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Impacts on Human Health and Safety of Naturally Occurring and Supplemental Hormones in Food Animals

Economic Impacts of COVID19 on Food and Agricultural Markets

Stewardship Challenges for New Pest Management Technologies in Agriculture

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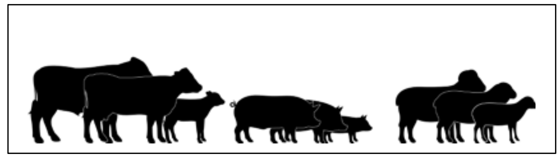
The Borlaug CAST Communication Award recognizes professionals actively working in the agricultural, environmental, or food sectors who are promoting agricultural science in the public policy arena. **The 2020 award goes to Alexa Lamm**, Associate Professor of Science Communication at the University of Georgia. As a leader in the field of social science research, Lamm exemplifies the skills, dedication, and success this award is designed to recognize.

CAST Commentary QTA 2020-4
July 2020
Material excerpted from original CAST document

Impacts on Human Health and Safety of Naturally Occurring and Supplemental Hormones in Food Animals



The use of growth enhancing technologies (GETs) has improved the quality of meat products by repartitioning fat into muscle mass and reducing fat content of meat products. There are six GETs approved by the Food and Drug Administration (FDA) in the United States and 30 other countries for use in beef animals. Three of these are naturally occurring (testosterone, estrogen, and progesterone) and three are synthetic—melengestrol acetate, trenbolone acetate, and zeranol. In addition, bovine somatotropin is approved for use in lactating dairy cows to increase yield of milk. Oxytocin, gonadotropin hormone releasing hormone, prostaglandins, and gonadotropins are approved for use in improving reproductive performance of domestic animals.

- All of these compounds have undergone rigorous testing for human and animal safety under guidance of the FDA Center for Veterinary Medicine.

Hormones produced by animals that are involved in regulation of growth, reproduction, and other biological functions are present throughout the body and are found naturally in meat, milk, and eggs.

- In general, the amounts of naturally occurring hormones in milk and dairy products are significantly lower than production of the same hormones by humans.
- The FDA guidelines state that no physiologic effects could be expected when consumption is ≤1% of the endogenous quantities produced by the segment of the population with the lowest daily production.
- No hormonal products are or have been approved or used for poultry production, therefore no exogenous hormonal residues exist in eggs.

Steroids, gonadotropin hormone releasing hormone, gonadotropins, luteinizing hormone, follicle stimulating hormone, prostaglandins, and oxytocin have approval for use in cattle, sows, and ewes for estrus and breeding management according to label directions.

- There is an inherent interval of days to months between use of the hormonal product and harvest for human food. For milk, there is no inherent interval between use of the products and milk consumption.

In the United States, livestock producers have used various types of GETs such as steroidal implants to improve carcass leanness, increase average daily gain, alter dry matter intake, and produce heavier weight and leaner animals when harvested at equal duration of days on feed.

- The most common and widely used type of GET are steroidal implants with anabolic activity that are used for beef cattle.
- Beta-adrenergic agonists are delivered through feed. These compounds are approved as growth regulators in cattle, swine, and turkey, and are fed during the last 7 to 42 days prior to harvest depending upon the species.
- Melengestrol acetate is used in finishing heifers as a means to combat estrous cyclicity and is also used in female breeding synchronization programs.
- Gonadotropin releasing hormone antagonist is used in beef and pork production around the world as an alternative to castration.

Perhaps the most recognized hormone used in dairy management is bST, which is naturally produced by the pituitary gland to regulate growth and lactation.

- The FDA reported that there is no legal basis requiring the labeling of milk from cows that were supplemented with rbST since the milk is indistinguishable from milk from cows not supplemented with bST.
- The FDA, WHO, and National Institutes of Health have independently stated that dairy products from rbST-treated cows are safe for human consumption.

Hormone and hormone-like products used for livestock production are regulated in the United States by the FDA.

- Data on residues of xenobiotic hormones are used to establish a no observed effect level (NOEL) which is accepted as the no observed adverse effect level (NOAEL). A safety factor is applied to the NOEL to obtain an allowable daily intake. A safety factor of 100 fold is used unless a product is believed to have potential to be a carcinogen, which uses a SF of 1,000 or greater.

