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USGS John Wesley Powell Center
Working Group on Global Croplands and Water Use for Food Security in the 21st Century
An international science networking initiative

(http://powellcenter.usgs.gov/globalcroplandwater)

Working Group on Global Croplands and Water Use for Food Security in the Twenty-first Century

http://powellcenter.usgs.gov/current_projects.php#GlobalCroplandsAbstract

USGS WORKING GROUP on GLOBAL CROPLANDS:

http://powellcenter.usgs.gov/globalcroplandwater

In 2011, The U.S. Geological Survey's (USGS) Powell Center funded an international Working Group on Global Croplands (WGGC) to create a knowledge warehouse to facilitate global food security in the twenty-first century by identifying and making available an advanced geospatial information system on croplands and their water use.

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WORKING GROUP GOAL

The overarching goal of the U. S. Geological Survey's Working Group on Global Croplands is to create a warehouse of data, products, approaches, methods, algorithms, models, and maps pertaining to global croplands and their water use that contributes to global food security in the twenty-first century. Initially the WGGC has been funded by the USGS John Wesley Powell Center for a 3 year period starting June 2011. However, WGGC has a long term vision to continue research and outreach activities in this area by seeking internal and external funding.

Food Security
Causes of Increasing Threat

- Expanding urbanization and industrialization displacing croplands;
- Converting agriculture to non-food crops (e.g., bio-fuels)
- Deteriorating land and water quality (e.g., salinization, pollution);
- Changing climate patterns (e.g., droughts, floods)

RESEARCH QUESTIONS

We will focus on 18 crops that occupy 85% of global croplands (Table 1) to inform the following questions:

1. Where are these 18 key crop types currently grown and how is their area and spatial distribution changing?
2. How much water is used for production of each of these 18 crops by region and how is that water use changing over time and space?
3. What is the relationship between agricultural water use (blue and green) and water scarcity and how is that changing over time and space?
4. Where are food security problem areas?
5. What are the links between crop production, water use and food security?
6. What are the key priorities for improving food security?

For each objective, we will:

(a) Establish the current state of knowledge;
(b) Synthesize the evidence and present the findings;
(c) Determine uncertainties in the quantitative assessment;
(d) Establish how remote sensing "adds value" to quantifying each objective;
(e) Discuss the key drivers that can impact the quantitative assessment;
(f) Relate to "synthesizing existing evidence" rather than undertaking new research.

Table 1. Area and relative proportion of the 18 major crop characteristics. (Monfreda and others, 2008)

Crop	Area (1000km^3)	Relative Fraction (%)
Wheat	4,028	22
Maize	2,271	13
Rice	1,956	11
Barley	1,580	9
Soybeans	927	5
Pulses	794	4
Cotton	534	3
Pototoes	501	3
Sorghum	501	3
Millet	331	2
Sunflower	290	2
Rye	288	2
Rapeseed/Canola	283	2
Sugar cane	265	1
Groundnuts/peanuts	247	1
Cassava	235	1
Sugar beets	154	1
Oil palm fruit	72	less than 1
Total major 18 crops	15,256	85
Others	2,664	15

APPROACH to RESEARCH

We will define a set of best practices that will lead to development of a remote sensing based advanced geospatial information system (RS/GIS) on croplands and their water use. Such a system will be global and consistent across nations and regions. The RS/GIS will provide information on on cropland extent/area as well as many other characteristics such as: (a) crop types; (b) precise location of crops; (c) cropping intensities (e.g., single crop, double crop); (d) cropping calendars; (e) crop health/vigor; (f) watering methods (e.g., irrigated, supplemental irrigated, rainfed); (g) flood and drought information; (h) water use assessments; and (g) yield or productivity (expressed per unit of land and/or unit of water). Opportunities to set-up such a global system are best achieved using fusion of advanced remote sensing (e.g., Landsat, Resourcesat, MODIS) in combination with national statistics, ancillary data (e.g., elevation,precipitation), and field-plot data.

Such a system, at the global level, will require coordination between multiple agencies leading to the development of a seamless, scalable database and repeatable methodology.

GLOBAL FOOD SECURITY SCENARIO

The global population has just topped the 7 billion mark and will be over 9 billion by 2050, a stark reminder that food security is the greatest threat facing humanity in the 21st Century. Society faces real challenges ahead, particularly in managing water and food supplies, as well as energy production. These issues are intimately connected with achieving global food security. By the year 2050, the world will need 70% more food and energy and 60% more fresh water. So how can we feed a burgeoning global population in a way that is both equitable and environmentally sustainable? In practical terms our future will be influenced by a mix of population growth and socioeconomic development, complicated by the need to produce more food with fewer resources.

