Earth observation and big-data analytics for building resilient agro-ecosystems

Innovation, Investment, Intervention and Impact

Chandrashekar Biradar, PhD
Principal Scientist (Agro-Ecosystems)
Head-Geoinformatics Unit
c.biradar@cgiar.org

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Hyderabad, India
Droughts in Drylands
and the consequences and conflicts

Drought in middle east is worst of past 900 years

Conflicts and migration

Precipitation trend and history of droughts with 3-year tendencies

- Population 12.11 million
  - GPC Gap: 30MT
- Population 22.28 million
  - GPC Gap: 70MT

ICARDA Station
Tel Hadya

- 35-year pluvial
- 1990s drought
- 2010s drought

Source: NASA, 2016

(Biradar, et al., 2016)
Water Stress Around the World

(Source: World Resources Institute)
Impact of on agriculture

Wheeler and Baum, 2013.

World bank Development report 2010
http://wdronline.worldbank.org/
Global Drylands and CGIAR

Area (km²)
- Tropical Drylands: 29.33 million
- Non-tropical Drylands: 95.52 million

Population
- Tropical Drylands: 1.89 billion
- Non-tropical Drylands: 2.68 billion
Two-thirds of the global population (4.0 b) live under severe water scarcity and almost all of population in non-tropical dry areas.

Location and context specific interventions

Biradar et al., 2015; ICARDA
Changing Water Balance

Increasing deviation from long-term averages

- Large fluctuation in water balance
- Climate variability and extreme events
- Crop rotation and economic drive
- Depleted soil organic carbon

Baseline AET data, Senay et al., 2015; USGS
Towards Resilient Agro-Ecosystems

Increased land, water and system productivity while safe guarding the environmental flows and ecosystem services

- more **crop** per **drop**  -water focus
- in a **inch of land** and a **bunch of crop**  -multi dimensions
-**integrated systems**

Knowledge based prioritization (space & time) for better strategy for investment, intervention, implementation and impact

**Genes and Gains**
**Eco-Crop Zoning**
**Input Use Efficiency**
**Bridging Yield Gaps**
**Conservation Practices**
**Carbon Sequestration**
**Land Degradation**
**Technology Scaling**

- food and environmental security
- resilience and risk reduction
- adaption and mitigation
- citizen science and collective actions
- trade, social security and stability

[ICARDA Logo]
Role of Geospatial Science, Technology and Applications (GeSTA) in Dryland Systems

- Ensuring Food Security
  - Specific mutual-interaction & synergies between plant and animal species and management practices
  - Integrated agro-ecosystems: innovative approaches and methods for sustainable agriculture, while safeguarding the environment

- Safeguarding Environmental Flows and ESs
  - Cooperative Research and Partnerships
  - Gender
    - Address social inequities, greater roles and priorities

- Drylands
  - 41% Earth’s land area

- Measuring the impact at spatial scales, rate, magnitude, synergy among the systems, CRPs, cross-regional synthesis

- Innovations & Integration
  - Mapping present, emerging, future land use/land cover dynamics, land degradation and desertification, changing demographics, climate change adaptation and impacts

- Reducing Vulnerability
  - Quantification of dryland agricultural production and livelihood systems
  - Characterization of vulnerable areas for increasing resilience and assist in identifying mitigation pathways with biophysical, socioeconomic and stakeholder feedback as well as specific needs & constraints

- Sustainable Intensification
  - Current status, trends, extent, characteristics of crops, pattern, productivity, water use, livestock, biodiversity, soils, & climate

- Geospatial commons, KM sharing, stakeholder feedback
  - Farmers, stakeholders, policymakers, mobilization, & marketing

- Assessing the impact of outcomes in Action Sites, post-project implementation, & M&E

- Nutrition
  - Changing diet patterns, nutrition and health

- Location specific and ecological intensification

- Delineation of potential, suitable areas for sustainable intensification, diversification of production systems

- Mapping the extent of existing & traditional practices, indigenous knowledge, diversity, potential areas for modern & improved, productive, profitable, and diversified dryland agriculture, & linkages to markets

- Improving Livelihoods
  - Mapping the extent of potential sources of food production

- Geographical Enrichment and its role in food security, risk mitigation, & sustainability

- Biodiversity
  - Spatial enrichment and its role in food security, risk mitigation, & sustainability

- People
  - 2.5b Live in Drylands
  - 1.5b Depend on Drylands

- Livestock
  - Assessment of present, emerging & future droughts, floods, pests & diseases, extreme events, infrastructure, migration

- Integrated Production Systems for Improving Food Security and Livelihoods in Dry Areas

- Agriculture Intensification
  - Cropping Intensity
  - Increase in Arable Land
  - Reducing Cropping Intensity
  - Location specific interventions.

