LEVERAGING RESEARCH TO INFORM CALIFORNIA CLIMATE SCOPING PLAN: AGRICULTURE & WORKING LANDS SECTORS

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INTRODUCTION

This report summarizes a recent UC Davis forum on "Leveraging Research to Inform California Climate Change Impacts and Greenhouse Gas Mitigation Strategies for the Agriculture & Working Lands Sectors" held on February 11, 2016. The workshop aimed to inform strategies in the agriculture and working lands sector for meeting California's new 2030 targets to reduce greenhouse gas emissions under the State's climate plan.

The specific objectives of the workshop were:

- State of research: quantification of GHG emissions from specific practices
- Potential metrics for measuring progress other than GHG emissions
- Priority gaps for future research
- Implications of practice adoption for water and economic sustainability

In 2008, the Economic and Technology Advancement Advisory Committee, established by Assembly Bill 32, identified research and technology development investment opportunities to enable the State to meet its climate goals. This report showed possibilities for California agriculture to contribute to GHG mitigation, but required more ground-truthing of the practices and technologies in California contexts. Now in 2016, we report on more than 50 studies conducted in California that were stimulated by this landmark climate legislation and that provide evidence of practices in agriculture and rangeland management that can assist California growers and ranchers to mitigate as well as adapt to climate change. We note that the California Department of Food and Agriculture's (CDFA) USDA Specialty Crop Block Grant program, along with grants funded by the California Air Resources Board (ARB), California Energy Commission (CEC), and California Department of Water Resources (DWR), have been critical to enabling the science that informs this report.

It is important to begin by putting California agriculture into context. Agriculture and working lands contribute only eight percent of California's greenhouse gas emissions (ARB, 2015). Just over half of that is from livestock production, 23 percent is from crops, and 11 percent is from fuel use. Food production in California is very energy efficient compared to most other regions of the world. Further, as California produces more than half of the fruits, vegetables, and dairy consumed in the U.S. and thus plays an essential role in the security and nutritional quality of the U.S. food system.

It is also important to recognize other environmental regulatory drivers that will likely play a significant role in mitigating greenhouse gas emissions from California agriculture in the future. These include stricter monitoring of nitrogen management to reduce nitrates in groundwater, with may lead to more precise nitrogen fertilizer use, thus reducing nitrous oxide emissions. The Sustainable Ground Water Management Act may impact the number of irrigated acres and promote further gains in water use efficiency, reducing carbon dioxide emissions associated with energy use in irrigation pumping. A number of new and ongoing state incentive programs also play a critical role in advancing state climate goals, including but not limited to SWEEP (State Water Efficiency and Enhancement Program) and the new Healthy Soils Initiative, which seeks to increase soil organic matter in California farmlands, storing carbon while improving overall agronomic efficiency.

With over 76,000 farm and ranch operations in California, covering over 43 million acres of land, there are no “one size fits all” solutions. But as we outline below, there are numerous opportunities to both reduce GHG emissions and sequester carbon across diverse agricultural operations – small to large, organic to conventional, crop to livestock. Perhaps most importantly, many of these practices have co-benefits for water conservation, restoration and conservation of natural lands, or economics, which together with state investment in the resilience of California agriculture and working lands, can promote adoption of these practices.

Given the complexity of integrated and diverse agricultural systems, and the difficulty of measuring emissions across heterogeneous environments, combining at least two metrics could provide reliable measures of progress toward greenhouse gas reduction goals for the agriculture and working lands sectors. Among those that might be considered for further development include:

- Participation rates in USDA Natural Resource Conservation Service programs, such as EQIP and Conservation Farm Plans.
- Calibration and use of more precise GHG emission calculators including COMET-FARM, International Wine Industry Greenhouse Gas Accounting Protocol, and new dairy methodologies cited below.
- Use of mapping, aerial, and satellite imaging to monitor adoption of practices such as cover cropping, riparian corridors, and rangeland stocking rates.
- Surveys, sampling, and benchmarking protocols can be used to gauge management practice adoption. This could be done collaboratively with producer organizations, universities, non-governmental organizations.

