MODIS-based Modeling of Corn and Soybean Yields in the US

American Geophysical Union Fall Meeting - San Francisco - 13 December 2013

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Geographer
United States Department of Agriculture
National Agricultural Statistics Service

Furlough Day # 3
Maryland Soybean Field 10/3/2013
Annually derived Cropland Data Layer (CDL)

Major Land Cover Categories

Agriculture
- Pasture/Grass
- Corn
- Soybeans
- All Wheat
- Other Hay
- Fallow/Idle Cropland
- Alfalfa
- Cotton
- Other Crops
- Vegetables/Fruits/Nuts
- Sorghum
- Other Small Grains
- Rice

Non-Agriculture
- Woodland
- Shrubland
- Urban/Developed
- Wetlands
- Water
- Barren
- Perennial Ice/Snow

Freely available over Internet via “Cropscape”
Region with the bulk of corn and soybean production
United States Yield (bushels/acre)

- Corn
- Soybeans

- Timeline: 1860 to 2000
- Y-axis: 0 to 180 bushels/acre
NASS Crop Production reports

Corn Area Planted for All Purposes and Harvested for Grain, Yield, and Production – States and United States: 2009-2011 (continued)

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Crop Production 2011 Summary (January 2012)
USDA, National Agricultural Statistics Service

Crop Production

Published no later than the 12th of each month.
Yields results primarily derived from two surveys

Agricultural Yield
- Farmer reported survey data of expected crop yields.
- Data obtained throughout the growing season.
- Conducted in all states except Alaska and Hawaii.
- Sample size in the 1000s per state.
- Farm operator contacts are selected from the March Crops/Stocks survey (small grains) and the June Crops/Stocks survey (late season crops and tobacco).
- Primarily telephone based.

Objective yield
- Corn, Cotton, Soybeans, Wheat, Potatoes.
- Only done in states where the commodities are primarily found.
- Samples selected from areas found in June Area Survey (“Acreage”).
- Performed at 100s of sample sites per state.
- Biophysical plant/seed measurements obtained.
- Each plot revisited a few times per season.
Remote Sensing for Yield Estimation

A third method...

• Premise
  – There is a known relationship between crop
    • Biomass, vigor, “greenness”, NDVI
    – and
    • Crop yield
  – Also temperature and rainfall too.
• Utilize MODIS data to obtain biomass and temperature variables
• Utilize Nexrad Ground radar to estimate precipitation
• Produce for national, state, ASD, and county
  – Corn and soybeans only
  – “Speculative” region only
    • i.e. Corn Belt
• Be independent of other methods
Phenology with Crop Production report timing

Corn 5-year average 2006-2010

16-day composite median date


0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0

Terra MODIS mean NDVI

State
Arkansas
Illinois
Indiana
Iowa
Kansas
Louisiana
Minnesota
Missouri
Mississippi
North Dakota
Nebraska
Ohio
Oklahoma
South Dakota
Wisconsin

8/1 9/1 10/1
Moderate Resolution Imaging Spectroradiometer (MODIS)
MODIS NDVI data example
Calculation from surface reflectance and use of NDVI

\[
\text{NDVI} = \frac{\text{NIR} - \text{VIS}}{\text{NIR} + \text{VIS}}
\]

- **NIR** = near-infrared
- **VIS** = visible

Ranges from -1.0 to 1.0

NDVI is a related to:
- Plant health
- Cholophyll content
- “Greenness”
- Biomass
- Vegetation vigor
MODIS LST data example
Nexrad-based Precipitation estimates

- GIS-ready product
  - ESRI Shapefile format
- Generated daily
  - Little latency
- ~4km grid
- 2005 - current
NexRad Rainfall Data example
Intersecting corn “mask” with MODIS data
Establishing the pixels that are only corn

NASS CDL

MODIS-scaled High probability sample of corn areas
County-level modeling with “composite” modeling

