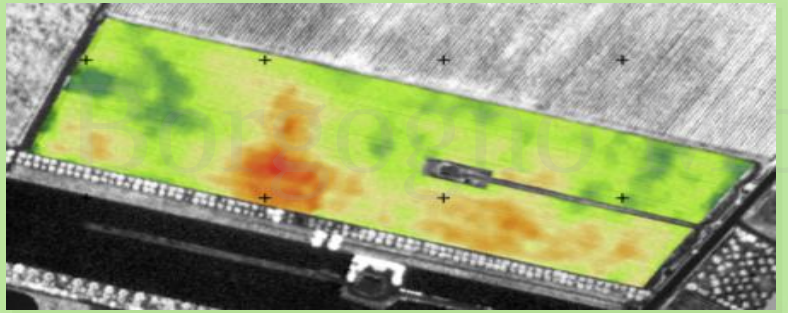
Agronomic Exploitation of Spectral Information from Optical Remote Sensing



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DISAFA – University of Torino

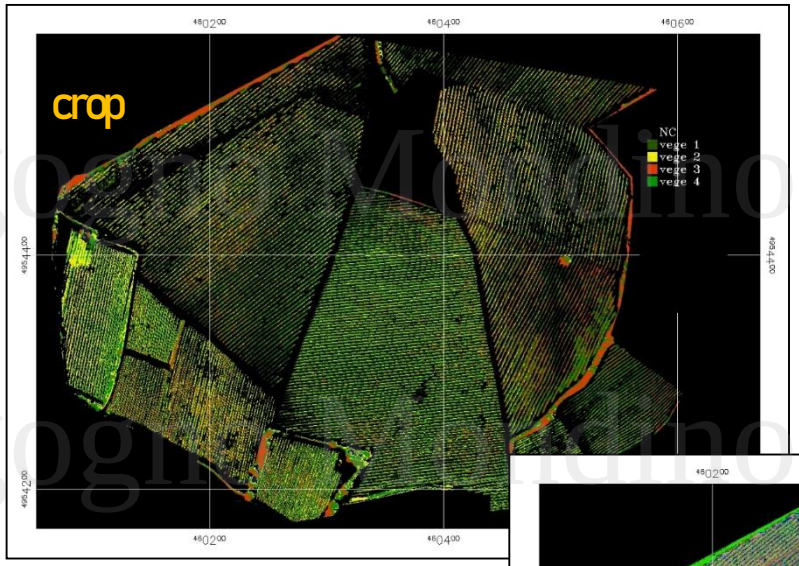
EXPECTED ROLES OF REMOTE SENSING IN AGRICULTURE

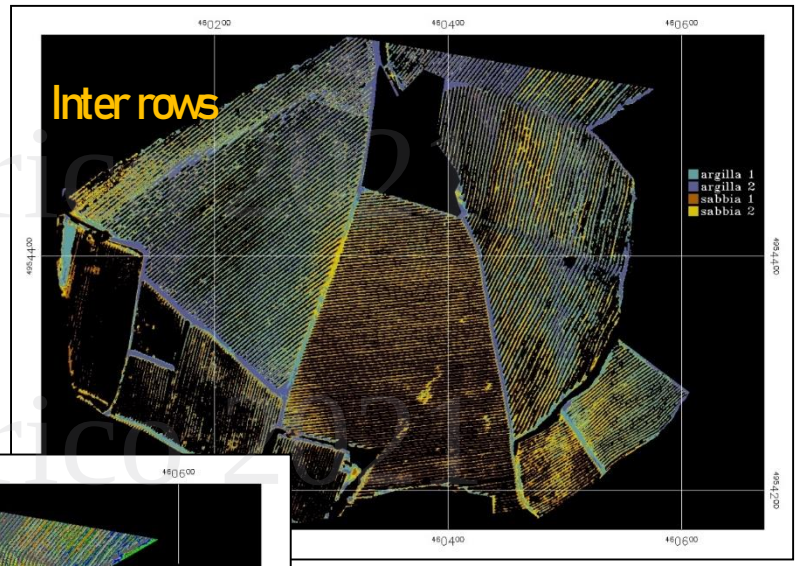
1. CROP SYSTEMS CLASSIFICATION (crop + soil) → CAP controls
2. ZONATION → CLUSTER ANALYSIS
3. MANAGEMENT OF VARIABLE RATE APPROACHES → PRESCRIPTION MAPS
4. MAPPING SPATIAL DISTRIBUTION OF AGRONOMIC PARAMETERS (e.g. N, Orgnaic Carbon, water potential, Evapotranspiration etc.)

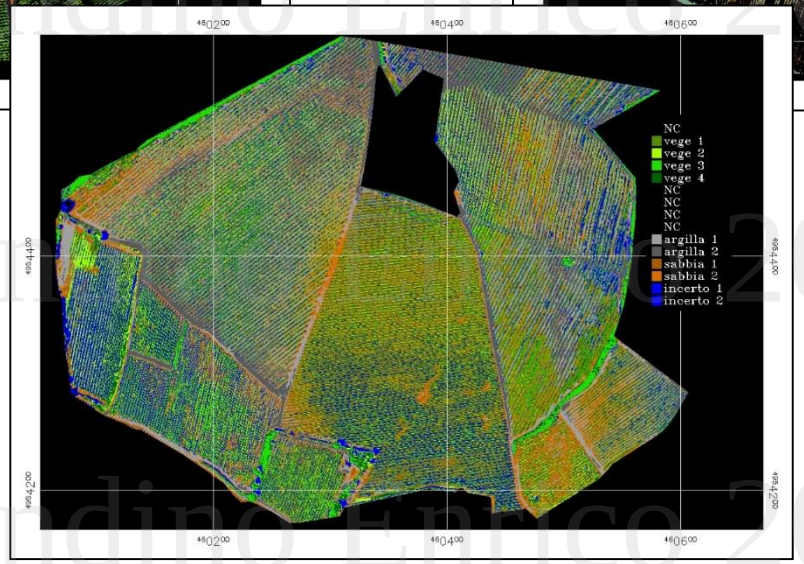
WHICH SPECTRAL DISCRIMINANTS?

- SPECTRAL SIGNATURE AT THE SINGLE TIME (along the growing season of crop)
- TEMPORAL PROFILE OF SPECTRAL INDEX (VI)
  - Yearly VI temporal profile
  - Phenological metrics
- GEOMETRIC FEATURES OF CROPS DERIVED FROM CANOPY HEIGHT MODELS (digital photogrammetry/LiDAR)

MAIN APPLICATIONS IN PRECISION FARMING
CROP AND SOIL CLASSIFICATION







→ PIXEL-BASED CLASSIFIERS ARE PREFERABLE An OBJECT-BASED approach could limit the detection of some important effects of local variability of crops/soil

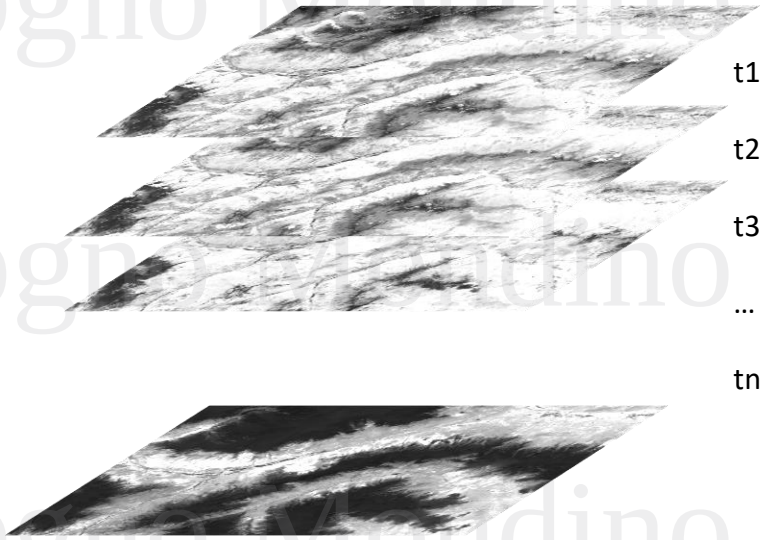
Joint classification

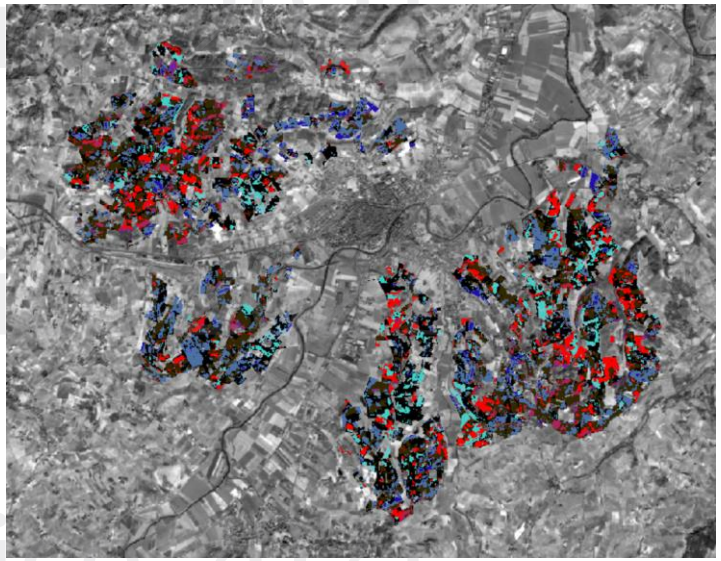
MAIN APPLICATIONS IN PRECISION FARMING

ZONATION

Prescription maps can be also considered as intra-plot zonation, making possible to map those areas having different agronomic behaviour within a single field.

