Does Soil Affect Yield Stability in the U.S. Crop Production?

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Introduction

- Improving the premium rating accuracy of the U.S. Federal Crop Insurance Program is an ongoing effort. One potential direction of improvement is to include soil information in the rating algorithm, given that soil is a most critical factor impacting crop growth and yield.
- Previous studies primarily focused on soil’s impacts on the mean yields (i.e., productivity). However, a question more related to yield risk is whether soil also affects yield variability. Do some soil types bring more stable crop yields than others, given the same climate pattern and farm management practices? If so, those soils should be priced at lower premium rates.
- Until recently there are few empirical studies addressing this question.
- Research Objective: This study empirically examines whether soil is related to crop yield stability using the U.S. county level data.

Data

- County-level yields for upland cotton collected from NASS. Balanced panel of 84 counties (9 in Arkansas, 11 in Mississippi, and 64 in Texas) over 1972-2005.
- Both irrigated and non-irrigated yields are included.
- Soil data are obtained from USDA-NRCS gSURGO data. Soil characteristics are measured using the USDA soil texture classifications. The most commonly seen soil texture in each county is identified as the county soil texture.
- Distribution of sample counties by soil and state is shown in Table 1. Because some soil textures have very small number of counties, we group them into four larger soil groups (I, II, III, and IV), each contains similar soil textures. The relative similarities between those soil textures can be shown in the soil texture triangle of Figure 1.

<table>
<thead>
<tr>
<th>Soil group</th>
<th>Soil texture</th>
<th>AR</th>
<th>MS</th>
<th>TX</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Clay</td>
<td>13</td>
<td>4</td>
<td>1</td>
<td>20</td>
</tr>
<tr>
<td>II</td>
<td>Silty clay</td>
<td>0</td>
<td>4</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>Silty clay loam</td>
<td>4</td>
<td>2</td>
<td>2</td>
<td>8</td>
</tr>
<tr>
<td>III</td>
<td>Silt loam</td>
<td>2</td>
<td>1</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>IV</td>
<td>Clay loam</td>
<td>0</td>
<td>0</td>
<td>24</td>
<td>24</td>
</tr>
<tr>
<td></td>
<td>Loam</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>9</td>
<td>11</td>
<td>64</td>
<td>84</td>
</tr>
</tbody>
</table>

- Beyond soil, crop yield stability (year-to-year variability) is also closely related to historical weather pattern (mainly precipitation and temperature) and farming management (main irrigation).

Model

- Correctly controlling for weather and irrigation effects is a complicated modeling effort. Here we build on the Moment-based Maximum Entropy Model proposed by Tack et al. (2012). It is a flexible technique to estimate not only the mean yield but also the overall shape of yield distribution conditional on weather and irrigation. We further allow the parameters to vary across soil types.

\[
y'_{ij} = \alpha_i + \beta_{i,low}\text{med} + \beta_{i,med}\text{med} + \beta_{i,high}\text{med} + \beta_{i,irr,med} + \beta_{i,irr,irr} + \beta_{i,irr,irr} + \beta_{i,irr,irr} + \beta_{i,irr,irr} + \epsilon_i
\]

- \(y'_{ij}\): the yield distribution function, \(i\) is soil group, \(j\) is county, and period \(t\)
- \(\text{low, med, high}: \) the growing degree days of low (0-14°C), medium (15-31°C), and high temperature (>32°C)
- \(p: \) precipitation \(\text{irr}: \) irrigation dummy \(t: \) time trend

- \(x: \) soil group (I, II, III, and IV as defined in Table 1 and Figure 1); note all \(\alpha\) and \(\beta\) parameters are soil \((s)\) specific

- Step 1: Distribution estimate using the method of maximum entropy

\[
f = \text{arg max} \ H(f)
\]

Subject to the moment constraints:

\[
\int y' f(y') \text{dy'} = 1
\]

\[
\int y' f(y') \text{dy'} = \mu_i, \quad j=1, 2, 3
\]

where \(f()\) is the yield distribution function, \(H()\) is the entropy function, and \(\mu_i\) is the expectation of moment \(E(y')\)

Results

- County yield distribution estimated conditional on the county average weather (baseline) and a 1°C uniform increase in temperature.

- Table 1. Soil types of sample counties

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<td>24</td>
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<tr>
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- Soil group II (Silty clay, silty clay loam, silt loam)
- Yield distribution is not very sensitive to weather changes
- Dryland yields become more stable with temperature increase
- Irrigated yields distribution have little change

- Soil group III (Sandy clay loam, sandy loam)
- Yield distribution is quite sensitive to weather changes
- Dryland yields have larger concentration near the mean, but also a much larger probability of zero yield with temperature increase
- Irrigated yields become more dispersed and have higher deep low probabilities, too

- Soil group IV (Clay loam, loam)
- Yield distribution responses to weather changes
- Dryland yields become more dispersed and larger densities for low yield
- Irrigated yields have higher densities for low yield and deep loss

Conclusions

Yields on sandy clay loam, sandy loam, loam, and clay loam soils are more sensitive to weather changes based on U.S. cotton production data, while yields on clay, silty clay, silty clay loam, and silt loam soils are more stable.