EK - USDA - YCEDA Final RoadMap Summary
For Soil Health and Soil-borne Disease affecting Fresh Produce

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Prepared by
Earth Knowledge and the USDA Agricultural Research Service

For each of the Key Technical Topics Addressed, the RoadMap Summary includes:

A. Key relevant research related to YCEDA needs;
B. How the technology was developed, for which crop, and how it's applicable to YCEDA needs;
C. Technology Readiness (including research usefulness, applicability and ease of making operational for growers) reported on a scale of 0 to 5 [5 representing a high level of readiness and 0 or 1 representing interesting research ideas without immediate direct field applicability];
D. Extent of further work required to make research more applicable;
E. What are key “gaps” missing to make research more applicable to YCEDA needs;
F. Key Researchers (and affiliations)
G. List of related literature (alphabetical - key reports highlighted in gray).

Key Technical Topics Addressed:

1. Soil-borne Diseases
2. Cropping Systems
3. Sensor Technology
4. Analytics, Models, and Decision Tools
5. Scaling of Information

1. **<u>Soil-Borne Disease</u>:**
   Soil-borne Disease research is predominantly focused on two major areas of interest, including (a) ***Pathology*** - which focuses on the specific diseases caused by pathogens and environmental conditions, and (b) ***Cultural Practices*** - which focuses on grower field practices that can contribute to disease and those modifications to fields practices that can alleviate disease stress.

   a. **<u>Key</u> <u>Relevant</u> <u>Research</u>** - Key research in this area has and continues to be conducted by researchers at the University of Arizona and the University of California and their associated Cooperative Extension

Programs. Important research also is being conducted by USDA ARS Plant Pathology) staff located in the Salinas area.

This research has focused mostly on leafy-green produce and soil-borne disease pathogen groups, with a specific emphasis on the biology of the pathogens, their survival on plant debris, their distribution in soils, diagnosis and monitoring, and control option.

A significant body of the research stresses the key biophysical factors influencing infections, including but not limited to soil type, texture, pH, soil moisture, soil temperature, soil nutrient levels, oxygen/aeration, air temperature and humidity.

b. **Applicability -** This research has almost direct applicability as the majority of the work is focused specifically on leafy-green produce grown in the central coast of California and the desert regions of both California and Arizona.

c. **Technology Readiness -** The research has direct usefulness and applicability but will require some work to operationalize the information and knowledge contained into a usable decision tool. It therefore is given a *Technology Readiness Score of 4*.

d. **Additional Work Required -** Additional work will be required to assess the geographic and microclimatic variation and the transferability of the biophysical properties information from this research to the growing regions of interest to the YCEDA growers.

e. **Key Gaps -** The key gap is the lack of a systematic method for transferring information about specific pathogens and soil-borne diseases to different geographic locations and different specific microclimates.

f. **Key Researchers -**
Steven Koike (UCCES - Monterey)
Jeness Scott (UC - Davis)
Thomas Gordon (UC - Davis)
Mike Matheron (University of Arizona)
Sharon Kirkpatrick (UC- Davis)
Mike Davis (UC - Davis)
Jim McCreight (USDA ARS - Salinas)

g. **Related Literature** -
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2. **<u>Cropping Systems</u>:**
   Relevant research generally associated with cropping systems includes any number of best management and cultural agricultural practices carried out on a

farm before, during, and after planting crops that contribute to a systematic and consistent yield and quality of crops.

Cropping system practices include but are not limited to the following activities such as site selection; land clearing and grading; bed development; seeding, planting, or transplanting; thinning; soil amendment; water management; soil health and nutrient management; weed and pest control; and harvesting.

The USDA ARS National Laboratory for Agriculture and the Environment directed by Dr. Jerry Hatfield conducts research to generate information that addresses critical problems in agriculture leading to innovative solutions that increase the efficiency of agricultural / cropping systems and reduce environmental risk. This transdisciplinary research addresses many research aspects of cropping systems; agricultural systems management; and soil, water and air resources that interact to affect the biophysical and cultural management practices that can influence the development and propagation of soil-borne diseases. Key research is highlighted that has direct relevance to understanding, predicting the occurrence of, and managing soil-borne disease.

a. **Key Relevant Research** - in this area (conducted by USDA ARS National Lab for Agriculture and the Environment and its collaborators) that is related to soil-borne diseases can be grouped into two general areas: (1) Soil Health and Plant Health and the Remote Sensing Techniques used to assess them, and (2) Plant and Soil Stress caused by Agricultural Intensification and Climate Variability and Weather Extremes.

