**Introduction and objectives**

An effective establishment of a winter cover crop is important for reducing nitrogen leaching to groundwater in the maize-based cropping system of the Netherlands. Cover crop establishment after maize cultivation is obliged by law for sandy soils and consequently implemented in nearly all maize fields, but the vegetative ground cover in winter varies significantly between fields. This study's objective is to evaluate to what extent differences in winter vegetative cover can be explained by the timing of cover crop establishment and weather conditions in two growing seasons (2017-18). We focused on the Province of Overijssel.

**Data**
- Sentinel-2 imagery: cloud-masked NDVI series derived from Level-2A data from the THEIA land data centre
- Dutch Basic Registration Parcels (BRP): an annually updated census dataset including the location and boundary of maize parcels.
- Gridded (20x20km) daily minimum/maximum temperature
- Surveys on cover crop sowing dates for eight maize parcels in 2017.

**Methods**
- To retrieve phenology from plot-level Sentinel-2 NDVI time-series, a piecewise smoothing method was applied. Two local double-logistic functions were fitted to describe 1) the maize growth and decline, and 2) the maize decline and cover crop growth:
  \[ f(t) = a_1 \left( \frac{1}{1 + e^{-b_1(t-c_1)}} \right) + a_2 \left( \frac{1}{1 + e^{-b_2(t-c_2)}} \right) \]
- Both local functions were merged (overlapping period \([t_L, t_R]\)) to obtain a single global function:
  \[ f(t) = \alpha(t) \left( a_1 \left( \frac{1}{1 + e^{-b_1(t-t_L)}} \right) + a_2 \left( \frac{1}{1 + e^{-b_2(t-t_R)}} \right) \right) \]
  where \(\alpha(t)\) linearly drops from 1 at \(t_L\) to 0 at \(t_R\).
- From the global function, we extracted two parameters: a) cover crop sowing date: the time of fitted minimum NDVI between maize-cover crop rotation; b) \(\text{NDVIDec}\): the fitted NDVI value for 1 December. \(\text{NDVIDec}\) represents the quality of cover crop establishment at the start of the winter season.
- Logistic regression between \(\text{NDVIDec}\) and cover crop sowing date, and between \(\text{NDVIDec}\) and accumulated growing degree days (GDD):
  \[ \text{GDD} = \sum_{t_{	ext{min}}}^{t_{	ext{max}}} (T_{	ext{max}} - T_{	ext{min}}) / 2 - T_{	ext{base}} \]
  where \(T_{	ext{base}} = 4^\circ\text{C}\).

**Conclusions**
- Sentinel-2 image time series can effectively retrieve seasonality parameters (e.g., sowing of cover crop) for small agricultural parcels.
- We found a strong link between cover crop sowing date and its ground cover in winter season.
- A method for determining optimal cover crop sowing date is presented and provides technical support for the national new regulation that requires a cover crop to be sown no later than 1 October.

**Results**
- Sentinel-2 retrieved sowing date is an efficient proxy of on-farm actual sowing date, with low root mean-squared error (RMSE=6.6 days, Figure 1).
- The hot, dry summer of 2018 resulted in an earlier cover crop sowing date (on average 19 days) and an \(\text{NDVIDec}\) value that was 0.2 higher than in 2017 (Figure 2).
- \(\text{NDVIDec}\) decreases with later sowing dates, with these dates explaining 55% of \(\text{NDVIDec}\) variability. This corresponds to a positive relationship between \(\text{NDVIDec}\) and accumulated GDD until reaching 400 GDD (Figure 3).
- Based on accumulated GDD, for the past two decades 20 September and 21 September are on average the optimal cover crop sowing dates for weather station ‘Twente’ and ‘Heino’, respectively (Figure 4).

**Figures**
- Figure 1. Cover crop sowing date retrievals for eight maize-cover crop rotated parcels with ground reference data.
- Figure 2. Phenology results for maize parcels in Overijssel: spatial variations of \(\text{NDVIDec}\) in 2017 (a) and 2018 (b); cover crop sowing date (day of year) in 2017 (c) and 2018 (d).
- Figure 3. Logistic regression between \(\text{NDVIDec}\) and cover crop sowing date (a), and between \(\text{NDVIDec}\) and accumulated GDD (b). Note that \(\text{NDVIDec}\) increases until accumulated GDD reaches 400.
- Figure 4. Optimal cover crop sowing date estimation based on temperature data captured from weather stations ‘Twente’ and ‘Heino’ for the past two decades.