Part of the answer lies in understanding global croplands, both rainfed and irrigated, their geography and how they can be better managed, particularly since croplands

account for nearly 80% of all freshwater extractions. There is a need to identify regions where there is scope for improving cropland water productivity to reduce the 'yield gap' – the difference between potential and actual yield – a widespread problem constraining food production in both the developed and developing world. There is also a need to understand better the links between food production and water scarcity, and the impacts that climate change might have on global croplands. Technologies such as remote sensing will play an increasingly critical role, providing new spatial information to help manage croplands in a more productive and sustainable way.

Data acquired from spaceborne remote sensing sensors is ideal for creating a complex agricultural monitoring system that is globally consistent, repeatable, and scalable. The specific remote sensing advances (Thenkabail and others, 2010) enabling global cropland mapping and the resulting statistics rely on factors such as: (a) free access to well calibrated and guaranteed data such as Landsat and MODIS; (b) frequent temporal coverage of data such as MODIS backed by high resolution Landsat data; (c) free access to high quality secondary data such as long-term precipitation, evapotranspiration, surface temperature, soils, and Global Digital Elevation Model (GDEM); (d) global coverage of the data; (e) web-access to data and faster download; (f) advances in computer technology; and (g) advances in processing.

Opportunities to set-up such a global system are best achieved using fusion of advanced Earth Observing (EO) data from multiple remote sensing platforms (e.g., Landsat, IRS Resourcesat, SPOT, MODIS, and NPOESS VIIRS; active and passive microwave systems such as TRMM, AMSR-E, ALOS PALSAR, RADARSAT and ENVISAT ASAR; thermal infrared imagers; and commercial data from systems such as IKONOS, Quickbird, GEOEYE, Rapideye) in combination with national statistics, ancillary data (e.g., elevation, precipitation, temperature, soils), and systematic collection of field-plot data. Such a system, at a global level, will be complex in data handling and processing and require coordination between multiple agencies leading to development of a seamless, scalable, and repeatable methodology. The availability of global remote sensing pathfinder and\or time-series datasets allows us to develop a cropland history of the world going back to 1970s. The sources of these datasets include AVHRR GIMMS (1981-2006), MODIS time-series (2000-present), and Landsat Global Land Survey (GLS) nominal 30 m mosaics for 1970s, 1980s, 1990s, 2000s, 2005s, and 2010s.

REMOTE SENSING of GLOBAL CROPLANDS, CROP TYPES, WATERING SOURCE

The first focus of the WGGC is to build a global agricultural monitoring system. Currently, there are about 1.5 billion hectares of global croplands (Figure 1). Of this, approximately 1.1 billion are rainfed croplands and 400 million are irrigated croplands (Thenkabail and others, 2009 a,b). There are uncertainties in current cropland estimates due to variations in the definitions used in mapping, coarse resolution imagery that fails to pick fragments of croplands, uncertainties in sub-pixel estimates of areas, lack of coordinated and systematic global ground data collection and dissemination system as well as a host of other issues. Figure 1 illustrates the global distribution of the 5 dominant crops (wheat, rice, maize, barley and soybeans) of the world (Ramankutty and others, 2008, Monfreda and others, 2008). This remote sensing derived global irrigated and rainfed cropland area map was produced by the International Water Management Institute (IWMI; Thenkabail and others, 2011, 2009 a, b).

Global Agricultural Monitoring System Importance, Need, and Scope

Effective monitoring requires:
(a) Rapid and repeatable mapping of croplands (e.g., year after year, season after season);
(b) An automated algorithm;
(c) An accurate knowledge layer of croplands to calibrate the algorithm and produce desired accuracy.

Current cropland mapping is both tedious and inaccurate over regional scales. There is a critical need for advanced methods (e.g., automated algorithms) and approaches (e.g., multiple remote sensing data fusion).
Accurate cropland mapping using advanced remote sensing enables:
(a) Frequent (e.g., yearly, seasonal) update of agricultural statistics;
(b) Consistent regional mapping; and
(c) A spatial and temporal view of croplands distribution and changes.