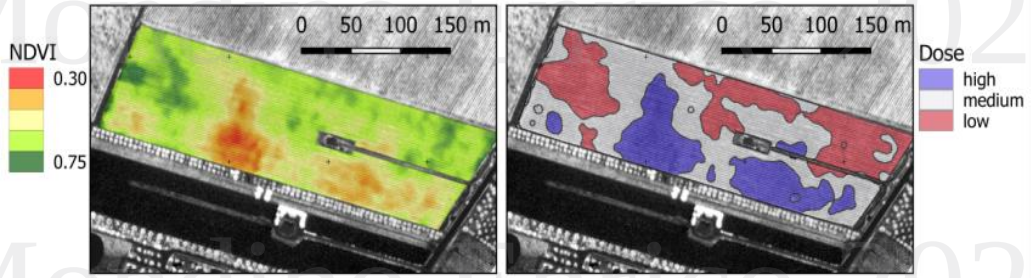
working at landscape level, zonation can be used to map average FIELD behaviour making possible to calibrate deductions for a proper management by Consortia or big farm companies. This is typical, for example, when looking for atmospheric adversities effects (drought, hail, storms, etc.) or when deciding the time of harvest at field level.



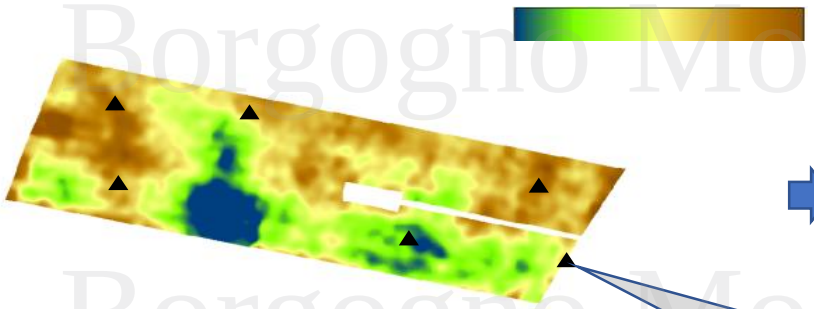


SPECTRAL INDICES
MAIN APPLICATIONS IN PRECISION FARMING

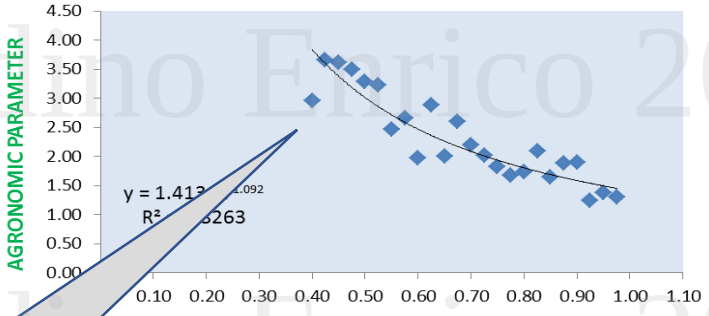
1. PRESCRIPTION MAPS: spectral index maps can be thresholded or clusterized to derive PRESCRIPTION MAPS to be interpreted by variable rate machineries to distribute agronomic treatments with different intensity



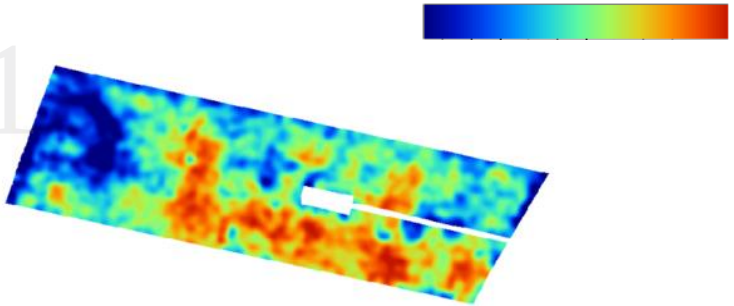
2. ESTIMATION MAPS: Ground measures at a single o multiple times are compared with Spectral Index local values to calibrate regressive models useful for generating estimates of biophysical parameters



Spectral index map (e.g. NDVI)



Ground measure and VI is known here



Estimation maps (e.g. N content)

PRESCRIPTION MAPS (PM)

SPECTRAL INDICES

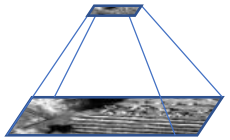
MAIN APPLICATIONS IN PRECISION FARMING

1. PRESCRIPTION MAPS (PM)

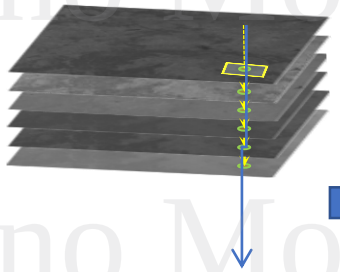
A) Zoning is made at field level

B) One image at the right time along the growing season of crop can be enough to derive a useful PM

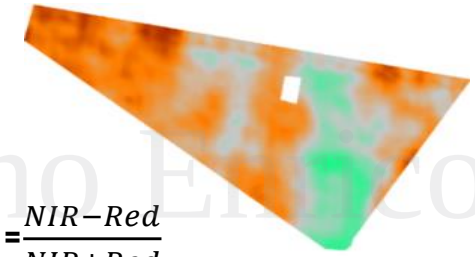
C) Relative spectral index differences are more important than absolute values → a simplified (qualitative and relative) remote sensing is enough to generate reliable results.



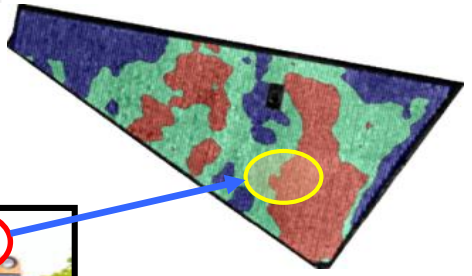
Multispectral image



Spectral index map (es. NDM)



Es. NDM = $\frac{NIR-Red}{NIR+Red}$

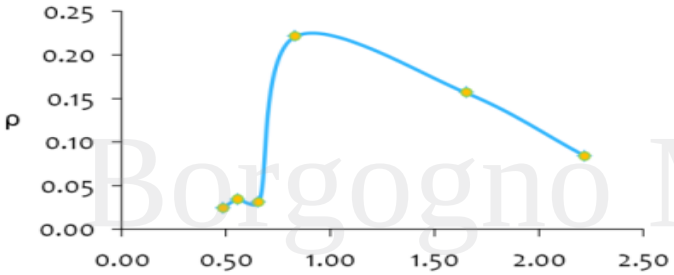


ZONES

Interpretation of ZONES → PRESCRIPTION MAPS

Variable rate machineries fo PA

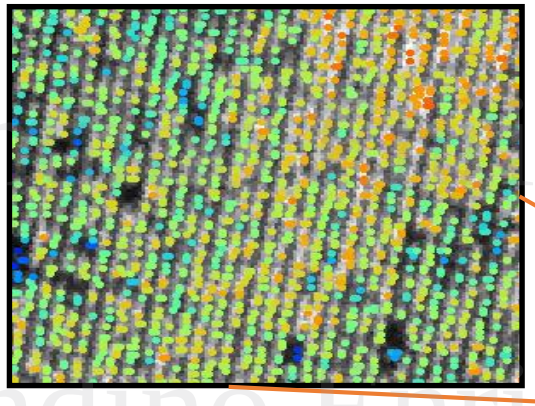
Spectrum of crop

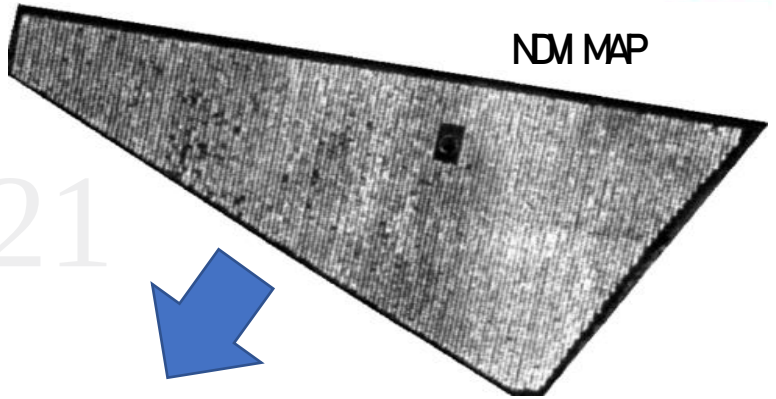


SPECTRAL INDICES

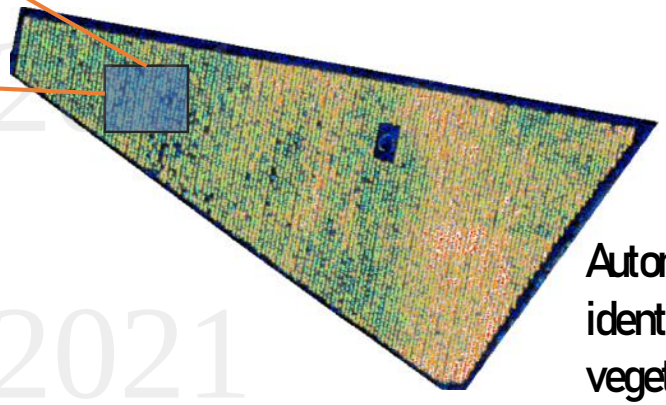
MAIN APPLICATIONS IN PRECISION FARMING

When working with very high resolution imagery (e.g. DRONES) some further steps have to be done, especially when working with crops like orchards or vineyards where monitored crop is not continuous

