Role of geoinformatics in ensuing global food security with special reference to dryland agro-ecosystems

Chandrashekhar M. Biradar
International Center for Agricultural Research in Dry Areas (ICARDA), Amman, Jordan
c.biradar@cgair.org

Xiangming Xiao,
Department of Microbiology and Plant Biology, University of Oklahoma, Norman, USA
xiangming.xiao@ou.edu

William Payne
International Center for Agricultural Research in Dry Areas (ICARDA), Addis Ababa, Ethiopia
w.payne@cgiar.org

Prasanna H. Gowda
Conservation and Production Research Laboratory, USDA, Bushland, USA
Prasanna.Gowda@ARS.USDA.GOV

Abstract*—Agriculture plays an important role in providing food security in developing countries. Better agricultural information is one of the key factors in understanding current trends and status that determine food security from local to global scales. Open-access policies for sharing geospatial information and technology are becoming an integral part of solving the food security equation. Geospatial technologies (remote sensing, global positioning system and geographical information system) have progressed rapidly in the 21st century, and will keep expanding to provide powerful tools in almost every aspect of food security, including research, development and aid delivery programs, policy, and outreach. Recent advances in Geoinformatics have created new opportunities to apply to agro-ecosystems research. The International Center for Agricultural Research in Dry Areas (ICARDA) is one of the research centers of the Consultative Group on International Agricultural Research (CGIAR). ICARDA works closely with national agricultural research programs and partners worldwide to develop new technological solutions to improve dryland agriculture and productivity to provide food security while protecting fragile ecosystems in those countries. It also leads the CGIAR Research Program (CRP) on Dryland Systems, which targets the poor and highly vulnerable populations of the dry areas. The CRP on Dryland Systems aims to develop technology, policy, and institutional innovations to improve food security and livelihoods using an integrated systems approach. The proposed presentation highlights the role of the Geoinformatics in ensuring global food security with special references to dryland agro-ecosystems.

Keywords— Agriculture; Food security; Geoinformatics; Drylands; CGIAR CRP Dryland Systems

I. INTRODUCTION

With ever increasing human population and increased demand for food and industrial needs has put tremendous pressure on land resources. Dry areas of the developing world occupy about 41% of the Earth‘s land area, and are home to 2.5 billion people and 1.5 billion livestock while have limited natural resources and face serious environmental constraints that are likely to worsen as a result of climate change[1]. There is a definite need for an integrated approach for managing world's agricultural resources to improve the productivity level in a sustainable way while safeguarding the environment. Better agricultural data and information are key factors to understanding currents trends and status of agricultural resources, and to finding optimal approaches to achieve reduced vulnerability and sustainable intensification in developing countries that depend upon dryland production systems for food security and livelihoods. Therefore, an open access policy to geospatial information, technology, and sound knowledge sharing and management mechanisms are becoming an integral part of the food security equation. Geospatial technology (remote sensing, global positioning system and geographical information system) has progressed rapidly in the 21st century, and will keep expanding its role in almost each and every aspect of food security, including research, programs, policies, and outreach (Figure 1).

Enormous efforts are underway throughout the world to gather data and information on crops, rangeland, livestock and other related agricultural resources and their production mechanisms. However, in many instances, these are collected at very course resolution, ranging from several hundred meters to tens of kilometers. Such information or data are often used in many global and regional scale models to assess status or trends at the landscape level or even larger units. However, at these scales, such data may fail to reflect ground realities that are often very different from information or data collected at larger scales, and therefor fail to capture the complex nature of agro-ecosystems. This is especially so in the developing world, where landholdings are small, and production systems are highly diverse and complex. Complexity is associated with many factors, ranging from goods and services that are produced, soils, land scape position, water availability, elevation, aspect, localized weather events, poverty distribution, infrastructure, migration, local policies on land tenure, market access, conflict, etc.

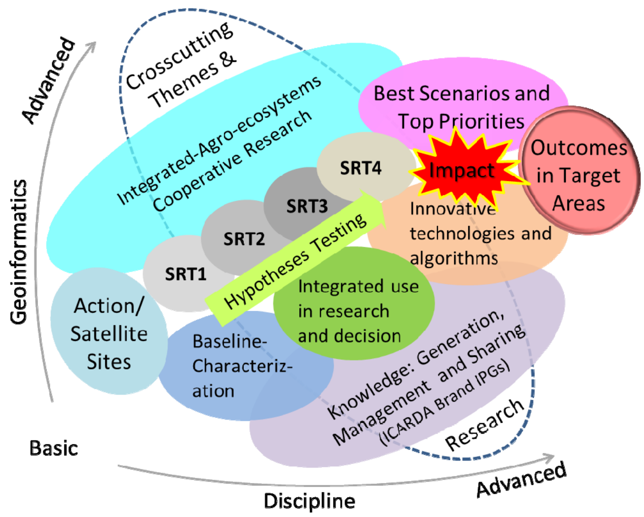

Fig. 1. Role of Geoinfotmatics in CGIAR Research Program- Dryland Systems (CRP-DS).