- Historical NASS county-level yields as dependent variable
  - 2006-2011
- Analysis over “Speculative” corn and soybean region
- Four timely possible predictor (independent) variables
  - NDVI (Normalized Difference Vegetation Index)
    - derived from Terra satellite MODIS surface reflectance imagery
  - LST (Land Surface Temperature) from day and night
    - derived from Aqua satellite MODIS thermal imagery
  - Precipitation
    - derived from NOAA/NWS NEXRAD composite
- Utilizing 8-day composited mosaic products for each
  - Mid-February through late September
- Modeling/mining using Rulequest Cubist software
  - Regression tree based
County-level database developed

- Potential predictor variables (independent)
  - State (All major production Corn Belt states)
  - County (for each that had a published estimate, ~1000 of them)
  - Year (2006 – 2011)
  - 32 for each ranging every 8 days from February 18 – October 30
    - NDVI
    - Daytime LST (1:30 PM)
    - Nighttime LST (1:30 AM)
    - NWS Precipitation estimates
      - Thus 132 in total
- Forecast variable (dependent)
  - NASS published county level yield
- Sample size to evaluate ~5000 records
Corn yield dependence at county level speculative region, 2006-2011
Soybean yield dependence at county level speculative region, 2006-2011
“Voodoo Modeling”

• Rulequest Cubist
  – Learning tool to predict continuous rather than discrete outcomes
  – Allow for “composite” predictions using both
    • Instance-based
      – “Nearest neighbor”
      – Predicts the target value of a new case by finding the n most similar cases in the training data, and averaging their target values.
    • Model-based, via decision trees and piecewise linear regression
      – Divide and conquer strategy
      – Recursive splitting of training data to minimize intra-subset variation
  • Thus, for composite of instances and models:
    – Cubist finds the n training cases that are "nearest" (most similar) to the case in question. Then, rather than averaging their target values directly, Cubist first adjusts these values using the rule-based model.
  – Also, does “Committee” models
    • made up of several rule-based models. Each member of the committee predicts the target value for a case and the members' predictions are averaged to give a final prediction
Rulequest Cubist

Results for CS_corn_5year

Model 1:

```java
Rule 1: [47 cases, mean 66.59, range 10.3 to 135.6, est err 17.24]
if
MDW_14 <= 5792.634
MDW_22 <= 6741.989
EST.1330_02 <= 14435.63
EST.1330_04 <= 24906.01
then
yield = -120.36 + 0.1008 LOT.1330.02 - 0.0002 LOT.1330.04
      + 0.0455 LOT.1330.08 + 0.5752 MDW_11 + 0.0379 EST.1330.07
      - 0.0150 MDW_13 + 0.0021 MDW_23 + 0.0152 EST.1330.23
      + 0.0054 EST.1330.03 + 0.0170 MDW_20 - 0.0141 MDW_12
      - 0.0127 EST.1330.22 + 0.0142 MDW_12 - 0.0122 MDW_11
      + 0.0067 EST.1330.21 + 0.0113 MDW_14 + 0.0144 MDW_23
      - 0.0013 MDW_19 + 0.0044 EST.1330.30 + 0.0244 EST.1330.32
      - 0.0035 EST.1330.24 + 0.0045 EST.1330.14 + 0.0611 MDW_22
      - 0.0027 MDW_39 + 0.00306 MDW_01 - 0.0013 EST.1330.19
      + 0.0005 MDW.34 + 0.0005 MDW.01 + 0.0008 MDW_19
      + 0.0022 EST.1330.26 + 0.0007 MDW.11 - 0.0001 MDW.12
      - 0.0022 EST.1330.13 - 0.0022 EST.1330.21 - 0.0042 EST.1330.11
      - 0.0002 MDW.98 - 0.0022 EST.1330.09 - 0.0008 MDW.10
      + 0.0004 MDW.21 + 0.0001 EST.1330.12

Rule 2: [44 cases, mean 100.60, range 49 to 161, est err 9.41]
if
MDW_05 >= 2600.681
MDW_14 <= 6742.634
MDW_22 <= 4340.545
MDW_31 <= 2297.235
MDW_32 <= 12902.97
EST.1330.05 <= 14870.28
EST.1330.12 <= 35486.29
EST.1330.32 <= 16165.42
then
yield = -1575.12 + 0.0073 LOT.1330.02
        + 0.0478 LOT.1330.04 - 0.0318
        + 0.0303 LOT.1330.08 + 0.0181 LOT.1330.08
        + 0.0281 LOT.1330.14 + 0.0621 MDW.39
        - 0.0032 MDW.17 - 0.0062 MDW.03

Rule 3: [37 cases, mean 104.21, range 37]
if
MDW.04 <= 2956.286
MDW_14 <= 6732.634
MDW_16 <= 6598.462
MDW_17 <= 6340.541
EST.1330.02 <= 14435.63
EST.1330.04 <= 24906.01
then
yield = -515.78 + 0.0009 MDW.05 + 0.0183 MDW.14 - 0.0109 MDW
        + 0.0154 MDW.16 + 0.0149 MDW.20
```

