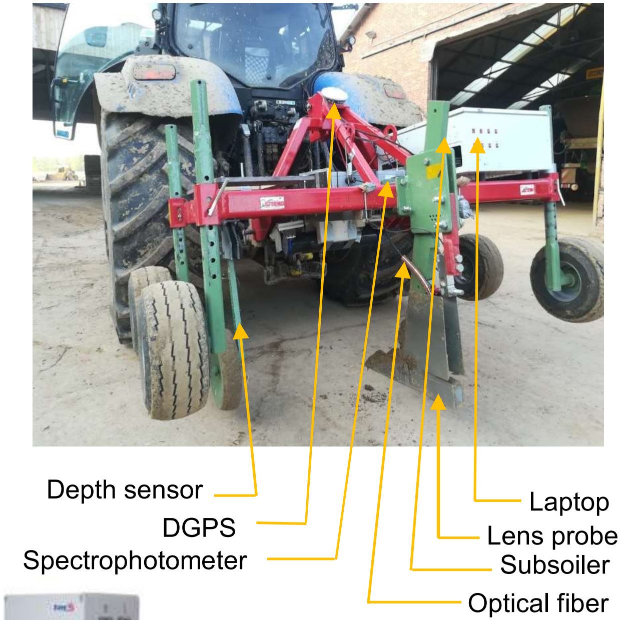


≈39 ha

GHENT UNIVERSITY

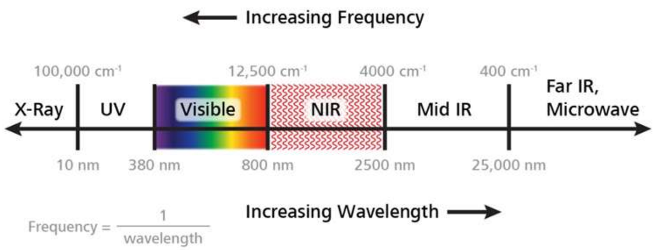
MULTI-SENSOR PLATFORM

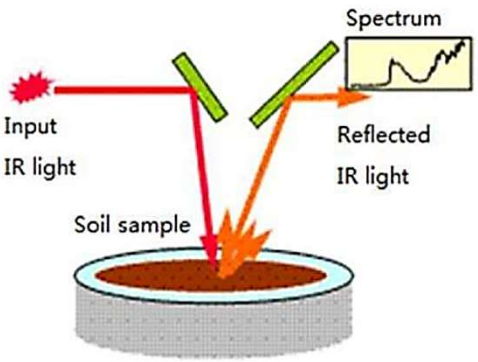
On-line sensing platform

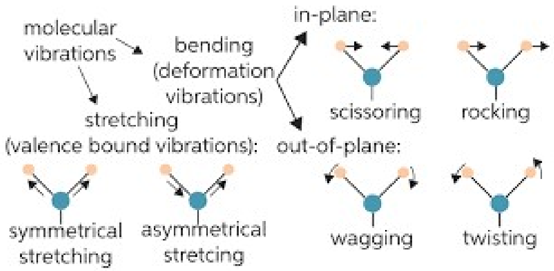


On-line view

VIS-NIR SPECTROSCOPY







Energy absorption

⇕

Molecule vibration

REFERENCE ANALYSIS

-Fresh sample

-Cleaned from debris

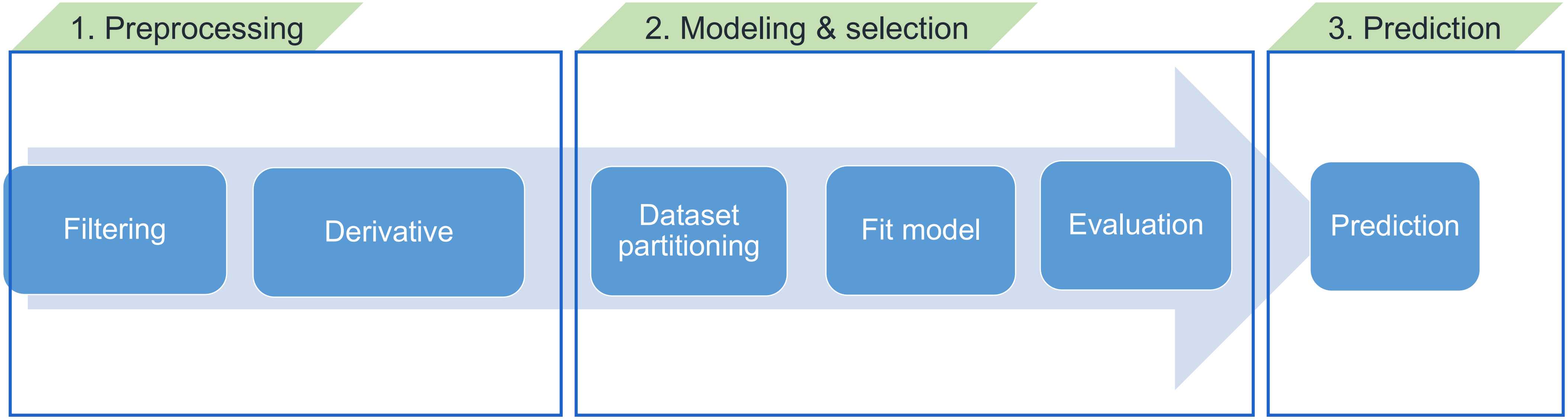
-Quartering & mixing well

-Analyzing soil pH, OC, P, K, Mg, Ca, Na…

-MC (Oven dry)

GHENT
UNIVERSITY

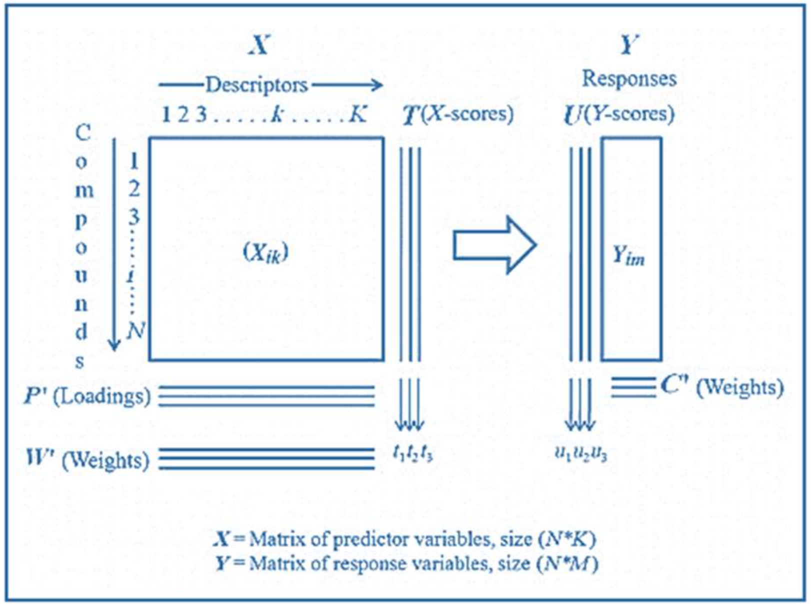
STEPS TO FOLLOW



GHENT UNIVERSITY

MULTIVARIATE CALIBRATION

- **Partial least squares regression (PLSR)**



$$RMSE = \sqrt{\left(\frac{\sum_{i=1}^{n}(\overline{y_i} - y_i)^2}{n-1}\right)}$$

