Crop Yield Forecasting using Agromet Model: Indian experience

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OUTLINE

• Objective
• Background of AAS system
• Weather Monitoring & Forecasting
• Agromet Models and Database
• In-season Crop Yield Forecast
• Future Plan
FASAL (Forecasting Agriculture using Space, Agrometeorology and Land based observations)

Objective: Providing multiple pre-harvest production forecasts of crops at National/State/District level

Forecast schedule:
- F1: Vegetative
- F2: Flowering
- F3: Pre-Harvest stage.

Crops under FASAL:
- Rice
- Wheat
- Maize
- Jowar
- Bajra
- Ragi
- Groundnut
- Sugarcane
- Rape seed & Mustard
- Cotton
- Jute

Crops under CHAMAN:
- Potato
- Tomato
- Chilli
- Onion
- Mango
- Banana
- Citrus
Agromet Advisory Service (AAS) System to support the Objectives of FASAL

- IMD
  - Agro-climate level agro-met data
  - Preparation of district wise medium range weather forecast by State Met Centre

- 130 Ag.Met. Field Units
  - District-wise agro-met data

- District Level Agencies (DAO/KVK/ATMA/NGOs)
  - Feedback analysis

- Farmers
  - (Through media agencies, IT Service, Personal Contact)

- Dissemination of district level agro-advisories

**Agromet Advisory Service (AAS) System** to support the Objectives of FASAL

*Indian Meteorological Department (IMD)*
Weather Monitoring & Forecasting
Weather Observation System

Automatic Weather Stations (675)

Automatic Rainguage Stations (1289)

Surface Observatories

Agrometeorological Observatories (264)

Location of DRMS

Doppler Weather Radar (22)
Weather Observation System …

Gridded Weather data

Rainfall: 1.0*1.0 degree,
0.5*0.5 degree,
0.25*0.25 degree

Max & Min Temperature: 1.0*1.0 degree
0.5*0.5 degree

Satellite data: Insolation,
Land Surface Temperature (LST),
Soil Moisture,
NDVI based sowing dates.

(for use in crop model)
Agromet Models and Database
AGROMET MODELS

- Statistical Models
- Crop Simulation Models
Statistical model based on weather indices

- Correlation coefficients after adjusting yield for trend effect
- Effects as linear function of respective correlation coefficients
- Effects of quadratic terms of weather

\[ Y = A_0 + \sum_{i=1}^{p} \sum_{j=0}^{1} a_{ij} Z_{ij} + \sum_{i\neq i'=1}^{p} \sum_{j=0}^{1} a_{ii'j} Z_{ii'j} + cT + e \]

Where,

\[ Z_{ij} = \sum_{w=1}^{m} r_{iw}^j X_{iw} \quad \text{and} \quad Z_{ii'j} = \sum_{w=1}^{m} r_{ii'w}^j X_{iw} X_{i'w} \]

- Models using correlation coefficients based on yield adjusted for trend effect better
- Inclusion of quadratic terms of weather did not improve the model
- Second power of correlation coefficient did not improve the model

\[ r_{iw} \] is correlation coefficient of yield with \( i^{th} \) weather variable \((x)\) in \( w^{th} \) period

\[ r_{ii'w} \] is correlation coefficient of yield with product of \( i^{th} \) and \( i'^{th} \) weather variables \((x)\) in \( w^{th} \) period

\( m \) is period of forecast

\( p \) is number of weather variables used

\( e \) is random error distributed as \( N(0,\sigma^2) \).

