Crop science is a highly integrative science employing the disciplines of conventional plant breeding, transgenic crop improvement, plant physiology, and cropping system sciences to develop improved varieties of agronomic, turf, and forage crops to produce feed, food, fuel, and fiber for our world’s growing population. During the last century, crop science has achieved feats which are now part of everyday life and taken for granted.

Despite these scientific achievements, the world today faces ever-growing challenges of widespread food insecurity and malnutrition, negative impacts of climate change, environmental degradation, and dependence on fossil fuel energy. Solutions to these challenges will be found, in part, through sustained, federal investment in crop science to address these challenges. The Crop Science Society of America (CSSA) organized a committee to identify key Grand Challenges associated with crop science which, when addressed, will provide the tools, technologies, and solutions required to address these challenges.
Grand Challenge #1

**Genotype the major crop germplasm collections to facilitate identification of gene treasures for breeding and genetics research and deployment of superior genes into adapted germplasm around the globe.**

**Background:** Germplasm collections are a wonderful treasure trove of genetic diversity and the foundation for all crop improvement programs. A germplasm collection for a single crop species may contain more than 50,000 distinct genetic plant types, yet the genomic profiles are not readily available, limiting application of information contained in the collections. However, new inexpensive technologies for developing detailed genetic profiles to entire collections, offering a low-cost remedy. As a result, new genomics information will enhance our ability to correlate a plant’s genotype with its agricultural performance for plant breeding purposes, in a way never before possible.

To translate the economically important diversity of germplasm collections into food and other agricultural products, it is critical that we integrate this new genomics information with a series of field-breeding positions specifically targeted at ‘mining’ germplasm collections. Field breeders will use hybridization and selection, informed by genomics, to produce novel, agronomically important genetic types that work effectively in agriculture. As a result, development of crops will be accelerated to avoid famines and market-place catastrophes resulting from fluctuations in rainfall, diseases and pests, thus enabling greater food security in the U.S. and around the world.

**Key Questions:**

1. Can we develop a system and the resources to employ high throughput gene chip technology to create genetic profiles of individual entries within germplasm bank collections of major crops?

2. What information management systems and related protocols can we develop which enable breeders, geneticists, and biological information technologists understand, access and effectively use extensive DNA marker profiles for germplasm collections of major crops?

3. Can we develop a system and the resources to employ high throughput gene chip technology to create genetic profiles of individual entries within germplasm bank collections of major crops?

4. Can we capitalize on the value of novel gene discoveries by developing crop specific molecular markers to facilitate rapid cultivar improvement?

5. Can improved methods for establishing genotype-phenotype relationships be developed for vital genes in all major crops?

6. Can genetic manipulation techniques and new genetic tools be customized for each major crop and incorporated into plant breeding practices (e.g. doubled haploidy, transformation, marker-assisted breeding strategies, and genome-wide selection) to accelerate the time to field evaluation stage?

7. Can the capabilities and capacities of regional and international research centers be enhanced to expedite new cultivar releases?

8. Can we create a new cadre of plant scientists and field-oriented plant breeding positions specifically targeted at ‘mining’ the genetic diversity found in germplasm collections and integrating new genomics information above, to produce novel agronomically important breeding materials?
Expected Outcomes:

1. Intelligent sampling strategies for gene mining within germplasm collections to expand the dangerously narrow genetic base of our major crops.
2. Allow use of many genes from different sources to create multiple strategies controlling diseases, combating insects, and minimizing climate stresses to create higher crop yields.
3. Enhanced food security, greater research efficiency and production stability.
4. Efficient and sustained translation of products from gene discovery to agronomically adapted breeding materials for farmers’ fields to proactively address shifts in pest dynamics and climate.

Grand Challenge #2

Increase the speed with which agriculture can adapt to climate change by using crop science to address abiotic stresses such as drought and heat.

Background: Drought is the number one limitation to crop productivity in the world. As climate changes, the incidence and duration of drought and heat stress on our major crops will increase in many regions, negatively affecting crop yields and food security. Solutions to this complex problem can best be found by forming research teams, bringing a spectrum of scientific expertise—breeders, physiologists, and molecular geneticists—to bear on the problem. Because the majority of the progenitors of most crops were developed under periodically dry conditions, drought tolerance genes already exist in most crop germplasm collections. These important genes have not all persisted in modern cultivars because agriculture has concentrated on breeding varieties adapted for to favorable environments and responsive to irrigation. The need to incorporate genes for drought tolerance takes on new urgency with predictions of more wide-spread and severe drought. Agriculture must produce more “crops per drop” of water and develop strategies to share water resources at the rural/urban interface where water can be bought and diverted to non-agricultural uses.