Finally, we conclude by identifying priority research opportunities that would advance our understanding of the potential climate benefits of combining practices along with potential trade-offs or barriers to larger scale adoption.

Farmland Preservation

An estimated 40,000 acres of agriculture land is converted to urban development each year (CDFA). This area represents the single largest opportunity for agriculture to contribute to the State's climate plan. Research from Yolo County estimates that GHG emissions per hectare of urban land are more than 70 times greater than those from irrigated cropland (Haden et al., 2013; Jackson et al., 2012a). With continued population growth in the state, policies that promote more energy efficient patterns of urban development are critical to meeting greenhouse gas emissions targets. As shown in the example of one county, coupling such urban development polices with farmland conservation could reduce vehicle mileage and transportation emissions by 25% under a low-emissions scenario by 2050 (Wheeler et al., 2013).

Soil and Nutrient Management

Soils are complex biological systems that provide key ecosystem services and can be managed to store carbon, reduce emissions and provide important environmental and economic co-benefits. Given the diversity of California agriculture, no single management practice can achieve our reduction goals. It is only the integration of different management strategies that shows considerable mitigation or sequestration potential and provides important co-benefits to enhance the sustainability of California agriculture (Kellenbach et al., 2010; Suddick et al., 2010).

Soil and Crop Management

Soil GHG emissions increase with soil moisture and nutrient availability. Correspondingly, research shows that significant reductions in GHG emissions can be achieved by shifting management practices toward more efficient irrigation and fertigation systems such as micro-irrigation and subsurface drip. Integrating conversion to micro-irrigation combined with fertigation, reduced/no tillage, and cover cropping decreased nitrous oxide emissions by two to three fold in California processing tomatoes (Kallenbach et. al, 2010; Kennedy et al., 2013).

Cover crops are used to fix or assimilate nitrogen in the soil, suppress weeds, build up soil carbon and scavenge excess soil nutrients from prior crops (Seiter et al., 2004; Jackson, 2000). Studies conducted in California suggest that type and method of irrigating cover crops impacts GHG emissions and certain combinations can reduce emissions. Use of subsurface drip versus furrow irrigation and use of non-leguminous cover crops can lead to decreased emissions (Kallenbach et al., 2010; Kennedy et al., 2013). With an increase in soil organic matter, plant-soil nitrogen cycling becomes more tightly coupled, decreasing soil nitrate and the propensity for nitrogen losses, while still satisfying plant demands (Bowles et al., 2015).

In Mediterranean and semi-arid regions such as California, no-till practices reduce emissions by 14-34% after ten years of continuous management; however, emissions increased up to 38% under shorter time horizons for these management strategies (Six et al., 2004; van Kessel et al., 2013). A combination of practices: combining no-till, microirrigation (Sánchez-Martín et al., 2008; Sánchez-Martín et al., 2010), use of organic fertilizers (Sánchez-Martín et al., 2010), fertilizer placement depth (van Kessel et al., 2013), and cover-cropping have shown reductions in GHG emissions in California settings (Kallenbach et al., 2010; van Kessel et al., 2013; Kennedy et al., 2013). California's dry climate may reduce the efficacy of no-till when compared to the combined use of microirrigation, organic fertilizers and cover cropping (Mitchell et al., 2009). A number of socio-economic and biophysical limitations unique to California (namely, the capital required for conversion to no-till, the need for more nitrogenous fertilizer in the first years of adoption and relatively slow accumulation of soil carbon) have led to low no-till adoption rates in California at 2%, compared with the rest of the United States at 23% (Mitchell et al., 2009). It should be noted that immediate reductions in on-farm fuel use will be observed when converting to no-till from decreased use of farm machinery (Frye et al., 1984; Archer et al., 2002; West et al., 2002).