b. **Applicability -** These two general areas of research are particularly relevant (1) to understanding and monitoring the biophysical characteristics that contribute to healthy soil and plant conditions and (2) can potentially help to understand and detect biophysical conditions that can contribute to the emergence of pathogens in soil and plant stress.

c. **Technology Readiness -** The concepts and techniques used to understand and describe soil health, monitor and predict plant growth or soil conditions contributing to health plant growth, and the remote sensing techniques used in both of these efforts is well developed and fairly mature with application currently being applied to numerous crop and soil types and numerous geographic locations. These techniques therefore are given a *Technology Readiness Score of 5*. The concepts and techniques used to understand and describe plant stress caused by agricultural intensification and/or climate variability and weather extremes while developing rapidly still required some maturity as to application to a wider variety of crop types and weather/climate/microclimatic conditions. It therefore is given a *Technology Readiness Score of 4*.

d. **Additional Work Required -** Additional work is necessary to evaluate the plant-scale, field-scale, and farm-scale variations in biophysical characteristics that occur to both plants and soils as a result of agricultural intensification and microclimatic variation. These variations and responses need to be observed at the plant to region scale for different crops and in different geographic locations. Additional work can be conducted to monitor, record, and analyze the conditions, processes, and responses to changing conditions in both the plant and the soil at these varying scales. Simplifications of these relationships can be tested and adapted for use in decision tools monitoring soil-borne disease.

e. **Key Gaps -** The biggest gap that exists at this time is the absence of specific relationships between biophysical conditions, specific crops and specific variations in agricultural intensification and microclimatic variability in the YCEDA-specific crops and growing regions.

f. **Key Researchers -**
Jerry Hatfield (USDA - ARS - NLAE)
John Prueger (USDA - ARS - NLAE)
Charlie Walthall (USDA - ARS - Headquarters)
Mark Tomer (USDA - ARS - NLAE)
L.E. Jackson (UC - Davis)
K.J. Boote (University of Florida)
J.W. Jones (University of Florida)

g. **Related Literature** -

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3. **Sensor Technology**:

   a. **Key Relevant Research** - in this area that is related to soil-borne diseases can be grouped into the following three topics, including: (1) Remote Sensing Technology including unmanned and manned Space and Air Platforms, (2) Proximal Soil Sensing, (3) Soil-Plant Health, Soil-Plant-Water Interactions and how they are measured and/or monitored using Remote Sensing.

   b. **Applicability -** These three general areas of research are particularly relevant to the development of operational tools that can help understand, detect, and monitor soil-borne diseases in fresh produce because they

i. provide rapidly evolving hardware platforms of sensors that are beginning to possess both the spatial resolution (to detect individual plants with appropriate clarity) and the spectral resolution (to detect changes caused by a change in soil conditions, plant stress, or soil-borne diseases);

ii. provide proximal (ground-surface or near-surface) sensors that allow users to correlate ground-conditions with measurements or readings provided by space- or air-based platforms; and they

iii. provide a collection of relationships, algorithms, and/or mathematical models that help translate the measurements in biophysical relationships between soil, plant, and water that ultimately result in understanding the presence, absence, or triggers of soil-borne disease on the farm.

c. **Technology Readiness -** The table below provides a list of existing sensor platforms and associated spatial and spectral resolutions along with other relevant characteristics including the assigned *Technology Readiness Score*. While platforms with higher spectral and spatial resolution provide benefits of detection they currently have characteristics that make them less operational and less easy-to-use including the overflight recurrence, the volume of data management required, the flexibility of flight schedule and the acquisition costs of the data.