Key Questions:

1. How can teams of breeders, geneticists, physiologists, and agronomists be created with sustained support to conduct research in abiotic stress tolerances through all phases of testing to produce economically viable tolerant varieties?
2. Can we develop networks of abiotic stress prone fields (laboratories/sites) and efficient screening methods to identify genotypes tolerant of stresses such as drought and heat stress?
3. What economically important abiotic stress tolerant genetic resources exist in germplasm collections and in applied breeding programs?
4. What are the physiological mechanism(s) by which abiotic stress tolerance genes interact with each other and with the environment to impart abiotic stress tolerance?
5. What are the physiological and genetic mechanisms by which temperature reduces pollen viability and seed-set, and can genetic tolerance to temperature stress be achieved?
6. How can we exploit variation in the morphology, rooting depth, and/or functionality of roots, leaves, or stems to mitigate the effects of abiotic stress?

Expected Outcomes:
1. Fundamental knowledge regarding traits, genes, and breeding stocks that convey economically important levels of stress tolerance.

2. Cultivars genetically improved for stress tolerance will provide sustained or higher crop yields that will help stabilize crop production in the face of projected climate changes.

3. Adequate infrastructure (laboratories, personnel, experience with integrated approaches) to mount a sustained long-term responsiveness to continuing abiotic stresses.

**Grand Challenge #3**

**Develop sustainable biofuel feedstock cropping systems that require minimal land area, optimize production, and improve the environment.**

**Background:** The role of crop plants as feedstock for biofuel production will increase in the coming years. Crops are a source of sugar, starch, and cellulose which can be converted to ethanol and seed oil that can be converted to biodiesel. All bioenergy crops will need to be grown in a way that optimizes biomass yield while minimizing inputs of fertilizer, irrigation, and pesticides.

It is important to minimize the competition between biofuel crops and human food crops. Therefore, in the future, ethanol–based biofuel crops likely will be non-food crops grown on land that is marginal for other crop production. Because biodiesel is the product of seed oil, this biofuel must be produced using existing seed crops. Therefore biodiesel research needs to concentrate on oil seed crops that are less used for feedstock but very productive, such as peanut. The composition of biofuel crops will need to be modified to make them easy to convert for energy use, but these modifications may make them more vulnerable to stresses and pests. As a result, there is a need:

- to modify crop compositions according to processing requirements;
- to increase yield in low-input production systems;
- to understand plant response to changes in environment in tandem with changes in composition for accurate modification;
- to understand the ecosystem services (carbon sequestration, water quality, wildlife habitat, etc.) from perennial bioenergy crop production on arable and marginal lands; and
- to develop new production systems that thrive in low-input situations.

**Key Questions:**

1. What genetic improvements to the composition and field productivity of biofuel feedstock crops optimize conversion processes while also improving production efficiency?
2. What steps do we need to take to develop/tailor biofuel feedstock cropping systems appropriate to diverse agroecosystems?
3. What crop management strategies can we develop and use to increase soil carbon, minimize production inputs, and ultimately increase economic return for the grower?
4. How do we optimize use of nitrogen-fixing plants into bioenergy cropping systems?
5. What biomass biofuel crops and cropping systems can be developed which are highly productive and reduce the total land area required to meet demand?

**Expected Outcomes:**

1. Reduced dependence on fossil fuels by providing sustainable renewable energy alternatives.
2. Increased number of crops and cultivars that have proven metrics for productivity and high fuel conversion efficiency rates.

3. Low-input management systems for the production of biofuel crops in diverse ecosystems.

4. Meeting the increasing global demand for food, feed, fiber and fuel on a decreasing land base with fewer inputs.

5. Increased profitability for producers of bioenergy feedstocks

Grand Challenge #4

Increase durability of resistance to biotic stresses that threaten food security in major crops.

Background: Organisms that cause biotic stress in crop plants are continually adjusting their pathogenic mechanisms to take advantage of the plant’s limited defenses. Unfortunately, with new intensive management practices being adopted and climate change altering environmental conditions, the rate of adjustment by some pathogens has accelerated. Furthermore, crop uniformity can increase genetic vulnerability to various pests. For example, U.S. soybean cultivars are almost uniformly susceptible to two relatively new U.S. biotic stresses: soybean aphid and soybean rust.

Contemporary best management practices which retain plant residues on the field result in increased soil organic matter, improved soil quality, and additional sequestered carbon; however, they also provide an environment where pathogens can prosper and cause reduced yields. Examples include pathogens such as gray leaf spot of corn whose inoculum grows on previous crop residue. Carcinogenic aflatoxins are produced by fungi whose proliferation increases in stress environments of drought, high temperature, and/or high humidity. Thus, there is a need for plant genomic tools that can identify novel resistance genes and assist in their rapid incorporation into improved cultivars.

Key Questions:

1. What are the molecular and physiological mechanisms by which various pathogens and pests interact with plants? How can these interactions provide novel and durable approaches for defense mechanisms?

