Appendix 4

Crop Systems Suitability

Contents

Crop Systems Suitability

Theme Subcommittee Members

The Flood-MAR Crop Systems Suitability Subcommittee consists of 2 co-chairs, 15 sub-committee members, and a theme coordinator. Subcommittee members are listed by name, title, and affiliation below.

Position	Name and Title	Affiliation	Email
State Co-Chair	Amrith Gunasekara, Science Advisor to the Secretary	California Department of Food and Agriculture	amrith.gunasekara@cdfa.ca.gov
Non-State Co-Chair	Doug Parker Director, California Institute for Water Resources	University of California (UC), Division of Agriculture and Natural Resources	Doug.Parker@ucop.edu
Sub-committee Member	Toby O'Geen, CE Specialist	UC Davis	atogeen@cudavis.edu
Sub-committee Member	Helen Dahlke, Assistant Professor	Department of Land, Air and Water Resources, UC Davis	hdahlke@ucdavis.edu
Sub-Committee Member	Dan Putnam, CE Specialist	UC Davis	dhputnam@ucdavis.edu
Sub-committee Member	Patrick Brown, Professor	UC Davis	phbrown@ucdavis.edu
Sub-Committee Member	Ladi Asgill, Sr. Agronomist	Sustainable Conservation	LAsgill@suscon.org
Sub-committee Member	Matthew Fidelibus, CE Specialist	UC Davis	mwfidelibus@ucdavis.edu
Sub-committee Member	Don Cameron, Grower	Terranova Ranch	dcameron@terranovaranchinc.com

Position	Name and Title	Affiliation	Email
Sub-committee Member	Jim Morris, Grower	Bryan-Morris Ranch	jim@bryan-morrisranch.com
Sub-committee Member	Al Costa, Grower		teraredrose2002@yahoo.com
Sub-committee Member	Gabriele Ludwig, Research Lead	Almond Board	gludwig@almondboard.com
Sub-Committee Member	Danield Munk, Farm Advisor	UC Division of Agriculture and Natural Resources	dsmunk@ucanr.edu
Sub-committee Member	Kurt Kautz, CE Specialist	Kautz Farms	kkautz@kautzfarms.com
Sub-committee Member	Akif Eskalen, CE Specialist	UC Davis	aeskalen@ucdavis.edu
Sub-committee Member	Cassandra Swett, CE Specialist	UC Davis	clswett@ucdavis.edu
Sub-committee Member	Ajay Singh, Assistant Professor	Department of Environmental Studies California State University, Sacramento	Singh@csus.edu
Theme Coordinator	Francisco Flores-Lopez, Water Resources Engineer	California Department of Water Resources	Francisco.FloresLopez@water.ca.gov

Engagement Process

The subcommittee’s objective was to identify the existing information and gaps in cropping systems suitability relative to timing, duration, and frequency of water for manage aquifer recharge.

The State and non-State co-chairs were proposed by the DWR Flood-MAR team. Both co-chairs were selected based on their leadership skills and well-known expertise and experience in the corresponding fields and organizations.

The co-chairs in collaboration with the DWR Flood-MAR team identified a list of potential members to integrate the subcommittee. The identified candidates were experts, practitioners, researchers, and farmers with experience and expertise on the Crop System Suitability theme. The final list of members who accepted to participate in the theme as subcommittee members is shown in the above table.

The subcommittee members had three in-person meetings that lasted from 3 to 6 hours of work each one and several phone call meetings between co-chairs and the theme coordinator to organize, process, and review the theme’s contribution to the RAC.

The crop systems suitability theme faced the challenge of characterizing a research arena with a large gap in research and consequently knowledge in order for scientist to provide recommendations on crop systems suitability.

Available Research, Data, and Tools

The tables below summarize the available research, data and tools related to the Crop Systems Suitability theme. This information presented is based on subcommittee members suggestions.

Table 1 Soil Agricultural Groundwater Banking Index

Category: Tool Scale: State Availability: Available
Other Themes That Will Benefit:
Public Benefits Informed By:
Description, including Connection to Flood-MAR: This tool identifies soil suitability for Flood-MAR based on five soil and site characteristics. In its design authors considered perennial crop suitability through a questionnaire directed at UCCE experts.
Website: https://casoilresource.lawr.ucdavis.edu/sagbi/ Contact: Toby O'Geen Email: atogeen@ucdavis.edu

Table 2 Series Extent Explorer

Category: Tool Scale: State Availability: Available
Other Themes That Will Benefit:
Public Benefits Informed By:
Description, including Connection to Flood-MAR:
Website: https://casoilresource.lawr.ucdavis.edu/see/ Contact: Toby O'Geen Email: atogeen@ucdavis.edu

Table 3 SoilWeb

Category: Tool Scale: State Availability: Available
Other Themes That Will Benefit:
Public Benefits Informed By:
Description, including Connection to Flood-MAR: This tool provides online access to soil survey data. It contains a wide range of soil information that in concert with crop type could be used to identify suitability for Flood-MAR.
Website: https://casoilresource.lawr.ucdavis.edu/gmap/ Contact: Toby O'Geen Email: atogeen@ucdavis.edu

Table 4 SoilWeb Earth

Category: Tool Scale: State Availability: Available
Other Themes That Will Benefit:
Public Benefits Informed By:
Description, including Connection to Flood-MAR: This tool is identical to SoilWeb (above) but uses Goggle Earth instead of Google Maps. In some instances, this tool could be preferable such as site planning where google earth pro may be used in visualizing a site.
Website: https://casoilresource.lawr.ucdavis.edu/soilweb-apps Contact: Toby O'Geen Email: atogeen@ucdavis.edu

Table 5 Plant Waterlogging: Causes, Responses, Adaptations and Crop Models

Category: Research

Scale: State

Availability: Available

Other Themes That Will Benefit:

Public Benefits Informed By:
Understanding of abiotic factors that influence plant health and yield under waterlogged conditions.

Description, including Connection to Flood-MAR: Ph.D. thesis that researched waterlogging effects on plant health and crop yield. Research identifies physical factors causing waterlogging, plant morphological factors that indicate abiotic stress, causes of abiotic stress, and adaptation and responses to water logging. Most research is presented for many species. Research conducted in Australia.

Website: https://digital.library.adelaide.edu.au/dspace/bitstream/2440/94087/3/02whole.pdf
Contact: Helen Dahlke
Email: hdahlke@ucdavis.edu

Table 6 Effect of Ridging on the Performance of Young Grapevines on a Waterlogged Soil

Category: Research

Scale: State

Availability: Available

Other Themes That Will Benefit:

Public Benefits Informed By:
Understanding of abiotic factors that influence plant health and yield under waterlogged conditions.

Description, including Connection to Flood-MAR: Study investigated the effect of ridging on root development, vegetative growth and yield of young grapevines cv. Chenin bland99R in a field trial on a soil naturally waterlogged during winter and early summer. Ridging tended to improve root efficiency as well as general grapevine performance compared to unridged soil. There was no significant difference in vegetative growth of grapevines planted on 400mm-high double row, 600mm-high double row or 400mm-high, single-row ridges. Yield, however, decreased where the surface to volume ratios of double row and single row ridges were less than 0,6 and 1,0 respectively. This implied that excessively dry and warm soil conditions had occurred during ripening where the ridges were too large. Irrigation in combination with ridging resulted in significantly improved vegetative growth and higher yield compared to the unripped control treatment. Preliminary ripping of compacted subsoil to a depth of 550 mm tended to improve vegetative growth and yield of ridged as well as unridged treatments. Ridging had no signiticant effect on total soluble solids, total titratable acidity and pH of musts.

Website: http://www.journals.ac.za/index.php/sajev/article/view/2274
Contact: Helen Dahlke
Email: hdahlke@ucdavis.edu

Table 7 Selection of Rootstocks for Flooding and Drought Tolerance in Citrus Species

Category: Research

Scale: State

Availability: Available

Other Themes That Will Benefit:

Public Benefits Informed By: Understanding of abiotic factors that influence plant health and yield under waterlogged conditions.

Description, including Connection to Flood-MAR: The tolerance levels of citrus trees to different degrees of drought and flooding was studied by using twenty-three species and varieties. Rough lemon, trifoliate orange, lemon and Cleopatra mandarin were evaluated as the most flooding tolerant; Yuzu, 'Kawano' natsudaidai, Kinukawa-mikan, 'Tanaka' navel orange and Ponkan as medium; and Hana-daidai, Kosuito, Naruto-mikan and Natsudaidai as least tolerant. Trifoliate orange, Yuzu, Shiikuwasha, Hana-daidai, 'Tanaka' navel orange, Natsudaidai, Shute, Yamabuki , Ponkan and 'Shiranui' were evaluated as the most drought tolerant; Cleopatra mandarin, Naruto-mikan and Murcot as medium and Rough lemon, lemon, Ban-okan and 'Kawano' natsudaidai as drought intolerant. The effect of flooding and drought on 1-aminocyclopropane-1-carboxylic acid (ACC) content and ethylene production in the roots of these several species and varieties was determined. The ACC content and ethylene production in the roots increased more rapidly in sensitive species in response to water stress. Under flooding conditions, roots maintained higher ethylene production levels than control roots. Sensitive species showed a little greater levels in ethylene production than the tolerant ones. This study was conducted in Japan.

Website: http://www.docsdrive.com/pdfs/ansinet/pjbs/2002/509-512.pdf
Contact: Helen Dahlke
Email: hdahlke@ucdavis.edu

Table 8 Growth Response of Alfalfa to Duration of Soil Flooding and to Temperature

Category: Research

Scale: State

Availability: Available

Other Themes That Will Benefit:

Public Benefits Informed By: Understanding of abiotic factors that influence plant health and yield under waterlogged conditions

Description, including Connection to Flood-MAR: Alfalfa (Medicago saliva L.) is very sensitive to excessive soil water, yet few studies have been done under controlled conditions to quantify the extent of this sensitivity. The objective of these studies was to investigate the effect of wet soil conditions on alfalfa production. The growth of roots and tops was determined in a factorial greenhouse and growth chamber experiment with

treatments for duration of flooding and temperature. Five-week-old alfalfa plants, potted in pasteurized soil, were flooded to the soil surface for 4, 8, 12, 16, and 20 days at temperatures of 16, 21, and 27 C, and for 3, 6, 9, and 12 days at 32 C. Root and top dry weights (DW) of flooded and control plants were measured upon draining. Three weeks after draining, the plants were cut to a 2.5 cm stubble and top DW was measured. After 2 subsequent weeks of regrowth, top and root DWs were again measured. Results demonstrated that root growth stopped during flooding. As measured over the 3 weeks following drainage, the rate of top growth of plants was reduced by 50% with 8 days of flooding at 16 C, 4 days at 21 C, 3 days at 27 C, and 2 days at 32 C. No net top growth occurred during the 3 weeks following drainage in plants flooded for over 14 days at 16 C, 10 days at 21 C, 8 days at 27 C, and 6 days at 32 C. In most cases, the negative response to flooding occurred before the disease Phytophthora megasperma Drechs. is thought to have been able to have an influence. This argues for a physiological as opposed to a pathological basis for the injury. Study was conducted in New York state (Cornell University).