Effective Resolution	Platform	Bands	Spatial Resolution	Overflight Recurrence	Data Volume	Flight Schedule Flexibility	Acquisition Costs	Technology Readiness
30 m	High Earth Orbit Satellite	Blue, Green, Red, NIR1, NIR2, Mid-IR	Marginal	2x/Month	Minimal	None	Free	[5]
5 m	Low Earth Orbit Satellite	Blue, Green, Red, Red-Edge, NIR	Marginal	1 to 5 Days	Moderate	None	Low/Moderate	[5]
1 m	Low Earth Orbit Satellite	Coastal, Blue, Green, Yellow, Red, Red-Edge, NIR1, NIR2	Marginal	Daily	Moderate	None	Low/Moderate	[5]
0.500 m (50 cm)	Low Earth Orbit Satellite	Blue, Green, Red, NIR1	Yes	Daily	Significant	None	Low/Moderate	[5]
0.300 m (30 cm)	Low Earth Orbit Satellite	Blue, Green, Red, NIR1	Yes	Daily	Significant	None	Low/Moderate	[5]
0.089 m (8.9 cm)	Unmanned Aircraft	Thermal	Useful	As Needed	Significant	Limited	High	[3-4]
0.068 m (6.8 cm)	Unmanned Aircraft	Blue, Green, Red, Red-Edge, NIR	Exceptional	As Needed	Significant	Limited	High	[3-4]
0.025 m (2.5 cm)	Manned Aircraft (Cessna)	Blue, Green, Red, NIR	Exceptional	As Needed	Tremendous	Flexible	Low/Moderate	[4]
0.013 m (1.3 cm)	Unmanned Aircraft	Blue, Green, Red	Exceptional	As Needed	Tremendous	Limited	High	[3-4]
0.013 m (1.3 cm)	Unmanned Aircraft	Blue, Green, NIR	Exceptional	As Needed	Tremendous	Limited	High	[3-4]
0.013 m (1.3 cm)	Unmanned Aircraft	Red, Green, NIR	Exceptional	As Needed	Tremendous	Limited	High	[3-4]
0.007 m (0.7 cm)	Unmanned Aircraft	Blue, Green, Red	Exceptional	As Needed	Tremendous	Limited	High	[3-4]

With respect to proximal soil sensing techniques, there are sufficiently mature tools available that can provide accurate measurements and ground-truth to correlate to space- or air-based remote sensors these are assigned *Technology Readiness Score of 5*.

The broad area of research tying remote sensing data and information to a better understanding of soil-plant-water relationships is also rapidly evolving. The USDA ARS has made significant investment of resources into this research over the last several decades. As a result, between USDA ARS staff at the National Lab for Agriculture and the Environment, USDA ARS Headquarters, Earth Knowledge, and both of their collaborators there exists a substantial body of data, information, and knowledge to operationalize these capabilities to address the fresh produce soil-borne disease issues facing YCEDA. These approaches are assigned a *Technology Readiness Score of 4*.

d. **Additional Work Required -** The main focus of additional work for the above described sensor technologies is to sufficiently link the three main groups of technologies into an integrated system that provide seamless detection, from air or space, correlation to ground conditions, quick analysis of the data, and presentation into a simple and usable presentation of information for the grower and their field staff.

e. **Key Gaps -** The biggest gap that exists at this time is the absence of specific linkages between the sensor platforms (Space, Air, and Ground) and the algorithms and models developed by researchers describing soil-plant-water interactions with soil-borne disease or even more general "precision crop management" tools. This is an area that has very good potential for research opportunities for YCEDA.

f. **Key Researchers -**
Jerry Hatfield (USDA - ARS - NLAE)
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Charlie Walthall (USDA - ARS - Headquarters)
J. Alfieri (USDA - ARS - Headquarters)
Martha Anderson (USDA - ARS - Headquarters)
Bill Kustas (USDA - ARS - Headquarters)

g. **Related Literature** -

V.I. Adamchuk, McGill University; B. Allred, *USDA-ARS-Soil Drainage Research Unit*; J. Doolittle, *USDA-NRCS-NSSC*; K. Grote, University of Wisconsin-Eau Claire; and R.A. Viscarra Rossel, CSIRO, Land and Water Flagship, Chapter on *Tools for Proximal Soil Sensing* in Book:Soil Survey

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R. A. Viscarra Rossel, V. I. Adamchuk, K. A. Sudduth, N. J. McKenzie, and C. Lobsey ,2011 *Proximal Soil Sensing: An Effective Approach for Soil Measurements in Space and Time*. In Donald L. Sparks, editor: Advances in Agronomy, Vol. 113, Burlington: Academic Press, 2011, pp. 237-282..

C. Walthall, W. Dulaney, M. Anderson, J. Norman, H. Fang, and S. Liang, "*A comparison of empirical and neural network approaches for estimating corn and soybean leaf area index from Landsat ETM+ imagery*, Remote Sens. Environ., 92, 465-474 (2004).

A. Zerger, R.A. Viscarra Rossel, D.L. Swain, T. Wark, R.N. Handcock, V.A.J. Doerr, G.J. Bishop-Hurley, E.D. Doerr, P.G. Gibbons, C. Lobsey, 2010, *Environmental sensor networks for vegetation, animal and soil sciences*, International Journal of Applied Earth Observation and Geoinformation, Vol. 12, No. 5, pp. 303-316.

