Basic information

1. Factor: NDVI (Normalized Vegetation Index, remote sensing data)

2. Area: Four Central European countries (NUTS2) - Germany (part), Poland, Czech Republic, Slovakia, 34 provinces

3. Time: 2012 - 2016, 7 March - 28 June

4. Source: NASA Terra (GLAM) MODIS (Moderate Resolution Imaging Spectroradiometer), Corine Land Cover Program, EUROSTAT (European Statistical System)

5. Subjects: Cereals (wheat, barley, rye, oats, triticale, maize (, buckwheat, millet)), with a 2-month backward time offset for maize

Overall results

1. Strong correlation in the beginning (early March - mid-May)

- Czech Republic, Slovakia: strongest at the beginning of April (correlation coefficient 0.80 - 1.00)

- Poland: fairly strong; Germany: weak, inconsistent

2. Regression coefficient: 10.8 - 26.2 at the beginning of April -> 0.1 increase in NDVI, 1.1 - 2.6 t/ha increase in cereal production (average +2 t/ha/+0.1 NVDI)

3. German region: highest yields; Eastern Poland: lowest yields

- Intensity of production (type and consumption of fertilizers, etc.), differences in management level

- Soil quality and weather conditions have less influence

4. Overall annual variation of production across the region: mainly temperature-related, with generally small differences

5. The lowest NDVI values occur in early March and the highest in early June (at the end of the flowering period) and are generally similar to those of arable land only

6. Strongest relationship: in early April, using this data for regression, RMSE ranged from 0.17 to 0.8 t/ha for total area and from 0.04 to 0.23 t/ha for arable area (both by year treatment)

7. From the end of May onwards, the relationship weakens

- NDVI saturates, leading to its small numbers

- NDVI decreases after flowering

Other results

1. One region in Argentina: strong relationship (R2 = 0.52) between wheat yield and NDVI at flowering (late October - early November, about one month before harvest), +1.1 t/ha/+0.1 NDVI; the other also one month before harvest, R2 = 0.75

2. Kansas (KS) and Ukraine: maximum adjusted (by soil reflectance) NDVI and winter wheat yield have strong relationship: errors of 7% and 10% (based on 6 weeks pre-harvest data, considering only wheat field data)

- NDVI predicts well for winter wheat in eastern Ukraine, RMSE = 0.18 t/ha, wheat subgroups used, low yields, best data reached at 6 weeks before harvest

3. Selected counties in eastern China: strong relationship between NDVI and winter wheat in mid-April (linear regression, R2 = 0.88, error 5%); MODIS CASA model also predicts with an error of 6% (R2 = 0.56, RMSE = 1.22 t/ha)

4. Parts of Canada: NDVI is strongly, but not exactly linearly, related to barley, rape, pea and wheat yields

- Barley: yield = a \* NDVIb

- Wheat: coefficients of determination for flowering and setting belong to [0.47, 0.90]

5. Various Canadian cereals combined: (another study) strongest correlation (R2 ∈ [0.49, 0.71]) from late June to early August, non-linear regression, +0.8-1.0 t/ha/+0.1 NDVI with low yields and potential

6. At flag leaf emergence: strong possible relationship between NDVI and spring wheat yield (R2 = 0.83)

7. Starting from the end of June (three months before harvest), NDVI has a strong relationship with maize yield (R2 ∈ [0.77, 0.84]), calculated separately for different N fertiliser levels

8. Hungary: strong relationship between NDVI (AVHRR) and yield of spring and winter crops (wheat, barley, maize, rye), error < 5%, better precision at 50 days before wheat harvest and 70 days before maize harvest

9. Hungary: (another study) strong relationship between NDVI and yield of winter wheat and maize (R2 ∈ [0.7, 0.8]), calculated at 6 - 8 weeks before harvest, RMSE < 19%

10. Australia: optimum yield reached about 3 months before harvest, lower yield, +0.23-0.43 t/ha/+0.1 NDVI

11. India: stratification for zonation, using NDVI at flowering, the error is 1.6% to 6.7%

Model analysis

1. Study: linear relationship between cereal yield and average NDVI over the whole area and arable land

2. Other MODIS-derived variables: CASA for wheat, WOFOST for wheat, CERES for maize, DSSAT-CERES for wheat, which can be used as additional factors

3. Separate consideration of: all NDVI areas, arable NDVI areas (see Corine Land Cover Database (CLC))

- Distinguish between arable land, other greenfield land; distinguish between rainfed, irrigated arable land

4. Insufficient accuracy of predictions when yields are too low (special years, sparse planting, too dispersed)

5. Methods: linear regression analysis, Pearson correlation

- Each areas individually, all years together

- Separate for each year, all areas together

6. Conclusions: strong influence during the growing season (determination of cereal area), less influence during the filling season (variety, climate, human protection, small/low extremes)

Cautions

1. Chlorophyll: absorbs red light (maximum absorption: 0.42 μm, 0.49 μm, 0.66 μm) and

- Higher concentrations: favourable situation, reflecting IR radiation

- Lower concentrations: unfavourable situation, absorption of IR radiation

2. NDVI: calculated from the difference between the reflectance in the near infrared (NIR) band and the reflectance in the red (RED) band

3. Also using data from AVHRR satellite sensors, or considering enhanced vegetation index (EVI), cumulative NDVI, etc.

4. Similar climatic conditions, similar crop growth cycles, similar varieties and management, similar annual precipitation (500 - 650 mm) in Central Europe

5. 60% of the area is covered by cereals in Central Europe, dominated by winter cereals (wheat (largest, half of the cereals), barley (second), rye, triticale)

Summary

1. Different environments (different regions, different scales, different time periods, different contexts or other factors) have different influencing factors; different values are considered, different influencing factors are considered, from general to local, spatial to temporal, from different perspectives

2. Use the relationship of the strongest factor in the best phase to treat, then expanding to consider others, to improve the accuracy