Website: https://dl.sciencesocieties.org/publications/aj/pdfs/73/2/AJ0730020329
Contact: Helen Dahlke
Email: hdahlke@ucdavis.edu

Table 9 The Response of Lucerne Cultivars to Levels Waterlogging

Category: Research

Scale: State

Availability: Available

Other Themes That Will Benefit:

Public Benefits Informed By: Understanding of abiotic factors that influence plant health and yield under waterlogged conditions.

Description, including Connection to Flood-MAR: Note: Note: Lucerne = alfalfa. Five lucerne cultivars were grown for 10 weeks during summer at two irrigation frequencies, specified by evaporation intervals of 38 and 76 mm. Changes in soil moisture were monitored by tensiometers installed at 15 and 30 cm depths. At the first harvest no significant difference in yield was found between treatments. At the second harvest, regrowth of all cultivars was depressed by frequent irrigation, but Du Puits was particularly affected. The yield depression caused by frequent irrigation continued for six months after the treatment ended. The reduced growth following frequent irrigation was related to low soil aeration. In this treatment air-filled pore space in the 15-30 cm horizon remained at or below 15 per cent, a critical level for plant growth. A period of waterlogging for 10 days when the temperature at 5 cm depth remained at approximately 30°C led to reduced production and high mortality in all cultivars. Yields of Lahontan and Siro Peruvian at the end of the waterlogging period were significantly higher than yields of the other three cultivars. The possibility is suggested of increasing the tolerance of lucerne to poor aeration by natural selection on wet soils.

This study conducted in Australia.

Website: http://www.publish.csiro.au/an/pdf/EA9740520
Contact: Helen Dahlke
Email: hdahlke@ucdavis.edu

Table 10 Interaction between Waterlogging Injury and Irradiance Level in Alfalfa

Category: Research

Scale: State

Availability: Available

Other Themes That Will Benefit:

Public Benefits Informed By: Understanding of abiotic factors that influence plant health and yield under waterlogged conditions.

Description, including Connection to Flood-MAR: This study investigates the interaction between irradiance and waterlogging injury in alfalfa (Medicago sativa L.) at various plant developmental stages. Alfalfa was subjected to flooding for 8 to10 d under high or low irradiance levels in controlled environmental chambers. Treatments were imposed on alfalfa 8 and 21 d after planting (DAP) and during regrowth following clipping at 31 DAP. Flooding significantly reduced dry matter accumulation regardless of growth stage, although damage was most severe when flooding was imposed on plants during regrowth after clipping. Irradiance levels primarily affected shoot and root dry matter in 21- and 31-DAP treatments. Much greater shoot dry matter accumulation in non-flooded high-irradiance plants was observed relative to low irradiance plants. A flooding irradiance interaction was found at every growth stage except for root dry weight in the regrowth stage after clipping. The flooding interaction was due to greater injury of flooded high-irradiance plants relative to flooded low-irradiance plants when injury was expressed as a percentage of the unflooded control. Results indicate that the irradiance level during flooding can influence damage rating when expressed as a percentage of control. Assimilate supply to roots was sharply reduced by low irradiance as evidenced by reduced root growth and carbohydrate concentration in unflooded controls. Flood-ing damage, however, was not enhanced under low irradiance, lending support to the hypothesis that carbohydrate (i.e., energy supply) is not a limiting factor in survival of alfalfa roots during short-duration flooding stress.

Website: https://dl.sciencesocieties.org/publications/cs/abstracts/42/5/1529
Contact: Helen Dahlke
Email: hdahlke@ucdavis.edu

Table 11 Flooding Tolerance of Forage Legumes

Category: Research

Scale: State

Availability: Available

Other Themes That Will Benefit:

Public Benefits Informed By: Understanding of abiotic factors that influence plant health and yield under waterlogged conditions.

Description, including Connection to Flood-MAR: We review waterlogging and submergence tolerances of forage (pasture) legumes. Growth reductions from waterlogging in perennial species ranged from >50% for Medicago sativa and Trifolium pratense to <25% for Lotus corniculatus, L. tenuis, and T. fragiferum. For annual species, waterlogging reduced Medicago truncatula by ~50%, whereas Melilotus siculus and T. michelianum were not reduced. Tolerant species have higher root porosity (gas-filled volume in tissues) owing to aerenchyma formation. Plant dry mass (waterlogged relative to control) had a positive (hyperbolic) relationship to root porosity across eight species. Metabolism in hypoxic roots was influenced by internal aeration.

Sugars accumulate in M. sativa due to growth inhibition from limited respiration and low energy in roots of low porosity (i.e. 4.5%). In contrast, L. corniculatus, with higher root porosity (i.e. 17.2%) and O2 supply allowing respiration, maintained growth better and sugars did not accumulate. Tolerant legumes form nodules, and internal O2 diffusion along roots can sustain metabolism, including N2 fixation, in submerged nodules. Shoot physiology depends on species tolerance. In M. sativa, photosynthesis soon declines and in the longer term (>10 d) leaves suffer chlorophyll degradation, damage, and N, P, and K deficiencies. In tolerant L. corniculatus and L. tenuis, photosynthesis is maintained longer, shoot N is less affected, and shoot P can even increase during waterlogging. Species also differ in tolerance of partial and complete shoot submergence. Gaps in knowledge include anoxia tolerance of roots, N2 fixation during field waterlogging, and identification of traits conferring the ability to recover after water subsides.

Website: https://www.ncbi.nlm.nih.gov/pubmed/27325893
Contact: Helen Dahlke
Email: hdahlke@ucdavis.edu

Table 12 Flooding Tolerance of Forage Legumes

Category: Research

Scale: State

Availability: Available

Other Themes That Will Benefit:

Public Benefits Informed By: Understanding of abiotic factors that influence plant health and yield under waterlogged conditions

Description, including Connection to Flood-MAR: We review waterlogging and submergence tolerances of forage (pasture) legumes. Growth reductions from waterlogging in perennial species ranged from >50% for Medicago sativa and Trifolium pratense to <25% for Lotus corniculatus, L. tenuis, and T. fragiferum. For annual species, waterlogging reduced Medicago truncatula by ~50%, whereas Melilotus siculus and T. michelianum were not reduced. Tolerant species have higher root porosity (gas-filled volume in tissues) owing to aerenchyma formation. Plant dry mass (waterlogged relative to control) had a positive (hyperbolic) relationship to root porosity across eight species. Metabolism in hypoxic roots was influenced by internal aeration.

Sugars accumulate in M. sativa due to growth inhibition from limited respiration and low energy in roots of low porosity (i.e., 4.5%). In contrast, L. corniculatus, with higher root porosity (i.e., 17.2%) and O2 supply allowing respiration, maintained growth better and sugars did not accumulate. Tolerant legumes form nodules, and internal O2 diffusion along roots can sustain metabolism, including N2 fixation, in submerged nodules. Shoot physiology depends on species tolerance. In M. sativa, photosynthesis soon declines and in the longer term (>10 d) leaves suffer chlorophyll degradation, damage, and N, P, and K deficiencies. In tolerant L. corniculatus and L. tenuis, photosynthesis is maintained longer, shoot N is less affected, and shoot P can even increase during waterlogging. Species also differ in tolerance of partial and complete shoot submergence. Gaps in knowledge include anoxia tolerance of roots, N2 fixation during field waterlogging, and identification of traits conferring the ability to recover after water subsides.

Website: https://www.ncbi.nlm.nih.gov/pubmed/27325893
Contact: Helen Dahlke
Email: hdahlke@ucdavis.edu

Table 13 Effect of Waterlogging on the Growth of Barley

Category: Research

Scale: State

Availability: Available

Other Themes That Will Benefit:

Public Benefits Informed By: Understanding of abiotic factors that influence plant health and yield under waterlogged conditions.

Description, including Connection to Flood-MAR: Waterlogging tolerance is one of the important breeding objectives in high rainfall areas. For this purpose, a project was set up for exchanging germplasm with China where barley has been selected for waterlogging for centuries. Experiments were conducted in both Australia and China to evaluate the effect of waterlogging on the growth of barley. Varieties showed different tolerance to waterlogging with some Chinese varieties showing much better tolerance than Franklin and Gairdner.

Website: http://www.regional.org.au/au//asa/2003/p/7/zhou.htm
Contact: Helen Dahlke
Email: hdahlke@ucdavis.edu

Table 14 Plant Waterlogging: Causes, Responses, Adaptations and Crop Models

Category: Research

Scale: State

Availability: Available

Other Themes That Will Benefit:

Public Benefits Informed By: Understanding of abiotic factors that influence plant health and yield under waterlogged conditions.

Description, including Connection to Flood-MAR: Ph.D. thesis that researched waterlogging effects on plant health and crop yield. Research identifies physical factors causing waterlogging, plant morphological factors that indicate abiotic stress, causes of abiotic stress, and adaptation and responses to water logging. Most research is presented for many species. Research conducted in Australia.

Website: https://digital.library.adelaide.edu.au/dspace/bitstream/2440/94087/3/02whole.pdf
Contact: Helen Dahlke
Email: hdahlke@ucdavis.edu

Table 15 Effect of Waterlogging in Wheat (T. aestivum L.)

Category: Research

Scale: State

Availability: Available

Other Themes That Will Benefit:

Public Benefits Informed By: Understanding of abiotic factors that influence plant health and yield under waterlogged conditions.

Description, including Connection to Flood-MAR: Waterlogging is an important factor influencing yield and yield components in wheat. The objective of this study was to evaluate the effect of waterlogging on yield, yield components, protein and proline content, and chlorophyll a and b in wheat. In the study, seven levels of waterlogging treatment, 0, 5, 10, 15, 20, 25 and 60 days of flooding were applied. Increasing waterlogging stress decreased yield, spike number per m2, seed weight and number per spike, protein content, and chlorophyll a and b; and caused increase in proline content. Results indicated significant linear responses for yield, spike number per m2, seed weight and number per spike, protein content, chlorophyll a and b.