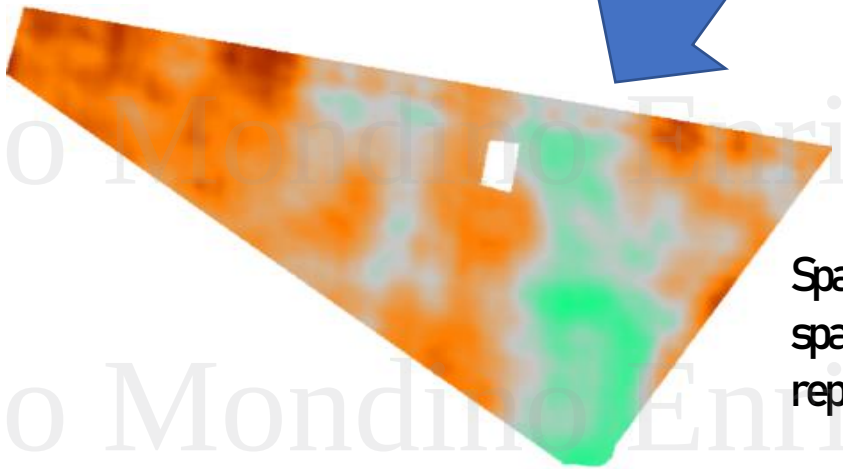




NDVI MAP



Automatic identification of vegetated pixels (vines)



Spatial interpolation to recover spatial continuity of representation → GEOSTATSTICS

SPECTRAL INDICES
REMAINING CRITICALITIES

1. WHICH IS THE "BEST" SPECTRAL INDEX?

Most limiting factor is the spectral resolution of available sensors

2. WHICH CRITERION has to be adopted to translate VIGOUR MAPS into the correspondent PRESCRIPTION MAPS?

Different criteria generate different prescription maps → different intensity of treatments over crops.

3. WHICH MINIMUM MAPPING UNIT (MMU) ?

Machinaries performances and architecture play an imprtant role to define this parameter → very high resolution imagery from sensors is really important?

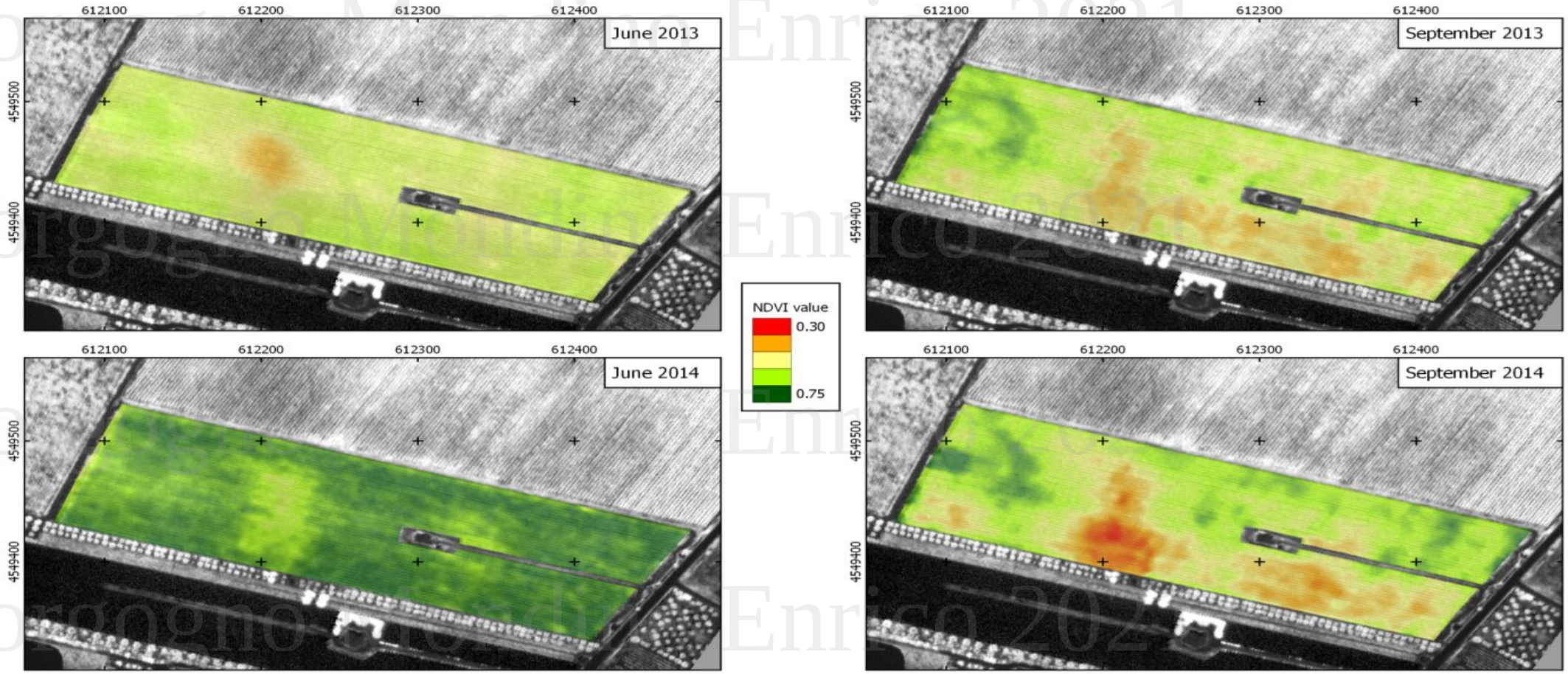
4. HOW MANY CLASSES OF INTENSITY OF TREATEMENTS MUST BE MAPPED IN PRESCRIPTION MAPS? VALLUE OF THRESHOLDS?

5. WHICH IS THE BEST TIME ALONG THE GROWING SEASON OF CROPS TO OPERATE THE ACQUISITION? ONE OR MORE ACQUISITIONS?

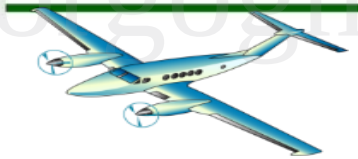
TIME OF THE ANALYSIS

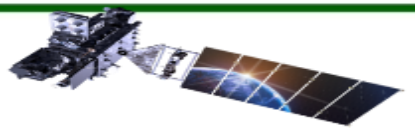
WHICH IS THE BEST TIME ALONG THE GROWING SEASON OF CROPS TO OPERATE THE ACQUISITION?

An example on vineyard



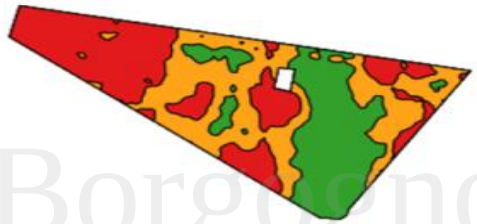
SPECTRAL INDICES
SCALE OF ZONATION



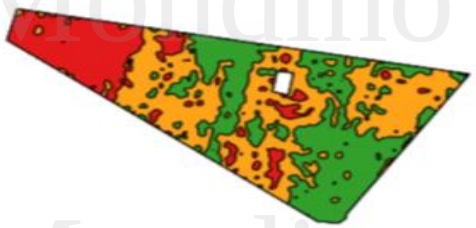


Aerial dataset (GSD = 1 m)

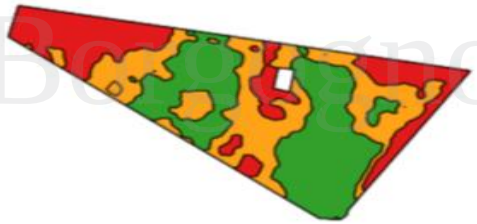
June 2013



Sept 2013



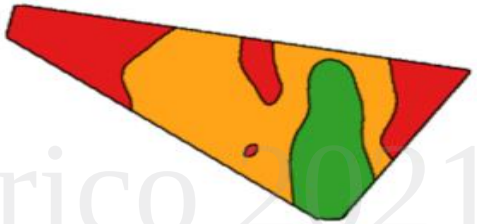
June 2014



Sept 2014

Satellite dataset (GSD = 30 m)