$$R^2 = 1 - \frac{SS_{error}}{SS_{total}}$$

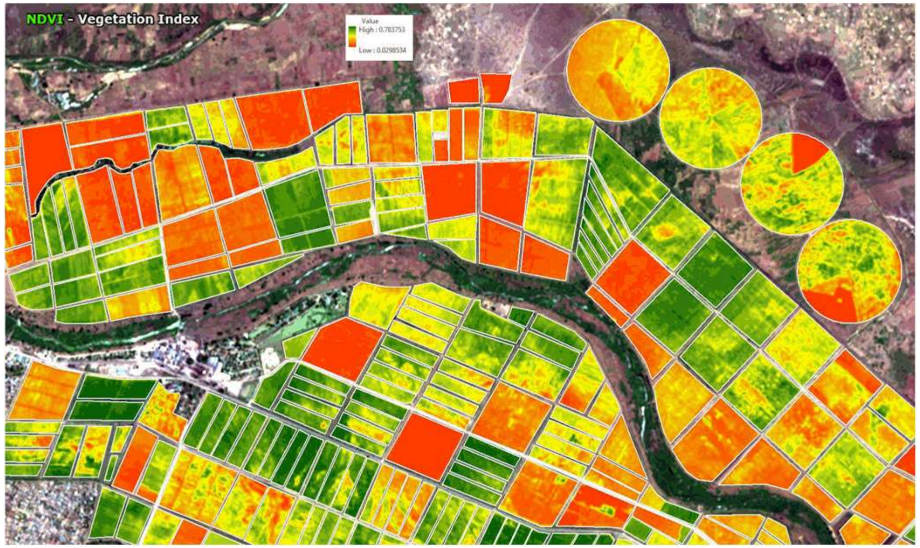
$$RPD = \frac{SD}{RMSE}$$

RMSE: root mean square error (prediction)
R^2: coefficient of determination
RPD: residual of prediction deviation, and
SD: standard deviation

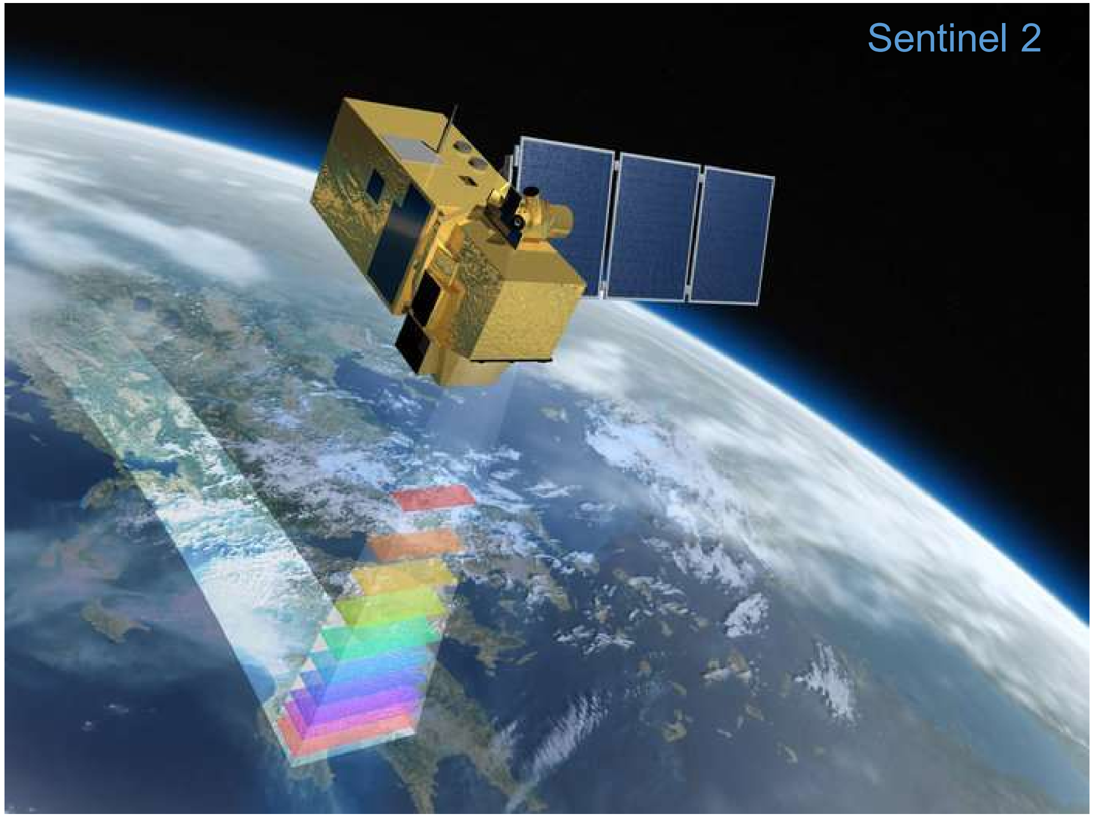
PLSR was found to be one of the best performing modelling technique for on-line measurement. *(Kuang et al., 2015)*