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Ag quick CAST
CAST Commentary 2020-3
June 2020
Material excerpted from original CAST document

Economic Impacts of COVID-19 on Food and Agricultural Markets

The challenge is to restore as much economic activity as possible while maintaining some measure of control and mitigation of the novel coronavirus. Federal economic policy will have to shift from sending families money to maintain social distancing to helping businesses maintain employment.

The World Trade Organization gives three scenarios for recovery: V-shaped, U-shaped, and L-shaped. Relative to the pre-pandemic baseline, real global GDP is forecast to decline in 2020 by -4.8%, 9.2%, and -11.1%, respectively. Forecast rates of recovery in 2021 are 4.2%, 8.1%, and 2.8%, respectively.

COVID-19 created an environment where there was a significant supply chain shift of food consumption. This demand shock and supply inflexibility created stress in the supply chain. Manufacturers adjusted variety to enable higher demand items to be produced in larger volumes. Hoarding behavior can result if large groups of consumers face similar information or face similar incentives. Consumers may have reasonability anticipated reduced mobility, leading consumers to "move forward" buying behavior and fill pantries. Moreover, if consumers anticipate higher prices or limited availability in the future, they have an incentive to buy more today.

Arguably, the most dramatic effect of the COVID-19 pandemic has been the near-complete loss of an entire distribution channel for food producers, and shippers tend to commit to either the food service or the retail channel. COVID-19 has seemingly impacted every stage in the meat supply chain. Initial shocks mainly corresponded with stay-at-home-order-induced changes in meat product flow, including large declines in food service activity and swift swings toward grocery stores as the predominant venue for meat and poultry purchases. COVID-19 has already created major disruptions in the forestry and wood products sector. COVID-19-related problems have originated from aggregate demand collapses in the manufacturing sector (wood using mills).

COVID-19 has led consumers to become increasingly interested in producing their own food, leading to stock-outs of backyard chickens and garden supplies. As food consumption shifted to home-cooked meals, some local food producers also experienced a boom in sales.

At least four factors could affect consumer food waste during the pandemic: (1) stockpiling behavior, (2) management of food stocks, (3) negative income shocks, and (4) rising food prices. Demand from large institutional buyers has fallen; producers have dumped 3.7 million gallons of milk and destroyed more than 107,000 eggs daily during the pandemic. The COVID-19 pandemic has drawn attention to the problem of food insecurity in the United States. Feeding America projects that there will be more than 54 million food insecure Americans in 2020. This is approximately 17 million higher than in 2018. For children, the food insecurity rates are projected to increase to 18 million, up nearly 7 million from 2018.

The impacts of the massive demand shock associated with the COVID-19 pandemic on crop markets looks to continue over the next couple of years. Implications for major field crops tend toward growing global ending stock levels, lower prices, and tighter margins. FAPRI estimates a decrease of $4.72, $2.05, $0.40, $0.61, and $4.08 billion in receipts in 2020 for the crop, soybean, wheat, cotton, and other crop sectors, respectively. Receipts are expected to fall by $9.57, $2.24, $0.05, $3.97, and $0.40 billion for the cattle, hog, poultry, milk, and other livestock sectors, respectively. Farm bankruptcies could spike over the next year or two due to a relatively weak liquidity position for many farm operations.

Agricultural activities expose workers to increased risk of contracting COVID-19 and spreading it to others. Layoffs in the service sectors and high unemployment rates may increase the local farm labor supply. However, workers do not generally return to the farm sector once they find jobs in the non-farm sector.

COVID-19 rates in rural communities are smaller than those in their urban counterparts. However, rural hotspots have emerged in communities with prisons, nursing homes, meat packing plants, persistently poor African-American communities, and tribal nations.

The pandemic has demonstrated the crucial importance of the agri-food supply chain and identified specific challenges facing agri-food supply chains that require better understanding and research. There is a need to reassess the regulation of new technologies in the United States and globally.

As a result of the COVID-19 pandemic, decision makers are currently operating in an exceptionally uncertain environment. The agricultural and applied economics profession exists to render conceptually sound, data-driven, actionable intelligence from a confusing swirl of information.