4. Analytics, Models, and Decision Tools:

a. **Key Relevant Research** - A long list of analytical and numerical modeling tools exist to represent and/or approximate biophysical processes of soil, water, crops, and cropping systems. For decades, the USDA ARS and its collaborators have invested a tremendous amount of research funding into the development of plant/soil growing-degree-day models, agroclimatic models, crop-system models, soil-water assessment models, surface-water and ground-water models with integrated farm processes, soil nutrient balance models, and soil-water salinity models.

b. **Applicability -** Many of these tools have important capabilities that can be used to assist in the development of decision tools to guide growers in their efforts to understand and combat soil-borne diseases. With a focus on selecting the most likely tools to help growers in the short term, the most simple biophysical models are the most appropriate. These include the straight-forward growing-degree-day models and the agroclimatic models. For a detailed description of each model see the details provided in the list of "Related Literature" - Section G Below.

c. **Technology Readiness -** The Technology Readiness Scores for the long list of Models and Decision Tools are included in the list of "Related Literature" - Section G Below. [Additional descriptions of each model or decision tool is also included.]

d. **<u>Additional</u> <u>Work</u> <u>Required</u> -** With respect to growing-degree-day models and agroclimatic models, additional work is necessary to evaluate specific crops and specific geographic regions. This effort will require working with growers to record model-specific variables for each crop and to run models to derive crop specific versions.

All of the models listed require varying degrees of testing to understand the degree to which they can be integrated. Some standouts like DSSAT and MODFLOW-OWHM have developed significant modular capabilities. These capabilities should be explored to better understand how this modular approach can be adapted for integrating different combinations of the models listed.

e. **<u>Key</u> <u>Gaps</u> -** The biggest gap that exists at this time is the absence of specific models for the specific fresh produce crops and the specific geographic regions important to YCEDA. This will be a key focus of collaborative efforts with USDA ARS NLAE.

f. **<u>Key Researchers</u> -**
Jerry Hatfield (USDA - ARS - NLAE)
K.J. Boote (University of Florida)
J.W. Jones (University of Florida)
SWAT Development Team at Texas A&M University and USDA ARS
MODFLOW Developers at USGS and University of Kansas
DNDC Developers at University of New Hampshire

g. **<u>Related Literature</u>** -

<u>Top-Tier - Models / Decision Tools - Technology Readiness of 4 - 5</u>

Plant / Soil Growing-Degree-Day Models (Various Developers)

Kumudini, S., Andrade, F.H., Boote, K.J., Brown, G.A., Dzotsi, K.A., Edmeades, G.O., Gocken, T., Goodwin, M., Halter, A.L., Hammer, G.L., Hatfield, J.L., Jones, J.W., Kemanian, Kim, S.H., Kiniry, J., Lizaso, J.I., Nendel, C., Nielsen, R.L., Parent, B., Stockle, C.O., Tardieu, F., Thomison, P.R., Timlin, D.J., Vyn, T.J., Wallach, D., Yang, H.S., and Tollenaar, M., 2014, *Predicting Maize Phenology: Interconnection of Functions for Development Response to Temperature*, Agronomy Journal, Vol. 106, Issue 6, pp. 2087-2097.

Agroclimatic Models (Various Developers) - Incorporate factors affecting the shift of crop growing regions as a result of climate variability and recurring extreme weather events.

Hatfield, J.L., and Dold, Christian, in prep, *Chapter 2: Climate Variability effects on agriculture land use and soil services*, in Book: Soil Health and Intensification of Agroecosystems (in prep)

Jackson, L.E., Wheeler, S.M., Hollander, A.D., O'Geen, A.T., Orlove, B.S., Six, J., Sumner, D.A., Santos-Martin, F., Kramer, J.B., Horwath, W.R., Howitt, R.E., Tomich, T.P., 2011, *Case study on potential agricultural responses to climate change in a California landscape*, Climate Change, Vol 109, Supplement 1, pp. S407-427

Klein, T., Holzkamper, A., Calanca, P., Seppelt, R., Fuhrer, J., 2013, *Adapting agricultural land management to climate change: a regional multi-objective optimization approach*, Landscape Ecology, p. 19.