GHENT UNIVERSITY

SATELLITE REMOTE SENSING



$$NDVI = \frac{NIR-RED}{NIR+RED}$$



GHENT UNIVERSITY

WITHIN-FIELD FERTILITY

Statistics	pH_H2O	pH_CaCl2	EC	Sand	Clay	Silt	Moisture	OM	TN	C/N	Phos	K	Ca	Mg	S	B
Mean	**6.38**	**6.10**	**0.53**	**75.62**	**14.97**	**9.42**	**2.00**	**1.43**	**0.07**	**15.70**	**241.72**	**230.02**	**744.40**	**316.84**	**47.59**	**0.57**
Standard Error	0.05	0.04	0.03	0.59	0.41	0.55	0.06	0.02	0.00	0.40	9.10	6.94	32.42	9.28	2.98	0.03
Median	6.40	6.10	0.44	75.00	15.00	9.00	1.88	1.38	0.06	14.50	229.50	218.00	690.50	298.50	40.85	0.48
Standard Deviation	0.47	0.44	0.28	5.94	4.06	5.53	0.62	0.25	0.01	4.04	90.97	69.41	324.19	92.79	29.82	0.28
Sample Variance	0.22	0.20	0.08	35.29	16.47	30.56	0.39	0.06	0.00	16.36	8275.80	4818.38	105096.91	8609.15	889.03	0.08
Kurtosis	0.73	0.70	1.90	-0.39	1.09	0.13	0.58	1.23	19.09	1.44	-0.23	0.92	51.29	1.61	2.37	39.58
Skewness	-0.47	-0.66	1.34	-0.02	-0.07	0.57	0.55	1.04	3.57	0.93	0.52	0.88	6.29	1.05	1.29	5.34
Range	2.50	2.40	1.39	28.00	23.00	26.00	3.71	1.32	0.09	23.00	384.10	372.80	3060.00	520.00	162.50	2.36
Minimum	4.90	4.70	0.18	59.00	3.00	0.00	0.27	1.00	0.06	9.00	82.90	89.20	414.00	169.00	12.50	0.40
Maximum	7.40	7.10	1.57	87.00	26.00	26.00	3.98	2.32	0.15	32.00	467.00	462.00	3474.00	689.00	175.00	2.76
Count	100	100	100	100	100	100.00	100	100	100	100	100	100	100	100	100	100

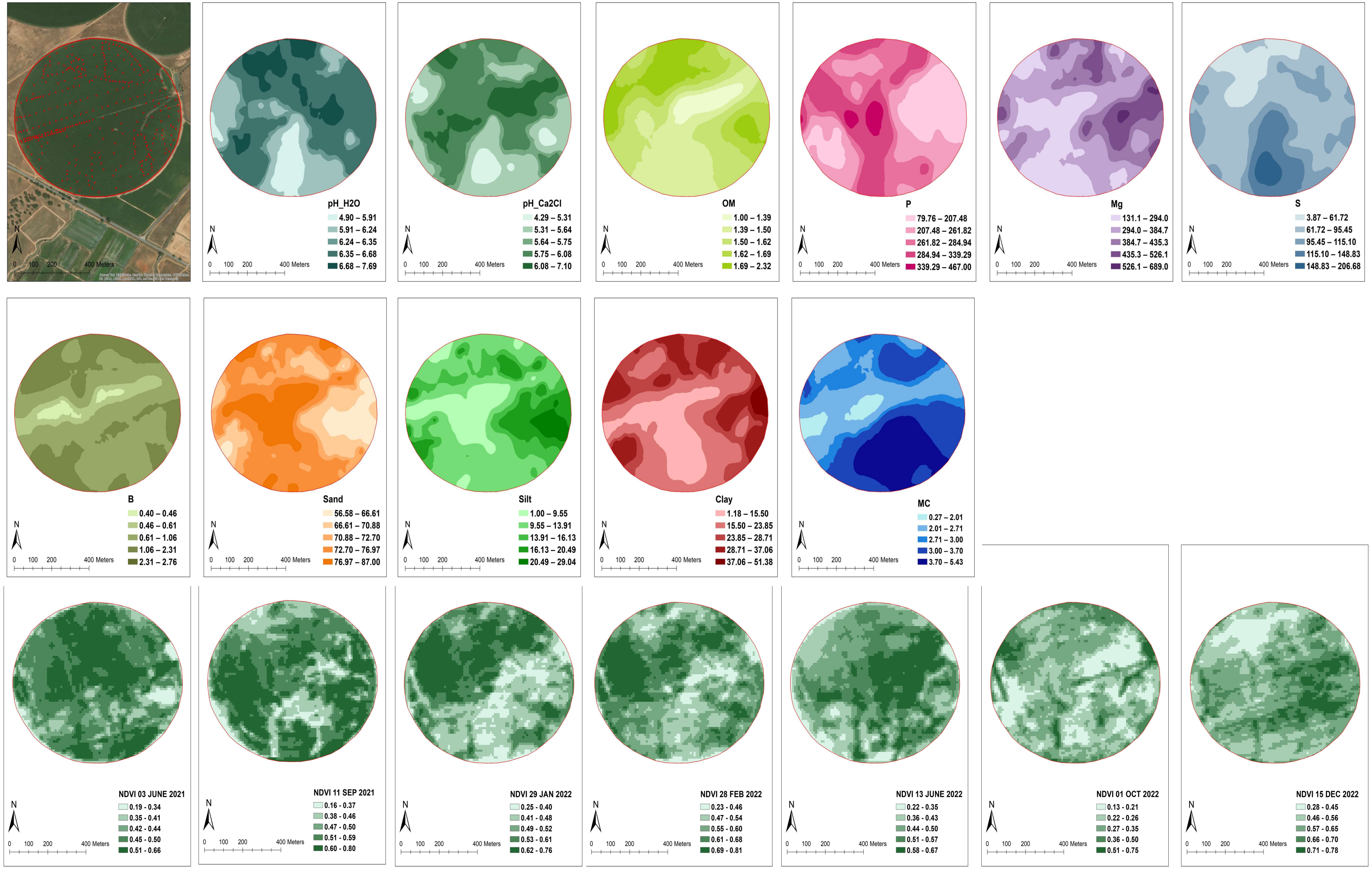
GHENT UNIVERSITY

MODELS

Soil attributes	R2		RMSE		MAE		RPD		RPIQ		nComp
	Cal	Val	Cal	Val	Cal	Val	Cal	Val	Cal	Val	
pH_H2O	0.72	0.50	0.24	0.34	0.19	0.27	1.92	1.44	2.70	1.18	7
pH_CaCl2	0.79	0.68	0.26	0.29	0.20	0.23	2.17	1.79	3.04	2.25	6
Sand	0.84	0.74	2.90	2.98	2.23	2.42	2.50	2.01	5.0	3.02	4
Clay	0.70	0.70	1.61	1.57	1.31	1.44	1.83	2.04	2.48	2.55	
Silt	0.71	0.62	3.61	3.54	2.81	3.05	1.88	1.65	3.46	2.54	4
MC	0.55	0.41	0.51	0.54	0.44	0.44	1.49	1.32	2.38	1.05	5
OM	0.94	0.74	0.07	0.15	0.05	0.12	4.05	2.02	5.93	1.96	RF
P	0.62	0.70	59.04	39.93	46.47	30.36	1.63	1.86	2.21	2.63	3
Mg	0.73	0.73	37.89	48.64	29.36	34.39	1.95	2.06	2.64	2.24	6
S	0.81	0.58	15.06	22.44	11.58	18.47	2.29	1.58	4.51	1.15	7
B	0.69	0.65	0.09	0.10	0.07	0.08	1.81	1.76	2.74	1.65	