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CAST Commentary QTA 2020-2
May 2020
Material excerpted from original CAST document

Stewardship Challenges for New Pest Management Technologies in Agriculture

The ability to feed and clothe a growing human population has relied upon agricultural innovation for centuries, and will continue to do so.

- Several studies have shown that the widespread adoption of Bt crops can reduce population sizes of target pests and associated damage across large areas, with pest suppression benefits extended to growers not planting Bt crops.
- GM crops introduced in 1996 that were resistant to the broad spectrum herbicide, glyphosate, have benefitted producers by providing flexibility of application and increased profits while managing difficult weed problems.
- By 2015, GM crops were providing more than $15 billion in annual economic benefits, with cumulative global economic benefits valued at $167 billion since their initial introduction.

However, a number of potential risks come with these technological developments as well. They include resistance development, off-target movement of pesticides, worker safety, risks to beneficial insects, gene flow, threats to water quality, and risks to pollinators.

The dependency on technology is quite understandable given the size of modern farming operations, as well as the complexity of management issues that farmers face. Farmers must simultaneously manage for weeds, pests, soil fertility, erosion, and other problems while responding to constantly changing weather conditions, public policies, and recommendations from experts. In other words, integrated stewardship is high complex, time consuming and often costly, and thus, anything that can help farmers simplify their management approach is helpful and desirable in their eyes. Unfortunately, and as the evolution of weed resistance has demonstrated, nature is characterized by heterogeneity and complexity, and integrated stewardship must necessarily recognize the complexity of agricultural production systems.

There are two excellent examples of growers working together cooperatively to address pest management problems. The codling moth control program used natural enemies, knowledge of the mating habits, pheromones, and targeted insecticide applications over a wide area. By the end of this project, codling moth trap captures fell by more than 90%, and a single pesticide application was sufficient to reduce damage to less than 0.2%. Similarly, area-wide pink bollworm control strategies focused on Bt cotton utilization, targeted pesticide applications, mating disruption, cultural practices crop residue management, planting date restrictions, and sterile moth release. Factors related to their success included:

- The pests were controlled using a diverse array of chemical and non-chemical tactics.
- While chemical-based strategies implemented at the farm level proved ineffective, diverse tactics were employed in a collective fashion relying on multiple decision-making bodies, operating across vertical and horizontal networks.
- Both programs relied on incrementalism. Programs expanded in terms of geography and complexity, but built on more modest localized successes.
- Finally, successful completion required long time frames and continued long-term commitment by retailers, grower-leaders, State Departments of Agriculture, Cooperative Extension, Independent consultants and USDA professionals.

The authors recommend five actions to improve the stewardship of pest management technologies in agriculture.

- Engage inclusive stakeholder groups to inform the stewardship program
- Develop improved research capacity that identifies the incentives, risks and constraints that influence effective stewardship of pest management technologies
- Build human management skills associated with pest technology stewardship
- Promote voluntary community-based stewardship for pest management technologies
- Reform public and private policies that work against effective stewardship

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CAST Commentary 2020-1-QC
April 2020
Material excerpted from original CAST document

Producing Food Products from Cultured Animal Tissues

There are many questions that need to be addressed before cell cultivated meat is ready for the dinner table.

- The nutritional composition and sensory characteristics of cell cultivated meat will need to undergo appropriate scientific investigation to determine the true similarities or differences when compared with conventional meat.
- A framework for the regulatory oversight of these products has been outlined, but as the technology improves, cell cultivated meat products may be developed that will, in turn, raise new questions to be answered with regulatory policy.
- The success of cell cultivated meat products will depend on consumer acceptability.

In order to survive and grow both within and outside of the body, cells need a water-based environment with a supply of nutrients and growth factors needed for various cellular processes and have metabolic waste products removed from the growth environment.

- The basic cultivating process of cell cultivated meat products will likely include cell line development, cell cultivation, and tissue cultivation.
- Tissue structuring, also called tissue engineering or tissue synthesis, embeds cells within a three-dimensional scaffold, which simulates connective tissue.

Cell line development, or cell line engineering, begins with extracting individual cells from a tissue biopsy of an animal.

- Cells used for cultivation of cell cultivated meat can be derived from various kinds of stem or precursor cells found in animal embryos, bone marrow, or muscle tissue.
- The three dominant cell types that influence meat flavor and texture are skeletal muscle cells, intramuscular fat cells, and connective tissue cells called fibroblasts.
- Skeletal muscle and fat cells can be incorporated into both unstructured and structured products.