LINKING GLOBAL CROPLANDS AND THEIR WATER USE

Humans use about 4000 km^3/yr of freshwater of which about 70% goes for agriculture to produce food (World's Water Volume 7 by Gleick, 2011). Just 4 countries use 52% of this 70%: India 684 km^3/yr, China 364 km^3/yr, USA 197 km^3/yr, and Pakistan 172 km^3/yr. However, estimates by other researchers, as discussed in detail by Thenkabail and others (2010), show that the total water use by global croplands varies between 6,685 to 7,500 km^3 with 4,586 km^3/yr utilized by rainfed croplands (green water use) and the rest (2099 km^3/yr) by irrigated croplands (blue water use). Water withdrawn for irrigation is often wasted, with only 30 to 50% of withdrawn water actually being utilized in the overwhelming proportion of global croplands. A lack of consistency in measuring and mapping cropland area, crop type, cropping intensity, and water use by crops (in different geographic locations to produce a unit of food) is a major challange to efficient evaluation. The global croplands working group will look into this issue. Assessment of croplands (Figure 1) will help us determine the blue and green water use (Figure 2). Blue water is typically associated with crop production under irrigated conditions and the water is withdrawn from lakes, reservoirs, rivers, ice caps, and ground-water (saturated zone). Green water is typically associated with crop production under rainfed conditions and constitutes the bulk (70%) of water used by croplands. This is the water in the soil moisture, available in the unsaturated zone, readily available for consumptive use by crops. The blue and green water metaphor has enhanced policy discussion regarding water scarcity and food security.

Blue water use (agricultural context): water used by irrigated areas coming from reservoirs, lakes, rivers, and deep aquifers. Also, rain falling directly on irrigated croplands.

Green water use (agricultural context): water used by rainfed croplands from direct rain falling on croplands and water available as soil moisture in the unsaturated zones of the soils.

REMOTE SENSING of GLOBAL CROPLAND WATER USE

The second main focus of the WGGC is to advance our understanding of the fate of water used to produce crops. Water applied to crops either soaks into the soil, evaporates at the surface, or is taken up by the vegetation and then transpired. Evapotranspiration (ET) is the name given to water that is evaporated or transpired. ET is routinely measured in the field to provide information on water use efficiencies.

In the past decade or so, new ground and remote sensing tools have dramatically

increased our ability to measure ET at the plot scale and to scale it over larger regions. Moisture flux towers and micrometeorological stations have been deployed in numerous natural and agricultural biomes and provide continuous ET measurements. These measurements can be scaled to larger landscape units using remotely-sensed vegetation indices (VIs), Land Surface Temperature (LST), and other satellite data. However, the errors in predicting ET over wide areas by coupling satellite data with flux tower measurements need to be reduced for regional ET estimates to be useful for global agriculture assessments. The high fidelity between ET and VIs over agricultural fields and natural ecosystems where precise ground estimates of ET are available suggests that this might be an achievable goal if ground methods for measuring ET continue to improve. Accurate regional ET estimates are important, given that ET is the second largest term in the terrestrial water budget after precipitation. Over 75% of terrestrial ET is due to transpiration by plants and ET is expected to increase with global warming. Remote sensing is the only feasible means for projecting ET over large landscape. Numerous remote sensing methods for estimating ET have been developed. Some methods are based on thermal band measurements, which estimate sensible heat flux then calculate the latent heat of evaporation due to ET as a residual in the surface energy balance equation. These include the related Surface Energy Balance Algorithm for Land (SEBAL, Baastiaanssen and others, 1998) and the Mapping Evapotranspiration at High Resolution with Internalized Calibration (METRIC) models, described in Allen and others (2011), and the Surface Energy Balance System (SEBS) (Su, 2002). Other methods are based on vegetation indices, which estimate the amount of green leaf area available to carry out ET (Glenn and others, 2011). Other methods combine the two approaches, as in the dual-source models (e.g., Kustas and Anderson, 2009).