Systems approaches are increasingly used to manage more productive, stable, and environmentally sound agriculture production because they provide a methodology for addressing complex and interactive sets of issues that are increasingly 'information-driven'. Implementation and intervention of new management paradigms to ensure food security and improved livelihoods requires access to better information in space and time. Therefore, Geoinformatics must play an ever-increasing role.

II. ROLE OF GEOINFORMATICS

Geospatial science, technology and applications have become indispensable tools for modern day research, especially in natural resources and sustainable agro-ecosystem studies. The use of spatial data in agricultural research has recently proliferated due to: a) recent advances in satellite sensor technology, b) guaranteed availability of quality time-series data, c) open (free) access to high quality satellite sensor images, d) advances in processing and handling of large amounts of data, e) rapid increase in computational power, processing chain and storage/archiving mechanisms, f) decreases in cost of proprietary software, and g) ease and increasing expertise in handling these complex datasets.

Over the last 5 years, there has also been increased release of high quality datasets into the public domain, resulting in greater use of spatial data and the development of machine learning algorithms for thematic research. This trend is likely to increase in coming years and has ushered in a new era of 'open access.'

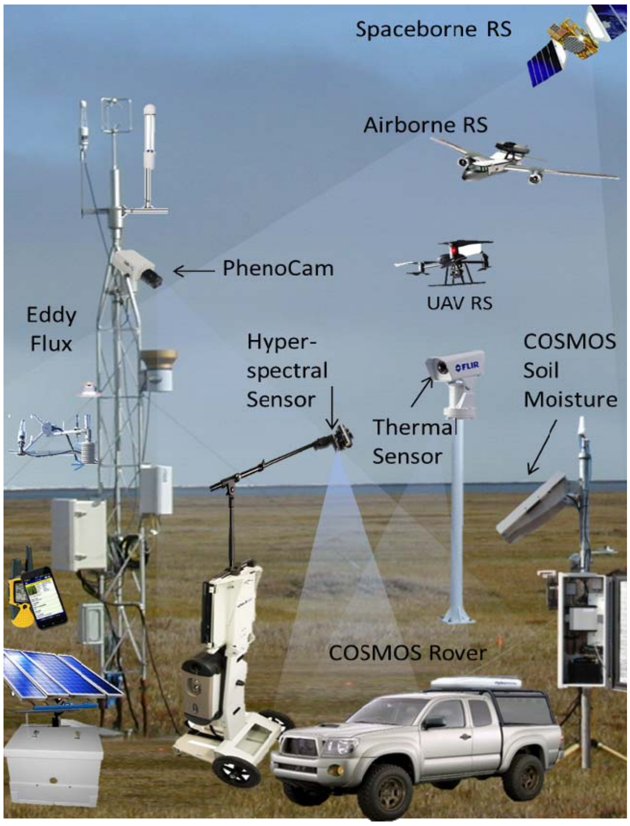

Fig. 2. An example of a modern remote sensing observation platform to study the dynamic of water, carbon and energy fluxes in the agro-ecosystems.

A. *Increased resolution*

The recent development of advanced sensor technology (e.g., specific bands, red-edge, yellow bands), platforms (e.g., spaceborne, airborne, UAVs), satellite constellation (e.g., increased orbital speed (WorldView2), multiple-clone satellites (RapidEye), onboard capacity and grounding stations, etc. has opened another new era--that of remote sensing applications. Just 3 years ago, it was a dream to get very high resolution images on a daily basis. Today, one can get satellite imagery on a near-real time basis at sub-meter (<60cm) each day for any given location. The quality and details of the imagery and therefore of the inherent information has increased dramatically. Simultaneously, software companies and open-access platforms are developing necessary calibration and processing tools to make such information easily available to a range of end-users.

B. *Improved processing*

Armed with increased computational power and speed for faster image processing, better GIS infrastructure, and a host of tools including new algorithms for modeling, the geoinformatics community can now study and characterize agricultural production systems at scales ranging from the field to the globe. One of the primary objectives of the CRP on Dryland Systems is to develop detailed, baseline databases for different "action sites" to characterize and understand the current status and extent of different production systems in terms of land use and land cover types, as well as various processes such as land degradation, water use, etc.. These databases will allow researchers and stakeholders to track the progress and assess impact of various program interventions. For example, the capability to identifying different land management units or production systems through their associated spectral properties is a major step forward in our ability to classify and monitor dryland systems.