Website: https://www.tandfonline.com/doi/abs/10.1080/09064710701794024?journalCode=sagb20
Contact: Helen Dahlke
Email: hdahlke@ucdavis.edu

Table 16 Development of Waterlogging Damage in Wheat Seedlings (triticum aestivum l.) Ii. Accumulation and Redistribution of Nutrients by the Shoot

Category: Research

Scale: State

Availability: Available

Other Themes That Will Benefit:

Public Benefits Informed By: Understanding of abiotic factors that influence plant health and yield under waterlogged conditions.

Description, including Connection to Flood-MAR: Decreases in the concentrations of nitrogen, phosphorus, potassium, calcium and magnesium in the shoots of wheat seedlings soon after the start ofwaterlogging were mainly attributed to an inhibition of ion uptake and transport by roots in the oxygen deficient soil. There was a small net accumulation of nitrogen, phosphorus and potassium by the aerial tissues, principally the tillers rather than the main shoot. By contrast, calcium and magnesium accumulated in both tillers and main shoot. With waterlogging; nitrogen, phosphorus and potassium were translocated from the older leaves to the younger growing leaves, and in the case of nitrogen this was associated with the onset of premature senescence. Calcium and magnesium were not translocated from the older leaves, the younger leaves acquiring these cations from the waterlogged soil. The promotion ofleaf senescence by waterlogging was counteracted by applications of nitrate or ammonium to the soil surface, or by spraying the shoots with solutions of urea, but the beneficial effects on shoot growth were small.

The role of mineral nutrition in relation to waterlogging damage to young cereal plants is discussed.

Website: https://link.springer.com/article/10.1007/BF02205847
Contact: Helen Dahlke
Email: hdahlke@ucdavis.edu

Table 17 Effect of Waterlogging on the Growth, Grain and Straw Yield of Wheat, Barley and Oat

Category: Research

Scale: State

Availability: Available

Other Themes That Will Benefit:

Public Benefits Informed By: Understanding of abiotic factors that influence plant health and yield under waterlogged conditions.

Description, including Connection to Flood-MAR: Both soil composition and waterlogging had a significant effect on plant yield but the effect of waterlogging was much greater. Waterlogging reduced root growth and penetration, the production of tiller sand fertile heads, and delayed ear emergence and plant maturation.

Reduction in plant growth rate was measurable within three days from the onset of waterlogging. In the first experiment intermittent and continuous waterlogging reduced vegetative growth yield (mean of three cereals in three soils) by 37 per cent and 55 per cent respectively; and wheat grain yields by 40 per cent and 53 per cent respectively. However, there was no differential effect of the two waterlogging treatments on the grain yield of barley and oats, the mean reduction being 39 per cent for barley and 48 per cent for oats. In the second experiment waterlogging at the earliest growth stage resulted in the greatest reduction in root, herbage and grain yield. Waterlogging at ear emergence killed some tillers and roots and reduced the plants stability at maturity. Grain size was reduced in some treatments. Application of nitrogen fertilizer compensated, either partially or fully, for reduction in grain yield due to waterlogging treatments on all three cereals.

Some reasons for yield reduction in the three species and the practical implications of the results are discussed

Website: http://www.publish.csiro.au/EA/pdf/EA9760114
Contact: Helen Dahlke
Email: hdahlke@ucdavis.edu

Table 18 Barley Responses to Combined Waterlogging and Salinity Stress: Separating Effects of Oxygen Deprivation and Elemental Toxicity

Category: Research

Scale: State

Availability: Available

Other Themes That Will Benefit:

Public Benefits Informed By: Understanding of abiotic factors that influence plant health and yield under waterlogged conditions.

Description, including Connection to Flood-MAR: In this study, whole-plant physiological responses to individual/combined salinity and waterlogging stresses were studied using two barley varieties grown in either vermiculite (semi-hydroponics) or sandy loam. Two weeks of combined salinity and waterlogging treatment significantly decreased plant biomass, chlorophyll content, maximal quantum efficiency of PSII and water content (WC) in both varieties, while the percentage of chlorotic and necrotic leaves and leaf sap osmolality increased. The adverse effects of the combined stresses were much stronger in the waterlogging-sensitive variety Naso Nijo. Compared with salinity stress alone, the combined stress resulted in a 2-fold increase in leaf Na^+, but a 40% decrease in leaf K^+ content. Importantly, the effects of the combined stress were more pronounced in sandy loam compared with vermiculite and correlated with changes in the soil redox potential and accumulation of Mn and Fe in the waterlogged soils. It is concluded that hypoxia alone is not a major factor determining differential plant growth under adverse stress conditions, and that elemental toxicities resulting from changes in soil redox potential have a major impact on genotypic differences in plant physiological and agronomical responses. These results are further discussed in the context of plant breeding for waterlogging stress tolerance.

Website: https://www.ncbi.nlm.nih.gov/pubmed/23967003
Contact: Helen Dahlke
Email: hdahlke@ucdavis.edu

Table 19 A Review of the Impacts of Mycorrhizal Fungi on Walnuts and Grapes Resistance to Pathogens in Ukrainian Orchards

Category: Research

Scale: State

Availability: Available

Other Themes That Will Benefit:

Public Benefits Informed By: Understanding of abiotic factors that influence plant health and yield under waterlogged conditions.

Description, including Connection to Flood-MAR: This paper provides a nice list of abiotic and biotic factors to grow walnuts and grapes in. Specifically states that walnuts do not like waterlogged and saline soils. Because many walnut varieties were imported from eastern Europe, this research from the Ukraine might be important.

Website: https://www.ujecology.com/articles/impact-of-mycorrhizal-fungi-on-walnuts-and-grapes-resistance-to-pathogens-in-ukrainian-orchards--a-review.pdf
Contact: Helen Dahlke
Email: hdahlke@ucdavis.edu

Table 20 Performance of Tomatoes (Lycopcrsicon lycopcrsicum L.) Karsten l under Waterlogged Condition

Category: Research

Scale: State

Availability: Available

Other Themes That Will Benefit:

List

Public Benefits Informed By: Understanding of abiotic factors that influence plant health and yield under waterlogged conditions.

List

Description, including Connection to Flood-MAR: The effects of waterlogging on some morphological, physiological, biochemical and anatomical charac-teristics of three varieties of tomato at three growth stages in relation to growth and yield were inves-tigated. Waterlogging significantly reduced plant height, leaf area, leaf chlorophyll content, respiration rate, percent survival, fruit set, total yield, seed set and dry weight of the whole plants and root free praline content. it increased epinastic curvature, stomatal resistance, leaf free praline content and the cross-sectional area of the in tercellular spaces and cortical cells.

Of the three varieties useci, 'R-3025' was found to be the most resistant, followed by C-32d' and 'Nag-carlan' in that order. 'R-3025' had the highest percent survival, respiration rate of adventitious root, lowest leaf and root free praline content, and the biggest cross-sectional area of the intercellular spaces of adventitious roots despite its lower yield, as compared to 'Nagcarlan' and C-32d'. Sensitivity to waterlog-ging was highest at the flowering stage as yield, fruit set and seed set were greatly reduced regardless of the genotype.

This research was conducted in the Phillipines.

Website: http://agris.fao.org/agris-search/search.do?recordID=PH1983088264
Contact: Helen Dahlke
Email: hdahlke@ucdavis.edu

Table 21 Flooding Tolerance of Tomato Genotypes during Vegetative and Reproductive Stages

Category: Research

Scale: State

Availability: Available

Other Themes That Will Benefit:

Public Benefits Informed By: Understanding of abiotic factors that influence plant health and yield under waterlogged conditions.

Description, including Connection to Flood-MAR: A greenhouse experiment was conducted to investigate the effect of flooding on two tomato cultivars and two wild related species. Forty days old tomato plants were subjected to a continuous flooding stress of different durations: 0, 2, 4 and 8 days. Plant pots were placed inside larger plastic pots; they were irrigated with excessive quantity of tap water at 250C so that the level of water above the surface of soil was 15 cm throughout the flooding period. At the bottom of each plastic pot a drilled hole allowed complete drainage of the pot after flooding. Parameters studied include plant height, number of leaves, leaf length, chlorophyll fluorescence, chlorophyll content, wilting, leaf senescence, adventitious root formation, number of flowers and fruits from cluster 2 to 6, average weight per fruit, fruit length and width, total fruit weight from cluster 2 to 6, total yield per plant. LA1579 genotype was more subjected to the deleterious effect of flooding on almost all the parameters studied. Therefore, LA1579 genotype is flooding sensitive. Genotypes CLN2498E, and CA4 showed high tolerance to flooding while LA1421 genotype was tolerant to some extent. This experiment provides information that could help in the identification of physiological and agronomical parameters associated with flood-tolerance in vegetables.

Website: http://www.scielo.br/scielo.php?script=sci_arttext&pid=S1677-04202010000200007
Contact: Helen Dahlke
Email: hdahlke@ucdavis.edu

Table 22 The impact of prolonged flood-irrigation on leaf gas exchange in mature pecans in an orchard setting

Category: Research

Scale: State

Availability: Available

Other Themes That Will Benefit:

Public Benefits Informed By: Understanding of abiotic factors that influence plant health and yield under waterlogged conditions.

Description, including Connection to Flood-MAR: Woody perennials subjected to root oxygen-stress often respond with varying levels of reduced assimilation and leaf gas exchange. Yet in most of these studies, seedlings grown in pots were subjected to experimental conditions that rarely exist in nature for mature trees. To determine if flooding mature orchard-grown pecan (Carya illinoiensis (Wangh) K. Koch) results in a similar depressed photosynthetic rate (Pn), transpiration (E), and stomatal conductance (gs) as found in potted seedling studies, 27 year-old trees were continuously flooded for 35 days during which gas exchange measurements were compared with non-flooded controls. Flood-treated trees exhibited a continuous decline in Pn, gs, and E without any apparent recovery throughout the treatment period, and progressively higher levels of intercellular CO2 (Ci). Flooded trees also exhibited widespread interveinal 'bronzing' in subtle blotchy patterns, sporadic adaxial interveinal scorching, and simultaneously put on a flush of new growth, not seen in the control trees. Mechanisms are considered relating a putative disruption in carbohydrate export to the reduced levels of photosynthesis.

Website: http://ijpp.gau.ac.ir/article_534_dfbefc0c19a55928bfdb57c4ef85d616.pdf
Contact: Helen Dahlke
Email: hdahlke@ucdavis.edu

Table 23 Phymatotrichopsis Root Rot in Pecan

Category: Research

Scale: State

Availability: Available

Other Themes That Will Benefit:

Public Benefits Informed By: Understanding of abiotic factors that influence plant health and yield under waterlogged conditions.

