POTENTIAL OF SENTINEL-1 AND SENTINEL-2 DATA FOR MAPPING IRRIGATED AREAS AT PLOT SCALE

PhD Student

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**BACKGROUND**

- Irrigation plays a significant role in agricultural production in order to meet the global food requirement under changing climatic conditions.
- Irrigated Agriculture is 20% of agricultural zone and contributes to 40% of the total food produced (FAO-AQUASTAT, 2014)
BACKGROUND

• Irrigation efficiency which is the ratio between the water requirement and the amount of water withdrawn is 56%.

• Accurate information on the irrigated area extent helps in managing water resources that affect global food security.

• Several irrigation products are available at different spatial resolutions (FAO, GMIA 5.0, MIRCA2000).

• The low spatial resolution of these products is an obstacle for using them in irrigation management especially in small to medium agricultural areas.
Remote sensing allows optimized water management information on large areas and very high spatial-temporal resolution on soil moisture status and vegetation.

The Sentinel-1 satellite provides an exceptional combination of high spatial and high temporal resolutions for dual polarization SAR data (six days of temporal resolution and a 10 m × 10 m pixel spacing).

The Sentinel-2 satellite offers optical data at 10 m spatial resolution for visible and Near Infrared bands.
Radar remote sensing is sensitive to the water content of soil due to the increase in the dielectric constant with the increase of the soil water content.

Several studies have reported that the SAR signal is highly affected by soil moisture content.

- **Irrigation** ➔ Artificial Application of water ➔ Increase in surface soil moisture ➔ Increase in SAR backscattering signal

- **BUT!** Rainfall and Irrigation may have the same effect on SSM and SAR signal

⇒ We need to remove the ambiguity between rainfall and irrigation for better detection of irrigation.
• Through literature, several studies demonstrated the potential of optical data to map irrigated areas

• Irrigation supplements water deficit for crops and is usually combined with fertilizer thus making crop growth healthier and faster.

• This implies that vegetation spectral information from remotely sensed imagery can be used to identify irrigation

• Studies tend to use optical indices such as NDVI and LSWI to map irrigated areas
CONTEXT — STUDY SITE

- Catalonia, North East Spain
- Plot Limits: SIGPAC Data
- Irrigation Information: SIGPAC Data
- SAR Satellite: Sentinel-1
- Optical Satellite: Sentinel-2
- Scale of mapping: Plot Scale
- Classification Approaches Tested:
  - Random Forest
  - Convolutional Neural Network
METHODOLOGY

• The detection of irrigation activities using SAR data at plot scale requires a good separation of irrigation events from rainfall events.

• Additional information about the rainfall is required to remove the ambiguity between rainfall events and irrigation events in SAR temporal series.

• An indicator of an existing rainfall event could be the increase of the surface soil moisture obtained within a grid scale (5 km, 10 km, 20 km).

   ➔ Remove the ambiguity between rainfall and irrigation events by comparing between the SAR signal obtained at plot scale and the SAR signal obtained at 10 km grid scale.
METHODOLOGY

• Mapping irrigated plots with optical data relies on the difference in the temporal series in the vegetation indices.

• The NDVI (Normalized Differential Vegetation Index) has been widely used to perform irrigated/non-irrigated area mapping.

• Among optical sensors, MODIS and Landsat have been extensively used to map irrigated areas.

• In this study, the potential of Sentinel-2 images by means of NDVI temporal series to map irrigated areas is envistigated.
METHODOLOGY — DATA PREPARATION

**Satellite Data**

- **Sentinel-1 images**
  - Period: September 2017 — December 2018
  - $\sigma^0$ at each plot each SAR date ($\sigma^0_{\text{Plot}}$)
  - $\sigma^0$ at each 10km x 10km cell each SAR date ($\sigma^0_G$)

**Sentinel-2 images**

- Period: September 2017 — December 2018
- Mean of NDVI at each plot each optical date

**SIGPAC Data**

- **Plot boundaries and Irrigation Information**
- Period: September 2017 — December 2018
  - Mean of NDVI at each plot each optical date
METHODOLOGY — DATA PREPARATION

**Satellite Data**

- Sentinel-2 images
  - Period: September 2017 – December 2018
  - Mean of NDVI at each plot each optical date

**SIGPAC Data**

- Plot boundaries and Irrigation Information

**NDVI Temporal Series at plot scale**
METHODOLOGY - TEMPORAL PROFILES

Non Irrigated Plot

Irrigated Plot
METHODOLOGY - WORKFLOW

\[ \sigma^0_{\text{Grid}} \]

- SAR data at each Agricultural Plot

\[ \sigma^0_{\text{Plot}} \]

- Principal Component Analysis (PCA)

\[ \Delta \sigma^0_{PG} \]

- Wavelet Transform (WT)

- SAR Wavelet Coefficients

- Random Forest (50% Training, 50% Validation)