\( T \) is technology factor
<table>
<thead>
<tr>
<th>SN</th>
<th>District</th>
<th>Equation</th>
<th>Weather Parameters</th>
<th>Forecast Yield (kg/ha)</th>
<th>$R^2$</th>
<th>F</th>
<th>Std Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Cooch Behar</td>
<td>$Y=3652.94+37.91<em>Time+ 12.37</em>Z51-0.01*Z230$</td>
<td>RHII, Tmin*RF</td>
<td>2077</td>
<td>0.93</td>
<td>64</td>
<td>92</td>
</tr>
<tr>
<td>2</td>
<td>Jalpaiguri</td>
<td>$Y=3045.95+43.96<em>Time+ 53.93</em>Z21+0.18<em>Z41-4.04</em>Z21$</td>
<td>Tmin, RHI</td>
<td>2032</td>
<td>0.94</td>
<td>58.6</td>
<td>79.8</td>
</tr>
<tr>
<td>3</td>
<td>South Dinajpur</td>
<td>$Y=1338.07+57.32<em>Time+ 1.44</em>Z31$</td>
<td>RF</td>
<td>2807</td>
<td>0.92</td>
<td>136</td>
<td>123</td>
</tr>
<tr>
<td>4</td>
<td>Uttar Dinajpur</td>
<td>$Y=1245.73+48.29<em>Time+ 0.76</em>Z151+0.10*Z150$</td>
<td>Tmax*RHII</td>
<td>2647</td>
<td>0.89</td>
<td>77</td>
<td>136</td>
</tr>
<tr>
<td>5</td>
<td>Burdwan</td>
<td>$Y=188.33+43.77<em>Time+ 0.77</em>Z231+0.271*Z251$</td>
<td>Tmin<em>RF, Tmin</em>RHII</td>
<td>3207</td>
<td>0.80</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>6</td>
<td>Mursidabad</td>
<td>$Y=1740.92+36.01<em>Time+ 0.25</em>Z451+0.04<em>Z131+ 0.78</em>Z251$</td>
<td>Tmax, Tmin, Rainfall, RHI, RHII</td>
<td>2830</td>
<td>0.89</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>7</td>
<td>Nadia</td>
<td>$Y=1623.00+27.54<em>Time+ 3.45</em>Z121 +0.04<em>Z131+ 2.14</em>Z151+0.53*Z150$</td>
<td>Tmax<em>Tmin, Tmax</em>RF, Tmax*RHII</td>
<td>2680</td>
<td>0.84</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>8</td>
<td>Howrah</td>
<td>$Y=3056.37+7.09<em>Z141+ 2.18</em>Z140 +16.85<em>Time + 0.02</em>Z341$</td>
<td>Tmax<em>RHI, RF</em>RHI</td>
<td>1482</td>
<td>0.76</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>9</td>
<td>Hooghly</td>
<td>$Y=2164.86+50.91<em>Time- 0.24</em>Z351+ 208.24 <em>Z41+ 142.46</em>Z51-1.15<em>Z451+0.75</em>Z131</td>
<td>RF<em>RHII, RHI, RHII, RHI</em>RHII, Tmax*RF</td>
<td>3651</td>
<td>0.90</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>10</td>
<td>North 24 Parganas</td>
<td>$Y= -287.60+41.32<em>Time+ 1.14</em>Z151+1.20*Z241$</td>
<td>Tmax<em>RHII, Tmin</em>RHII</td>
<td>2834</td>
<td>0.89</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>11</td>
<td>West Midnapur</td>
<td>$Y=975.68+Time<em>45.67+ Z120</em>3.77$</td>
<td>Tmax*Tmin</td>
<td>2839</td>
<td>0.87</td>
<td>91.82</td>
<td>273.89</td>
</tr>
<tr>
<td>12</td>
<td>Bankura</td>
<td>$Y=1674.88+Time*43.27$</td>
<td>---</td>
<td>3059</td>
<td>0.80</td>
<td>122.0</td>
<td>433.57</td>
</tr>
<tr>
<td>13</td>
<td>Birbhum</td>
<td>$Y=1737.32+Time*48.85$</td>
<td>---</td>
<td>3300</td>
<td>0.84</td>
<td>154.2</td>
<td>468.80</td>
</tr>
<tr>
<td>14</td>
<td>Purulia</td>
<td>$Y=7831.85+Time<em>29.04+ Z11</em>114.91+Z151*0.41$</td>
<td>Tmax, Tmax*RHII</td>
<td>2468</td>
<td>0.85</td>
<td>50.6</td>
<td>429.33</td>
</tr>
<tr>
<td>15</td>
<td>Malda</td>
<td>$Y=58.707<em>Time+146.53</em>Z11+0.05*Z231+2714.88$</td>
<td>Tmax, Tmin*RF</td>
<td>3065</td>
<td>0.92</td>
<td>100.5</td>
<td>167.12</td>
</tr>
<tr>
<td>16</td>
<td>South 24 Parganas</td>
<td>$Y=34.48<em>Time+91.88</em>Z11+ 0.73<em>Z31+46.66</em>Z41+520.41$</td>
<td>Tmax, RF, RHI</td>
<td>2171</td>
<td>0.89</td>
<td>48.8</td>
<td>135.31</td>
</tr>
<tr>
<td>17</td>
<td>East Midnapore</td>
<td>$Y=1251.57+169.43<em>Time+ 0.05</em>Z351$</td>
<td>RF*RHII</td>
<td>2724</td>
<td>0.73</td>
<td>29.7</td>
<td>178.2</td>
</tr>
</tbody>
</table>
Crop Growth Simulation Model estimates