June 2013



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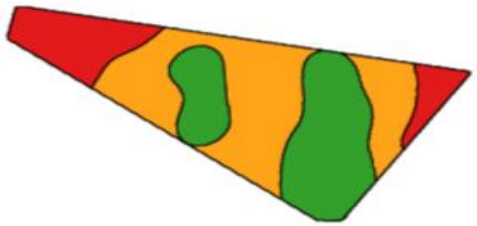
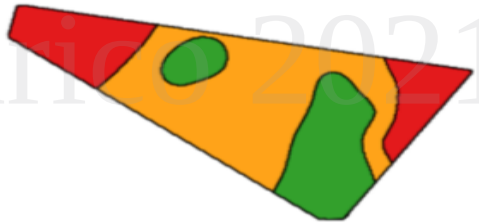
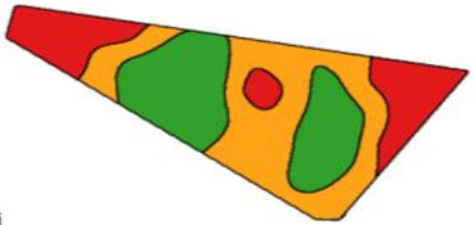


June 2014

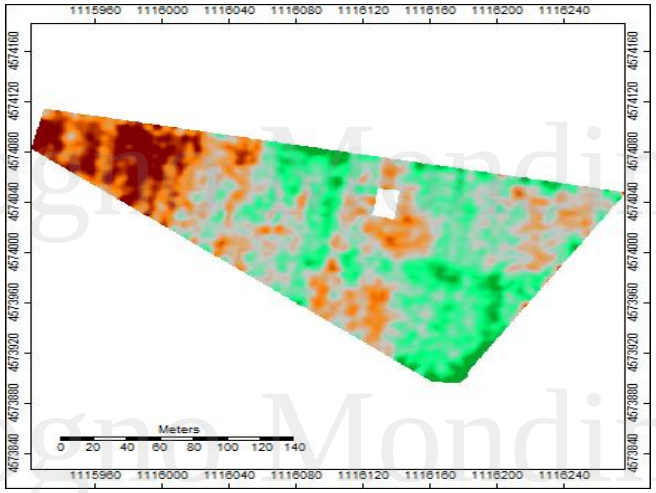


Sept 2014

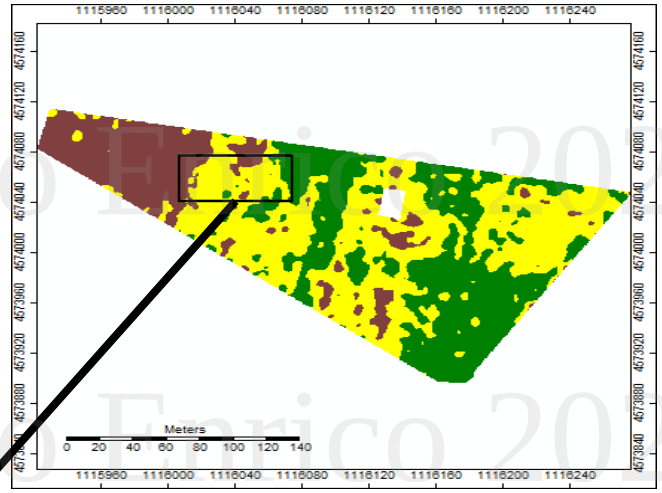


SPECTRAL INDICES
NUMBER OF CLUSTERS

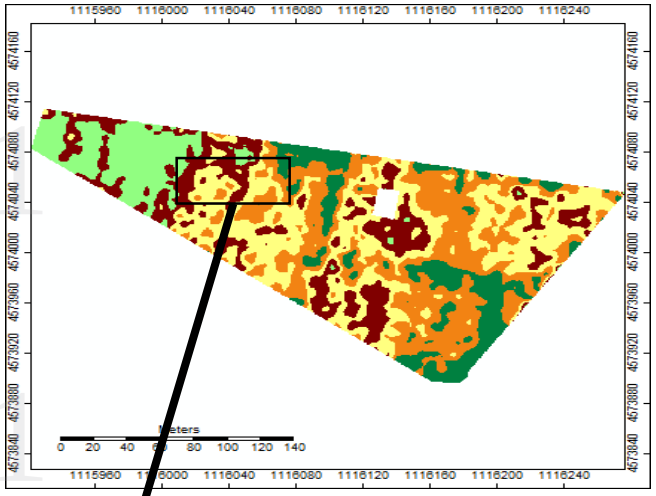
HOW MANY CLASSES?



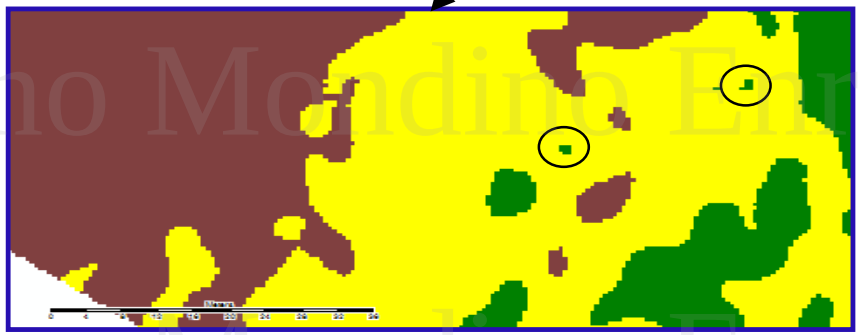
NDM map

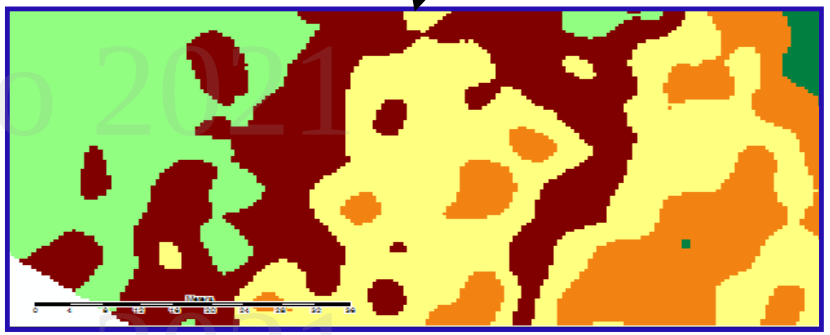


3 vigour classes



5 vigour classes





MINIMUM MAPPING UNIT (MMU)?

SPECTRAL INDICES
FROM INDEX/ESTIMATE to ZONES

Prescription maps can be obtained by ZONING maps of opportune spectral indices (NDM, NDRE, etc.) or, directly, maps of ESTIMATES of agronomic parameters obtained by REGRESSION or ARTIFICIAL INTELLIGENCE-based systems relating them to spectral measures.

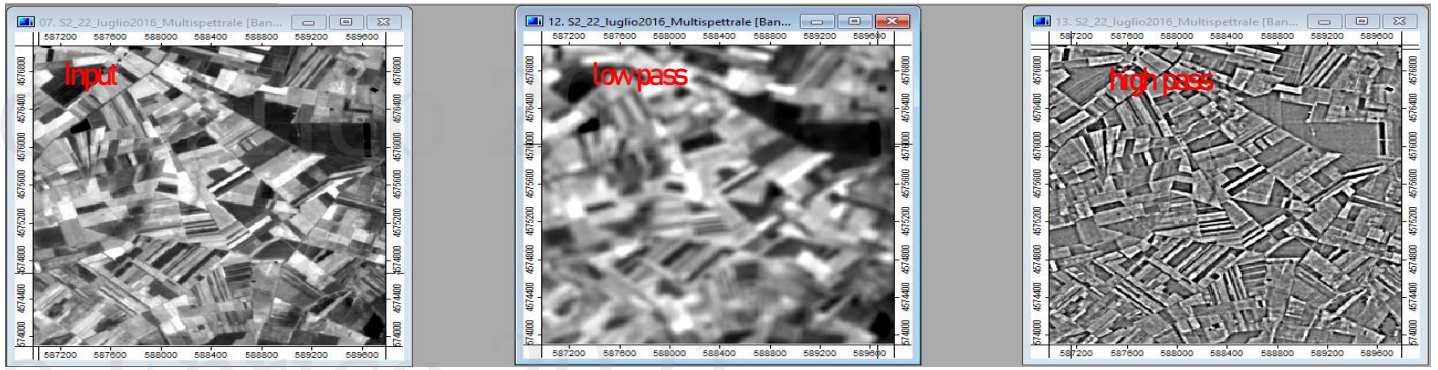
ZONING can be achieved

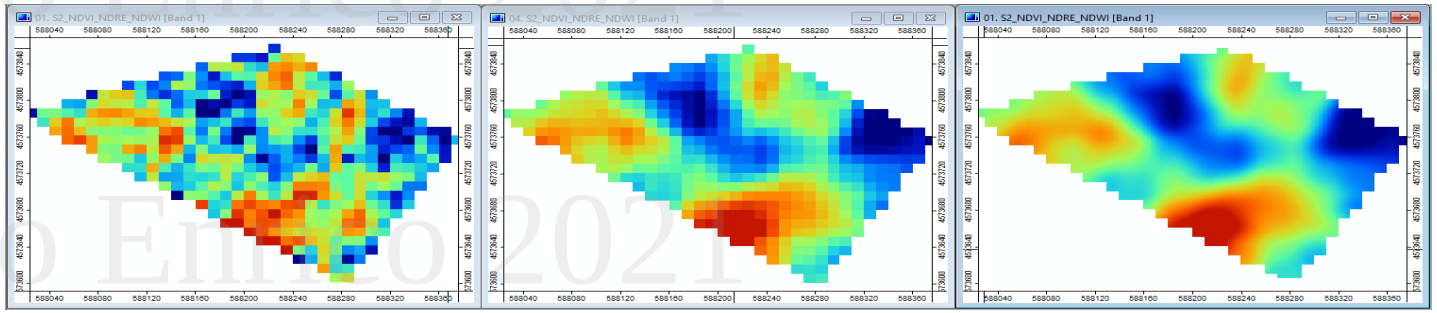
a) MANUALLY/INTRACTIVELY, possibly interpreting the HISTOGRAM of the map to be ZONED
b) AUTOMATICALLY by CLUSTER ANALYSIS

When working with satellite data, to refine spatial patterns, it is possible to oversample the data. A better result can be achieved by preventively FILTERING (low pass) the map and then (over-) RESAMPLE it.