- PCA Irrigation Map

- Random Forest (50% Training, 50% Validation)

- WT Irrigation Map

- Random Forest (50% Training, 50% Validation)

- CNN Irrigation Map

- NDVI Irrigation Map

- NDVI temporal series

- Principal Component Analysis (PCA)

- NDVI Principal Components

- Random Forest (50% Training, 50% Validation)

- NDVI Irrigation Map
### Main Results — PCA RF

<table>
<thead>
<tr>
<th>Method</th>
<th>Class</th>
<th>Precision</th>
<th>Recall</th>
<th>F-score</th>
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</thead>
<tbody>
<tr>
<td>PC-RF 328</td>
<td>Irrigated</td>
<td>0.95</td>
<td>0.79</td>
<td>0.86</td>
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<tr>
<td></td>
<td>Non-Irrigated</td>
<td>0.90</td>
<td>0.98</td>
<td>0.94</td>
</tr>
<tr>
<td></td>
<td>OA</td>
<td>91.2%</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>Kappa</td>
<td>0.79</td>
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<td>PC-RF 15</td>
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<td>0.81</td>
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<tr>
<td></td>
<td>F-score</td>
<td>0.91</td>
<td></td>
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</tbody>
</table>

### Important Variables

- Irrigated: 0.92, 0.81, 0.86
- Non-Irrigated: 0.90, 0.96, 0.93

OA: 91.2%

Kappa: 0.79

F-score: 0.91
# RESULTS — WT RF

<table>
<thead>
<tr>
<th>Method</th>
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<th>F-score</th>
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<tr>
<td></td>
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<tr>
<td></td>
<td>Kappa</td>
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<td></td>
<td>F-score</td>
<td>0.91</td>
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<tr>
<td>WT-RF</td>
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<tr>
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<td>OA</td>
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<td>Kappa</td>
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<td>F-score</td>
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**256 Variables**

**18 Important Variables**
# MAIN RESULTS — SAR CNN

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<td>0.96</td>
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<tr>
<td></td>
<td>OA</td>
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<td>94.1%±0.06</td>
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<tr>
<td></td>
<td>Kappa</td>
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<td>0.87±0.0014</td>
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<td></td>
<td>F-score</td>
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<td>0.94±0.0006</td>
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</table>

### SAR BRANCH

**Input Layer**
- $2\times1 \times 82$
- $64@1\times76$
- $64@1\times36$

**Convolutional Layers**
- Conv (64, 1x7) Strides = 1
- Conv (64, 1x5) Strides = 2
- Conv (128, 1x5) Strides = 1
- Conv (128, 1x5) Strides = 2
- Conv (256, 1x5) Strides = 1
- Conv (256, 1x5) Strides = 1
- Conv (256, 1x3) Strides = 1
- Conv (256, 1x3) Strides = 1
- Conv (256, 1x1) Strides = 1

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<th>Method</th>
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### MAIN RESULTS — NDVI RF AND CNN

#### RF - NDVI

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<td>F-score</td>
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<td><strong>NDVI-RF 7 Important Variables</strong></td>
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#### CNN - NDVI

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<td>Non-Irrigated</td>
<td>0.91</td>
<td>0.97</td>
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<td>0.94</td>
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<tr>
<td>OA</td>
<td>91.6%±0.06</td>
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<tr>
<td>Kappa</td>
<td>0.81±0.0016</td>
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<tr>
<td>F-score</td>
<td>0.91±0.0006</td>
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</tbody>
</table>
MAIN RESULTS — MAPPING

WT-RF

PC-RF

CNN

(a)

(b)

(c)

Non-Irrigated  Irrigated

0 20 40 60 km
MAIN RESULTS — INTERCOMPARISON

- **S1-SAR**
  - OA: 90
  - Kappa: 80
  - F-score: 90

- **S2-Optical**
  - OA: 90
  - Kappa: 70
  - F-score: 90

- **S1+S2**
  - OA: 90
  - Kappa: 70
  - F-score: 90

Red (RF) and Blue (CNN) bars are used to compare the performance.
MAIN FINDINGS

• Sentinel-1 SAR data is efficient for mapping irrigated plots

• The SAR signal at basin scale could be a good representative of rainfall events

• Adding the SAR signal at grid scale to the classification approach remarkably improved our classification accuracy where the overall accuracy increased by more than 15%

• This enhancement confirms the relevance of our assumption of using conjointly $\sigma_p^0$ and $\sigma_G^0$ to in order to remove the rainfall-irrigation ambiguity
MAIN FINDINGS

• The CNN deep-learning is superior to the classical RF machine-learning approach in the classification

• The gain in the performance offered by the CNN is clearly visible on the irrigated class

• The increase of the overall accuracy when using the CNN approach is mainly caused by better detection of irrigated plots

• Fusion of Optical and SAR data enhanced the accuracy of the RF classification but did not significantly change the overall accuracy of the CNN model.
Thank you

Question!