Crop yield assessment and mapping by a combined use of Landsat-8, Sentinel-2 and Sentinel-1 images

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  - T. Newby (Agriculture Research Council Institute for Soil, Climate and Water, S. Africa)
  - + JECAM

- **Objective:**
  - to develop a new algorithm and products for agriculture monitoring, namely **crop yield assessment** and **mapping**, by combining moderate spatial resolution images acquired by **Landsat-8**, **Sentinel-2** and **Sentinel-1/SAR** remote sensing satellites

- **Crops:**
  - wheat
  - corn
  - soybean
Study area

- **Agriculture in Ukraine**
  - *Wheat*: 7th world largest **producer** and 6th world largest **exporter** (in 2017)
  - *Sunflower*: 1st world largest **producer** and 8th world largest **exporter** (in 2017)

  ![Source: USDA FAS](https://example.com/source)

- **Study area**
  - Kirovohradska oblast with 21 districts (counties)
    - Geographical area: 65–165 thousand ha
    - **Cropland** area: 27–112 thousand ha
  - **Winter wheat**
    - Accounts for 20% of production of all crops in the region
    - Mainly rainfed
    - Yield range: **2.8–4.7 t/ha**

Land cover map of the study area in 2017 at 30 m spatial resolution derived from Landsat 8, Sentinel-2 and Sentinel-1 data (Kussul et al. 2017 IEEE GRSL)
Data

- **Remote sensing**
  - **HLS: Landsat-8 & Sentinel-2A/B**
  - 8 Sentinel-2 tiles
  - Overall 3565 scenes
    - March-July 2016-2018

- **Statistical data**
  - Department of Agro-Industry Development of Kirovohrad State Administration (http://apk.kr-admin.gov.ua)

- **Meteorological**
  - MERRA2 from NASA
    - For calculating growing degree days (GDD)

Coverage of Landsat-8 scenes and Sentinel-2A tiles over the study area

False color composites (SWIR1-NIR-Red) from Landsat-8 and Sentinel-2A/B
Methodology

Winter crop mapping

- Cropland mask
  - Run Gaussian mixture model (GMM) over cropland mask
  - Calculate maximum NDVI from March 1 to April 6
  - Winter crop map

Landsat-8
Sentinel-2A
Sentinel-2B

Phenological fitting

Yield model

Winter wheat yield map

Meteorological data

Reference data

Winter crop yield mapping
Need for satellite data normalization

Average number of cloud-free observations for winter crop pixels depending on satellite data usage. The number of pixels was taken from March until the end of June, which the period of winter crop growth.

Spatial distribution of the number of cloud free observations from Landsat 8 and Sentinel-2 from March through the end of June in 2018.
Phenological fitting: VIs

\[ y_{sat} = a_0 + a_1 \times AGDD + a_2 \times AGDD^2 \]

AGDD = accumulated growing degree days
Phenological fitting: SRs

Green Accumulated GDD, C

\[ y = 7\times 10^{-8}x^2 - 0.0001x + 0.0874 \]
\[ R^2 = 0.7891 \]

Red Accumulated GDD, C

\[ y = 1\times 10^{-7}x^2 - 0.0001x + 0.0822 \]
\[ R^2 = 0.869 \]

NIR Accumulated GDD, C

\[ y = -2\times 10^{-7}x^2 + 0.0004x + 0.2623 \]
\[ R^2 = 0.9313 \]

SWIR1 Accumulated GDD, C

\[ y = 1\times 10^{-7}x^2 - 0.0002x + 0.2623 \]
\[ R^2 = 0.6291 \]
### Phenological fitting: VIs and SRs

<table>
<thead>
<tr>
<th>VI / SR</th>
<th>RMSE</th>
<th>%</th>
<th>$R^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>DVI</td>
<td>0.015</td>
<td>8.4</td>
<td>0.92</td>
</tr>
<tr>
<td>EVI2</td>
<td>0.024</td>
<td>6.6</td>
<td>0.92</td>
</tr>
<tr>
<td>NDVI</td>
<td>0.030</td>
<td>5.0</td>
<td>0.93</td>
</tr>
<tr>
<td>Green</td>
<td>0.005</td>
<td>8.9</td>
<td>0.60</td>
</tr>
<tr>
<td>Red</td>
<td>0.005</td>
<td>10.2</td>
<td>0.80</td>
</tr>
<tr>
<td>NIR</td>
<td>0.015</td>
<td>6.7</td>
<td>0.88</td>
</tr>
<tr>
<td>SWIR1</td>
<td>0.013</td>
<td>7.1</td>
<td>0.75</td>
</tr>
</tbody>
</table>

Averaged over 2016-2018 phenological fitting metrics for winter crops. Only pixels with >6 cloud-free observations available from HLS during the March-June period.
From 1-D to multi-dimension “trajectories”

DVI ($a$) and NIR-red ($b$) dynamics for the same district over three years with variations in winter wheat yields.

\[ y_{\text{yield}} = \omega_0 + \omega_1 a_{0,NIR} + \omega_2 a_{1,NIR} + \omega_3 a_{2,NIR} + \omega_4 s_{NIR} + \omega_5 a_{0,\text{red}} + \omega_6 a_{1,\text{red}} + \omega_7 a_{2,\text{red}} + \omega_8 s_{\text{red}} \]

\[
\hat{W} = \arg\min_W (\|Y - WR\|^2 + \alpha \|W\|^2)
\]

Overfitting
Results

- Leave one out **cross-validation** (2 years calibration, 1 for test)

<table>
<thead>
<tr>
<th>Model</th>
<th>RMSE, t/ha</th>
<th>RRMSE, %</th>
<th>R²</th>
</tr>
</thead>
<tbody>
<tr>
<td>AUC–DVI</td>
<td>0.257</td>
<td>6.9</td>
<td>0.60</td>
</tr>
<tr>
<td>AUC,coefficients–DVI</td>
<td>0.218</td>
<td>5.8</td>
<td>0.68</td>
</tr>
<tr>
<td>AUC,coefficients–NIR+red+green+SWIR1</td>
<td>0.218</td>
<td>5.8</td>
<td>0.73</td>
</tr>
<tr>
<td>AUC,coefficients–NIR+red</td>
<td><strong>0.201</strong></td>
<td><strong>5.4</strong></td>
<td><strong>0.73</strong></td>
</tr>
</tbody>
</table>

*Graph showing the relationship between Estimated yield t/ha and actual yield t/ha with the following metrics:

- RMSE = 0.201 t/ha
- RRMSE = 5.4%
- R² = 0.73*
Results: impact of multi-source use

- Benchmark model: AUC-DVI

Average number of cloud-free observations for winter crop pixels depending on satellite data usage. The number of pixels was taken from March until the end of June, which the period of winter crop growth.

Coefficient of determination $R^2$ between AUC-DVI and reference yields.
Conclusions

- Satellite data should be normalized for crop yield studies.

- Spectral reflectance’s for winter wheat can be fitted against accumulated GDD using a quadratic function.

- More information may be retrieved from SR dynamics than just VIs for crop yield estimation.
  - For wheat, NIR-red with area + fitting coeff’s + regularization → the best model.

- Combination of Landsat 8 and Sentinel 2 outperforms a single satellite usage for winter wheat yield assessment.
Acknowledgment

- NASA-funded project “Crop Yield Assessment and Mapping by a Combined Use of Landsat-8, Sentinel-2 and Sentinel-1 Images” (#80NSSC18K0336)

- NASA’s Harmonized Landsat Sentinel-2 (HLS) product

- Presentation contains modified Copernicus Sentinel data (2016-2018) processed by ESA
Thank You!