- Food Security
  - Environmental Flows and ESs
  - Ensuring Efficiency
  - Productivity
  - Environmental Flows and ESs

- Fletters for Biodiversity
  - Integrated Production
  - Systems for Improving Food Security and Livelihoods in Dry Areas

- Geoagro.icarda.org
### EO Matrix at Farmscape to Landscape

#### Example of One Sensor in each Platform/Scale

<table>
<thead>
<tr>
<th>Platforms</th>
<th>Ground/in-situ</th>
<th>Airborne</th>
<th>Spaceborne</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mode</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hyperspectral</td>
<td>Hyperspectral</td>
<td></td>
<td>WorldView-2</td>
</tr>
<tr>
<td>Multispectral</td>
<td>Multispectral</td>
<td></td>
<td>Landsat</td>
</tr>
<tr>
<td><strong>Sensor</strong></td>
<td></td>
<td></td>
<td>MODIS</td>
</tr>
<tr>
<td>ASD FieldSpec</td>
<td>ASD FieldSpec</td>
<td></td>
<td>ICESat*</td>
</tr>
<tr>
<td>M× Camera</td>
<td>M× Camera</td>
<td></td>
<td>PALSAR</td>
</tr>
<tr>
<td><strong>Spectral</strong></td>
<td>350-2500nm</td>
<td>4 bands</td>
<td>8 bands</td>
</tr>
<tr>
<td><strong>Spatial resolution</strong></td>
<td>0.1-1.5m</td>
<td>0.1-0.2m</td>
<td>0.46m Pan; 1.84m MS</td>
</tr>
<tr>
<td><strong>Swath</strong></td>
<td>1-4m</td>
<td>2-10m</td>
<td>16.4km</td>
</tr>
<tr>
<td><strong>Revisit</strong></td>
<td>--</td>
<td>--</td>
<td>1.1 days</td>
</tr>
<tr>
<td><strong>Biophysical</strong></td>
<td>Plant biomass</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td></td>
<td>Plant height</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td></td>
<td>LAI, fPAR, LST</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td></td>
<td>NDVI, EVI, LSWI</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td><strong>Biochemical</strong></td>
<td>Erosion, Salinity</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td></td>
<td>Soil moisture</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td></td>
<td>Chllophyll</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td></td>
<td>Nitrogen</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td></td>
<td>Phosphorous</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td></td>
<td>Plant water</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td><strong>Product</strong></td>
<td>GPP</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td></td>
<td>NPP</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td><strong>LULC</strong></td>
<td>land cover/use</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td></td>
<td>phenology</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td></td>
<td>Irrigation</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td><strong>Terrain</strong></td>
<td>DEM</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td></td>
<td>Derivatives</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td><strong>Scale</strong></td>
<td>Tier 1 AOs</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td></td>
<td>Tier 2 action sites</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td></td>
<td>Tier 3 AEZs</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td></td>
<td>Tier 4 Target</td>
<td>x</td>
<td>x</td>
</tr>
</tbody>
</table>

**RS data characteristics**

**Ground/in-situ**

- **Airborne**
  - Optical
  - LiDAR

**Spaceborne**

- Optical
- LiDAR
- SAR

**Example of One Sensor in each Platform/Scale**

- **Biospectral – Biophysical Product**
- **LULC Terrain Scale**
- **RS data characteristics**
- **Ground/in-situ**
- **Airborne**
- **Spaceborne**

**Leaf Area Index**

- **Leaf Pigments**
  - **Leaf Chlorophyll**
  - **LSWI**

**Leaf Water**

**Science for Better Livelihoods in Dry Areas**

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**ICARDA**
Across the scales

Scaling Trade-on/offs
Farmscapes to Landscapes

Big-Data Analytics
Citizen Science
Precision Decisions

Vegetation Dynamics
Pest and Diseases Risk
Crop Modeling (Physio)
Agro-hydrology

Agro-ecosystems
L&W Productivity
Land Use Change

Cropping Systems Dy
Ag Water Productivity
Yield Gap Analysis

Crop Fallows
Intensification
Feedstock

FIGS
HyRS
VarImpate

MODIS
SPOT Veg.