GHENT
UNIVERSITY

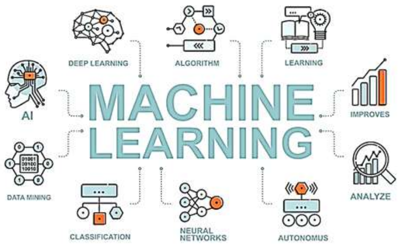
SOIL + CROP MAPS

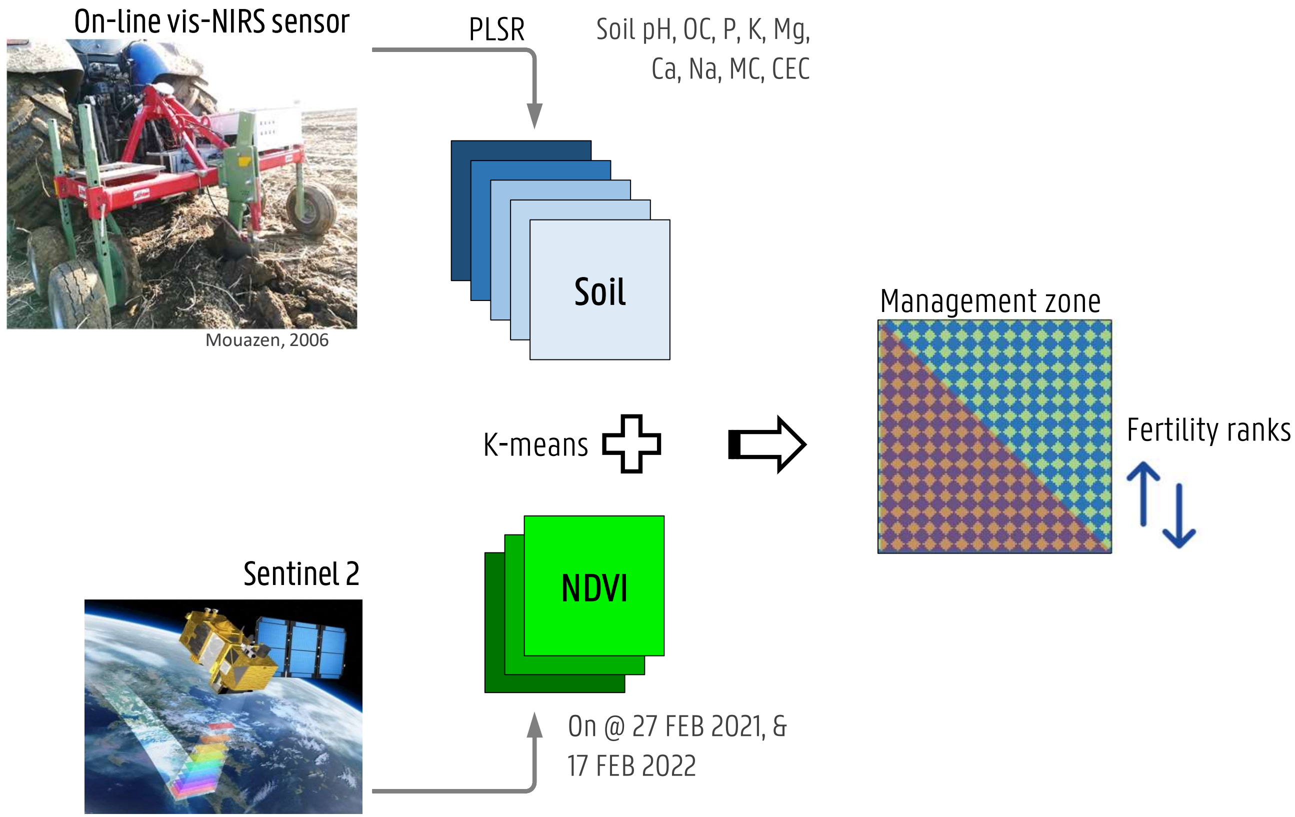


GHENT UNIVERSITY

MANAGEMENT ZONE

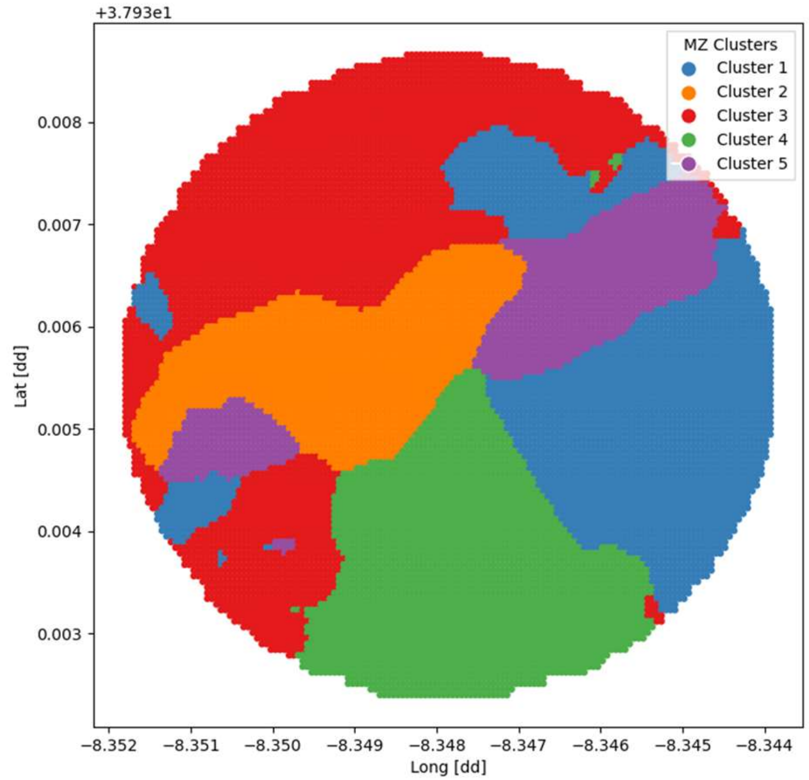
Clustering based fusion of soil and crop data

