Basic information

1. Main object of analysis: maize, winter wheat

2. Area: 92 administrative regions of France (most of them)

3. Influencing factors: temperature, precipitation, solar radiation

4. Method: partial least square regression

5. Data source: MCYFS (635 French weather stations + 25\*25 km2 interpolation)

Overall results

1. Changes in temperature, solar radiation

- South, East, North - maize yield - most significant effect

- Change in temperature: East - winter wheat - main effect

2. Change in rainfall: central, north-west - maize production - most significant effect

Change in rainfall: north, north-west, south-east - winter wheat - main effect

3. Radiation: south-eastern impact > northern impact

4. Homogeneous regions

Winter wheat - Southwest (SWF), Southeast (SEF), Central East (CEF), Central West (CWF), Northwest (NWF)

Maize - South (SF), East (EF), Central (CF), North Central (CNF), North West (NWF)

5. Overall trends

- West – maize - higher variation, central, north - maize - lower variation

- North, west, south - winter wheat - higher variability

6. Spatial scale: maize < winter wheat -> greater dependence on water

- Irrigated areas: south-west, central, easternmost, Mediterranean -> uniform yields

- Larger irrigated area -> less influence of summer precipitation

7. Causes of impact

- Direct: temperature, water availability, radiation interception, carbon fixation

- Indirect: nutrient availability, pest and disease incidence

- Overall environment: heat spell, drought, inundation

- Extreme weather (leading to overestimation of data)

Specific results

1. Maize.

- Main origin: southwest, duration: April - September, main impact: July/August

- Rainfall positive influence, temperature and solar radiation negative influence

- Wet, cold: early maize - limits leaf size - limits photosynthetic capacity

- Heat wave, drought: late maize - poor pollination of ovules - limits the number/size of developing kernels

- Maize - flowering (July/August) - most sensitive: negative effects of temperature, solar radiation, positive effects of precipitation

- North-west, north-central, central: most sensitive in August; south, east: most sensitive in July: different planting times

- Southwest: similar in July/August, solar radiation, temperature effects > other effects

- South, east, northeast: temperature most dominant, negative influence; west: solar radiation most dominant

- Western half - mild maritime climate - temperature effects < solar radiation, precipitation effects

- Northwest, central north: early season (May) - leaf surface index growth - solar radiation more influential, temperature positive effect

- Irrigation reduces the effect of precipitation: South - large irrigated area - small effect of precipitation; Central - small irrigated area - large effect of precipitation in July/August

2. Winter wheat

- Main origin: north, timing: October - July (+1 year)

- Regional variation > maize, more dispersed

- Temperature: strong influence from south-west, east, precipitation: west, strong influence from Mediterranean

- Solar radiation: strong influence, especially in the south

- October/November sowing -> high impact of excessive humidity, solar radiation: positive impact

- November/December tillering -> negative influence of precipitation

- April/May: flowering period - sensitive - positive influence of precipitation/temperature - avoid runners

- Central-west, south-west, north-west -> strong influence in January/February, but with significant internal variability

- Central, far west: strong influence of precipitation in February - mild and wet winter - inundation, solar radiation positive influence, temperature negative influence

- Middle east, south-east: negative influence of temperature in March - germination phase - premature end of hibernation - frost damage

- Southwest, southeast, central and west: high impact in April, middle east: high impact in May

- Northwest, middle east: high impact in June/July - positive impact of precipitation - filling period

- Middle east, south west: low impact in July - already mature

- Southwest: strong influence of temperature

Model analysis

1. Crop models: provide a comprehensive description of a crop production system - requires a large number of inputs

2. Statistical models: crop yield changes linked to a set of variables

3. Hybrid models: mix of the above 2 models

4. Hierarchical clustering: identifying spatially homogeneous areas of interannual crop yield variability

5. Partial least squares regression (PLSR): relationship between meteorological variables (X) and crop yield time series (Y)

- Can solve strong covariance problems (explanatory variables are strongly correlated)

- Includes principal component analysis, multiple regression

- Extracts a subset of latent variables (covariance of maximise transformed X and Y)

- X = TPT + E, Y = UQT + F -> Y = TDQT + r, U = TD + H

- P and Q: weight matrices; T and U: latent variable matrices, E, F and H: residual matrices; D: diagonal matrices

6. Bootstrap: used to determine the number of latent variables, significance of explanatory variables

- Number of variables: bootstrap validation

- Importance of variables: variable importance predictive (VIP)

- Standardised regression coefficients: degree and direction of impact (attention: cumulative impact)

7. De-trending: removal of other factors (agricultural management, socio-economic factors)

- Mainly in terms of trends -> analysis of annual changes rather than trends

- Difficult to filter out temporary factors

8. Number of latent variables.

- 70 provinces - maize - 2 (3 for others)

- 68 provinces - winter wheat - 2 (3 for others)

9. PLSR performance: good for areas where key weather factors determine yield

- Areas with strong overall explanatory power -> significant factor variability

- Areas with fair overall explanatory power -> weak factor variability

10. Models differ in their ability to explain external factors such as irrigation, depending on their strength

- Southwest, west, far east - maize - strong explanatory power

- South, west - winter wheat - strong explanatory power

- Overall: winter wheat > maize -> less irrigation

11. Optimised models.

- Improve data quality: weather station statistics, data interpolation

- Consideration of factor interactions: irrigation - lower leaf temperatures - less weather effects

- Longer time series: more data, higher costs

- Separate analysis of different periods (development, flowering, fruiting)

Points to note

1. Different growth stages -> different impacts: separate analysis of each stage, superimposed effects

2. French climate types: maritime, Mediterranean, continental, mountainous

3. Excluded data: Haute-Garonne 31, Aude 11, Isère 38, Bouches-du-Rhône 13, Var 83, Alpes-de-Provence 04, Lozère 48, Alpes-Maritimes 06, Cantal 15

4. Reasons for error: same crop yield values for three consecutive years (or more); clearly incorrect yields (yields higher than 14 t/ha); sudden drop or increase in yield values (breakpoints)

Summary

1. Specific data, specific analysis results

2. Models: PLSR (parameter calculation, model evaluation, impact removal, model evaluation, optimisation)

3. Different geographical areas, different times: separate analysis and then aggregation, consideration of chain factors (time, between factors)

4. Specific analysis and removal of other human factors such as irrigation