Description, including Connection to Flood-MAR:

Text.

Website: https://extension.arizona.edu/sites/extension.arizona.edu/files/pubs/az1771-2018.pdf

Contact: Helen Dahlke
Email: hdahlke@ucdavis.edu

Table 24 Establishing a Pecan Orchard

Category: Research

Scale: State

Availability: Available

Other Themes That Will Benefit:

Public Benefits Informed By: Understanding of abiotic factors that influence plant health and yield under waterlogged conditions.

Description, including Connection to Flood-MAR: One of the most important decisions a pecan producer makes is about the establishment of a new orchard. A well-planned, organized orchard will be more efficient, require less input and offer larger potential returns. Select the orchard location based on its soil type, drainage, water table and land topography. Straight rows in planted orchards make maintenance, irrigation and harvest easier. Tree growth and spacing requirements can also be anticipated for the early planting and subsequent orchard thinnings.

Website:http://extension.uga.edu/publications/detail.html?number=B1314&title=Establishing%20a%20Pecan%20Orchard
Contact: Helen Dahlke
Email: hdahlke@ucdavis.edu

Table 25 Soil Management in irrigated Pecan orchards in the Southwestern United States

Category: Research

Scale: State

Availability: Available

Other Themes That Will Benefit:

Public Benefits Informed By: Understanding of abiotic factors that influence plant health and yield under waterlogged conditions.

Description, including Connection to Flood-MAR:

Website: http://horttech.ashspublications.org/content/5/3/219.full.pdf
Contact: Helen Dahlke
Email: hdahlke@ucdavis.edu

Table 26 Analysis of the Regulation Networks in Grapevine Reveals Response to Waterlogging Stress and Candidate Gene-Marker

Category: Research

Scale: State

Availability: Available

Other Themes That Will Benefit:

Public Benefits Informed By: Understanding of abiotic factors that influence plant health and yield under waterlogged conditions

Description, including Connection to Flood-MAR: Owing to the climate change impacts, waterlogging is one of the most hazardous abiotic stresses to crops, which also can result in a serious reduction in the quantity and quality of grape berry and wine production during the rainy season. Therefore, the exploration of the response mechanism of grape to waterlogging is necessary, for which the analysis of the transcriptomic regulation networks of grapevine leaves in response to waterlogging stress was carried out. In this study, 12,634 genes were detected in both waterlogging stress and control grapevine plants, out of which 6,837 genes were differentially expressed. A comparative analysis revealed that genes functioning in the antioxidant system, glycolysis and fermentation pathway, chlorophyll metabolism, amino acid metabolism and hormones were activated to reduce injury to grapes under the waterlogging stress. Meanwhile, genes encoding class-2 non-symbiotic hemoglobin were determined as important in waterlogging acclimation. Additionally, the expression variations of three marker genes were found to be informative and can be used to predict the viability of the grapevines subjected to waterlogging. This research not only probes the molecular mechanism underlying grapevine waterlogging tolerance but also puts forward an idea about the application of gene expression information to practical management.

Website: http://dx.doi.org/10.1098/rsos.172253
Contact: Helen Dahlke
Email: hdahlke@ucdavis.edu

Table 27 Effects of Waterlogging, Rootstock and Salinity on Na, Cl and K Concentrations of the Leaf and Root, and Shoot Growth of Sultana Grapevines

Category: Research

Scale: State

Availability: Available

Other Themes That Will Benefit:

Public Benefits Informed By: Understanding of abiotic factors that influence plant health and yield under waterlogged conditions.

Description, including Connection to Flood-MAR: Potted Sultana vines (Vitis vinifera L. cv. Sultana) on own-roots or grafted onto Ramsey, Harmony, Schwarzmann or 1,613 rootstocks were irrigated with solutions containing 1, 10, 20, 40 or 60 mM NaCl. Half the vines had free-draining rootzones and the other half were waterlogged for the first week in a 2-week cycle. The vines were harvested after seven cycles.

Raising the irrigation salinity from 1 to 60 mM caused growth to decline by 47% in vines with free-draining rootzones and by 61% in vines with waterlogged rootzones. Under saline conditions, the use of chloride excluding rootstock reduced leaf chloride concentration by 60% in vines with free-draining rootzones but by only 18% in vines with waterlogged rootzones. Waterlogging decreased the root chloride concentration in all rootstocks. The leaf potassium concentration was reduced by waterlogging at irrigation salinities less than 20 mM NaCl and increased by waterlogging at higher salinities. Waterlogging altered the relative effects of rootstock on leaf potassium.

Website: http://www.publish.csiro.au/cp/pdf/AR9950541
Contact: Helen Dahlke
Email: hdahlke@ucdavis.edu

Table 28 Ridging — A Soil Preparation Practice to Improve Aeration of Vineyard Soils

Category: Research

Scale: State

Availability: Available

Other Themes That Will Benefit:

Public Benefits Informed By: Understanding of abiotic factors that influence plant health and yield under waterlogged conditions.

Description, including Connection to Flood-MAR: Waterlogged soil conditions during early spring can result in poor grapevine performance. In this study the effect of ridging as a method of soil preparation on the depth to the water table, soil air composition and vine reaction, as indicated by leaf water potential and stomata! resistance, was quantified. The soil and plant para-meters were monitored throughout an entire growing season on 600mm-high ridges and flat control plots. Soil air analyses showed that under waterlogged conditions, oxygen in the soil air is to a large extent replac-ed by carbon dioxide. A linear relationship was found between oxygen and carbon dioxide concentrations, except during the phase of aeration directly following a period of continuous waterlogging. The production of ethylene, which is believed to be detrimental to vine growth, could not readily be traced under prevailing anoxic conditions. Ridging increased the depth to the water table, which resulted in higher oxygen and lower carbon dioxide concentrations in the soil air. Soil oxygen levels of below 16% may have resulted in the decrease in leaf water potential and increase in stomata! resistance noted for the control plots. These condi-tions of physiological stress prevailed until the water table dropped to a level below 600mm. It is concluded that ridging, an alternative to deep soil preparation on waterlogged soils, produced a favorable environment for root growth on this marginal soil based on improved internal drainage and thus soil aeration. tolerance but also puts forward an idea about the application of gene expression information to practical management.

Website: https://www.tandfonline.com/doi/abs/10.1080/02571862.1991.1063483
Contact: Helen Dahlke
Email: hdahlke@ucdavis.edu

Table 29 Effect of Flooding on Shoot and Root Growth of Rooted Cuttings of Four Grape Rootstocks

Category: Research

Scale: State

Availability: Available

Other Themes That Will Benefit:

Public Benefits Informed By: Understanding of abiotic factors that influence plant health and yield under waterlogged conditions.

Description, including Connection to Flood-MAR: Tested different severities of root flooding at budbreak and 70 days after budbreak (8-12 leafe stage) on root and shoot growth of four grape rootstocks. When two-thirds or more of rootstock was flooded at budbreak, root and shoot growth were strongly inhibited. At 100% flooding there was no root growth.

Website: https://www.jstage.jst.go.jp/article/jjshs1925/65/3/653455/pdf
Contact: Helen Dahlke
Email: hdahlke@ucdavis.edu

Table 30 Flooded Vineyard Case Studies

Category: Research

Scale: State

Availability: Available

Other Themes That Will Benefit:

Public Benefits Informed By: Understanding of abiotic factors that influence plant health and yield under waterlogged conditions.

Description, including Connection to Flood-MAR: Flooding across large areas of New South Wales and Victoria during March 2012 has resulted in flooded vineyards in several of the states' winegrape-growing regions. These case studies aim to inform growers of some immediate issues to consider and issues for next season based on other observations.

Flooding may be caused by from heavy localized rains, flood waters slowly flowing across the landscape or a combination of both. Whatever the cause, the duration and timing of flooding are important to consider. Flooding of well-drained soil types, where water disappears in one or two days, usually has little impact on vine growth. Where flood water is slow to recede, either due to soil type or the volume of water, some issues may arise.

When soil becomes waterlogged, it becomes anaerobic as air is forced out from pores in the soil. Roots need air to function, and waterlogged roots will die over a period of time. However, flood events from 2011 have shown vines are resilient, and can return to production in the following season without significant side-effects. To minimize the impact of flood on vineyards, water should be encouraged to drain away, or pumped from the vineyard as soon as possible.

Website: https://www.wineaustralia.com/getmedia/4ddeda8b-d142-4b01-8ead-5ef41ca55ed4/2012-flooded-vineyard-case-studies.pd
Contact: Helen Dahlke
Email: hdahlke@ucdavis.edu

Table 31 Artificial Ground Water Recharge By Flooding During Grapevine Dormancy

Category: Research

Scale: State

Availability: Available

Other Themes That Will Benefit:

Public Benefits Informed By: Understanding of abiotic factors that influence plant health and yield under waterlogged conditions.

Description, including Connection to Flood-MAR: The potential for artificial ground water recharge by continuous flooding of dormant grapevines was evaluated in the San Joaquin Valley of California using the cultivar Thompson Seedless. The study was started in 1982 and was completed in 1985 after three complete flooding cycles during dormancy. An average daily rate of recharge of 80 mm/thy for a 32-day period each year was achieved through a clay loam soil. There were no adverse effects on the grapevines and yields in the flooded plots in any of the growing seasons following recharge periods. Yields were higher in the recharge plots than in the control plots in the last year of the study. We conclude that artificial ground water recharge by continuous flooding during grapevine dormancy is a viable recharge method.

Website: http://dx.doi.org/10.1098/rsos.172253
Contact: Helen Dahlke
Email: hdahlke@ucdavis.edu

Table 32 Effect of Waterlogging Condition on the Photosynthesis of 'Campbell Early' Grapevin

Category: Research

Scale: State

Availability: Available

Other Themes That Will Benefit:

Public Benefits Informed By: Understanding of abiotic factors that influence plant health and yield under waterlogged conditions.