The goal of cell cultivation is to yield a large biomass of edible cells originating from a master cell bank of upwards of thousands of kilograms expanded from a working cell bank.

- Scaling up of cell cultivation has several technology hurdles, including lowering the cost of media, developing cell lines that can be propagated indefinitely and possess specific palatable and nutritional characteristics; establishing scalable bioprocesses, reducing the operational costs of large-scale biomanufacturing facilities, and disposal, recycling or amelioration of waste products.

The development of cell cultivated meat as a potential human food has resulted in considerable debate about how such materials would be regulated in the United States.

- Both the FDA and USDA-FSIS have entered into a Memorandum of Understanding that stipulates that the FDA will oversee cell collection and propagation up to harvesting as cell cultivated meat, at which point USDA-FSIS becomes the responsible agency.
- There is the expectation that the USDA will require an inspection system that includes sanitation, physical product inspection, HACCP verification, product testing, and records review, as well as prior label approval before a product may be distributed in interstate commerce.
- "Cultivated meat", "clean meat", "cultured meat", "lab meat", "fake meat", "cell cultivated meat", and "in vitro meat" are all terms currently being used to describe meat produced through cell culture technology.
- In accordance with the FDA and the USDA policies, all foods for human consumption must be evaluated for potential biological, chemical, and physical hazards.

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Ag quick CAST
CAST Issue Paper 67
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Material excerpted from original CAST document

Impact of Recruitment and Retention of Food Animal Veterinarians on the U.S. Food Supply

Food animal veterinarians (FAV) safeguard the health and welfare of livestock, poultry, and aquatic food animals and food safety and quality along the entire "farm to fork" continuum.

- Of particular importance is the role veterinarians play in preparation for and mitigation of disease outbreaks.
- A 2015 study estimated that the total economic impact of an outbreak of foot-and-mouth disease in the United States would range from $16 to $140 billion.

The veterinary profession has struggled with a central workforce related question—why is it difficult to recruit and retain FAV in the United States?

- Underlying factors impacting recruitment and retention include food demand and food animal production intensity, both of which are driven, in part, by population growth.
- The availability of FAV in *rural* areas extends to livestock producers, rural communities, and veterinary colleges, even reaching national news media and warning of risks to livestock and the food supply.
- Multiple social and economic factors can be identified in driving the recruitment and retention of rural veterinarians including comparative wage rates, lifestyle preferences, social and community support systems, access to services, and veterinary practice infrastructure.
- The rural nature of many of the FAV practices is a disincentive for veterinarians that seek greater access to services, employment opportunities for family members, and a more robust social support system than many smaller communities can provide.
- Salaries for rural mixed practices are generally lower than for specialized, exclusive FAV and companion animal veterinarians and when added to a very high student debt load poses further challenges for rural mixed FAV.

An adequate supply of FAV starts with getting students interested in FSVM, getting them adequately trained and employed in FSVM jobs, and finally, keeping them in those FSVM jobs.

- Many of the recruitment factors such as student debt, rural living, gender, and generation influences are also retention factors that lead to career or job switching by FAV.
- High student debt is arguably the biggest issue facing the veterinary profession. When asked about issues important to the veterinary profession, FAV interested students in particular ranked debt highest.
- Many students interested in FSVM come from rural communities and have experience in animal agriculture and these students are thought to be an important pool of future FAV.

Practices that create an environment where employed veterinarians feel appreciated, supported, and successful are likely to have higher retention rates.

- Establishing a clear plan for mentorship and following through on that plan provides an excellent return on investment through veterinary employee retention.
- The increased use of veterinary technicians/nurses is linked to higher practice efficiency and revenue.
- Telehealth, or using technology to deliver health information, education, or care remotely, also presents opportunities for expanded scope and reach of services for rural practices.

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Ag quick CAST

CAST Issue Paper 66
October 2019
Material excerpted from original CAST document

Interpreting Pesticide Residues in Food

Pesticides provide a useful tool to control insects, weeds, plant diseases, as well as other agricultural pests.

- The agricultural use of pesticides has enabled food producers to increase their crop yields significantly in the United States and throughout the world.
- One consequence of using pesticides in agriculture is that pesticide residues are often detected on our foods. The use of pesticides does not necessarily imply that residues will be encountered.