Ameliorated computational storage, processing power, and automated machine learning algorithms have been playing a greater role in enhancing pixel-based image analysis of high resolution data acquired over complex and highly variable agro-ecosystems. To be sure, there are still certain limitations associated with time-variant identical spectral characteristics among different land use and land cover types. However, the combined use of higher spatial, spectral and temporal resolution images has enabled us to produce better thematic maps with higher classification accuracy.

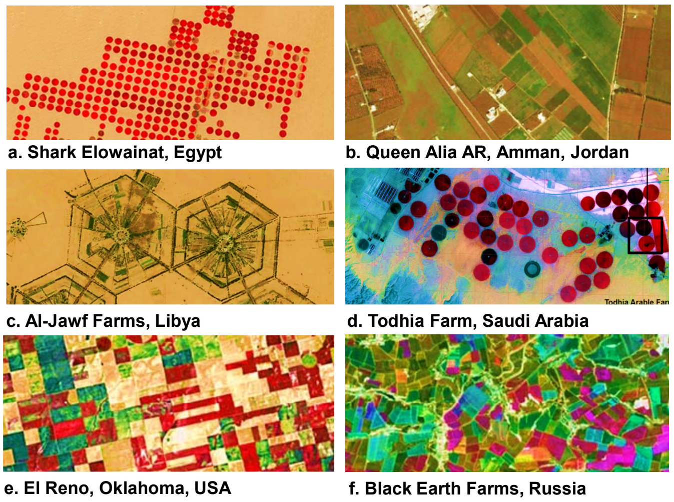

Fig. 3. The diversity of agro-ecosystems in dry areas observed from the space (sources: earthasart.gsfc.nasa.gov, Google)

C. Decreased cost of operations

In the past, operational cost of Geoinformatics was one of the major bottle necks in adopting the technology to a wide array of applications. A major portion of the cost used to be associated with satellite image acquisitions, followed by the cyber infrastructure for processing and handling the satellite data, and high prices of major software packages and expertise. However, such overhead costs have been declining in the last few years due to increased open access to data, open source program and algorithms, decreased cost of the mass storage and increased computational efficiency.

The drastic reduction in the operational costs have led researchers to use geoinformatics tools and technology across wide areas of application in agricultural research starting from molecular level research to landscape level assessment in ensuring food and environmental security.

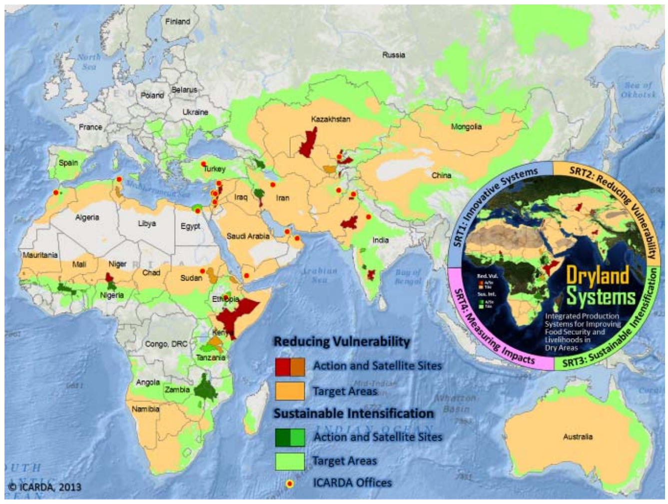

Fig. 4. Action sites, satellites sites and targets areas of the CRP Dryland System.

III. DRYLAND AGRO-ECOSYSTEMS

Dryland agro-ecosystems are areas where precipitation tends to be low and erratic, and often water supply is the most limiting factor for profitable agricultural production[2]. They are characterized by persistent water scarcity, extreme climatic variability, high susceptibility to land degradation, including desertification, and loss of natural resources, including biodiversity, at elevated rates.

Dryland agro-ecosystems, as name implies, consist of combinations of plant and animal species and management practices selected by farmers to pursue livelihood goals that are based on several factors, including climate, soils, markets, capital, and tradition. The CRP on Dryland Systems[1] led by ICARDA is therefore about developing an integrated approach to enhancing food security and improving livelihoods. To do so it must rely on innovative tools and technology in conjunction with traditional knowledge to mitigate risk and increase overall productivity. The CRP on Dryland Systems works through four Strategic Research Themes (SRTs)[2]:

SRT1: Innovative Systems

The core value of innovative systems is the synergies they achieve to enhance adoption rate of technologies and management practices through greater interaction of stakeholders and researchers.