Description, including Connection to Flood-MAR: This experiment was conducted to investigate the effect of dissolved oxygen on the photosynthesis, and related physiological response of two-year old “Campbell Early” grapevine (Vitis labrusca L.) under waterlogged condition from June 15 to July 27, 2005. For the experiment, two-year old grapevine seedlings were transplanted to 40 L pot with a sandy loam soil. Treatments consisted of non-treated control with controlled at -40 kPa of soil water tension (NC), waterlogging with continuous aeration to supply dissolved oxygen (WO), waterlogging with exchange of water twice a week (WE), and continuous waterlogging without aeration as well as exchange of water (WL). After 29 days of waterlogging, predawn leaf water potential of NC was the highest at -0.23 MPa in treatments, but other treatments were -0.35 MPa (WO), -0.50 MPa (WE), and -0.57 MPa (WL) respectively. Difference between air and leaf temperatures was higher in WO (0.9°C) than other waterlogging treatments except NC (l.5°C). Net CO2 assimilation (Aco2), stomata! conductance (gs), and transpiration rate (E) of waterlogged grapevines were decreased by continuous waterlogging but mitigated by supplying dissolved oxygen (WO). Leaf-to-air water vapor pressure deficit on leaf temperature (Vpdl) was increased by the prolongation of waterlogging but attenuated by WO treatment. From 8 days after waterlogging, Fv/Fm of WO in treatments was higher than other waterlogging treatments (WE, WO) except NC; also, there was no significant difference among the Fv/Fm of NC, WO and WE, but was significantly higher than WL at 24 and 31 days after waterlogging. Thus, it could be concluded that supplying dissolved oxygen by aeration decreases leaf temperature, increases predawn leaf water potential and Fv/Fm and resulted in alleviation of the reduction of photosynthesis of 'Campbell Early' grapevine under waterlogged condition.

Website: http://agris.fao.org/agris-search/search.do?recordID=KR2009001666
Contact: Helen Dahlke
Email: hdahlke@ucdavis.edu

Table 33 Winter Water Management in Almond Orchards

Category: Research

Scale: State

Availability: Available

Other Themes That Will Benefit:

Public Benefits Informed By: Understanding of abiotic factors that influence plant health and yield under waterlogged conditions.

Description, including Connection to Flood-MAR: Recharge was conducted at three almond orchards in the Central Valley. 24 inches of water were applied in addition to rainfall in December and January. Deep percolation efficiency of recharge water ranged from 77% at Orland to 96% and 99% at Modesto and Delhi, respectively. Reduced conditions did not occur in the root zones at Modesto or Delhi at any time. Midday stem water potential (SWP) for the flood treatment was not different from the control at any site. Trees in the recharge plot produced more roots than in the control plot at the well-drained Delhi site. Lifespan for these roots was increased, leading to significantly greater standing root length for the trees in the recharge plot.

More information can be found at https://lf.almonds.com/WebLink/customsearch.aspx?SearchName=AdvancedSearch&cr=1

Website: https://lf.almonds.com/WebLink/ElectronicFile.aspx?docid=14974&dbid=0
Contact: Helen Dahlke
Email: hdahlke@ucdavis.edu

Table 34 Artificial Groundwater Recharge by Flooding

Category: Tool

Scale: State

Availability: Available

Other Themes That Will Benefit:
7. Water Quality
11. Economic Analysis
13. Tool and Application Development

Public Benefits Informed By: Aquifer replenishment, drought preparedness.

Description, including Connection to Flood-MAR: Winter flooding (1.1 to 3.6 m applied water) for groundwater recharge had little or no effect on growth, yield, or quality of own-rooted Thompson seedless table grapes in Fresno. Raises possible concern of nitrates or pesticides from vineyards contaminating groundwater.

Website: https://onlinelibrary.wiley.com/doi/abs/10.1111/j.1752-1688.1987.tb00809.x
Contact: Matthew Fidelibus
Email: mwfidelibus@ucdavis.edu

Table 35 Biology and Management of Grape Phylloxera

Category: Tool

Scale: State

Availability: Available

Other Themes That Will Benefit:
13. Tool and Application Development

Public Benefits Informed By: Aquifer replenishment, drought preparedness, working landscape preservation and stewardship.

Description, including Connection to Flood-MAR: Winter flooding of vineyards for 40-50 days decreases phylloxera (destructive root aphid pest of grapes) populations and their damage to grapes. However, flood waters can potentially disperse phylloxera from one vineyard to another.

Website: https://www.annualreviews.org/doi/10.1146/annurev.ento.46.1.387
Contact: Matthew Fidelibus
Email: mwfidelibus@ucdavis.edu

Table 36 Responses of Fruit Crops to Flooding

Category: Tool

Scale: State

Availability: Available

Other Themes That Will Benefit:
13. Tool and Application Development

Public Benefits Informed By: Working landscape preservation and stewardship.

Description, including Connection to Flood-MAR: Flood responses among woody fruit crops are directly related to soil type, porosity, chemistry, degree and duration of anaerobiosis, soil microbe and pathogen status, vapor pressure deficits and soil and air temperatures, plant age and state of development or season of the year, and plant preconditioning responses as a result of prior climatic and edaphic conditions.

Tolerance mainly determined by rootstock, not scion.

Citrus and walnut sensitivity depends on rootstock; plum, cherry, peach and fig are very sensitive. grapes are moderately tolerant.

Some species (blueberry, for example) can tolerate extended flooding in dormant season but are intolerant in growing season.

Diseases caused by Oomycetes such as Phytophthora can increase under flooded conditions. other soil diseases or pests, for example nematodes, may decrease under flooded condition depending on their biology.

Review mainly focused on flooding during growing season.

Website:https://www.researchgate.net/publication/229724734_Responses_of_Fruit_Crops_to_Flooding
Contact: Matthew Fidelibus
Email: mwfidelibus@ucdavis.edu

Table 37 Soil Suitability Index Identifies Potential Areas for Groundwater Banking on Agricultural Lands

Category: Tool

Scale: State

Availability: Available

Other Themes That Will Benefit:

6. Land Use Management
8. Recharge and Extraction Methods and Measures
11. Economic Analysis
13. Tool and Application Development

Public Benefits Informed By: Drought preparedness, aquifer replenishment, working landscape preservation and stewardship.

Description, including Connection to Flood-MAR: Developed a groundwater banking index that considered deep percolation, root zone residence time, topography, chemical limitations and soil surface condition.

Provides survey results indicating flood tolerance of various perennial crops grown in California.

Notes potential soil chemical groundwater contamination concerns.

Notes that trees and vines are generally more tolerant of flooding during the dormant period, but “cutoff” time to complete flooding is difficult to determine.

Notes potential disease issues with phytophthora.

Website: http://calag.ucanr.edu/Archive/?article=ca.v069n02p75
Contact: Matthew Fidelibus
Email: mwfidelibus@ucdavis.edu

Table 38 Influence of Rootstock on the Response of Seyval Grapevines to Flooding Stress

Category: Tool

Scale: State

Availability: Available

Other Themes That Will Benefit:

Public Benefits Informed By: Working landscape preservation and stewardship.

Description, including Connection to Flood-MAR: Demonstrated that grapevine rootstocks vary with respect to flood tolerance.

Flooding occurred during growing season, but as pointed out in another manuscript, dormant season flooding could result in water logged soils after budbreak depending on when flooding was stopped and to other factors.

Rootstock use only slightly increased flooding tolerance of serval grapevines.

Website: http://www.ajevonline.org/content/44/3/313
Contact: Matthew Fidelibus
Email: mwfidelibus@ucdavis.edu

Table 39 A Review of Horticultural Crops and Climate Change

Category: Tool

Scale: State

Availability: Available

Other Themes That Will Benefit:

Public Benefits Informed By: Climate change adaptation, working landscape preservation and stewardship.

Description, including Connection to Flood-MAR: Noted that annual crops, especially vegetables, are particularly sensitive to flooding, especially under higher temperatures.

Flooding stress in tomato is associated with ethylene accumulation.

Grafting onto flood tolerant rootstocks might be helpful for vegetables.

Website: https://www.researchgate.net/publication/312937658
Contact: Matthew Fidelibus
Email: mwfidelibus@ucdavis.edu

Table 40 Effect of Flooding on Shoot and Root Growth of Rooted Cuttings of Four Grape Rootstocks

Category: Tool

Scale: State

Availability: Available

Other Themes That Will Benefit:
13. Tool and Application Development

Public Benefits Informed By: Working landscape preservation and stewardship.

Description, including Connection to Flood-MAR: If ≥ two-thirds rootzone was flooded in dormancy, budbreak still occurred but shoot and root growth was strongly inhibited.

Although flooding stunted the vines, none of them died even after a 50-day flooding period.

Rootstocks differed in their tolerance to flooding.

Initiation of flooding after budbreak more strongly suppressed shoot and root growth than when flooding was initiated during dormancy.

Website: https://www.jstage.jst.go.jp/article/jjshs1925/65/3/65_3_455/_article
Contact: Matthew Fidelibus
Email: mwfidelibus@ucdavis.edu

Table 41 Abiotic Stress Adaptation in Plants

Category: Tool

Scale: State

Availability: Available

Other Themes That Will Benefit:

Public Benefits Informed By: Climate change adaptation, working landscape preservation and stewardship.

Description, including Connection to Flood-MAR: Notes that water logged soil in the growing season inhibits flowerbud initiation anthesis, fruit set, fruit size and quality, and leads to fruit cracking of various fruit crops.

Cautions that flooding can bring salt to the soil surface due to capillary action and may move salt from adjacent areas.

Notes negative impact of flooding on aerobic soil microbes such as mycorrhizal fungi (beneficial symbionts).

Website: https://www.springer.com/us/book/9789048131112
Contact: Matthew Fidelibus
Email: mwfidelibus@ucdavis.edu

Table 42 Abiotic Stress Physiology of Horticultural Crops

Category: Tool

Scale: State

Availability: Available

Other Themes That Will Benefit:
13. Tool and Application Development

Public Benefits Informed By: Climate change adaptation, working landscape preservation and stewardship.

Description, including Connection to Flood-MAR: Noted plants subjected to flooding develop symptoms siliar to those of heat or drought stress including elevated internal ethylene concentration, decreased stomatal conductance, suppressed shoot and root growth, changes in osmotic and nutrient uptake (less N, P, K, Ca and Mg), reduced chlorophyll content and photosynthesis, and increased severity of certain diseases, especially root-rotting fungi.

Suggested some cultural practices to recover from flooding (fertilizer and pesticide applications, for example).

Reviews flood tolerance literature of various horticultural crops relevant to California, including tomato, onion, pepper, and grape.

Website: https://www.springer.com/us/book/9788132227236
Contact: Matthew Fidelibus
Email: mwfidelibus@ucdavis.edu

Table 43 Walnut (*Juglans* spp.) Ecophysiology in Response to Environmental Stresses and Potential Acclimation to Climate Change

Category: Tool

Scale: State

Availability: Available

Other Themes That Will Benefit:

13. Tool and Application Development

Public Benefits Informed By: Climate change adaptation, working landscape preservation and stewardship.

Description, including Connection to Flood-MAR: Notes that there is little research on the effects of flooding on walnut physiology.