In the United States, pesticides are primarily regulated by the United States Environmental Protection Agency (EPA).

- The EPA will not permit specific uses of pesticides unless consumer exposure to the pesticide from all sources represents a "reasonable certainty of no harm".
- The calculation of a "reasonable certainty of no harm" involves assessing realistic levels of human exposure through consideration of pesticide residue levels and food consumption patterns as well as comparisons of exposure estimates with toxicological criteria such as the reference or benchmark dose.

The U.S. Food and Drug Administration is the primary federal agency responsible for enforcing pesticide tolerances.

- The FDA found that a majority of samples contained no detectable pesticide residues while most of the detectable residues were within tolerance levels.
- Pesticide residue violations can occur when residue levels exceed the tolerance established for the specific pesticide/food combination, and when residue levels—at any level—are detected on foods for which a tolerance is not established.

The presence or absence of pesticide residues is not a valid indicator of health risk to the consumer.

- "The dose makes the poison." It is the amount of exposure and not the presence or absence of a chemical that determines the potential for harm.
- In the 2004-2005 FDA Total Diet Study, residues of 77 pesticides were detected and exposure estimates were compared to the chronic reference dose. Three pesticides exceeded 1% of the cRfD. Fourteen were between 0.1–1.0%. Nineteen were between 0.01–0.1%. Forty-one pesticides were below 0.01%. An exposure of 0.01% of the cRfD represents an exposure one million times lower than the highest dose that does not cause effects.

There remains the concern among some consumers that detectable exposures to pesticides may lead to certain diseases.

- Some epidemiological studies have shown correlations between pesticides exposure and health effects but none have established cause and effect. The types of health effects correlated with pesticide exposure include male adult reproductive effects and development and behavioral effects in infants and children.
- Six studies evaluated the insecticide chlorpyrifos and intelligence. Two of the six reported a statistically significant decrease in IQ with increased estimates of exposure but neither correlation was derived from food exposure. Four studies failed to correlate chlorpyrifos exposure with decreased IQ.

Since the 1970s, the trend in agriculture has been towards a more sustainable, integrated systems approach to the challenges of pest management.

- Pesticide products are often a key part of the integrated system and this is true for both conventional and organic production.
- The trend over time has been towards pesticides that are intrinsically much less toxic to humans or the environment than their predecessors.
- For crops that are harvested by hand, pest damage can greatly reduce the picking efficiency, meaning the pounds that can be collected per hour of effort.

Food security and a diverse, affordable, healthy food supply are key societal benefits enjoyed in the developed world in the modern era.

- For crops like apples and potatoes that go into long term storage, very high pest control standards are needed in the field to sustain storage life.
- Areas with more rainfall tend to have more fungal pest issues. Warmer climate tends to have more insect challenges.

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Ag quick CAST

CAST Issue Paper 65
September 2019
Material excerpted from original CAST document

Protecting Food Animal Gene Pools for Future Generations

A paper in the series on The Need for Agricultural Innovation to Sustainably Feed the World by 2050

In the face of the mounting depletion of genetic diversity among livestock species, there is an urgent need to expand the sampling program, sustain the preservation effort, and evaluate the remaining livestock and poultry gene pools.

- Livestock breeders produce the genetic resources necessary to address domestic consumption and supply genetic resources to the world.
- The highly specialized livestock industries in North America are dominated by a small number of productive breeds for which there is a concomitant downward trend in the effective number of breeding animals and a general contraction of genetic diversity, particularly in the commercial dairy and poultry breeds.

Genetic diversity can be preserved through living populations or cryopreserved for future use.

- Living populations are advantageous because they can adapt to changes in the natural or production environment.
- Genetic material from livestock and poultry can be cryopreserved in several forms: male gametes (spermatozoa), female gametes (oocytes), embryos, embryonic cells, gonadal tissue, primordial germ cells (PGC), and somatic tissues.
- The bovine is the only farm animal species for which cryopreservation of sperm is commercially routine. The success of semen cryopreservation in sheep and goats is lower than that of cattle, but better than swine. Among the major mammalian food animal species, the pig poses the greatest challenge for semen cryopreservation.