1. Phenological development or duration of growth stages as influenced by plant genetics, weather, and soil factors.

2. Growth of leaves, stems, roots and grains

3. Biomass production and partitioning

4. Effects of soil-water deficit and nitrogen deficiency on photosynthesis and photo-synthate partitioning in the plant system.
Agricultural Models - System approach

Used under Indian condition

- DSSAT
- WOFOST
- APSIM
- EPIC
- WTGROWS
- INFOCROP
- ORYZA
- BRASSICA
## What are the Crops covered

<table>
<thead>
<tr>
<th>Cereals</th>
<th>Legumes</th>
<th>Oil seeds</th>
<th>Tuber crops</th>
<th>Horticultura l Crop</th>
<th>Cash Crop /other crops</th>
</tr>
</thead>
<tbody>
<tr>
<td>Barley</td>
<td>Chickpea</td>
<td>Canola</td>
<td>Cassava</td>
<td>Pepper</td>
<td>Sugar cane</td>
</tr>
<tr>
<td>Maize</td>
<td>Cowpea</td>
<td>Sunflower</td>
<td>Potato</td>
<td>Cabbage</td>
<td>Cotton</td>
</tr>
<tr>
<td>Pearl millet</td>
<td>Dry bean</td>
<td>Mustard</td>
<td>Tanier</td>
<td>Tomato</td>
<td>Bahia Grass</td>
</tr>
<tr>
<td>Rice</td>
<td>Faba bean</td>
<td></td>
<td>Taro</td>
<td>Sweet corn</td>
<td>Brachiaria</td>
</tr>
<tr>
<td>Sorghum</td>
<td>Lentil</td>
<td></td>
<td></td>
<td>Green bean</td>
<td></td>
</tr>
<tr>
<td>Wheat</td>
<td>Peanut</td>
<td></td>
<td></td>
<td>Pineapple</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Pigeon pea</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Soybean</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Velvet bean</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Moong bean</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Moong bean</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
INPUTS: Minimum Data Set

Weather Variables
- Solar radiation / bright sunshine hours
- Maximum air temperature
- Minimum air temperature
- Precipitation
- Latitude (to calculate day length)

Soil Variables
- General Soil classification
- Surface slope & Albedo
- Runoff
- Permeability & Drainage
- First stage soil evaporation

For each Soil layer
- Lower Limit
- Drained Upper Limit
- Saturated soil water content
- Bulk Density
- Clay & Silt (%)
- Relative root distribution
- Initial soil water content

Crop Management Variables
- Cultivar selection (genetic coeff.)
- Planting date
- Plant population
- Row spacing
- Irrigation (dates and amount)
- Fertilizer (dates and amount)
- Initial conditions
- Crop rotations
- Pest (damage)
Network programme

- **ICAR- AICRPAm:** All India coordinated Research Programme on Agrometeorology - 25 locations
- **FASAL:** 47 Agro-Met Field Units in different agro-climatic zones

**Crop Model calibration, validation and sensitivity analysis:**

- Continuous evolution of model by field experimental testing across diverse environment, soil and cultural practices
- Information feedback from scientist/farmers and farm managers
Field Experimental Layout

Field experiments proposed under FASAL project consider following aspects

- 1 or 2 popular cultivars grown in the region for each crop under study
- 3 - 4 Date of sowing
- N management - Time, amount and method of application
- Phenology
- Growth - Biomass at different stages
- LAI and soil moisture at different stages
- Crop observations serve purpose of ground truth for RS data to link with CSM
Indian workers have derived Genetic coefficients for few ruling cultivars of following crops in different agro-climatic zones –

- Rice, Wheat, Maize, Sorghum, Millet, Peanut, Soybean, Sugarcane, potato, chickpea, Sunflower

- A new crop cultivar needs model calibration and validation to derive the G.C. This requires crop observations from field experiments.
Available Database