Website: https://link.springer.com/article/10.1007/s13595-011-0135-6
Contact: Matthew Fidelibus
Email: mwfidelibus@ucdavis.edu

Table 44 Flooding Impact on Crops

Category: Tool

Scale: State

Availability: Available

Other Themes That Will Benefit:

13. Tool and Application Development

Public Benefits Informed By: Climate change adaptation, working landscape preservation and stewardship.

Description, including Connection to Flood-MAR: Focus is on agronomic crops.

Notes that most crops grown in North America are intolerant of flooding which depletes soil oxygen, increases disease infections and nitrogen losses (through deep percolation or denitrification).

Damage depends on type of crop, growth stage, temperature, duration, and conditions after flooding.

Website: https://www.pioneer.com/home/site/us/agronomy/crop-management/adverse-weather-disease/flood-impact
Contact: Matthew Fidelibus
Email: mwfidelibus@ucdavis.edu

Table 45 Managed Winter Flooding of Alfalfa Recharges Groundwater with Minimal Crop Damage

Category: Tool

Scale: State

Availability: Available

Other Themes That Will Benefit:

8. Recharge and Extraction Methods and Measures
11. Economic Analysis
13. Tool and Application Development

Public Benefits Informed By: Aquifer replenishment, drought preparedness, working landscape preservation and stewardship.

Description, including Connection to Flood-MAR: Over 90% of applied water percolated past the root zone.

Observed a close relationship between soil oxygen status and water content. Soil oxygen was reduced during the water application but quickly returned to aerobic condition after application ceased.

Water application timing had little effect on total deep percolation amounts but had important effects on root zone water content. Later water application sustained root zone water content further into the growing season compared to earlier water application.

Recharge treatments did not substantially affect yield.

Website: http://calag.ucanr.edu/archive/?article=ca.2018a0001#R33
Contact: Matthew Fidelibus
Email: mwfidelibus@ucdavis.edu

Table 46 Waters Recede, Damage Estimates Soar

Category: Tool

Scale: State

Availability: Available

Other Themes That Will Benefit:

Public Benefits Informed By: Climate change adaptation, working landscape preservation and stewardship.

Description, including Connection to Flood-MAR: Severe natural flood event in the SJV in first week of 1997. Walnuts, alfalfa, wine grapes, plums, prunes, and peaches were all severely damaged. It was noted that similar floods in 1986 and 1955 lead to the death of peach orchards and aerial phytophthora was also observed to kill some walnut and prune trees.

Noted potential indirect damage to bee pollinated crops due to difficulty in distributing bees to flooded orchards.

Website: http://calag.ucanr.edu/archive/?article=ca.v051n01p4
Contact: Matthew Fidelibus
Email: mwfidelibus@ucdavis.edu

Table 47 A Review of N_2O Emissions from California Farmlands

Category: Tool

Scale: State

Availability: Available

Other Themes That Will Benefit:

6. Land Use Management

Public Benefits Informed By: Climate change adaptation, working landscape preservation and stewardship.

Description, including Connection to Flood-MAR: Nitrous oxide emissions from almond, prune, and rice was only marginally different from uncropped agricultural soils.

Wine grape and tomato had higher N_2O emissions than the other crops listed. Most N_2O emissions from vineyards were emitted from the side/tractor row rather than the vine berm.

N_2O emissions are greatest when N application exceeds demand.

Website: http://calag.ucanr.edu/Archive/?article=ca.2017a0026
Contact: Matthew Fidelibus
Email: mwfidelibus@ucdavis.edu

Table 48 Whole Plant Adaptations to Fluctuating Water Tables

Category: Tool

Scale: State

Availability: Available

Other Themes That Will Benefit:

Public Benefits Informed By: Climate change adaptation, working landscape preservation and stewardship.

Description, including Connection to Flood-MAR: In this review the author notes that flood injury includes a variety of particular stresses including oxygen deprivation, exposure to reducing compounds in soil, interfernec in hormone production and transport, and facilitation of microbial attack.

Stresses that the seasonal aspect of flooding stress is extremely important and provides example of many temperate species being better able to tolerate prolonged inundation in winter. In temperate climates wintertime is usually when water tables are naturally most high.

Flooded plants also have to recover from “unflooding”.

Website: https://link.springer.com/content/pdf/10.1007%2FBF02803990.pdf
Contact: Matthew Fidelibus
Email: mwfidelibus@ucdavis.edu

Table 49 Rootstock Breeding for Stone Fruits

Category: Tool

Scale: State

Availability: Available

Other Themes That Will Benefit:

Public Benefits Informed By: Working landscape preservation and stewardship.

Description, including Connection to Flood-MAR: This review of progress in stonefruit rootstock breeding notes that many stone fruit species can be grafted onto other

Prunus species such that the same rootstock could be used for peaches, plums, apricots and almonds.

Plum germplasm has served as a good source of waterlogging tolerance for rootstocks to be used with peaches, plums, apricots and almonds.

Progress is also being made in cherry rootstocks tolerant of waterlogging.

Website: N/A
Contact: Matthew Fidelibus
Email: mwfidelibus@ucdavis.edu

Table 50 Rootstock Breeding in Prunus Species: Ongoing Efforts and New Challenges

Category: Tool

Scale: State

Availability: Available

Other Themes That Will Benefit:

Public Benefits Informed By: Working landscape preservation and stewardship.

Description, including Connection to Flood-MAR: This review of Prunus stonefruit rootstock breeding includes a discussion of "root ashphyxia", which results from waterlogged soils. Peach is noted to be particularly sensitive to hypoxia. The authors note that roots accumulate enzymes related to protection against oxidative damage that could occur post-anoxia. They also discuss the fact that the ethylene precursor ACC is synthesized in hypoxic roots and translocated to shoots where it is metabolized to form ethylene which, in turn, triggers symptoms such as epinasty and leaf senesecence. Ethylene also stimulates hpertrophied lenticels in stems.

Hypoxic roots have also been shown to become coated in lignin and suberin, presumably to reduce oxygen loss. However, this also reduces sap flow. The authors suggest a need for validating molecular responses of Prunus roots to hypoxia to identify markers that could be used in breeding programs.

Website: https://scielo.conicyt.cl/scielo.php?script=sci_arttext&pid=S0718-58392015000300002
Contact: Matthew Fidelibus
Email: mwfidelibus@ucdavis.edu

Table 51 2017 On-Farm Recharge Demonstration Site Monitoring and Analyses: Effects on soil hydrology and salinity, and potential implications on soil oxygen

Category: Research

Scale: Regional

Availability: Available

Other Themes That Will Benefit:

5. Soil suitability

Public Benefits Informed By:

Description, including Connection to Flood-MAR: In 2017, on-farm recharge was studied on almonds, grapes, walnuts and pistachios at seven locations in the San Joaquin Valley. Data from the study was used to calculate recharge quantities and infiltration rates as well as O2 and moisture conditions in soil during OFR

Final report being prepared for release:

Website: https://suscon.org/technical-resources/
Contact: Joe Choperena
Email: jchoperena@suscon.org

Table 52 Groundwater Recharge Assessment Tool (GRAT)

Category: Tool

Scale: State

Availability: Available

Other Themes That Will Benefit:

5. Soil Suitability
9. Recharge and Extraction Methods
12. Economic Analysis

Public Benefits Informed By:

Description, including Connection to Flood-MAR: The Groundwater Recharge Assessment Tool – GRAT™ gives agricultural water providers and Groundwater Sustainability Agencies (GSAs), essential insights to maximize groundwater recharge opportunities. GRAT's cloud-based application integrates hydrologic, agronomic and geologic science with best-available data from local, state and federal sources to create an indexed ranking of suitable recharge sites. As a planning tool, GRAT enables districts and GSAs to more efficiently create, evaluate and implement Groundwater Sustainability Plans (GSPs). As an operations tool, GRAT helps districts avoid missed opportunities to augment their water supplies by optimizing district recharge.

Website: www.suscon.org/GRAT/
Contact: Jan Merryweather
Email: jmerryweather@suscon.org

Table 53 On-Farm Infrastructure Needs Assessment And Costs To Implement Groundwater Recharge Using Flood Flows On Cropland – July 2014

Category: Research

Scale: Regional

Availability: Available

Other Themes That Will Benefit:

4. Crop Suitability
8. Recharge and Extraction Methods and Measures
11. Economic Analysis

Public Benefits Informed By:

Description, including Connection to Flood-MAR: Sustainable Conservation retained Summers Engineering to conduct a study of the on-farm infrastructure that would be needed to implement flooding of crop land for groundwater recharge. The study sets forth assumptions and constraints for typical farms in the Kings RiverBasin and evaluates the resulting infrastructure needs and costs.

Website: https://suscon.org/wp-content/uploads/2016/08/On-farm-Recharge-Engineering-Cost-Analysis-Report-FINAL.pdf
Contact: Joe Choperena
Email: jchoperena@suscon.org

Table 54 Crop Compatibility Calendar for On-Farm Recharge

Category: Tool

Scale: State

Availability: Available

Other Themes That Will Benefit:

5. Soil Suitability

Public Benefits Informed By:

Description, including Connection to Flood-MAR: A draft crop compatibility calendar was developed by Sustainable Conservation with initial input from farmers and field agronomists to compile information about the agronomic cycle of important perennial crops and their agricultural production practices. The calendar documents, on a weekly basis, typical milestones like timing of dormancy, bloom, and harvest; irrigation system types and volumes applied for ETc; and timing and types of nutrient and pesticide applications in a typical year. In addition, the calendar documents the experiences of pioneering growers who have applied additional water to cropland for recharge without agronomic harm

Note that this calendar is a component of the Groundwater Recharge Assessment Tool (GRAT).

Website: https://suscon.org/technical-resources/
Contact: Ladi Asgill
Email: lasgill@suscon.org

Table 55 Guidance in Establishing On-Farm Recharge Sites for Groundwater Basins

Category: Tool

Scale: State

Availability: Available

Other Themes That Will Benefit:

Public Benefits Informed By:

Description, including Connection to Flood-MAR: This guide is intended to provide support to growers, agencies and policy makers who are considering developing a successful on-farm recharge management program including operational elements, while addressing regional water quality needs.

Website: https://suscon.org/wp-content/uploads/2016/08/On-farm-Recharge-Guidance-Sheet.pd
Contact: Dan Munk
Email: dsmunk@ucanr.edu

Table 56 Nitrate Leaching Risk from Specialty Crop Fields During On-Farm Managed Flood water Recharge in the Kings Groundwater Basin – July 2017

Category: Tool

Scale: State

Availability: Available

Other Themes That Will Benefit:

4. Crop Suitability
5. Soil Suitability

Public Benefits Informed By:

Description, including Connection to Flood-MAR: USDA Project No: PIN #26174 - Assess whether on-farm groundwater replenishment efforts will intensify groundwater nitrate and salt contamination or improve groundwater quality; and Identify farm management and recharge strategies that minimize nitrate leaching.