Non-intrusive methods of measuring ET of Agricultural Croplands

- Eddy covariance flux towers (over 500 networked in worldwide FluxNet)
- Bowen ratio flux towers
- Sap flow sensors
- New satellites and sensor systems
- Operational remote sensing methods for ET in near-real time at local, regional and global scales of measurement (SEBAL, METRIC, SEBS)
- Automated Micrometeorological stations deployed in irrigation districts worldwide

Applications

- Irrigation scheduling
- Water conservation projects
- Natural resource management
- Basin-wide water budgets
- Climate change projections

THE WAY FORWARD

Remote sensing will play an important role in our ability to analyze global food security concerns and will require the development of an integrated system of cropland classification, characterization, and water use assessments. The components of such a system will include: a) fusing data from multiple satellites sensors (e.g., http://wgiss.ceos.org/lsip/satellites_midres1.shtml; http://www.ceos-cove.org/index.php); b) building mega file data cubes (MFDCs) that will harmonize, standardize, and integrate data from multiple satellite sensor systems enabling a seamless databank for analysis (Thenkabail and others, 2011); c) developing automated cropland classification algorithms for rapid, consistent, and accurate cropland mapping and generating their statistics; d) modeling crop productivity (e.g., biomass, yield), and water productivity ("crop per drop") of irrigated and rainfed crops; e) modeling crop water use by irrigated crops (blue water use) and rainfed crops (green water use); f) defining crop characteristics for establishing common mapping protocols; g) establishing a globally consistent field data collection and dissemination mechanism; h) producing a wide array of cropland products (models and maps) such as cropland extent, crop types, watering method (e.g., irrigated, rainfed, supplemental), cropping intensities (e.g., single, double, triple, continuous crops), and crop productivities (e.g., yield, biomass); and i) disseminating the global cropland products and statistics through web and data portals.

Figure 1. Spatial distribution of global cropland areas of about 1.5 billion hectares along with 5 dominant crops which occupy 60% of this area.

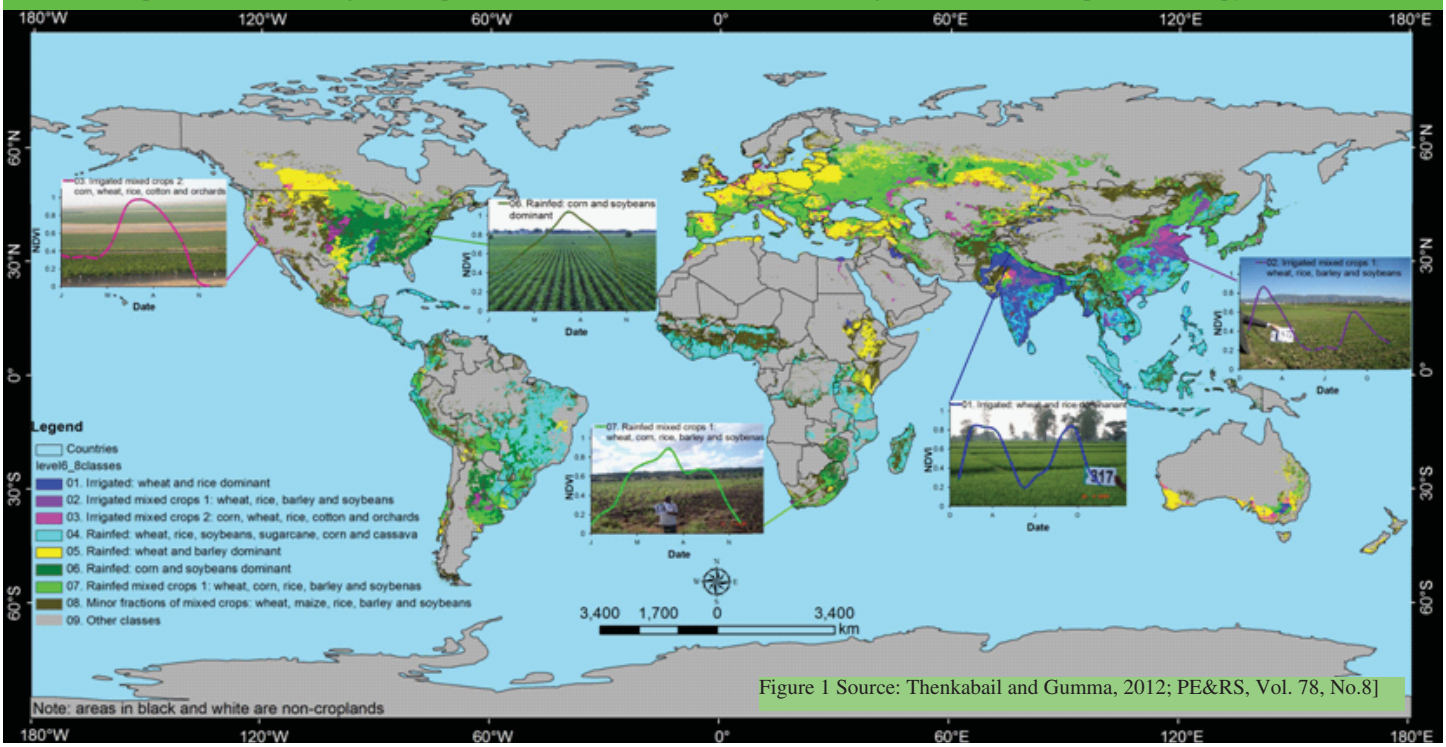

Figure 1 Source: Thenkabail and Gumma, 2012; PE&RS, Vol. 78, No.8]