MODIS
AWiFS

Landsat
IRS

WV series
RapidEye/BB
Cartosat

WVs/DG/UAVs
Water, Nutrition, Ecology and Climate Change

Why dryland crops and crop diversification?

• Economically-Nutritious
• Ecological-Soil Health
• Improved Productivity
• More Climate Resilient
• Reduce Virtual Water Trade

Water-Efficient-Ecological Food Production

- Daal/Falafel (1kg) 1,250 liters
- Chicken (1kg) 4,325 liters
- Mutton (1kg) 5,520 liters
- Beef (1kg) 13,000 liters

http://www.soyfoods.org/

Digital Agriculture Platform

On the fly demand driven query and cluster analysis

Cadastral, Object & Pixel based

Biophysical and socio-ecological

Machine Learning
Crop types, crop intensity, pattern, fallows, crop stress, AET-I8, soil moisture-SMAP

Citizen-Science Cellphone feedback

Direct Access and Markets/Trade

Precision Decision at Farm scales

Crowdsourcing, OA, Cloud Computing at Farm Scale

Landsat AWS

Image Based, Open Source Precision Decision at Farm scales

Timely-Access-Application-Trading (TAAT)

On the fly demand driven query and cluster analysis

Precision decision delivery at farm scales and feedback

Farming Stakeholders

Right Time Right Place

Citizen Science
Community of Practices
Existing Agricultural Production Systems

Where are they and what is going?

Biradar et al., 2009, 2015
Drylands of Developing World
Dynamics of Cropping Intensity and Pattern

- Integrated Agro-Ecosystems
- Sustainable Intensification and Diversification
- Input Use Efficiency - Conservation Agriculture
- Thematic Land-Water-Climatic Resilience

Agricultural Intensification: 72% Increase in Arable Land

How can we track and link?

Length of the crop fallows, start-date, end-date

(Biradar et al., 2015)

Double crops
Triple crops

Population Density

Double crops: < 0.135
Triple crops: > 54916

Biradar and Xiao, 2009
Quantification of its dynamics
Under changing Climate and Demography

Remote Sensing
- MODIS
- LANDSAT
- SENTINEL
- MICROS

GeoStats
AgCensus
Climate, Soils
Demography

Open Source
Cloud Computing
Algorithms

Biradar, 2016*
EOS in Precision Decisions

Automated workflow for operational mapping, monitoring and rural advisory

Yield Gaps, ET, WUE, WPM

Inter and intra annual dynamics of cropping systems – pattern, rotation, shift

Products of crop productivity, WUE, ET, etc.

Products of land use, land cover, crop type, etc.

Loss

Gain

Between Farms

Within farms
Better use of crop fallows for sustainable future.

Near real-time farm analytics at pixel to landscape scales.

**Cropping System**
- Crop Intensity
- Crop Calendar
- Crop Rotation
- Cropped Area

**Fallow Dynamics**
- Fallow area
- Duration
- Start date
- End date

**Yield Potential**
- Current
- Achievable

**Suitable Crop/Variety**
- Legumes
- Oil Seeds

**Soils**
- Soil Health (SHC)
- Soil Moisture (SMAP)

**Water use**
- Evapotranspiration
- Allocation/Irrigation Sch.

**Markets**
- ePlatform
- Ag Supply Chain
- Access (I/O)

**Monitoring**
- Pest/Diseases
- Crop Stress

**Citizen Science**

Ag Intensification & Diversification
Cropping Intensity and land use dynamics

(Biradar et al., 2015)
Length of crop fallows

(Biradar et al., 2015)
Inter and Intra Annual Dynamics over Decades

15 years cycle

Length of Crop Fallows (LCP): 2000-2015

Cropping Intensity and land cover: 2000-2014

Start and End Dates of Inter-annual Fallows

Start and End Dates of Intra-annual Fallows

(Biradar et al., 2015)
Crop-fallows for intensification

On-farm water management

Fallow from July to January (7 months)

March

December
Static Maps to see JPG maps showing regional similarity of IP sites and variety specific maps.