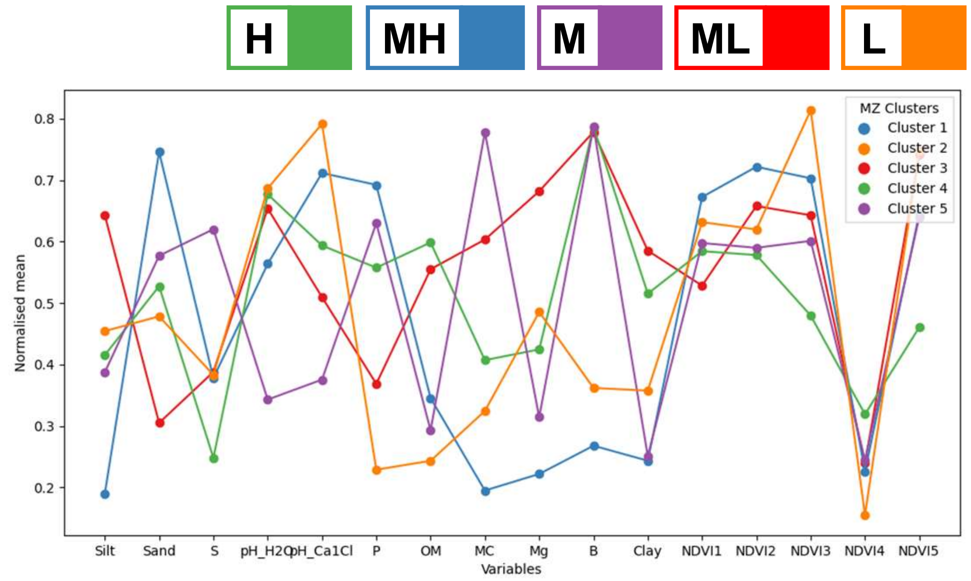




Vis-NIRS, visible-near-infrared reflectance spectroscopy; NDVI, normalised difference vegetation index; OC, organic carbon; P, phosphorus; K, potassium; Mg, magnesium; Ca, calcium; Na, sodium; MC, moisture content; CEC, cation exchange capacity.

MANAGEMENT ZONE





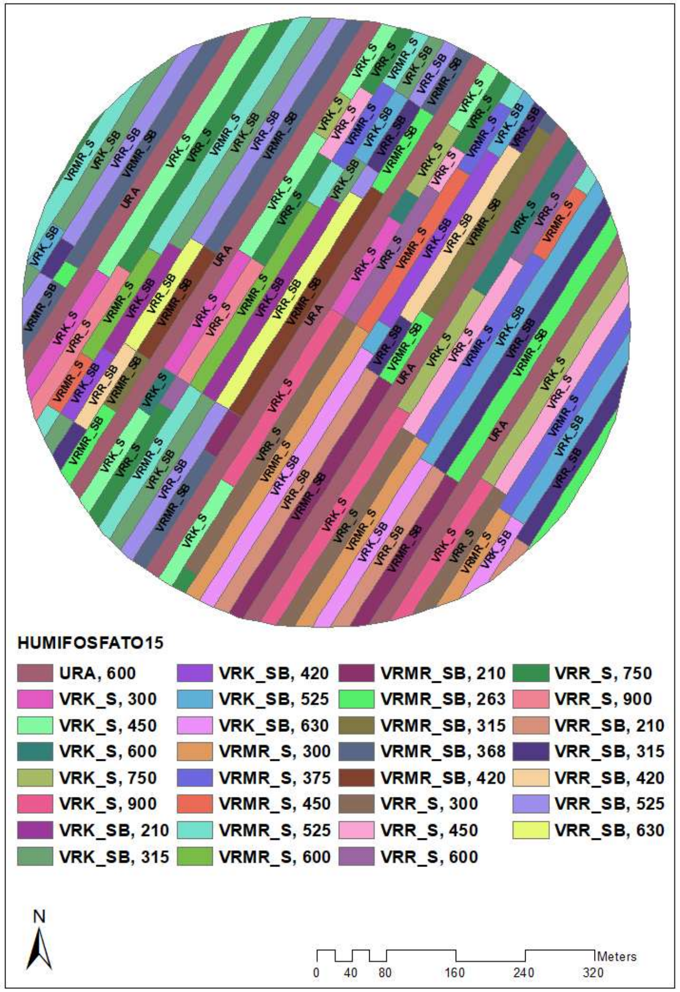
GHENT UNIVERSITY

C:\Users\mmunnaf\OneDrive - UGent\Documents\Research\Experiments\Lisbon\data\Model_15NOV2022\MZ_2023

APPLICATION MAP

7 treatments with 3 replications

1. URA: Uniform rate application
2. VRK_S: Variable rate synthetic NPK by Kings
3. VRR_S: Variable rate synthetic NPK by Robin Hood
4. VRMR_S: Variable rate synthetic NPK by Marginal Robin Hood
5. VRK_B: Variable rate bio + NPK by Kings
6. VRR_B: Variable rate bio + NPK by Robin Hood
7. VRMR_B: Variable rate bio + NPK by Marginal Robin Hood



GHENT UNIVERSITY

C:\Users\mmunnaf\OneDrive - UGent\Documents\Research\Experiments\Lisbon\data\Model_15NOV2022\MZ_2023\Application_LISBON_3\Final_Aplication_2023

EXPECTED RESULTS

AGRONOMIC

ECONOMIC

ENVIRONMENTAL

GHENT UNIVERSITY

PREVIOUS STUDY

GHENT
UNIVERSITY

SITE-SPECIFIC MANURE APPLICATION

KING

VR1:

Low Fertility =

Medium Low Fertility =

Medium High Fertility =

High Fertility =

ROBIN HOOD

VR2:

Low Fertility =

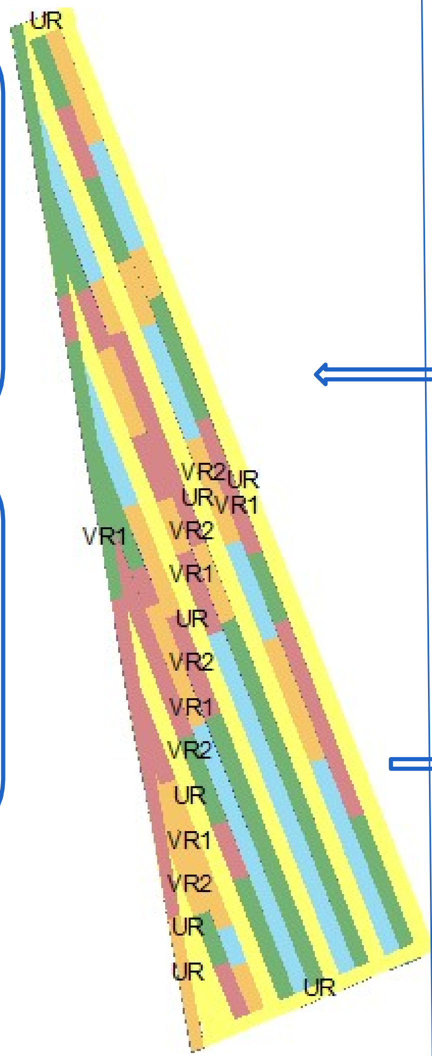
Medium Low Fertility =

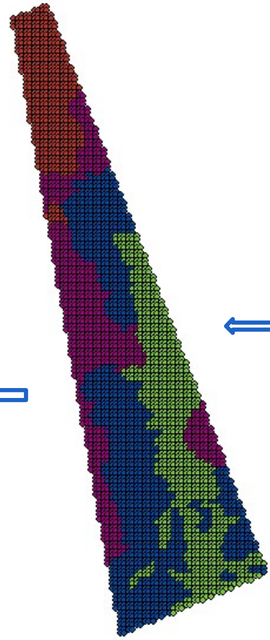
Medium High Fertility =

High Fertility =

UR: All fertility zones =

GHENT UNIVERSITY





ECONOMIC AND ENVIRONMENTAL BENEFIT

TREAT	AREA (Ha)	Manure t/ha	COST PER HECTARE (EUR)	YIELD (T/Ha)	Output (EUR)	PROFIT PER HECTARE (EUR)	COMPARISON PER HECTARE (EUR)	PROFIT PER TREATMENT (EUR)	SIMULATION PROFIT PER FIELD (EUR)
UR	3.40	35	-16.50	12.52	1903.04	1919.54	------	6523.55	18392.29
Kings VR1	3.14	36.9	-13.24	12.81	1946.36	1959.60	40.06	6156.83	18776.14
R. Hood VR2	3.04	32.52	-23.94	12.71	1931.92	1955.86	36.32	5948.24	18740.32

⬆ Yield 1.5 – 2.3 % ⬆ Profit 1.9 – 2.1 %

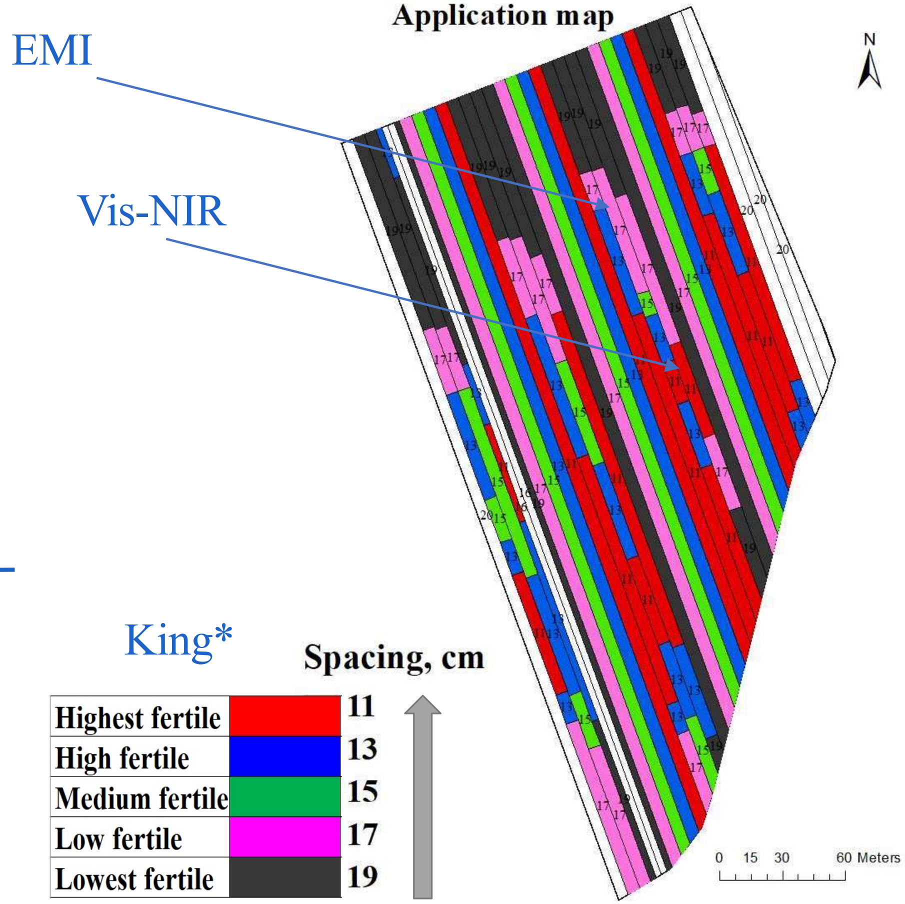
TREAT	Area (Ha)	Total N per entire area (kg/ha)	N applied (kg/ha)	Comparison (kg/ha)	Simulated N Kg / field	Comparison simulated N (kg/field)		Total P per entire area (Kg/ha)	P applied (Kg/ha)	Comparison (kg/ha)	Simulated P Kg / field	Comparison simulated P (kg/field)
UR	3.40	983.87	289.50		2773.88			178.42	52.50		503.03	
Kings VR1	3.14	925.96	294.71	5.21	2823.84	49.96		170.07	54.13	1.63	518.65	15.61
R. Hood VR2	3.04	844.22	277.59	-11.91	2659.78	-114.09		148.35	48.78	-3.72	467.38	-35.65