FILTERING: low pass FILTERING is useful to reduce local variability. High pass FILTERING is useful to emphasize radiometric borders. OUTPUT image preserve the same GSD as INPUT one

RESAMPLING: to virtually reduce GSD one can OVERSAMPLE. To virtually enlarge GSD one can DOWNSAMPLE



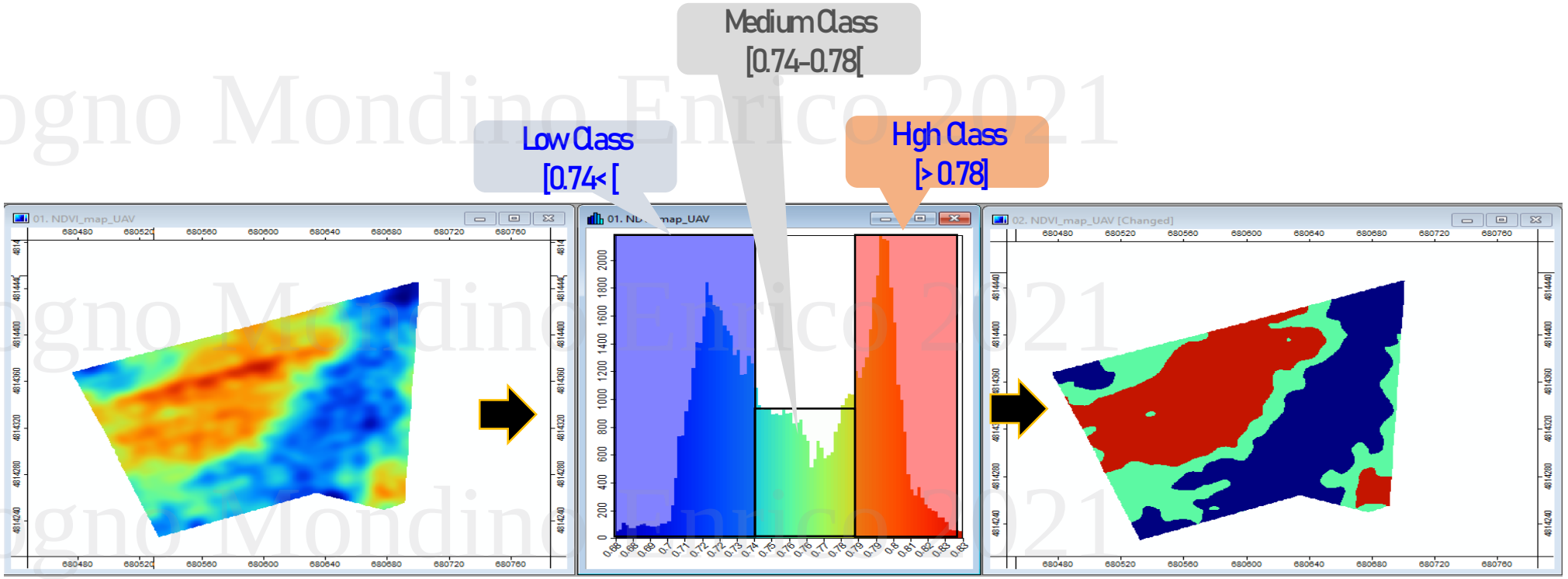


Input (GSD=10m) | Low pass filtered (GSD=10 m) | Oversampled (GSD=1 m)

SPECTRAL INDICES
FROM INDEX/ESTIMATE to ZONES

MANUAL/INTERACTIVE ZONING

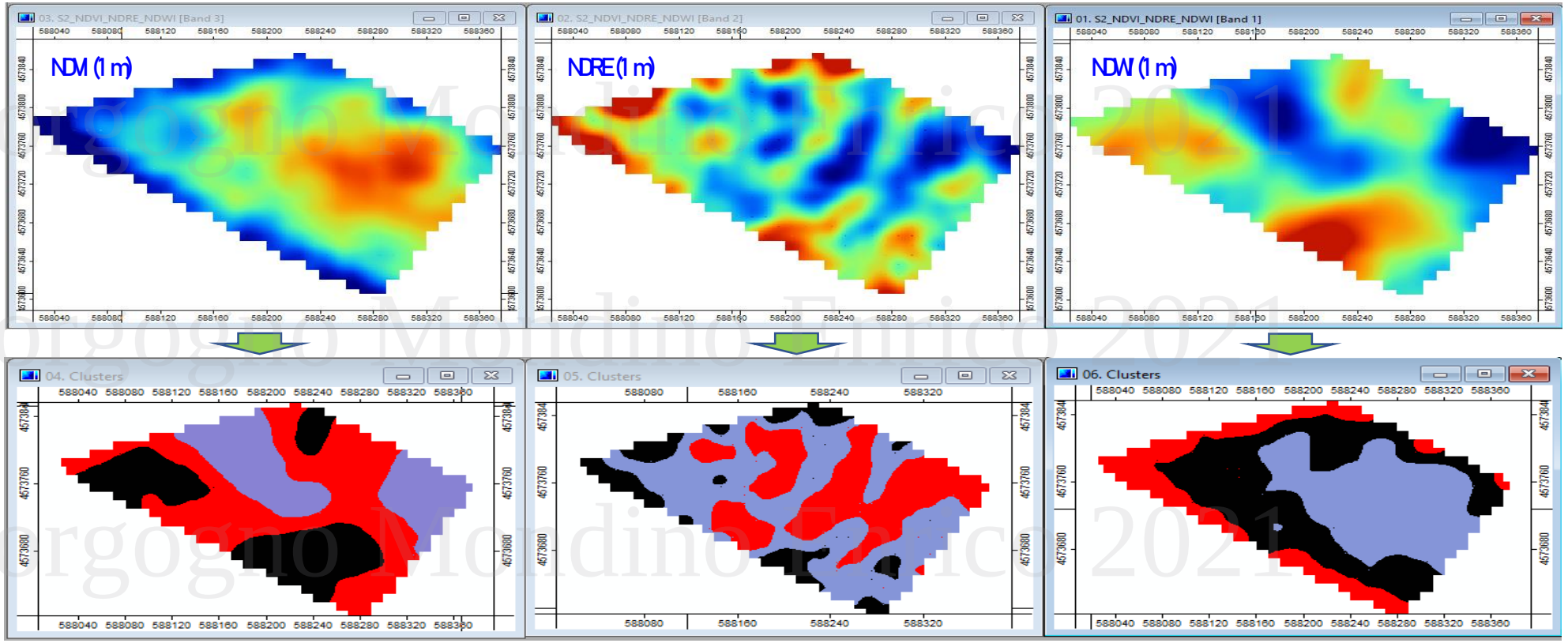
The user analyzes, perceptively, the IMAGE HISTOGRAM of the spectral index/parameters and proceed to define thresholds where significant brakes can be recognized



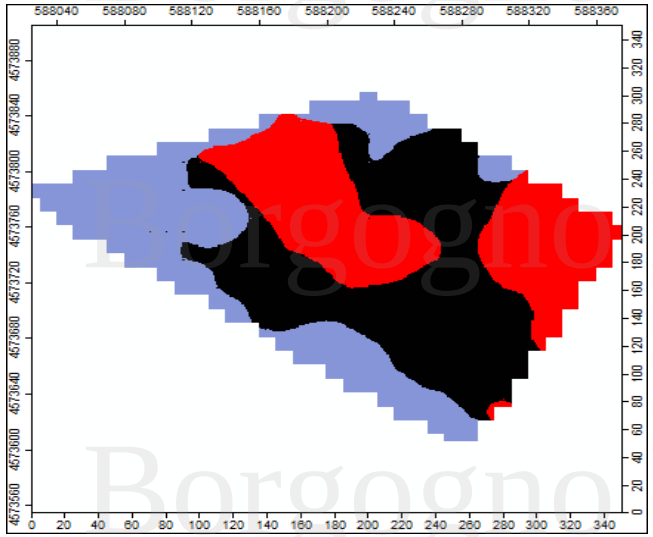
SPECTRAL INDICES
FROM INDEX/ESTIMATE to ZONES

ZONING by SPATIAL CLUSTERING

Ordinary UNSUPERVISED CLASSIFICATION algorithms (e.g. K-means) can be used to ZONE the field operating on a single band (NDVI, NDRE, etc.) or on multiple bands (NDVI+NDRE+NDWI etc..) or directly on native bands of the multispectral image.