Website: https://suscon.org/wp-content/uploads/2018/10/Nitrate_Report_FInal.pd
Contact:
Email:

Research Needs and Gaps

The tables below summarize needs and gaps in research, data, and tools related to Crop Systems Suitability theme. These needs and gaps were determined by the subcommittee members.

Table 57 Action Item 1: Identify the Effects of MAR Operations on Physiology and Biology of Crops

Category: Research, Data

Scale: State, Regional

Availability: Gap

Other Themes that will Benefit:

5. Soils, Geology, and Aquifer Characterization
6. Land Use Management
7. Water Quality
8. Recharge and Extraction Methods and Measures
9. Environment
11. Economic Analysis
12. Local, state, Federal Policies and other Legal Constraints
13. Tool and Application Development

Implementation Factors:

Primary – 5. Site Suitability

Secondary – 1. Governance and Coordination
3. Source Water
6. Recharge Method
8. Feasibility Analysis

Description and Connection to Flood-MAR:

Identify effects of MAR operations on physiology and biology of crops. Focus areas include:

a. Species sensitivity.
b. Conduct research to understand how crops and rootstocks respond to timing and duration of flooded winter conditions.
c. Chilling hours.
d. Conduct research to understand how flooded conditions impact crop winter chill hours.
e. Rooting characteristics (depth).

f. Conduct research to understand how root characteristics and performance may or may not change in flooded conditions.

g. Genetics.

h. Conduct genetics research to identify appropriate rootstocks and varietals tolerant of flooded conditions.

i. Nutrient management.

j. Conduct research to document how Flood MAR influences plant and soil nutrition, its management, and nutrient behavior and movement in the soil.

k. Yield and quality.

l. All the above research areas should be conducted in consideration of crop yields and quality to ensure agricultural systems continue to be economically viable and sustainable in California and in the global marketplace.

Draft Strategy for Implementation:

1. Attract funding to support a multi-year research fund to study the effects of MAR (frequency, timing and duration of saturated conditions) on physiological and biological attributes of crops.
2. Create an annual open call for research grants allowing commodity specific experts to bring their expertise to the issue.

Draft Cost Estimate:

Table 58 Action Item 2: Identify the Impact of Flood-MAR on Agricultural Practices and Operations

Category: Research, Data

Scale: State, Regional

Availability: Gap

Other Themes that will Benefit:

5. Soils, Geology, and Aquifer Characterization
6. Land Use Management
7. Water Quality
8. Recharge and Extraction Methods and Measures
9. Environment
11. Economic Analysis
12. Local, state, Federal Policies and other Legal Constraints
13. Tool and Application Development

Implementation Factors:

Primary – 5. Site Suitability

Secondary – 1. Governance and Coordination
3. Source Water
4. Conveyance
6. Recharge Method
8. Feasibility Analysis

Description and Connection to Flood-MAR:

Identifying the impact of Flood-MAR on agricultural practices and operations includes:

a. Cultural practices.

~~b. Investigate how existing cultural and management practices (timing of tillage, planting, field amendments) may or may not change as a result of Flood-MAR and how it will limit or enhance farm operations.~~

c. Irrigation infrastructure.

~~d. Investigate the extent to which irrigation practices including flooding, furrow, sprinkler, micro-sprinkler and subsurface drip irrigation can be used to deliver MAR. Identify the impact of MAR on irrigation system function and maintenance.~~

e. Field preparation.

~~f. Summarize all site development needs (berms, deep ripping, ridging, drainage), site access, and easements.~~

g. Organic residue management.

h. ~~Investigate the fate (e.g. redistribution) of organic residues during MAR~~.

i. Nitrogen, salt and pesticide management

j. ~~Identify how nitrogen, salts and pesticides should be managed before, during~~

~~and after MAR~~.

k. Economics.

~~l. Identify economic considerations and risks for MAR participants from issues identified above. Include the costs of on-farm infrastructure needs, economic costs and benefits, and economic impact of tradeoffs between practices.~~

Draft Strategy for Implementation:

1. Attract funding to support a multi-year research fund to study the effects of MAR (frequency, timing and duration of saturated conditions) on the logistics of cultural practices e.g. bed prep. application of agricultural amendments and chemicals, irrigation etc.
2. Create an annual open call for research grants allowing commodity specific experts, soil scientists and agricultural engineers to bring their expertise to the issue.

Draft Cost Estimate:

Table 59 Action Item 3: Identify the Effects of MAR operations on crop, pest and diseases~~impact of Flood-MAR on agricultural practices and operations~~

Category: Research

Scale: State, Regional

Availability: Gap

Other Themes that will Benefit:

5. Soils, Geology, and Aquifer Characterization
6. Land Use Management
7. Water Quality
8. Recharge and Extraction Methods and Measures
9. Environment
11. Economic Analysis
12. Local, state, Federal Policies and other Legal Constraints
13. Tool and Application Development

Implementation Factors:

Primary – 5. Site Suitability

Secondary – 1. Governance and Coordination
3. Source Water
6. Recharge Method
8. Feasibility Analysis

Description and Connection to Flood-MAR:

Conduct research to identify the effects of MAR operations on crop pests and diseases.

a. Identify short- and long-term impacts on diseases using flood-MAR.
b. ~~Determine which crop diseases may arise or spread as a result of flood MAR and identify potential solutions to reduce risk.~~
c. Identify impacts on weeds and weed management.
d. ~~Weeds and their seeds can spread via floodwater from non-agricultural areas to agricultural areas increasing pressures to use herbicides.~~
e. Impacts on rodents and rodent management.
~~f. Demonstrate how MAR can be used to manage rodents and or the potential to attract them to a site.~~
g. Identify impacts (or benefits) on insects and insect management (or enhancement).
~~h. To what extent does MAR promote the arrival and spread of insects.~~
i. Economics.
~~j. Identify economic costs and benefits from changes to pests and diseases caused by MAR.~~

Draft Strategy for Implementation:

1. Attract funding to support a multi-year research fund to study the effects of MAR (frequency, timing and duration of saturated conditions) on the spread and propagation of pests and diseases.
2. Create an annual open call for research grants allowing to bring their expertise to the issue.

Draft Cost Estimate:

Table 60 Action Item 4: Develop Decision Support Tool to Determine Crop Suitability for Flood-MAR

Category: Tool

Scale: State, Regional

Availability: Gap

Other Themes that will Benefit:

3. Infrastructure Conveyance and Hydraulics
5. Soils, Geology, and Aquifer Characterization
6. Land Use Management
7. Water Quality
8. Recharge and Extraction Methods and Measures
9. Environment
10. People and Water
11. Economic Analysis
12. Local, state, Federal Policies and other Legal Constraints
13. Tool and Application Development

Implementation Factors:

Primary – 5. Site Suitability

Secondary – 1. Governance and Coordination
2. Funding and Incentives
3. Source Water
6. Recharge Method
7. Groundwater Use
8. Feasibility Analysis

Description and Connection to Flood-MAR:

A decision support tool is needed that summarizes the findings of the top three action items. This tool will synthesize crop sensitivity, agricultural management considerations, and pest and disease issues in a place-based format. The tool will allow growers and managers to assess the risk of conducting MAR and understand how it will influence their economics and operations. This action item is the delivery and translation of knowledge gained from action items 1-3.

Draft Strategy for Implementation:

Integrate all action items and those of other relevant MAR committees to develop a place-based decision support tool to guide any Flood-MAR activity.

Draft Cost Estimate:

Table 61 Action Item 5: Identify Cropping System Specific Incentives and Barriers to Adoption of Flood-MAR

Category: Research, Data

Scale: State, Regional

Availability: Gap

Other Themes that will Benefit:

3. Infrastructure Conveyance and Hydraulics
5. Soils, Geology, and Aquifer Characterization
6. Land Use Management
7. Water Quality
8. Recharge and Extraction Methods and Measures
9. Environment
10. People and Water
11. Economic Analysis
12. Local, state, Federal Policies and other Legal Constraints
13. Tool and Application Development

Implementation Factors:

Primary – 2. Funding and Incentives

Secondary – 1. Governance and Coordination
3. Source Water
4. Conveyance
5. Site Suitability
6. Recharge Method
7. Groundwater Use
8. Feasibility Analysis

Description and Connection to Flood-MAR:

Some cropping systems have large incentives to Flood-MAR but have substantial barriers. For example, rice land is ideal for flooding in winter but the soils are not conducive to groundwater recharge. Lower value crops and or annual crops may have greater incentive for Flood-Mar but the spatial extent may be less significant. High value crops may be ideally suited due to their extent but crop value also fosters risk avoidance. Owners of certain cropping systems may have the flexibility to be incentivized to not grow a crop and fallow their fields for Flood-MAR. An assessment of the economic factors effecting the incentives and barriers to adoption is needed to implement these strategies.

Draft Strategy for Implementation:

Draft Cost Estimate:

Table 62 Action Item 6: Characterize Cropping System Economics Associated with Implementation of Flood-MAR

Category: Research, Data

Scale: State, Regional

Availability: Gap

Other Themes that will Benefit:

3. Infrastructure Conveyance and Hydraulics
5. Soils, Geology, and Aquifer Characterization
6. Land Use Management
7. Water Quality
8. Recharge and Extraction Methods and Measures
9. Environment
10. People and Water
11. Economic Analysis
12. Local, state, Federal Policies, and other Legal Constraints
13. Tool and Application Development

Implementation Factors:

Primary – 2. Funding and Incentives

Secondary – 1. Governance and Coordination
3. Source Water
4. Conveyance
5. Site Suitability
6. Recharge Method
7. Groundwater Use
8. Feasibility Analysis

Description and Connection to Flood-MAR:

Characterize cropping system economics associated with the implementation of Flood-MAR. Estimate overall costs and benefits of actions and challenges described in action items 2, 3, and 5. These economic calculations should be integrated into the decision support tool (4).