Gene banks have been established across the globe to protect livestock and poultry industries from loss of genetic diversity that could subsequently hinder their capacity to adapt to new environmental or market pressures.

- The USDA-ARS established the National Animal Germplasm Repository in 1999, and thereby began development of livestock and aquatic gene banking for species of agricultural importance.
- Since its initiation, the NAGP has developed into the world's largest and most comprehensive repository for farm animal genetic resources.
- Since 2005, the Animal-Genetic Resources Information Network (Animal- GRIN) has been the primary vehicle for storing information about animals in the NAGP's collection.

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Ag quick CAST

CAST Issue Paper 64
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Reducing the Impacts of Agricultural Nutrients on Water Quality across a Changing Landscape

Supplying external inputs of nutrients such as nitrogen (N) and phosphorus (P) to cropland in order to maximize crop production was first recognized nearly 200 years ago, and today 40 to 60% of [U.S.] crop yield is attributable to fertilizer.

- Although many sources contribute nutrients to water bodies, agriculture remains a significant source in many areas of the United States.
- U.S. agriculture faces an unprecedented challenge—support growing domestic and global agricultural product demands while minimizing environmental impacts on local and regional water resources.

Nutrient loss from agricultural fields and watersheds is determined by the complex interaction among numerous physical, chemical, and biological variables.

- Fertilizers and manures have the potential to elevate nutrient concentrations in surface runoff and subsurface leachate, particularly if applied beyond crop need.
- Research across diverse agricultural landscapes in the United States has shown that hydrological processes are an important component driving nutrient loss.

Nutrient management not only has direct implications for crop productivity, but it can also strongly influence nutrient losses to groundwater and surface water bodies.

- The right source of nutrient is dependent on the nutrient content, its solubility, and whether it is regionally available.
- Nutrient application rates are determined differently for P and N.
- Nutrient placement can have significant implications for both crop uptake and nutrient loss.
- The right timing of nutrient application aims to ensure there is adequate nutrient supply during peak crop uptake and critical crop growth stages.

Conservation practices can be used in combination with nutrient management to decrease nutrient loss from cropped fields.

- Vegetated filter strips, buffers, or riparian zones are often implemented between the edge of an agricultural field and a stream or drainage ditch.
- Integrating single or multispecies cover crops with the primary commodity crop system will decrease the amount of time that fields are left with bare soil.
- Sediment detention basins capture agricultural surface and subsurface drainage water and allow sediment and particulate nutrients to settle out prior to the water entering a stream or ditch.
- Constructed wetlands have the potential to remove nutrients from agricultural drainage water.
- For fields with subsurface tile drainage, drainage water management or controlled drainage can be used to artificially adjust the outlet elevation of the drainage network to a specified depth by restricting flow.
- Both bioreactors and P removal structures have been implemented using various designs and can be installed separately or in series.
- Two-stage ditch systems incorporate benches that function as flood plains in an attempt to restore or create natural alluvial channel processes.

The combined demands of increased agricultural production with reduced environmental impact require management strategies that can be sustained over the long term.

- Current knowledge of N and P rates is imprecise.
- Legacy nutrients may mask water quality impacts of current conservation efforts.
- Most implemented conservation practices do not address dissolved nutrients.
- Few conservation practices provide in-stream nutrient removal.
- Nutrient reductions for both nutrient management practices and conservation practices are field specific.
- Conservation program success requires collaboration and cost-effective implementation.

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Ag quick CAST

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Enabling Open-source Data Networks in Public Agricultural Research

The next generation of agricultural problem solving will require big science and linkages forged across data sets and disciplines.

- Agriculture's pathway forward requires dedicated partnering among domain researchers, data scientists, science administrators and agencies, professional societies, and private publishing entities.
- Teams must bridge expertise gaps through meaningful collaborations between agricultural researchers and data scientists.
- Initiatives to leverage assets should focus on surfacing grey-dark data not represented by peer-review publication.
- For research data to achieve and maintain public value, it must connect feedbacks to ensure data are useful and useable for informing the end-user "apps" designed to enhance and secure our current food supply and address environmental and social challenges.

Research has created the most efficient food production system in history through accrual of massive amounts of data, information, and knowledge.