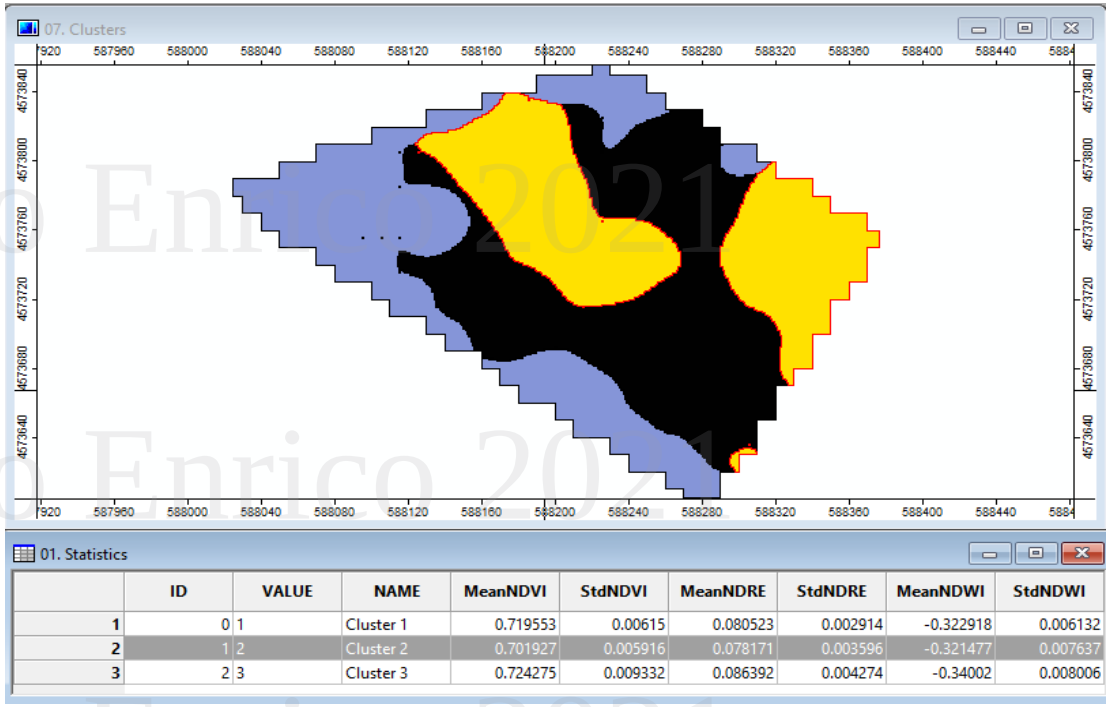
SPECTRAL INDICES
FROM INDEX/ESTIMATE to ZONES



ZONING by SPATIAL CLUSTERING

Different spectral indices can be also jointly used and processed by UNSUPERVISED CLASSIFICATION to generate ZONES averagely similar in terms of indices values.

Vectorization
(grid to vector)



	ID	VALUE	NAME	MeanNDVI	StdNDVI	MeanNDRE	StdNDRE	MeanNDWI	StdNDWI
1	0	1	Cluster 1	0.719553	0.00615	0.080523	0.002914	-0.322918	0.006132
2	1	2	Cluster 2	0.701927	0.005916	0.078171	0.003596	-0.321477	0.007637
3	2	3	Cluster 3	0.724275	0.009332	0.086392	0.004274	-0.34002	0.008006

INTERPRETING CLUSTERS

Once ZONES have been defined they have to be AGRONOMICALLY INTERPRETED.

A good starting point for INTERPRETATION is compute ZONAL STATISTICS for ZONES by ordinary GIS tools. STATISTICS may involve the starting NDVI map or, better other maps eventually available (other indices or bands or pedological infos,...).
ZONAL STATISTICS require that a vectorization of the ZONE MAP is achieved.

SPECTRAL INDICES
FROM ZONES to PRESCRIPTION

The translation of cluster spectral meaning into the correspondent agronomic information (intensity of differentiated treatment) needs a high level of knowledge from agronomists about the field the map is intended for.
The expected solution relies on "transfer functions" (field dependent) relating the VI value to the rate. This has to be developed comparing ground and spectral measures for years (difficult).

Alternatively, agronomists can try to operate relatively, by comparing the average values of cluster VI and translating the VI percentage difference into a difference of treatment. The "medium" cluster can be the one that the ordinary amount of treatment is assigned. The others can be derived using the previously computed differences.

Classi
- High
- Medium
- Low

	Moscato Reale	
	Class limit	μ NDVI
Low (<25° perc.)	0.523	0.498
Medium (25°-75° perc.)	0.570	0.548
High (> 75° perc.)	oltre	0.587
VD_{low} (LOW)		- 9.12%
VD_{high} (HIGH)		+ 7.16%

$$VD = \frac{(\mu_{L/H} - \mu_M)}{\mu_M} \cdot 100$$

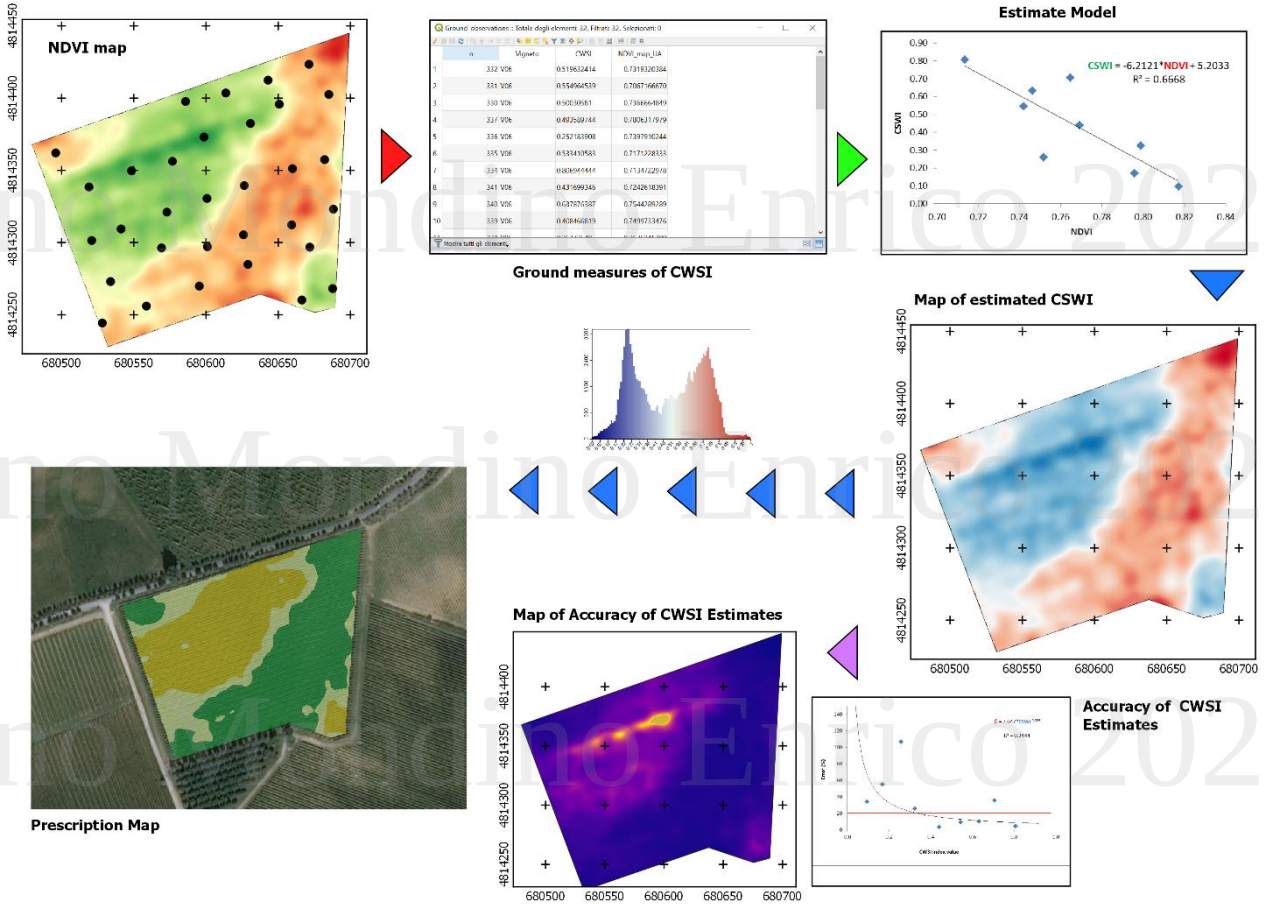
where $\mu_{L/H}$: «Low» and «High» cluster VI mean value
μ_M: «Medium» cluster VI mean value