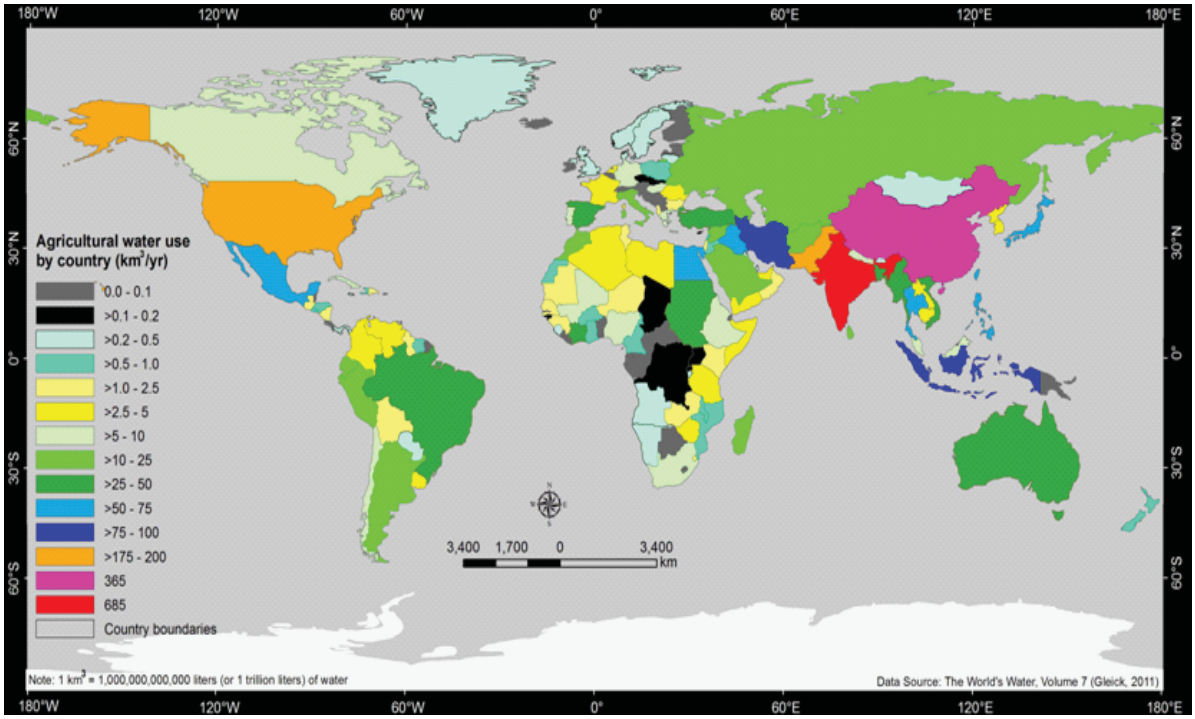

Figure 2. Country by country agricultural crop water use in km^3/yr. In India, China, and Pakistan as a result of double and triple cropping that are irrigated, the water use is dominated by irrigated croplands (blue water use). In USA, the water use is dominated by rainfed croplands (green water use). [Source: Thenkabail and Gumma, 2012; PE&RS, Vol. 78, No.8]

OUTPUTS (achieved, ongoing, expected) of the USGS POWELL CENTER WGGC

1. Create a web-based "knowledge warehouse of data and products" on global croplands and their water use contributing to global food security. Example:
http://powellcenter.usgs.gov/globalcroplandwater
2. Facilitate a system for sharing algorithms, models, and maps on global croplands and their water use contributing to global food security and allowing for model intercomparisons. Example: Automated Cropland Classification Algorithm:
www.sciencebase.gov/catalog/folder/4f79f1b7e4b0009bd827f548
3. Produce peer-review articles\special issues\ books on global croplands and their water use contributing to global food security. Example: PE&RS Special Issue on Global Croplands, August,2012 Issue (Vol. 78, No. 8).
4. Conduct outreach and dissemination (e.g., fact sheets, journal papers).