Crop data
- Area, Production & Productivity - district wise, 1990 onwards for all major crops of India
- Genetic coefficient of all major crops derived from field experiments

Weather Data

Soil Data
- Layer wise Hydro-physico-chemical properties required for CSM - district wise

Crowd sourcing is done regularly to improve the data accuracy through different networks.
District wise soil information - Layer 1

- **Layer 1: Soil Wilting Point**
  - Wilting Point
  - Minimum: 0.044
  - Maximum: 0.194
  - Sum: 86.30328
  - Mean: 0.123338
  - Standard Deviation: 0.035529

- **Layer 1: Soil Field Capacity**
  - Field Capacity
  - Minimum: 0.116
  - Maximum: 0.297026
  - Sum: 134.504813
  - Mean: 0.250194
  - Standard Deviation: 0.045548

- **Layer 1: Soil Saturation**
  - Saturation
  - Minimum: 0.240
  - Maximum: 0.7802
  - Sum: 231.974877
  - Mean: 0.43176
  - Standard Deviation: 0.054038

- **Layer 1: Soil Organic Carbon**
  - Organic Carbon
  - Minimum: 0.03
  - Maximum: 3.86
  - Sum: 324.22
  - Mean: 0.692939
  - Standard Deviation: 0.491704
Model Evaluation in Farmer’s field: CCE Yield Vs. Simulated Yield of Kharif Rice 2014

Shimoga

Yadgiri

Raichur: Rabi (2014-15)

Bulandshahr

Pratapgarh

East Godavari

East Godavari

Srikakulam

Bardhamaan
In-season Crop Yield Forecasting

Methodology & Result
Spatial Crop Yield Forecasting: Methodology and Data flow

Static Data
- Soil
- Crop and Management practices (Past experimental data for different cultivars) (Source: AMFUs & IMD)
- Used to calibrate, validate crop Model
- On going field Experiments (Source: AMFUs)

Dynamic Data
- Weather
  - Observed: Daily Tmax, Tmin, Rain Radiation (Source: MC/AMFU)
  - Daily normal or Forecast (Source: MC)
- Crop
  - Cultivars (Normal/excess or deficit monsoon) (Source: SAUs)
  - Area sown/transplanted (Source: DAC, SDA)
- Management
  - Time of sowing
  - Irrigated/Rainfed
  - N & Water schedule (Source: SAUs)
- RS Product
  - NDVI
  - LAI
  - Soil Moisture (Source: SAC)

CROP MODEL (DSSAT v4.5, INFOCROP) Run at AMFU & MC

Stage -2 output
Yield estimates & other parameters

Stage-1 Output
- Phenology
- Growth
- Water Balance

Refinement in crop Model (New genetic coefficients)

Verification using RS data (Adjust sowing date in crop model)
Crop Simulation Model based operational district level Rice Yield Forecast *Kharif* -2015

Rice Yield Forecast 2015 For 14 Different States of India

Yield in Kg/ha
<VALUE>
- 1500 - 2000
- 2000 - 2500
- 2500 - 3000
- 3000 - 35000
- 3500 - 4000

INDIA METEOROLOGICAL DEPARTMENT
Model performance for Rice Yield for different state-2015

Source: DAC&FW (MoAg&FW)
Bottlenecks in developing crop yield forecast

- Long term Meteorological data and/or crop yield data are not available for some districts.
- Poor accuracy of yield forecast models for the regions where there is high variability in weather and crop yield over the years.
- Due to socio-economical & Govt. policy, Sudden changes in cultivation practices and varieties causing sharp changes in yield pattern.
- Due to establishment of new districts, there is non-availability of long term weather and yield data for these districts.
- Damage caused due to Extreme events are not accountable in the model.
Future considerations

- Weekly progress of Area sown under different crops at district scale
- Improvement in Estimation of daily solar radiation using routine weather data such as MaxT, MinT, rain, cloud cover – important during monsoon season. Also Satellite derived insolation (8 km & 4 km res.)
- Improvement in soil data base
- Linking RS data with Crop model
  - Forcing of LAI etc. into CSM at the time of prediction
  - Re-run crop model- adjust sowing date to match simulated crop condition (LAI)
- Use of other crop model -InfoCrop model etc.
- Develop methodology to ensemble/ hybridize the multi crop simulation and statistical models’ estimates to improve final forecast
THANK YOU