ESTIMATING AGRONOMIC PARAMETERS

Inferential approach

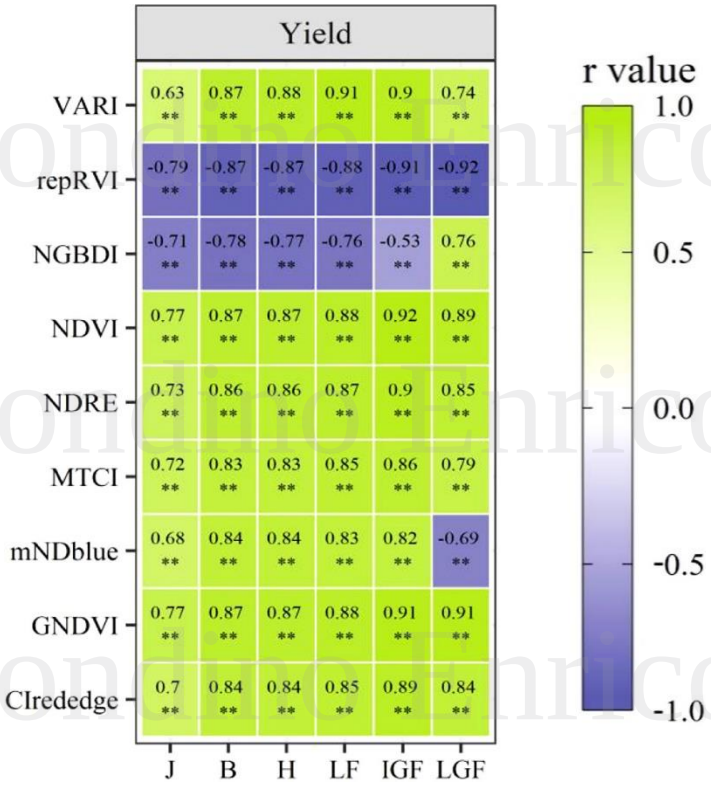
USING SPECTRAL INDICES TO ESTIMATE PLANT/SOIL PARAMETERS

Ground measures at a single, or multiple times, are compared with Spectral Index local values to calibrate REGRESSIVE MODELS useful for generating estimates of biophysical parameters. This step can preceed the one aimed at generating Prescription Maps, to make more immediate map interpretation. In fact, a farmer is more familiar with agronomic parameter values than spectra index ranges.



USING SPECTRAL INDICES TO ESTIMATE PLANT/SOIL PARAMETERS CHOOSING THE PROPER TIME ALONG THE YEAR

Heatmap for the correlation between vegetation indices and agronomic traits under different growth stages. J, Jointing stage; B, Booting stage; H, Heading stage; LF, Late flowering stage; IGF, Initial grain-filling stage; LGF, Late grain-filling stage; NS, not significant; *: $p < 0.05$; **: $p < 0.01$ (Liu, J., Zhu, Y., Tao, X., Chen, X., & Li, X. (2022). Rapid prediction of winter wheat yield and nitrogen use efficiency using consumer-grade unmanned aerial vehicles multispectral imagery. *Frontiers in Plant Science*, *13*)

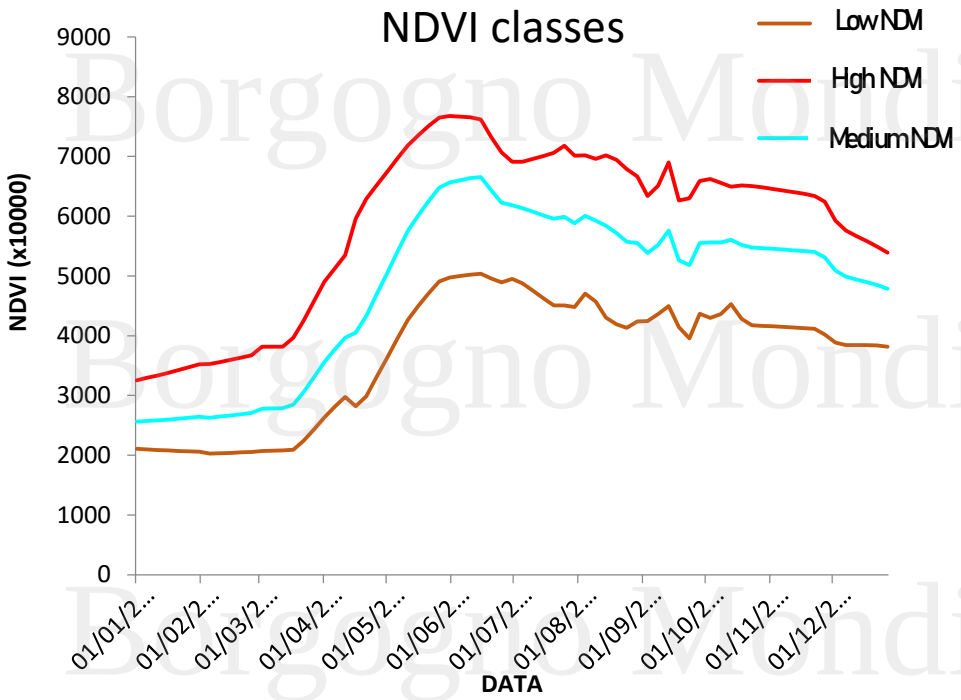


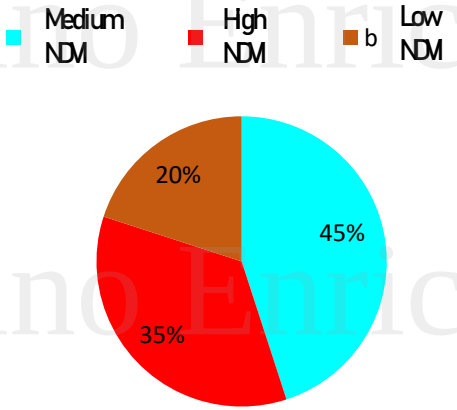
INTER-FIELD ZONATION

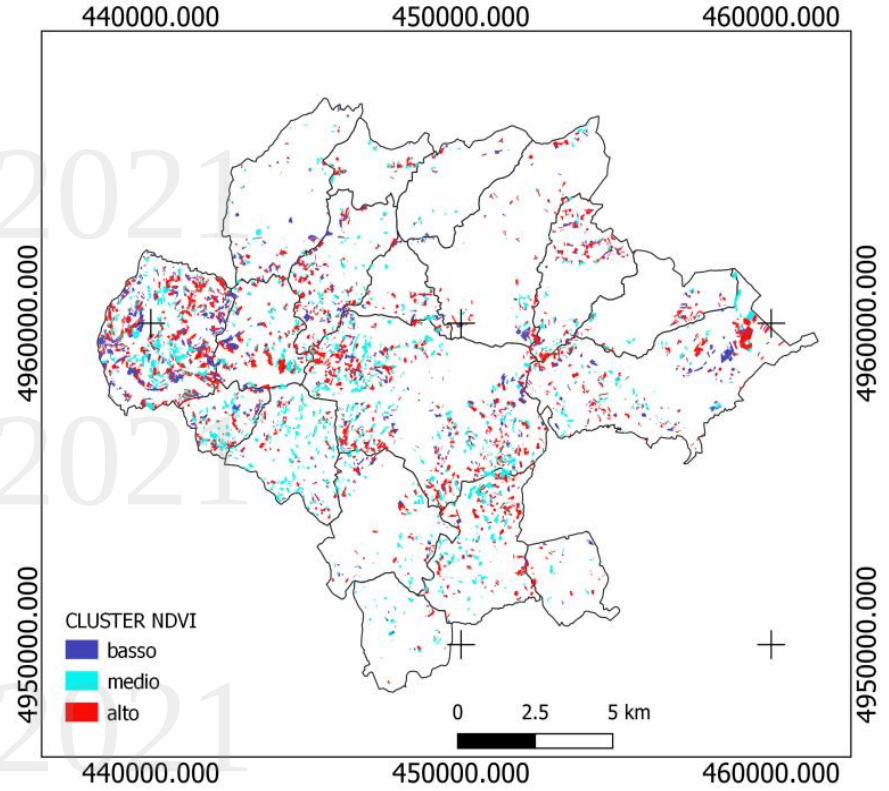
MAIN APPLICATIONS IN PRECISION FARMING

ZONATION

Working at landscape level, zonation can be used to map the behaviour of the same crop over a wide area making possible a proper management by Consortia or big farm companies. This is typical, for example, when looking for atmospheric adversities effects (drought, hail, storms, etc.) or when deciding the time of harvest at vineyard level.