⬆ Kings N 1.8 %
P 3.1 %

⬇ R. Hood N - 4.1 %
P - 7.1 %

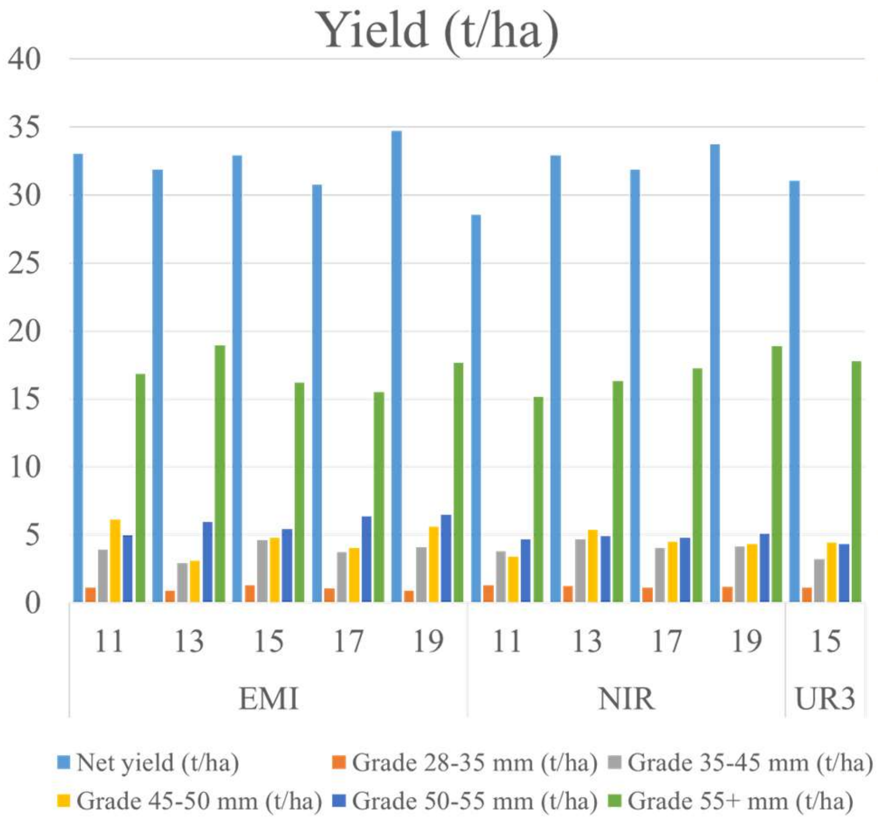
GHENT UNIVERSITY

SITE-SPECIFIC POTATO SEEDING



GHENT UNIVERSITY

COST-BENEFIT ANALYSIS



Treatment	Cost (€/ha)	Yield (t/ha)	Revenue (€/ha)	Net Profit (€/ha)	Relative profit (€/ha)
UR	2200	**31.06**	6728	4528	-
Vis-NIR	2186	**31.89**	7181	4995	**467**
EMI	2205	**32.42**	7152	4947	**419**