References

Allen, R.A and others, 2011. Satellite-based ET estimation in agriculture using SEBAL and METRIC. Hydro. Processes 25, 4011-4027.

Bastiaanssen, W.G.M. and others, 1998. A remote sensing surface energy balance algorithm for land (SEBAL). 1. Formulation. Journal of Hydrology. Vol. 212-213: 198-212.

Gleick, P. H., 2011. The World's Water Volume 7: The Biennial Report on Freshwater Resources. ISBN: 9781597269995. Island Press, Washington D.C.

Glenn, E. and others, 2011. Vegetation-Index-based crop coefficients to estimate evapotranspiration by remote sensing in agricultural and natural ecosystems. Special Issue: Remote Sensing of Hydrology, the science of Evapotranspiration (Eds. P Nagler and others). Hydrological Processes: (25) 4050–4062.

Gumma, M. and others, 2010. Mapping rice areas in South Asia. Rice Today. July-September, 2010. Pp. 42-43.

Kustas, W., and M. Anderson, 2009. Advances in thermal infrared remote sensing for land surface modeling. Agr. Forest Meteorol. 149: 2071-2081

Monfreda and others, 2008. Farming the planet: 2. Geographic distribution of crop areas, yields, physiological types, and net primary production in the year 2000, Global Biogeochem. Cycles, 22(1): GB1022.

Ramankutty and others, 2008. Farming the planet: 1. Geographic distribution of global agricultural lands in the year 2000, Global Biogeochem. Cycles, 22(1): GB1003.

Su, Z., 2002. The Surface Energy Balance System (SEBS) for estimation of turbulent heat fluxes. Hydrol. Earth Syst. Sci., 6 (1) (2002), pp. 85–99.

Thenkabail P.S. and Gumma, 2012. Assessing future risks to agricultural productivity, water resources and food security: how can remote sensing help?. Photogrammetric Engineering and Remote Sensing, PE&RS, 78(8), August 2012 special issue on global croplands.

Thenkabail, P.S. and others, 2011. Global Croplands and Their Water Use Remote Sensing and Non-Remote Sensing Perspectives. In "Advances in Environmental Remote Sensing: Sensors, Algorithms, and Applications". Taylor and Francis Edited by Dr. Qihao Weng. Pp. 383-419.

Thenkabail P.S. and others, 2010. A Holistic View of Global Croplands and Their Water Use for Ensuring Global Food Security in the 21st Century through Advanced Remote Sensing and Non-remote Sensing Approaches. Remote Sensing open access journal. 2(1):211-261. doi:10.3390/rs2010211. http://www.mdpi.com/2072-4292/2/1/211.

Thenkabail. P. S. and others, 2009a. Book entitled: "Remote Sensing of Global Croplands for Food Security" (CRC Press- Taylor and Francis group, Boca Raton, London, New York. Pp. 556 (48 pages in color). Published in June, 2009.

Thenkabail, P.S. and others, 2009b. Global irrigated area map (GIAM), derived from remote sensing, for the end of the last millennium. International Journal of Remote Sensing. 30(14): 3679-3733. July, 20, 2009.

GLOBAL CROPLANDS AND THEIR WATER USE - WEB RESOURCES:

http://www.iwmigiam.org
http://www.geog.mcgill.ca/~nramankutty/Datasets/Datasets.html
http://www.sage.wisc.edu/mapsdatamodels.html
http://www.fao.org/nr/water/aquastat/irrigationmap/index.stm
http://www.nass.usda.gov/research/Cropland/SARS1a.htm
http://www.pecad.fas.usda.gov/cropexplorer/datasources.cfm
http://www.geo.uni-frankfurt.de/ipg/ag/dl/forschung/MIRCA/index.html
http://www.geo.uni-frankfurt.de/ipg/ag/dl/forschung/GCWM/index.html
http://gcmd.nasa.gov/records/GCMD_SAGE_MAJORCROPS.html
http://www.mdpi.com/journal/remotesensing/special_issues/croplands/
http://www.earthobservations.org/cop_ag_gams.shtml
http://powellcenter.usgs.gov/current_projects.php#GlobalCroplandsAbstract
http://sharaku.eorc.jaxa.jp/GSMaP/index.htm
http://kuroshio.eorc.jaxa.jp/JASMES/index.html

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