Middle-Tier - Models / Decision Tools - Technology Readiness of 4 - 5

DSSAT - Decision Support System for Agrotechnology Transfer -- Univ of Florida / Univ of Georgia

- The Decision Support System for Agrotechnology Transfer (DSSAT) Version is a software application program that comprises crop simulation models for over 42 crops (as of Version 4.6).
- For DSSAT to be functional it is supported by data base management programs for soil, weather, and crop management and experimental data, and by utilities and application programs. The crop simulation models simulate growth, development and yield as a function of the soil-plant-atmosphere dynamics.
- DSSAT and its crop simulation models have been used for many applications ranging from on-farm and precision management to regional assessments of the impact of climate variability and climate change. It has been in use for more than 20 years by researchers, educators, consultants, extension agents, growers, and policy and decision makers in over 100 countries worldwide.
- The crop models require daily weather data, soil surface and profile information, and detailed crop management as input. Crop genetic information is defined in a crop species file that is provided by DSSAT and cultivar or variety information that should be provided by the user. Simulations are initiated either at planting or prior to planting through the simulation of a bare fallow period. These simulations are conducted at a daily step and, in some cases, at an hourly time step depending on the process and the crop model. At the end of the day the plant and soil water, nitrogen and carbon balances are updated, as well as the crop's vegetative and reproductive development stage.

- DSSAT combines crop, soil, and weather data bases with crop models and application programs to simulate multi-year outcomes of crop management strategies.

SWAT - Soil Water Assessment Tool -- USDA-ARS, Temple, TX

- Predict the effect of management decisions on water, sediment, nutrient and pesticide yields with reasonable accuracy in watersheds
- Model Components -- Weather, surface runoff, return flow, percolation, ET, transmission losses, pond and reservoir storage, crop growth and irrigation, groundwater flow, reach routing, nutrient and pesticide loading, water transfer.
- Comprehensive publications list can be found at http://swat.tamu.edu/publications/

MODFLOW-OWHM - Modular Surface-water / Ground-water Modeling with Farm Processes and additional capabilities -- US Geological Survey

- The One-Water Hydrologic Flow Model (MF-OWHM) is a MODFLOW-based integrated hydrologic flow model (IHM).
- It is designed for the analysis of a broad range of conjunctive-use issues.
- Conjunctive use is the combined use of groundwater and surface water.
- It allows the simulation, analysis, and management of human and natural water movement within a physically-based supply-and-demand framework.
- It includes detailed simulation of Farm Processes included crop-rotation and associated complex irrigation processes.

DNDC - DeNitrification and DeComposition Model -- Univ of New Hampshire

- Model of carbon and nitrogen biogeochemistry in agro-ecosystems.
- The model can be used for predicting crop growth, soil temperature and moisture regimes, soil carbon dynamics, nitrogen leaching, and emissions of trace gases including nitrous oxide (N_2O), nitric oxide (NO), dinitrogen (N_2), ammonia (NH_3), methane (CH_4) and carbon dioxide (CO_2).

Lower-Tier - Models / Decision Tools - Technology Readiness of 4 - 3

ESAP Model - Soil Salinity Model -- US Salinity Lab, USDA-ARS, Riverside, CA

- Statistical software package for estimating field scale spatial salinity patterns from electromagnetic induction signal data

SWMS-3D Model - Soil Salinity Model -- US Salinity Lab, USDA-ARS, Riverside, CA

- Simulates Water and Solute Movement in soils in three dimensions

HYDRUS 3D Model - Soil-Moisture Modeling in Three-Dimensions -- Princeton University

- Used in hundreds, if not thousands of applications referenced in peer-reviewed journal articles and many technical reports

REMM - Riparian Ecosystem Management Model -- USDA-ARS, Tifton, GA

- Developed as a modeling tool that can help quantify the water quality benefits of riparian buffers under varying site conditions.
- Processes simulated in REMM include: surface and subsurface hydrology; sediment transport and deposition; carbon, nitrogen, and phosphorus transport, removal and cycling; and vegetation growth.
- Simulations are performed on a daily basis and can be continued in excess of 100 years

Bottom-Tier - Models / Decision Tools - Technology Readiness of 3

CROPSYST 3.0 - Cropping Systems Modeling Framework -- Washington State University

- CropSyst is a is a user-friendly, conceptually simple but sound multi-year multi-crop daily time step simulation model.
- The model has been developed to serve as an analytic tool to study the effect of cropping systems management on productivity and the environment.
- The model simulates the soil water budget, soil-plant nitrogen budget, crop canopy and root growth, dry matter production, yield, residue production and decomposition, and erosion.
- Management options include: cultivar selection, crop rotation (including fallow years), irrigation, nitrogen fertilization, tillage operations (over 80 options), and residue management.