↑ *Yield 2.62%*

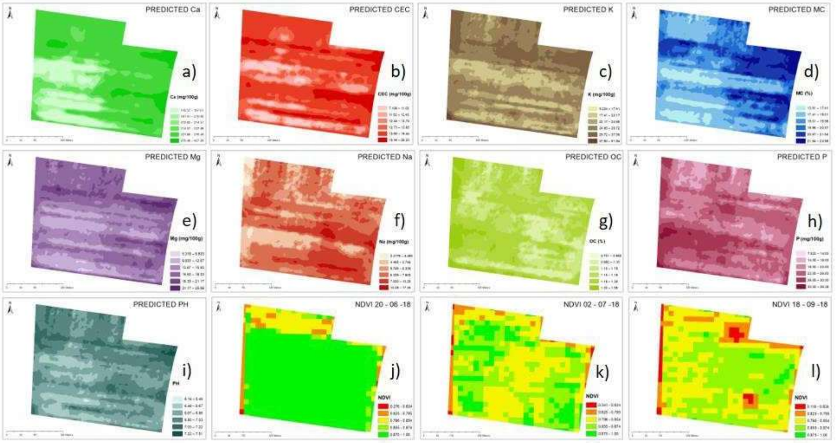
↓ *Cost 0.6%*

↑ *Profitability 10.32%*

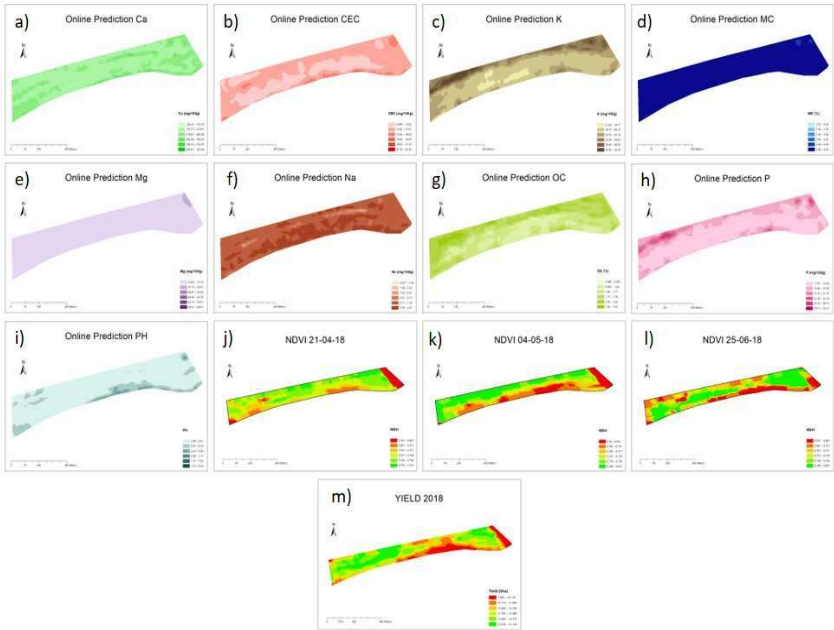
GHENT UNIVERSITY

SITE-SPECIFIC NITROGEN

1

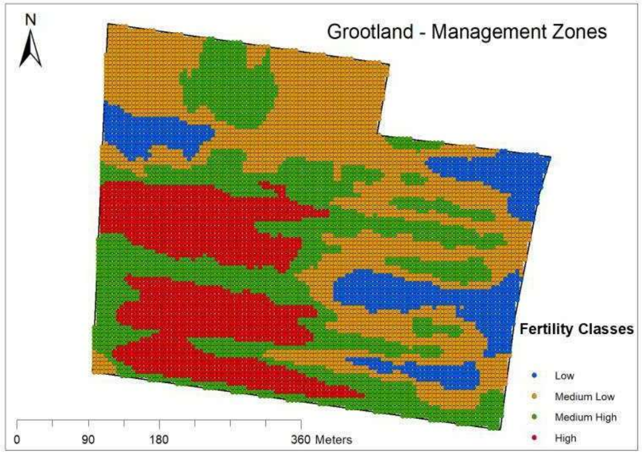


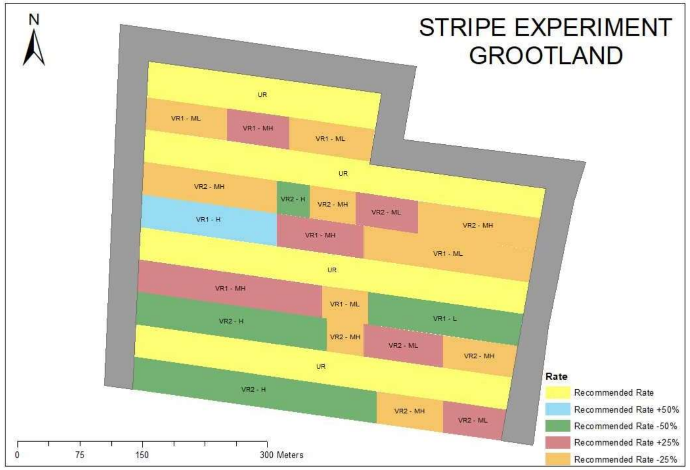
2

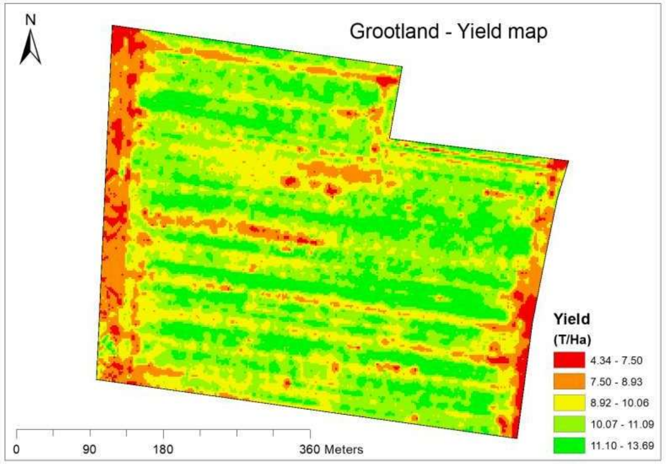


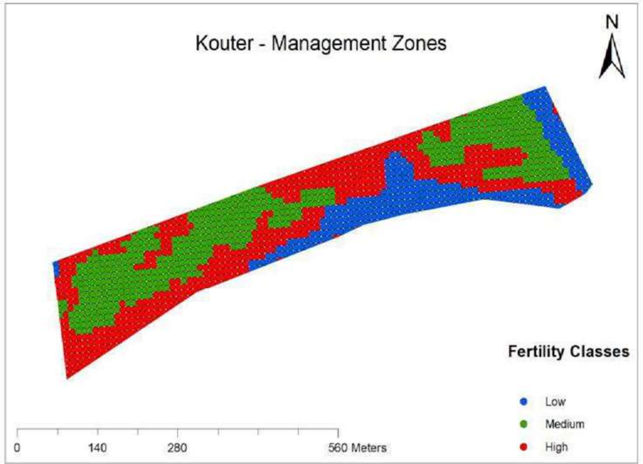
GHENT UNIVERSITY

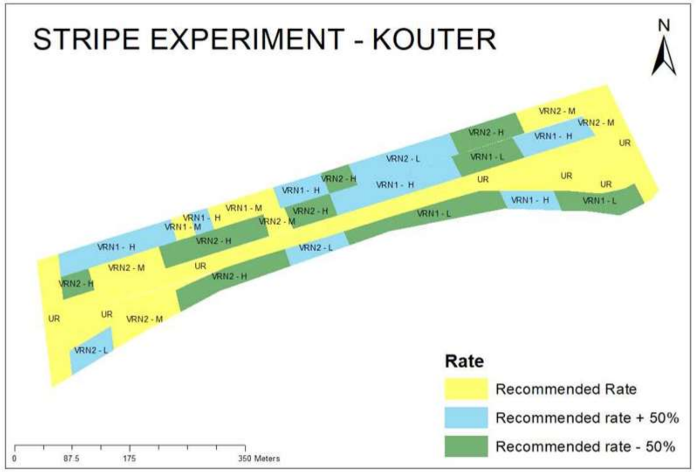
MZ, STRIPS EXPERIMENT, YIELD MAPS 2019

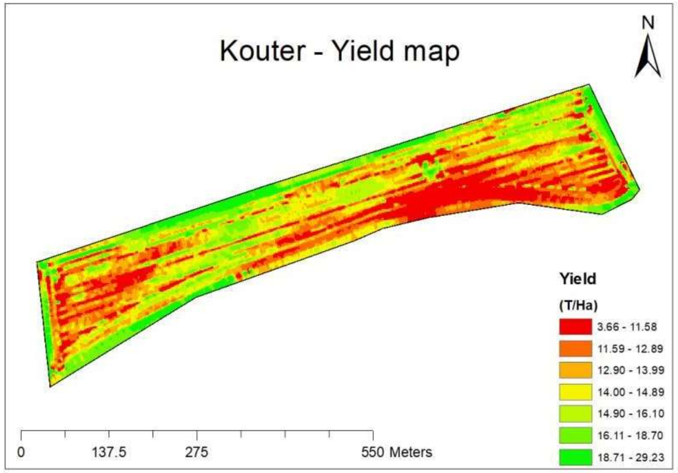












COST-BENEFIT AND ENVIRONMENTAL ANALYSIS

ECONOMOMIC BENEFIT

Field	Treatment	AREA (Ha)	Cost Per Hectare (Eur)	YIELD (T/Ha)	Output (EUR)	Profit Per Hectare (Eur)	UR-VR Profit difference (Eur/Ha)	Profit Per Treatment (Eur)	Simulation Profit Per Field (Eur)
GROOTLAND	UR	6.701	86.405	10.460	1673.600	1586.246	------	10629.364	26700.029
	Total VR1	4.741	85.088	10.482	1677.120	1591.097	+4.851	7543.418	26781.674
	Total VR2	5.390	69.605	10.456	1673.013	1602.643	+16.397	8638.628	26976.029
KOUTER	UR	4.983	81.175	8.040	1222.08	1140.90	-----	5684.70	15844.45
	Total VR1	4.291	92.658	8.966	1362.83	1270.17	+129.26	5449.90	17639.68
	Total VR2	4.614	73.350	8.967	1363.03	1289.68	+148.78	5951.00	17910.65

ENVIRONMENTAL BENEFIT

Field	Treatment	Area (Ha)	Fertilizer Used (N units)	Yield (t/Ha)	Units/Ha	UR-VR N difference (N units per Ha)	Simulation Total N Units Per Field	Savings of Simulation per Field Compared with UR
GROOTLAND	UR	6.701	924.732	10.460	138	------	2322.845	------
	Total VR1	4.741	644.295	10.482	135.898	-2.102	2287.465	-35.38
	Total VR2	5.390	599.229	10.456	111.1693	-26.831	1871.226	-451.619
KOUTER	UR	4.98	622.83	8.040	125	------	1735.952	------
	Total VR1	4.29	601.65	8.969	140.223	15.222	1947.354	211.401
	Total VR2	4.61	540.86	8.967	117.213	-7.786	1627.822	-108.13

GHENT UNIVERSITY

CONCLUSIONS

PA is an effective means to manage within-field heterogeneity through resource use optimisation

PA is a proven approach to increase farm productivity & profitability in sustainable means.

Data from single sensor is often insufficient, hence PA requires multi-layers information

Mapping within-field variation asks for a proper data fusion prior to accurate MZ delineation

PA necessitates intensive data handling and powerful processing algorithms

PA practice at farmers level is limited, requiring extensive proof of evidences