SRT2: Reducing vulnerability

Dryland ago-systems are prone to high risk and vulnerability due to several associated factors such as climate, soils, lack of capital, poorly developed markets, demographic challenges, and ever-increasing pressure on the land[2]. These systems are characterized by complex combinations and high diversity in terms of agronomic practices, cropping patterns and intensity, water use, rangeland, trees, livestock, fish, land holding size, etc. Because of their complexity and diversity, it is necessary to characterize these systems at very high spatial resolutions to understand the risk and vulnerability factors.

Mapping present, emerging, and future land use trends will better allow researchers to diagnose vulnerabilities and intervene to improve livelihoods by taking into account such factors as land cover dynamics, cropping pattern and intensities, water use and availability, changing demographics, infrastructure, poverty, markets, climate change, etc. Information generated in the preliminary analysis will be used to assess vulnerable areas for possible pathways to increased resilience and mitigation of risks whether biophysical (e.g., land degradation and drought) or socioeconomic (e.g., price shocks, or policy changes in land tenure).

TABLE I. FEW EXAMPLES OF THE POTENTIAL (NOT LIMITED TO) SATELLITE REMOTE SENSING IMAGERY FOR AGRO-ECOSYSTEM STUDY AT LOCAL TO GLOBAL SCALE (UPSCALING FROM ACTIONS SITES TO TARGET AREAS)

Satellite Sensors	**Spatial Resolution and Cost**		
	Pixel size (m)	***Pixels/ha***	***Cost ($/km^2)***
AVHRR	1000-8000	0.01-0.064	Free
SPOT-Veg.	1000	0.01	Free
MODIS	250-500	0.02-0.04	Free
Landsat	30	11.1	Free
PALSAR	10	100	Free
AWiFS	60	2.7	0.01
Liss3	23.5	18.1	0.15
Aster	15	44.4	0.04
Liss4	5	400	1.19
RapidEye	5	400	1.23
IKONOS	4	625	5.02
Cartosat1	2.5	1600	6.59
GeoEye1	2	2500	12.5
WorldView2	2	2500	14.5

a. Cost of the imagery is calculated based on the various sources and independent quotations please use it with caution and authors are not responsible.

b. Spatial resolution of multi-spectral bands only, although panchromatic resolution will be much higher

SRT3: Sustainable intensification

Based on perceived opportunities in dryland systems with potential for greater productivity, the SRT on sustainable intensification addresses priorities for more productive, profitable and diversified dryland agriculture with well-established linkages to markets. Major components of this SRT are to map the extent and patterns of existing and traditional practices, indigenous knowledge, diversity of the agro-ecosystems, and potential areas for more productive, profitable and diversified production systems, including improved linkages to value chains and markets. The high resolution spatial database in combination with *in-situ* data (e.g., field plots), stakeholder feedback (e.g., needs and constraints) and expert level attributes (e.g., wisdom) will be analyzed in the GIS domain to delineate the potential and suitable areas for sustainable intensification and diversification of the agricultural production systems.

SRT4: Anticipating and measuring impacts and cross-regional synthesis.

SRT4 includes a system-analysis platform to identify key indicators of best scenarios and top priorities based on biophysical and socioeconomic feedback to assess progress towards impacts. Outputs and outcomes measured at spatial scales will be analyzed across dryland systems (cross-regional synthesis) and across-CRPs to understand the rate and magnitude of impacts, and to identify the synergies and gaps (e.g., hot spot of good and bad impacts). The SRT also places emphasis on characterization and modeling to synthesize knowledge and provide a basis for scaling up and scaling out of successful innovations from various action sites. It also includes a mechanism for communication, and knowledge-sharing mechanism. Geoinformatics offer several powerful tools for characterization, modeling, and communication of knowledge for different scales.

IV. CONCLUSION

Recent advances in geoinformatics' tools and technologies have opened a new era for mapping and managing agricultural production systems and associated natural resources. Today, it is possible to dramatically better map and characterizes dryland production systems through of a) enhanced availability of very high resolution, remotely sensed data at reduced cost, b) increased institutional adoption of open-access data policy, and c) freely available geospatial data with spectral, spatial, and temporal attributes at medium to coarse resolutions. These allow better access to the knowledge needed by researchers, policy makers, and other stakeholders to improve food security and livelihoods across the developing world. The CRP on Dryland Systems is using these tools and technologies to move from mapping basic land units to quantitative description of the various components needed to improve overall system sustainability and productivity, and to develop and monitor key indicators across a range of cross-cutting themes needed to improve food security and livelihoods in dry areas of the world.

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