A review on crop yield and pasture health monitoring and forecasting in East Africa

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Outline

- Rationale
- Some Crop Yield Monitoring and Forecasting approaches/Models
- Some successful cases
- Case study
- Way forward
Rationale

- Since the last decades, people in the East Africa started shifting from subsistence to market-oriented agriculture.

- Huge investments have been put in new technologies such as irrigation and improved inputs especially tolerant seed varieties and fertilizers

- Need for strong crop/pasture Monitoring and yield forecasting tools which would combine environmental and farming practices in order to have a scientifically inspired business model.

- The mostly used models: Crop growth simulation, Crop weather and Empirical statistics
Rationale

- The advance in Geo-information helped the use of Multispectral and multi-temporal satellite images and various vegetation indices for a better monitoring/forecasting.

- In East Africa, those models combining field based and remotely acquired data have been underexploited by Governments and only International Organizations such as FAO and IUCN have been using them with the challenge that they are relying on global data as inputs.

- The current paper investigated different models that have been used for crop yield and pasture health monitoring and forecasting in East Africa.
Major parameters for crop/pasture yield
Monitoring and forecasting

Inputs

- **Weather**
  - Rainfall, Temperature, Humidity, Solar radiation, etc...

- **Crop**
  - Variety
  - Physiology
  - Phenology
  - Morphology

- **Agronomic Inputs**
  - Seed variety
  - Farming practices (irrigation, terracing,..),
  - fertilizers, pesticides

- **Soil**
  - Texture
  - Salinity
  - Sodicity
  - Fertility

- **Pests**
  - Type
  - Population

Crop Monitoring/Forecasting Models

Output

- Potential Yield estimation
- Yield gap estimation
- Yield forecasting

Decision

- Organizing Management practices (inputs, investment, farming practices,..)
- Assessing and coping with impacts of climate variability and climate change
- Plant type design and evaluation
Some models

- Crop-weather models: Combine inputs, farming practices and weather—it is the mostly used and helps to deal with crop calendar

- Crop growth models: simplified representation of the physical, chemical and physiological mechanisms underlying plant growth processes.

- Empirical statistical models: The weighting coefficients in these equations are by necessity obtained in an empirical manner using standard statistical procedures. It does not easily lead to an explanation of the cause and effect relationships but it is a very practical approach for the assessment or prediction of yields.
Earth Observation for crop monitoring and yield estimation

• The advance of Earth Observation helped to gather weather/climate, crop/pasture phenology at various spectral, spatial and temporal resolutions

• Course, medium and high resolution including UAVs have been useful for crop monitoring and yield forecast

• The multispectral remote sensing helps to collect many parameters at the same time

• The hyper temporal/time series data help to monitor crops/pastures at different phenological stages for better yield predictions
Earth Observation for crop monitoring and yield estimation

- Thanks to Earth Observation, various land uses/covers and vegetation indices could be easily retrieved

- Other indices concerning water and soil like SMI, etc...

<table>
<thead>
<tr>
<th>Index</th>
<th>Reference</th>
<th>Scale</th>
<th>Parameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>NDVI (Normalized Difference Vegetation Index)</td>
<td>Rouse et al., 1974</td>
<td>Canopy</td>
<td>Biomass; Vegetation Fraction</td>
</tr>
<tr>
<td>GNDVI (Green Normalized Difference Vegetation Index)</td>
<td>Gitelson et al., 1996</td>
<td>Canopy</td>
<td>Chlorophyll; Vegetation Fraction</td>
</tr>
<tr>
<td>PRI (Photochemical Reflectance Index)</td>
<td>Gamon et al., 1992</td>
<td>Canopy</td>
<td>Photosynthesis efficiency/ RUE</td>
</tr>
<tr>
<td>NDRE (Normalized Difference Red Edge)</td>
<td>Barnes et al., 2000</td>
<td>Canopy</td>
<td>Chlorophyll/ Nitrogen</td>
</tr>
<tr>
<td>CCCI (Canopy Chlorophyll Content Index)</td>
<td>Fitzgerald et al., 2006</td>
<td>Canopy</td>
<td>N Status/ Chlorophyll</td>
</tr>
<tr>
<td>RVI (Ratio Vegetation Index)</td>
<td>Jordan, 1969</td>
<td>Leaf</td>
<td>Biomass</td>
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<tr>
<td>EVI (Enhanced Vegetation Index)</td>
<td>Huete et al., 2002</td>
<td>Canopy</td>
<td>Biomass/ Vegetation Cover</td>
</tr>
<tr>
<td>EVI 2 (Enhanced Vegetation Index 2)</td>
<td>Jiang et al., 2008</td>
<td>Canopy</td>
<td>Biomass/ Vegetation Cover</td>
</tr>
<tr>
<td>VARIgreen (Visible Atmospherically Resistant Index)</td>
<td>Gitelson et al., 2002</td>
<td>Canopy</td>
<td>Vegetation Fraction/ LAI</td>
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<tr>
<td>VARI700 (Visible Atmospherically Resistant Index; 700 nm)</td>
<td>Gitelson et al., 2002</td>
<td>Canopy</td>
<td>Vegetation Fraction/ LAI</td>
</tr>
<tr>
<td>TVI (Triangular Vegetation Index)</td>
<td>Brodge and Leblanc, 2000</td>
<td>Canopy</td>
<td>Chlorophyll</td>
</tr>
<tr>
<td>MTVI 1 (Modified Triangular Vegetation Index 1)</td>
<td>Haboudane et al., 2004</td>
<td>Canopy</td>
<td>Chlorophyll</td>
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<tr>
<td>MTVI 2 (Modified Triangular Vegetation Index 2)</td>
<td>Haboudane et al., 2004</td>
<td>Canopy</td>
<td>Chlorophyll</td>
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<td>MTCI</td>
<td>Dash and Curran, 2007</td>
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</table>
Application of Multi-Temporal MODIS NDVI Data to Assess Practiced Maize Calendars in Rwanda