SALUS - System Approach to Land-use Sustainability -- Michigan State University

- The SALUS (System Approach to Land Use Sustainability) program is designed to model continuous crop, soil, water and nutrient conditions under different management strategies for multiple years.

- These strategies may have various crop rotations, planting dates, plant populations, irrigation and fertilizer applications, and tillage regimes.
- The program will simulate plant growth and soil conditions every day (during growing seasons and fallow periods) for any time period when weather sequences are available.
- For any simulation run, a number of different management strategies can be run simultaneously.
- By running the different strategies at the same time we can compare this effect on crops and soil under the same weather sequences.
- This also provides a framework whereby the interaction between different areas under different management practices can be easily compared.
- Every day, and for each management strategy being run, all major components of the crop-soil-water model are executed.
- These components are management practices, water balance, soil organic matter, nitrogen and phosphorous dynamics, heat balance, plant growth and plant development.
- The water balance considers surface runoff, infiltration, surface evaporation, saturated and unsaturated soil water flow, drainage, root water uptake, soil evaporation and transpiration.
- The soil organic matter and nutrient model simulates organic matter decomposition, N mineralization and formation of ammonium and nitrate, N immobilization, gaseous N losses and three pools of phosphorous.
- The development and growth of plants considers the environmental conditions (particularly temperature and light) to calculate the potential rates of growth for the plant.
- This growth is then reduced based on water and nitrogen limitations.

h. <u>Important Collaboration Opportunity with Modeling Community</u>

AgMIP (The Agricultural Model Intercomparison and Improvement Project) -- International Consortium

- Incorporate state-of-the-art climate products as well as crop and agricultural trade model improvements in coordinated regional and global assessments of future climate impacts
- Include multiple models, scenarios, locations, crops and participants to explore uncertainty and impact of data and methodological choices
- Collaborate with regional experts in agronomy, economics, and climate to build strong basis for applied simulations addressing key climate-related questions

- Improve scientific and adaptive capacity for major agricultural regions in the developing and developed world
- Develop framework to identify and prioritize adaptation strategies
- Key Publications include:

  Rosenzweig, Cynthia; Jones, J. W.; Hatfield, J. L.; Ruane, A. C.; Boote, K. J.; Thornburn, P.; Antle, J. M.; Nelson, G. C.; Porter, C.; Janssen, S.; Asseng, S.; Basso, B.; Ewert, F.; Wallach, D.; Baigorria, G.; and Winter, J. M., "***The Agricultural Model Intercomparison and Improvement Project (AgMIP): Protocols and pilot studies***" (2013). Papers in Natural Resources. Paper 445

  Antle, J. M., J. W. Jones and C. Rosenzweig, 2015. ***Towards a New Generation of Agricultural System Models, Data, and Knowledge Products: Introduction***. AgMIP, <http://goo.gl/MjNjHy>.

  Jones, J. W., J. M. Antle, B. O. Basso, K. J. Boote, R. T. Conant, I. Foster, H. C. J. Godfray, M. Herrero, R. E. Howitt, S. Janssen, B. A. Keating, R. Munoz-Carpena, C. H. Porter, C. Rosenzweig, and T. R. Wheeler, 2015. ***Towards a New Generation of Agricultural System Models, Data, and Knowledge Products: State of Agricultural Systems Science***. AgMIP, <http://goo.gl/f4eVl4>.

  Antle, J. M., B. O. Basso, R. T. Conant, C. Godfray, J. W. Jones, M. Herrero, R. E. Howitt, B. A. Keating, R. Munoz-Carpena, C. Rosenzweig, P. Tittonell, and T. R. Wheeler, 2015. ***Towards a New Generation of Agricultural System Models, Data, and Knowledge Products: Model Design, Improvement and Implementation***. AgMIP, <http://goo.gl/S9gpUH>.

  Janssen, S., C. H. Porter, A. D. Moore, I. N. Athanasiadis, I. Foster, J. W. Jones, and J. M. Antle, 2015. ***Towards a New Generation of Agricultural System Models, Data, and Knowledge Products: Building an Open Web-Based Approach to Agricultural Data, System Modeling and Decision Support***. AgMIP, <http://goo.gl/kg81jf>.