Scatter plot for CS_corn_5year

Average err: 7.82
Relative err: 0.33
Correl coeff: 0.93
### Example county-level prediction output

#### Weight by a 3-year average of harvested acres to derive ASD, state, and region estimates

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</table>

**Corn**

**Soybeans**

Weight by a 3-year average of harvested acres to derive ASD, state, and region estimates.
Estimated Soybean Yield

October 1, 2012
Reality check

Scene of a large hailstorm
2012 Remote sensing vs NASS yield

State level average error

corn = 5.8 bu./ac.  soybeans = 3.1 bu./ac.
The relative error magnitude is the ratio of the average error magnitude to the error magnitude that would result from always predicting the mean value; for useful models, this should be less than 1!

The correlation coefficient measures the agreement between the cases' actual values of the target attribute and those values predicted by the model.
Soybean yield regression-tree model performance v. data timing county level, speculative region, 2006-2011
Models improvements for 2013

- **Corn**
  - relative $|\text{err}|$
  - correl coeff
  - 2012: 0.33, 2013: 0.30
  - correl coeff: 0.93, 2013: 0.95

- **Soybeans**
  - relative $|\text{err}|$
  - correl coeff
  - 2012: 0.31, 2013: 0.30
  - correl coeff: 0.93, 2013: 0.94

- Absolute error unchanged
  - ~8.0 bu/ac for corn, ~2.5 for soybeans
MODIS-derived crop dynamics based on CDL areas

Daytime Land Surface Temperature (LST)

Normalized Difference Vegetation Index (NDVI)

Corn

Soybeans
This winter: Build full understanding all common MODIS derived variables and how they relate to various crops’ yields

• Explore fully beyond only corn and soybeans
  – Wheat
  – Rice
  – Potatoes
  – Sorghum
  – Cotton

• Compare the full suite of common MODIS variables
  – NDVI
  – LAI
  – FPAR
  – LST (daytime and nighttime)
  – and more....

• Test Both Terra and Aqua platforms
  – Assess the AM vs PM overpass time

• Look at pixel scale issues
  – 250 m vs. 500 m vs. 1000 m (particularly for NDVI)
Winter wheat yield dependence at county level
Kansas, 2006-2011
Cotton yield dependence at county level
TX & AR, 2005-2011

Correlation coefficient (r)

NDVI  Rainfall  LST-night  LST-day

AGU Fall Meeting
San Francisco  |  13 December 2013
Corn yield correlations to NDVI from the different MODIS platforms

8-day composite windows

- Terra
- Aqua
Corn yield correlations to LST from the different MODIS platforms

8-day composite windows

- Terra 1030
- Terra 2230
- Aqua 1330
- Aqua 0130
In summary

- Corn and soybeans yield predictors
  - NDVI most useful
  - Daytime LST also useful
  - Precipitation not useful
  - Nighttime LST not useful
- Full exploration of other MODIS variables and other crops has begun
Thanks

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