- Mugabowindecwe et al. 2018 assessed crop calendar in Rwanda
- Focused on agro-ecosystems with differences in climate and soil properties
- Used a multi-temporal MODIS NDVI stratification

<table>
<thead>
<tr>
<th>Agro-ecological Zone</th>
<th>Average Altitude (m)</th>
<th>Average Rainfall (mm)</th>
<th>Soil Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Buberuka highlands</td>
<td>2000</td>
<td>1200</td>
<td>Oxisols at high altitude</td>
</tr>
<tr>
<td>Congo-Nile divide</td>
<td>2100</td>
<td>1600</td>
<td>Humic acid soils</td>
</tr>
<tr>
<td>Bugarama plain</td>
<td>1100</td>
<td>1200</td>
<td>Alluvial soils</td>
</tr>
<tr>
<td>Impala</td>
<td>1700</td>
<td>1400</td>
<td>Heavy clayey soils derived from basalt</td>
</tr>
<tr>
<td>Kivu lake</td>
<td>1600</td>
<td>1100</td>
<td>Gravely sandy loam soils</td>
</tr>
<tr>
<td>Kivu lake side</td>
<td>1600</td>
<td>1200</td>
<td>Clay loam soil</td>
</tr>
<tr>
<td>Mayaga</td>
<td>1450</td>
<td>1050</td>
<td>Clayey soils derived from shale</td>
</tr>
<tr>
<td>Bugesera</td>
<td>1400</td>
<td>900</td>
<td>Oxisols</td>
</tr>
<tr>
<td>Central plateaus</td>
<td>1700</td>
<td>1200</td>
<td>Humic soils at medium altitude</td>
</tr>
<tr>
<td>Eastern ridges and plateaus</td>
<td>1500</td>
<td>950</td>
<td>Oxisols with high iron oxide</td>
</tr>
<tr>
<td>Eastern savannah</td>
<td>1400</td>
<td>850</td>
<td>Old infertile soils with texture variable</td>
</tr>
<tr>
<td>Volcanic summits and high plains</td>
<td>2200</td>
<td>1500</td>
<td>Ultisols derived from volcanic materials</td>
</tr>
</tbody>
</table>

Source: Clay and Dejaegher (1987).
Application of Multi-Temporal MODIS NDVI Data to Assess Practiced Maize Calendars in Rwanda

- NDVI increases in between growing and harvesting seasons
- It is lower in planting and harvesting seasons
- The optimum in NDVI/Chlorophyll content justifies adequate crop health and optimal yield
Application of hypertemporal NDVI data in grassland mapping and biomass estimation in the Masai Mara ecosystem, Kenya

- From Onyango, O.D., 2015
- Analysis of hyper-temporal Modis terra NDVI data to monitor NDVI contents in rangelands of Massai Mara-Kenya

Figure 18: Spectral profiles of Classes 18, 25 and 35; annual monthly averages
Application of hypertemporal NDVI data in grassland mapping and biomass estimation in the Masai Mara ecosystem, Kenya

- Unit E: High Biomass
- E is dominantly found in Masai Mara National reserve while the others are dominant in the surrounding conservancies and community land around
- Human disturbance affected biomass

Figure 19: Boxplots of Biomass by grassland vegetation cover types
Case Study: Crop Monitoring Using Sentinel images in the framework of AfriCultuReS Project

- **AfriCultuReS**: Enhancing Food Security in AFRIcan AgriCULTUral Systems with the Support of REMote Sensing
- Duration: 1 Nov 2017 – 30 Oct 2021 (48 months)
- Different partners: Research Institutions and Private Companies from all Corners of Africa and Europe:
  - Observatoire du Sahara et du Sahel (OSS) from Tunisia, LocateIT from Kenya, GeoSAS from Ethiopia, University of Rwanda, Centre for GIS and Remote Sensing (CGiS) from Rwanda, Centre for Remote Sensing and Geographic Information Services (CERSGIS) from Ghana for the Gulf of Guinea, Eduardo Mondlane University (UEM) from Mozambique and South African National Space Agency (SANSA) from South Africa.
  - European Partners are GMV AEROSPACE AND DEFENCE SA (GMV) from Spain, Aristotelio Panepistimio Thessalonikis (AUTH) and Draxis Environmental S.A. (DRAXIS) from Greece, Noort Harmannus, Conradus Pieter (HCP) from the Netherlands, UNIVERSITA DEGLI Studi Di Roma La Sapienza (SIA) from Italy, Universidad De Cantabria (UC) from Spain, University of Leeds (UNIVLEEDS) and University of Sheffield (USFD) from the United Kingdom.
Case Study: Crop Monitoring in Rwanda Using Sentinel images in the framework of AfriCultuReS Project

- Eastern lowlands with large monoculture of maize, banana and pasture lands
- Northern highlands with mosaic fields of crops including potatoes, climbing beans
- Southern and Central plateaus with a mixture of crops and large fields of cassava in Amayaga Region
- More croplands in central plateaus
- More grass and croplands in the Eastern lowlands
- More forest and crops in the Northern highlands
Conclusion and way forward

• It is clear that with Earth Observation, people can monitor crop health and forecast the yield
• The spectral, temporal and spatial resolutions of the used image have a big influence on the results
• What is next?
  – NDVI using Medium resolution images (This would work perfectly in the eastern lowlands and southern plateaus of Amayaga with large monoculture
  – Use High Resolution images even UAVs if possible to mosaic fields in the western highlands
  – Use crop weather simulation models to monitor not only the health by estimate the biomass