5. **Scaling of Information:**
   Scaling of information refers to the ability to scale a measurement, a sensor reading, a model outcome, or a decision tool prediction from the scale of observation to a different scale. For example, a measurement can be made at the plant scale and need to be "scaled" so that its relevance at the farm or the regional scale can be determined. The development of operational tools to assist with identifying, understanding, and informing decisions related to soil-borne

disease are highly dependent on the tool's ability to scale. The highest value comes from the ability to transfer and extrapolate a "limited" number of observations and information from a "small" number of filda to all fields in a grower's operation to all fields in a given growing region.

a. **Key Relevant Research** - Significant research advances have been accomplished by the USDA ARS Remote Sensing and Hydrology Lab in Beltsville, MD. Likewise, the ability to scale measurements and model outcomes from the field to the region has been a significant focus of the USDA ARS Team at New Mexico State University, in Las Cruces, NM.

b. **Applicability -** The importance of these capabilities cannot be overstated. The ability to transfer information or knowledge about a specific plant to an entire field to an entire growing region is critical to developing a decision tool that is truly useful and usable by growers throughout the Fresh Produce sector.

c. **Technology Readiness -** The tools and methods developed by the USDA ARS Remote Sensing and Hydrology Lab have focused specifically on the plant-to-field scale while the efforts of the USDA ARS Team in New Mexico have been focused on the field-to-region scale. WHile not specifically focused on Fresh Produce and soil-borne disease, these techniques represent the true state-of-the-art. They are assigned a Technology Readiness score of 4.

d. **Additional Work Required -** Additional work is required to specifically link measurements and model outcomes of specific crop-plants in and extrapolate to different field and different geographic regions. This work is a specific focus of both USDA ARS Teams.

e. **Key Gaps -** The biggest gap that exists at this time is the absence of specific extrapolations from specific crops and geographic regions to the same crop in different geographic regions. The Earth Knowledge - USDA ARS Initiative is specifically focused on addressing this complexity.

f. **Key Researchers -**
   Jerry Hatfield (USDA - ARS - NLAE)
   Debra Peters (USDA - ARS - New Mexico)
   Brandon Bestelmeyer (USDA - ARS - New Mexico)

g. **Related Literature** -

Eigenbrode, SD, Morton, L.W., and Martin, T.A., 2014, *Big interdisciplinarity to address climate change and agriculture: Lessons from* *three USDA Coordinated Agricultural Projects*, Journal of Soil and Water Conservation, Vol. 69, No. 6, pp. 170A-175A

Papanicolaou, A.N., Wacha, K.M., Abban, B.K., Wilson, C.G., Hatfield, J.L., Stanier, C.O. and Filley, T.R., 2015, From soilscapes to landscapes: *A landscape-oriented approach to simulate soil organic carbon dynamics in intensively managed landscapes*, J. Geophys. Res. Biogeosci., 120, 2375–2401.

Debra P.C. Peters, Brandon T. Bestelmeyer, and Monica G. Turner, 2007, *Cross–Scale Interactions and Changing Pattern–Process Relationships: Consequences for System Dynamics*, Ecosystems, Vol. 10, pp. 790–796

Debra P.C. Peters, Brandon T. Bestelmeyer, Jeffrey E. Herrick, Ed L. Fredrickson, H. Curtis Monger, and Kris M. Havstad, 2009, *Disentangling Complex Landscapes: New Insights into Arid and Semiarid System Dynamic*s, Bioscience, Vol. 56 No. 6, pp. 491-501

Rick Estell and Debra PC Peters, 2006, *Introduction to special issue—Landscape linkages and cross-scale interactions in arid and semi-arid ecosystems*, Journal of Arid Environments, Vol. 65, pp. 193–195

Debra PC Peters, Peter M Groffman, Knute J Nadelhoffer, Nancy B Grimm, Scott L Collins, William K Michener, and Michael A Huston, 2008, *Living in an increasingly connected world: a framework for continental-scale environmental science*, Front Ecol Environ, Vol. 6, No. 5, pp. 229–237.

Evertje Frederika Lawley, Megan M. Lewis, Bertram Ostendorf, *A remote sensing spatio-temporal framework for interpreting sparse indicators in highly variable arid landscapes*. Ecological Indicators, p. 14.

Partnership Opportunities

The ongoing research and potential new research opportunities described above present an important means for YCEDA to expand its own research activities and achieve its overall goal of providing actionable tools for industry growers.