- With much research data remaining unpublished, only partially available, or incompletely described, policy decisions and program design may lean disproportionately on expert opinion and partial information.
- For agriculture, the scope of opportunities and challenges linked to data is hard to overstate.
- Free and open access to information generated by federal funding is clearly in the spirit of the original legislation creating the USDA and the land-grant university system to develop and apply scientific knowledge in food production for the betterment of the U.S. population.

Although agricultural research has been slow in developing e-infrastructure and mechanisms that promote efficiencies and transparency via open data, examples from other domains demonstrate that open data can catalyze new discoveries, decisions, and economic growth.

- Reports in the agricultural literature have repeatedly highlighted the potential for such infrastructure to improve the quality of the primary agricultural literature and its use in evidence-based decision making.
- Numerous, large, data-sharing efforts initially developed for other, broader purposes are already bringing significant ancillary benefits to agricultural research.
- Moving agriculture from its present culture of short data life cycles and limited sharing to one valuing open data and data reuse requires development and implementation of best practices that ensure readability over time and between disciplines.

Simultaneous pursuit of four strategies will facilitate agriculture's pathway forward into data-driven research:

- Bridging gaps with novel teams and data sciences
- Institutional facilitation of team science and data sharing
- Leveraging assets and surfacing grey/dark data
- Connecting feedbacks to ensure data are useful and usable

Physical and cyber infrastructure require a business case for making open access data and data tools viable to start and sustain over the long term.

- Competitive grants programs could be extremely useful to build tools and apps but would not be efficient mechanisms for long-term data storage and curation.
- As agriculture considers pathways forward for data, careful examination of the various financial models currently under active consideration by other domains should be undertaken.
- Even with stronger requirements from funders for data preparation, some activities such as anonymization remain beyond the scope of the funded research.

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Aquifer Depletion and Potential Impacts on Long-term Irrigated Agricultural Productivity

Groundwater is the Earth's most extracted raw material.

- Approximately 70% of groundwater withdrawals are used for irrigated agriculture.
- Consequences of the long-term depletion of groundwater resources include the direct impacts of depleting the resource and global impacts of groundwater being released to the atmosphere and oceans once it is brought above ground.

Groundwater use has grown significantly across the United States over the last century, especially to supply irrigated agriculture.

- Technology began to be deployed extensively across the United States in the 1950s, which coincided with rural electrification across the nation that facilitated use of submersible pumps.
- A second factor increasing groundwater use has been long-term regional droughts, especially in regions with large agricultural sectors.
- Additional factors include over-allocation of surface water and local availability of groundwater as a "point-of-use" resource not requiring expensive distribution infrastructure.

Several large aquifer systems in the United States are experiencing substantial problems from the depletion of groundwater.

- The U.S. aquifer system with the greatest long-term groundwater storage depletion is the Ogallala aquifer in the Great Plains region of the United States.
- Two large aquifer systems in the Pacific Northwest region of the United States, the Columbia Plateau aquifer and the Snake River Plain aquifer, have had a net accretion of groundwater levels as compared to predevelopment conditions.

Although a large direct consequence of depleting groundwater resources is the loss of water supply, many other consequences of depletion also must be considered:

- Reduced flow to surface water systems and ecosystems
- Loss of productivity of groundwater wells
- Subsidence of land and ground failures
- Degradation of groundwater quality

There is a growing recognition of the consequences of groundwater depletion. This has led to several approaches to mitigate or reverse groundwater depletion.

- The most direct approach to decreasing the depletion of groundwater is to simply extract less groundwater from aquifers.
- Another direct approach to arresting groundwater depletion is to enhance groundwater replenishment using alternative water sources.
- Another method to decrease groundwater depletion is through changes to crop selection and agricultural practices.
- Since each state has primacy over its water resources, a wide range of policy and institutional approaches has developed to address groundwater depletion across the United States.

Use of a groundwater resource requires that the groundwater table must be drawn down to some degree before it can be used in a beneficial manner.

- Lowering of an aquifer's groundwater table in small amounts is unavoidable and not in and of itself a negative condition.
- The potential consequences of groundwater depletion need to be fully assessed to determine the trade-offs that exist between the undesired impacts of groundwater depletion and whether these impacts outweigh the benefits associated with groundwater use.

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Food Biofortification—Reaping the Benefits of Science to Overcome Hidden Hunger

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