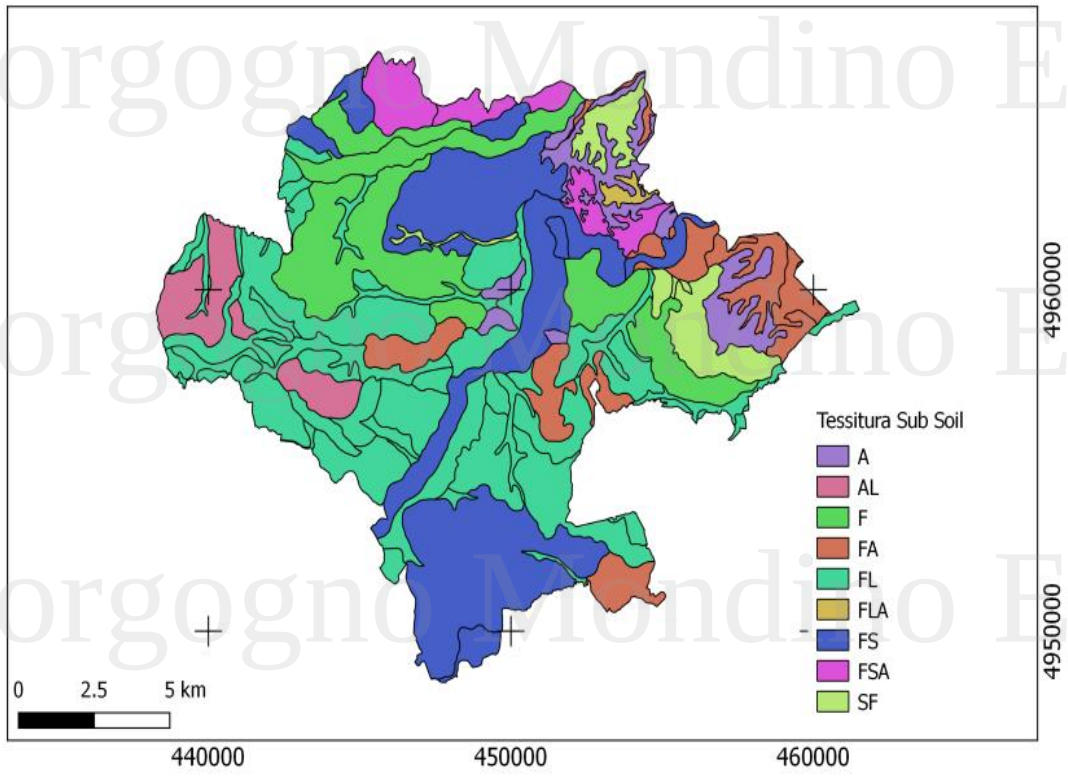




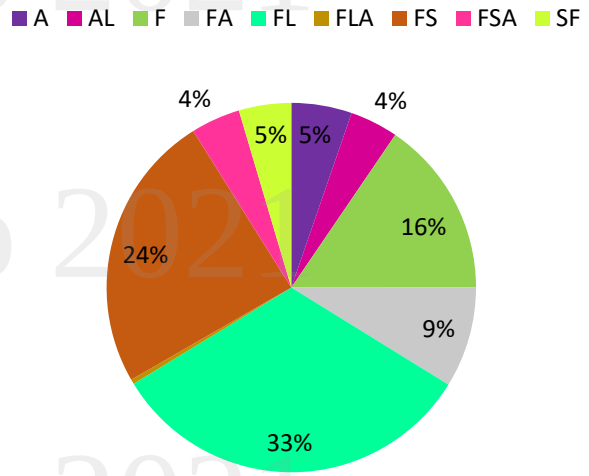


AUXILIARY DATA CAN HELP CLUSTER INTERPRETATION

SUB-SOIL TEXTURE

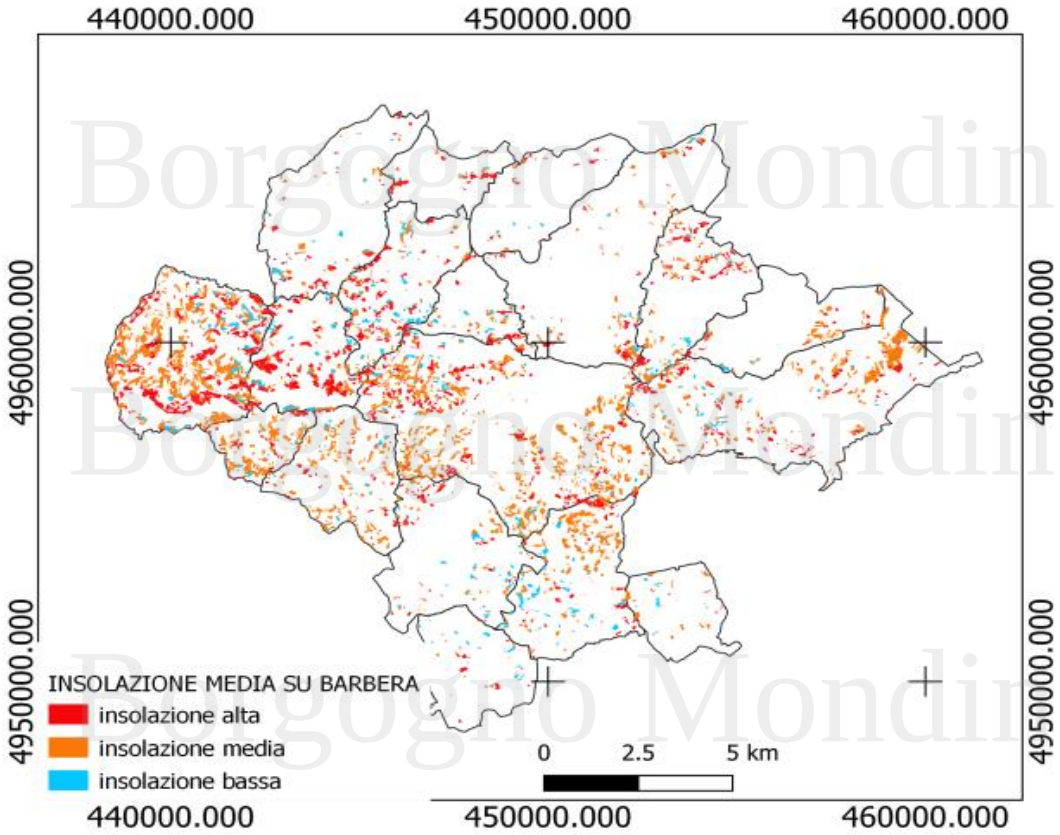


TEXTURE TYPE %



AUXILIARY DATA CAN HELP CLUSTER INTERPRETATION

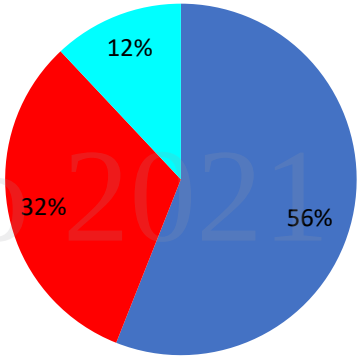
DTM (Digital Terrain Model) → Total Solar Radiation → Classes of Solar Radiation



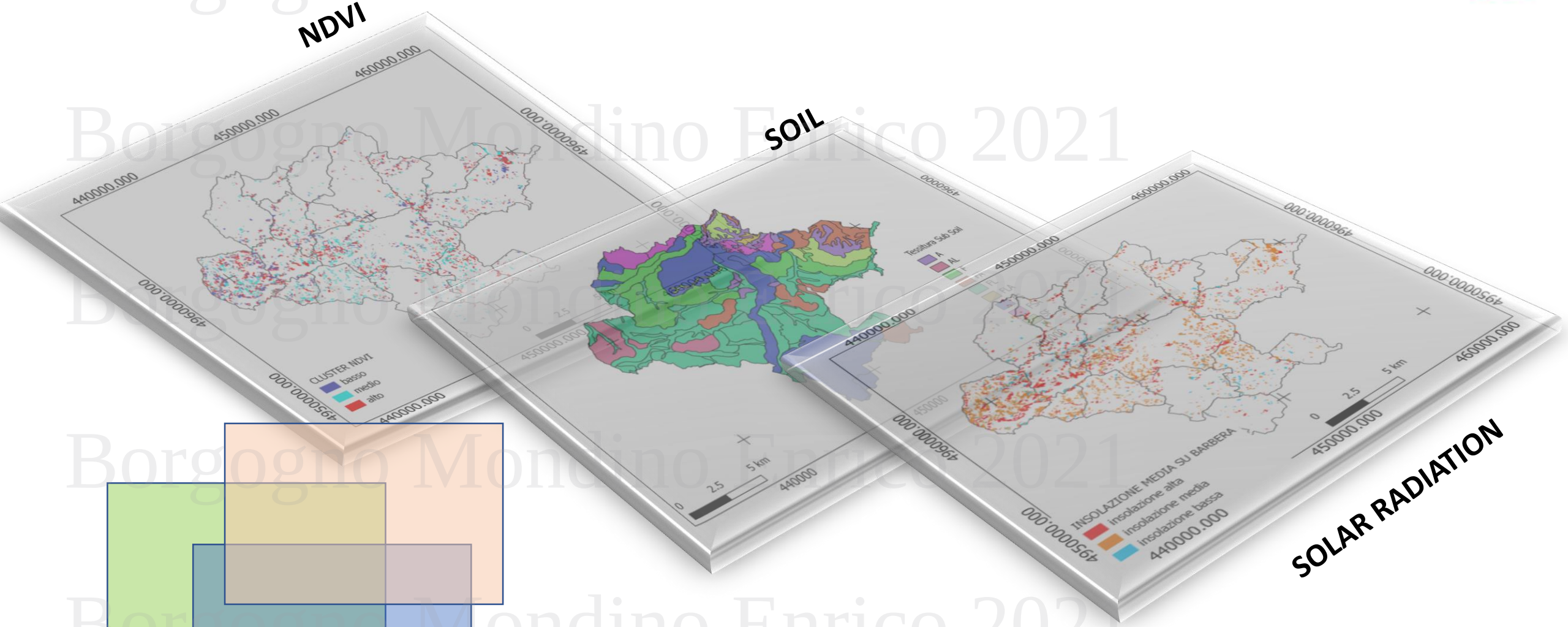
High (1311 KWh/m^2)

Medium (1211KWh/m^2)

Low (1044 KWh/m^2)



AUXILIARY DATA CAN HELP CLUSTER INTERPRETATION



Intersecting information can help to read the meaning of clusters