Draft Strategy for Implementation:

Draft Cost Estimate:

Table 63 Action Item 7: Identify Environmental Impacts and Benefits Associated with Flood-MAR for Cropping Systems

Category: Research, Data

Scale: State, Regional

Availability: Gap

Other Themes that will Benefit:

1. Hydrology Observation and Prediction
3. Infrastructure Conveyance and Hydraulics
5. Soils, Geology, and Aquifer Characterization
6. Land Use Management
7. Water Quality
8. Recharge and Extraction Methods and Measures
9. Environment
10. People and Water
11. Economic Analysis
12. Local, state, Federal Policies and other Legal Constraints
13. Tool and Application Development

Implementation Factors:

Primary – 5. Site Suitability

Secondary – 1. Governance and Coordination
2. Funding and Incentives
3. Source Water
4. Conveyance
6. Recharge Method
7. Groundwater Use
8. Feasibility Analysis

Description and Connection to Flood-MAR:

Identify environmental impacts and benefits associated with Flood-Mar for cropping systems. Certain crops may have high levels of residual nitrogen or pesticides that make them less suitable for Flood-MAR. These cropping systems need to be identified prior to widespread implementation. Research is needed to identify the effects of Flood-Mar on greenhouse gas emissions and carbon sequestration. Opportunities to support wildlife (habitat and food) should also be identified.

Draft Strategy for Implementation:

Draft Cost Estimate:

Prioritization Process

The theme subcommittee group was shaped of seventeen different academic experts and practitioners in different fields related to Crop Systems Suitability. In order to define the needs and gaps on research, data and tools relative to timing, duration, frequency of water for manage aquifer recharge, all subcommittee members listed identified gaps and needs in their corresponding field of expertise and other fields where gaps have been identified.

The list of needs and gaps was quite extensive that in order to prioritize them, a grouping of those subjects that were closed each other was needed. Subcommittee members identified eight different groups or categories with different subjects related to each other.

The next step was the prioritization process itself of those groups. The prioritization was done through an open and thoughtful discussion among all subcommittee members. The outcome of this prioritization exercise is the listed eight groups and corresponding subjects listed below:

1. Physiological and biological considerations for MAR operations (data and research)
    a. Species sensitivity
    b. Chilling hours
    c. rooting characteristics (depth)
    d. Genetics
        i. Rootstocks
        ii. Variety
        iii. Cover crops
    e. Yield and quality
2. Crop Suitability System Decision Support Tools
    a. Tools that apply specifically to this theme (13)
    b. Management and feasibility
    c. Soil probes
    d. Crop susceptibility models
    e. Risk assessment tool
    f. Management practices calendar

3. How does Flood-MAR impact management of cultural practices
    a. What cultural practices are appropriate for MAR?
    b. Irrigation infrastructure
    c. Economics
    d. Field preparation
        i. Site development (berms, deep ripping, ridging, drainage
    e. Site access and easement
    f. Residue management
    g. Mitigation options to address MAR challenges
    h. Bare and fallowed land
    i. Frost and wind protection
4. Pests and diseases and plant health (research)
    a. Long term impacts on diseases using flood-mar
    b. Disease impacts (risks or benefits) associated with MAR of fallowed fields. Impact of flooding on diseases
    c. Impacts on weeds and weed management
    d. Impacts on rodents and rodent management
    e. Impacts (or benefits) on insects and insect management (or enhancement)
5. How this would influence current farming practices
    a. Rates of adoption
    b. Research on incentives to adoption
    c. Barriers and motivation to adoption
6. Engineering Economics and economics analysis
    a. Implementation of low cost crops
    b. Costs of incentivization (including infrastructure)
    c. Cost and timing of permitting
    d. Low vs. high crops
    e. Regulation ILRP and CV salts
    f. SGMA
7. Environmental and agricultural impacts/benefits
    a. Wildlife habitat
    b. GHGs
    c. Offsite movement of pesticides
    d. Regulatory constraints
    e. Carbon sequestration
    f. Nutrients and soil
        i. Soil nutrient management

            ii. Groundwater nitrate contamination
        g. Impacts and benefits to soil health
8. Pesticides
    a. Soil pesticides
    b. Impacts on pesticide management
    c. Impacts on the environment

Top Three Research, Data, and Tools Actions

As part of the recommendations provided to the co-chairs during the Research Advisory Committee (RAC) meetings, the RAC coordinators suggested to present consistent levels of information for all of the research themes to support a coherent message throughout the R&D Plan. Another recommendation was to define the top three action items, corresponding description and connection to Flood-MAR, and the strategy for implementation to move forward in the R&D Plan.

Based on this recommendation, the lead theme consulted and had to make some adjustments to the information provided by all of the subcommittee members. These final top three contributions and the format of how it was submitted to the RAC committee is shown below.

Priority 1

Action: Perform case studies on agricultural land-based Flood-MAR projects completed to date.

Description and Connection to Flood-MAR: California has a large diversity of crops and soils making it challenging to document risks associated with flood-MAR. As a result, few studies exist that conclusively predict the suitability of a given crop or cropping system for flood-MAR. Moreover, only a fraction of California's cropping systems has been studied. Crop damage, life span, and yield may take several years to be expressed in perennial crops. Similarly, disease or pests may take time to develop and few studies if any have tracked long term response. There is no clear way to prioritize suitability (based on relative risk) of cropping systems for flood-MAR because of these gaps in knowledge, therefore scientists are hesitant to provide recommendations to growers.

Draft Strategy for Implementation: The goal of this research is to produce a summary and meta-analysis of all existing flood-MAR projects on agricultural land to outline the state of knowledge about cropping system suitability. The analysis will attempt to document a wide range of considerations which may or may not be available such as:

a. Crop type
b. Hydrologic conditions of the project's water application (water height, duration of standing water, duration of saturated conditions, number of applications per season, number of years)
c. Crop response (physiological, yield, yield quality)
d. Soil type and SAGBI rating
e. Lessons learned by practitioner

The strategy could be completed by a variety of entities but might be best accomplished by a land grant university with demonstrated experience with delivering scientific knowledge to growers. The intended audience would include growers, consultants, agency staff, and educators.

Estimated Timeline: 2 years

Draft Costs Estimate (breakdown): $300,000 The estimated cost is equivalent to 2-years of graduate students' salary and tuition plus fees. It includes travel expenses and publication fees.

Cost Estimate: $300,000

Priority 2

Action: Initiate and complete research on MAR gaps for California crops

Description and Connection to Flood-MAR: California has more than 200 crops, more than 2,000 different soil types, and several different agricultural growing areas making the state one of the more diverse agricultural food production regions in the country. For the research theme, the focus is the top crops which are the most likely to use in MAR projects. Research to identify the most suitable crops and prioritize regions for MAR is currently unknown. This action item will establish a scientific committee to determine which crops, regions and other variables to prioritize first in terms of future funding for research. Initiate and complete research on MAR gaps for California crops. Focus areas include:

1. Identify the effects of MAR operations on physiology and biology of crops.
2. Identify the impact of Flood-MAR on agricultural practices and operations.
3. Identify the effects of MAR operations on crop pests and diseases.

Draft Strategy for Implementation: Create an expert panel to prioritize and facilitate funding for research on the following gaps:

1. Identify the effects of MAR operations on physiology and biology of crops.
    - Species sensitivity.
- How do crops and rootstocks respond to timing and duration?
    - Chilling hours.
    - Rooting characteristics (depth).
- How do root characteristics and performance change?
    - Genetics.
- Identify flood tolerant rootstocks and varietals.
    - Nutrient management.
- How is plant and soil nutrition, its management, and nutrient behavior and movement in the soil effected?

The above research areas should be conducted in consideration of crop yields and quality to ensure agricultural systems remain economically viable and sustainable in California and in the global marketplace.

2. Identify the impact of Flood-MAR on agricultural practices and operations.
    - Cultural practices.
- How are existing cultural and management practices (timing of tillage, planting, field amendments) effected?
    - Irrigation infrastructure.
- What is the extent to which irrigation practices (flooding, furrow, sprinkler, micro-sprinkler and subsurface drip) can be used? What is the impact on irrigation system function and maintenance?
    - Field preparation.
- What site development is needed (berms, deep ripping, ridging, drainage)?
    - Organic residue management.
- What is the fate (e.g. redistribution) of organic residues?
- How should nitrogen, salts and pesticides be managed before, during and after?
    - Economics.

Identify economic considerations and risks from issues identified above.

Include the costs of on-farm infrastructure needs, economic costs and benefits, and economic impact of tradeoffs between practices.

3. Identify effects of MAR operations on crop pests and diseases.
    - Identify short- and long-term impacts on diseases.

- What crop diseases arise or spread and identify potential solutions.
    - Identify impacts on weeds and weed management.
    - Impacts on rodents and rodent management.
- Demonstrate how MAR can be used to manage rodents and or potential to attract them.
    - Identify impacts (or benefits) on insects and insect management (or enhancement).
    - Economics.
- Identify economic costs and benefits from changes to pests and diseases caused by MAR.

The research should be conducted by academic institutions, consultants, NGO's and state agency staff with the intended audience being growers. This research should commence after the case study analysis has identified gaps.

Estimated Timeline: Decades.

Draft Costs Estimate (breakdown): $15,000,000. This research is expensive and time consuming and would require highly controlled experimental design and treatments by a wide range of scientists to address the gaps outlined above with certainty.

Cost Estimate: $15,000,000

Priority 3

Action: Develop decision support tool to determine crop suitability for Flood-MAR.

Description and Connection to Flood-MAR: A decision support tool is needed that summarizes the findings of the top two action items. Growers require information on risk to make informed decisions. The tool should be designed in a way where information is easily obtained, transparent in terms of risk and uncertainty and easy to comprehend. The relative risk associated with flood-MAR on cropping systems may inform how sites are incentivized. The tool would exist as an online app that synthesizes grower response to key questions and delivers risk and management recommendations based on criteria outlined in action item 2.

Draft Strategy for Implementation: This tool will synthesize crop sensitivity, agricultural management considerations, and pest and disease issues to provide cropping system-specific guidelines. The tool will allow growers and managers to assess the risk of conducting MAR and understand how it will influence their economics and operations. This action item will first exist as the delivery and translation of knowledge gained from action item 1 and will evolve to include knowledge gained from action item 2. Ultimately, it will include outcomes from other themes.

The tool should be designed by a land grant institution or agricultural consulting institution with close collaboration with growers, industry, NGO's and agency staff. The intended audience is growers but may also be helpful for water resource planning.

The initial tool could be completed after the case study analysis (action 1); and would take approximately three years to complete. The tool will need to evolve over time as knowledge about cropping system suitability and management evolves.

Estimated Timeline: Draft Costs Estimate (breakdown): $2,000,000 for initial decision support tool; 1.5 years of professional services for planning, data organization and conceptual design, 1 year for decision support tool programmer; 0.5 years for beta testing and upgrades.

Cost Estimate: $2,000,000