Interactive Mapping based on user defined queries to find suitable varieties and extent of suitability.
Water productivity (WP) is defined as the kg of yield produced/m³ of water used or, alternatively, as value in $ of yield produced/m³ of water used.

Water productivity of the dryland crops are much higher than any production systems.

Where are those Yield Gaps?

Within the fields

Biradar et al., 2013

<table>
<thead>
<tr>
<th>Crop</th>
<th>Water Productivity (WP)</th>
<th>Value in $</th>
</tr>
</thead>
<tbody>
<tr>
<td>WP of Cotton</td>
<td>0.42 kg/m³</td>
<td>0.50 USD/m³</td>
</tr>
<tr>
<td>WP of Wheat</td>
<td>0.60 kg/m³</td>
<td>0.33 USD/m³</td>
</tr>
<tr>
<td>WP of Rice paddy</td>
<td>0.50 kg/m³</td>
<td>0.10 USD/m³</td>
</tr>
</tbody>
</table>
Adoption and out scaling of Innovative Technologies:

* e.g., Conservation Agriculture

<table>
<thead>
<tr>
<th>Suitability class</th>
<th>Area (km²)</th>
<th>Population</th>
<th>Density</th>
</tr>
</thead>
<tbody>
<tr>
<td>Highly suitable</td>
<td>40,956</td>
<td>10,021,600</td>
<td>243</td>
</tr>
<tr>
<td>Medium suitable</td>
<td>28,870</td>
<td>5,081,674</td>
<td>174</td>
</tr>
<tr>
<td>Low suitable</td>
<td>24,083</td>
<td>2,929,224</td>
<td>122</td>
</tr>
<tr>
<td>Not suitable</td>
<td>576,076</td>
<td>9,471,688</td>
<td>16</td>
</tr>
</tbody>
</table>

- productivity
- employment
- enterprise
Measuring Impact of Successful interventions
Soil Salinity, Dujaila, Iraq

Salinity Maps

1958
- < 4 dS/m
- 4 - 8 dS/m
- 8 - 16 dS/m
- 16 - 32 dS/m
- > 32 dS/m

MoA, Iraq

Pre-Reclamation Period

Satellite Images

April 1984

April 2013

Post-Reclamation Period

Yield Increase
1.92 to 4.0 t/h
**Measuring Impact of Successful interventions**

**Soil Salinity, Dujaila, Iraq**

**Dujaila, Iraq**

**Pre-salinity reclamation period**

Landsat April 1984

- Saline or Abandoned Croplands
- Active or Healthy Farmlands

Average yield in saline lands for five major crops

1.92 t/h

which is about 52% less than non-saline lands
Average yield in non-saline lands for five major crops

4.0 t/h

which is about 52% more than saline lands
Irrigation Infrastructure and land reclamation
Agricultural Intensification and Expansion

Land Use Map 2004/05 (Pre-Project)

Irrigation Induced Salinity Control and Reclamation Project
(World Bank Report, Biradar et al., 2012)
Irrigation Infrastructure and land reclamation
Agricultural Intensification and Expansion

Land Use Map 2008/09 (Post-Project)

(World Bank Reports, Biradar et al., 2012)
Current: 0%
32 m tons

S-1 : 72% Gain
61 m tons

8% Gain
40 m tons

Biradar, et al., 2016*
Agricultural production systems heavily compromised sustainable food production and health of the lives and planet earth by neglecting climate smart crops (dryland cereals and legumes).

Integrated farming systems with better soil, water, trees, and livestock management for nutritious food and agro-ecosystems for a sustainable future.
in an inch of land and bunch of crop

Harvesting multiple gains
- genetic and breeding? 15-20
- management and agronomy? 50-60
- socio-economy and ecology? 20-35

avoid the unmanageable and manage the unavoidable

- IPCC Confronting Climate Change:

Thank You
c.biradar@cgiar.org