2. How do we efficiently identify novel resistance genes in our extensive germplasm collections?

3. How do we incorporate resistance genes effectively without limiting progress for improving yield?

4. How can genomic tools be used with germplasm to uncover the molecular basis for resistance to biotic stress?

5. How best to develop and utilize gene-specific markers to combine and deploy resistance genes so that the risk of crop loss is minimized?

Expected Outcomes:

1. Prevention of widespread crop yield and quality losses as plant diseases and pests evolve and spread due to climate change.

2. Enhanced year-to-year stability of food, feed, fiber, and bio-fuel production.
3. Improved human and animal health by increasing crop resistance to mycotoxins and aflatoxin.

**Grand Challenge #5**

Create novel crop varieties and management approaches designed for problem soils and low-input farming to increase economic prosperity for farmers and overcome world hunger.

**Background:** Agricultural productivity is limited in many areas by poor soil conditions and high fertilizer prices. However, soil tilth issues including high soil pH, or toxic aluminum and salt levels are not easily remedied by conventional high-input approaches. As a result, new crop varieties and management practices are needed which reduce dependence on agricultural inputs and overcome common soil problems. Multi-disciplinary research teams will be the key to success, because they have the expertise to improve N fixation in legume crops, improve nutrient uptake and use, and can develop crop varieties which are tolerant of such soil limitations. Team research should focus on efficient and reliable methods to identify desirable crop germplasm that has the right genetic makeup to deliver these improvements. When coupled with technology transfer, these efforts will increase yields and quality of food crops and ameliorate food security and nutritional deficiencies at home and abroad.

**Key Questions**

1. How do soils, weather, genetics, and management practices interact and influence root growth and nutrient uptake and nitrogen fixation?

2. What are the most reliable, efficient, and inexpensive methods that accurately predict the worth of a genetic trait or gene in low input agriculture (for efficient use of limiting soil nutrients)?

3. Which genetic traits have the greatest impact on nutrient use efficiency; how do these traits interact with each other and the environment?

4. How do we ensure optimal partitioning of limited nutrient resources to the economically important portions of the crop?

5. Can genomic methods provide better understanding of host plant–rhizobial strain interactions and rhizobial-soil interactions?

6. How might crop, nutritional, and soil factors be managed in order to sustainably and consistently improve crop performance and yields? Can commercial mycorrhizae applications improve plant nutrient uptake?

**Expected Outcomes:**

1. Reduced need for the application of nitrogen fertilizers through enhanced biological nitrogen fixation by microorganisms in association with crop plants

2. Reduced need for phosphorus fertilization or use of other soil amendments, if roots/mycorrhizae systems can more adequately provide nutrient uptake for the crop.

3. Improved energy balance for biofuel production.

4. Farming systems that are more economically and environmentally sound.

5. Increased yields, crop nutrient quality, and food security in resource-scarce environments
Grand Challenges #6

Create novel crop management systems that are resilient in the face of changes in climate and rural demographics

Background: Agriculture is constantly adapting to change; consider the revolutions in agriculture due to irrigation, fertilizer, weed insect, disease control, and modern tillage systems. We will need to make similar changes to our cropping systems as we face future changes in our climate and an increased need for using resources efficiently.

Eighty to ninety percent of our food is produced on large-scale farms, usually operated by family entities. To ensure the greatest advances in productivity, environmental sustainability, and profitability, new crop management information and technology systems need to be adopted for farms of various scales. Such innovations should encourage integrated pest management and water and soil conservation in ways that are practical and convenient for large scale farms. There are several tools that can make this possible, such as remote sensing and other off-site monitoring. The synergy between variety development and crop management research has been responsible for yield gains of the last 50 years. The interplay between genetics (i.e. variety) and environment (i.e. cropping systems) must be continually optimized to produce food, feed, fiber and fuel for the U.S.

Key Questions:

1. How can we adapt the latest information on pest, crop, and soil management strategies to develop applications that are convenient and profitable in both small and large scale crop production systems?

2. Can crop growth simulation models and remote sensing be useful for advising mitigation strategies, and be accurately parameterized for climate change factors, species, cultivar, soils, and management effects on crop growth and yield?

3. How do we best define complex multi-level interactions involved in a full system analysis of producing food, feed, and raw materials for a specific ecological or market niche?

4. Can powerful applications be developed using massive multi-layer data sets -- including yield history, genetic, soil, and weather data -- to create practical decision-making tools to enhance crop productivity, environmental sustainability, and management convenience for growers?

5. How can crop residue management be optimized in ways that balance crop productivity and water, soil, and energy conservation with consideration of carbon policy?

Expected Outcomes:

1. Crop management strategies that simultaneously improve multiple factors within cropping systems and allow sustained crop production under climatic stress.

2. Cropping systems that conserve and protect soil resources, increase crop enterprise diversity, improve input efficiency at farm level, and increase production.

3. Practical and timely information delivery tools to help farmers make field level management decisions with increased convenience and profitability.