A clear understanding of existing research being conducted by the USDA ARS, their collaborators, and associated agencies and institutions highlights important themes (such as disease pathology, cropping systems, sensor technology, analytics, and field-to-region scaling), and also directs YCEDA to specific potential projects that can necessarily fill important gaps in the information and knowledge YCEDA seeks to address its organizational needs.

Throughout this exercise, researchers from the various USDA ARS offices, laboratories, teams, and division were asked about potential interest in partnering with YCEDA and the broader Fresh Produce sector. In every case, the response was consistently positive.

In addition to the obvious collaborations with research organizations, YCEDA should also look to partner with a broader set of industry groups in the Arizona and California region but also in related Specialty Crop sectors (fruit, grape/wine, citrus, tree nuts, etc) and in broader geographic regions (Northwest, Upper Midwest, Texas, and Southeast U.S. and International localities). These potential partners would have shared goals and interests in understanding and managing soil-borne disease and ultimately attaining higher produce yields and quality in similar microclimates and crops.

Possible partner groups and examples include:

- trade associations (Western Growers Association, United Fresh Produce Association)
- food production and distribution companies (Del Monte Foods, Dole Food Company, Driscoll's)
- specialized fresh produce growers (Grimmway Farms, R.D. Offutt Company, Lipman Farms)

Research Funding Opportunities

To assist in achieving many of these research goals, YCEDA should seek funding opportunities in three broad areas including government grants, foundation grants, and legislative initiatives. Examples of each are described below.

An important ***government grant program*** that addresses both the very specific research needs and the broad geographic reach of the industry problem of soil-borne diseases in fresh produce is the Specialty Crop Research Initiative (SCRI) sponsored by the US Department of Agriculture's National Institute of Food and Agriculture (NIFA) which is the main granting arm of the USDA.

The purpose of the SCRI program (which has maximum awards of $5M over 5 years) is to address the critical needs of the specialty crop industry by awarding grants to support research and extension that address key challenges of national, regional, and multi-state importance in sustaining all components of food and agriculture, including conventional and organic food production systems. Projects must address at least one of five focus areas (which is directly aligned with YCEDA's priorities):

- Research in plant breeding, genetics, genomics, and other methods to improve crop characteristics
- Efforts to identify and address threats from pests and diseases, including threats to specialty crop pollinators

- Efforts to improve production efficiency, handling and processing, productivity, and profitability over the long term (including specialty crop policy and marketing)
- New innovations and technology, including improved mechanization and technologies that delay or inhibit ripening
- Methods to prevent, detect, monitor, control, and respond to potential food safety hazards in the production efficiency, handling and processing of specialty crops.

A significant ***foundation grant program*** that likewise supports the specific YCEDA need and geographic reach is sponsored by the Foundation for Food and Agriculture Research (FFAR). FFAR builds unique partnerships to support innovative and actionable science addressing food and agriculture challenges. The Foundation was established by the Farm Bill passed in 2014 and charged with complementing and furthering the important work of the U.S. Department of Agriculture. Leveraging public and private resources, FFAR increases the scientific and technological research, innovation, and partnerships critical to enhancing sustainable production of nutritious food for a growing global population. FFAR is a 501 (c) (3) non-profit organization governed by a Board of Directors, chaired by former Secretary of Agriculture Dan Glickman. It's programs require a one-to-one match of cash and in-kind contributions from industry partners. FFAR has specific "Challenge Areas" dedicated to soil health and water scarcity which would dovetail with YCEDA's soil-borne disease initiative. Awards are typically $1M; however, the Foundation is still fairly new and has an innovative collection of advisory panels that might be open to new research themes, projects, and funding structures.

Another very significant funding opportunity exists in the potential to ***develop support for legislative action at the national level***. In discussions with USDA ARS, it became quite clear that the adverse economic impact of soil-borne diseases on the fresh produce industry issue has significant bearing on both national food security and national economic security. As a result, YCEDA along with other industry partners can solicit the development and passage of a Bill that specifically supports the development of information, tools, techniques, and adoption of soil-borne disease management in the fresh produce industry. A similar legislative effort resulted in the addition of the Specialty Crop Research Initiative to the National Farm Bill that is funded at around $40M each year. Both Earth Knowledge and the USDA ARS National Laboratory for Agriculture and the Environment have recommended the creation of a YCEDA special advisory group to spearhead innovative approaches to move such an initiative at the regional and national levels. A likely funding target would be in the area of $25M to $40M.