Nutrient Management

Improved nutrient management, mainly in the form of nitrogenous fertilizer, provides a high potential for reductions in emissions. N_2O emissions are commonly observed in agronomic systems following the application of synthetic and organic forms of fertilizer. N_2O emissions have been shown to respond linearly to surface fertilizer application in lettuce, tomato, wine grape and wheat systems in California (Burger et al., 2012). However, once fertilizer rate exceeds crop demand, emissions may increase at a greater rate (McSwiney et al., 2005). While reducing fertilizer rate may reduce N_2O emissions, there may be a significant crop yield reduction, mining of soil for nutrients and increased CO_2 emissions. One method to balance the trade-off in emissions has been to 'yield-scale' emissions where emissions are scaled against crop yield as a metric for fertilizer efficacy (Murray et al., 2011).

Fertilizer source has broadly shown to have an effect on N_2O emissions and may relate to certain fertilizers' ability to make soil more acidic, an ideal environment for N_2O production (Burger et al., 2011). However, only one California study has been done comparing synthetic fertilizer sources. This found that the use of calcium ammonium nitrate reduced N_2O emissions approximately 100 kg N ha^{-1} compared to the use of urea ammonium nitrate (Zhu-Barker et al., 2015). Another California study found emissions reductions of up to 34% (Brown et al., 2011; Schellenberg et al., 2012), however the results were not statistically significant. Recently, studies in California have shown that the use of manure and green waste fertilizers can increase emissions when applied to the soil surface (Zhu-Barker et al., 2016), particularly if their use not timed to crop demand (Lazcano et al., 2016). Fertilizer source and timing, along with the use of nitrification inhibitors are key areas of research that are currently lacking in the California context. Due to California's warm, dry summer growing season and cool, wet winter, specific research should be promoted to examine nutrient management implications to emissions in California.

While any one of these soil and nutrient management practices may have limited impact on emissions, they do have numerous co-benefits that can tip the scale, including: reductions in erosion and improved air quality (Madden et al., 2008), reduced fossil fuel demand from lower farm machinery use (Archer et al., 2002; West et al., 2002), reduced nitrogen leaching (Poudel et al., 2002), enhanced water infiltration and storage (Joyce et al., 2002; Shaver et al., 2002), and increasing carbon stocks below the root zone to improve carbon sequestration (Suddick et al., 2013). Long-term research is needed to determine the impact on these management practices on crop performance and soil carbon sequestration.

Integrated & Diversified Farming Systems

Integrated or diversified farming systems refer to multipurpose operations that may produce several commodities and utilize renewable resources. Examples include integrated crop and livestock systems, organic agriculture, orchard and annual crop intercropping, the use of perennial, salt-tolerant grasses irrigated with saline drainage water on other wise fallow, marginal land, and improved pastures. Through reliance on biological processes to build healthy soils and support above and below ground biodiversity, diversified systems offer reduced greenhouse gas emission potential and resiliency to climate perturbations along with other environmental co-benefits.

These systems have been shown to reduce soil nitrate and nitrous oxide emissions, and increase carbon sequestration both in soils and above ground biomass (Smukler et al., 2010; 2011; Williams et al., 2011; Bowles et al., 2015, Garland et al., 2011). Many of these studies examined California organic farms where multiple practices are often stacked, such as combining organic soil amendments, integrating cover crops into crop rotation for year-round plant cover, and reducing tillage. In addition, farmscaping with perennials on field margins and maintenance of vegetated riparian corridors sequester carbon in soil and in the woody biomass of trees and shrubs (Smukler et al., 2010; Hodson et al., 2014). Use of tailwater ponds and sediment traps also play an important role in soil and water quality (Smukler et al., 2011).

Diversified, multipurpose systems provide other co-benefits depending on the set of practices involved. Practices that increase soil carbon improve soil quality, structure, nitrogen-supplying power, and water-holding capacity (Burger et al., 2005). Filter strips and riparian corridors can reduce soil erosion and carried losses of topsoil and nutrients, and thereby contamination of surface water with valuable soil and nutrient resources, and pathogenic microbes (Tate et al., 2006). Hedgerows have been shown to increase pollinators and other beneficial insects in California (Morandin et al., 2011; Ponisio et al., 2015). Given the promise for multiple co-benefits, more types of California diversified systems deserve study, which would provide a better basis for metrics of evaluation than those that are currently available. It is also important to consider that clusters of farms in a watershed using integrated/diversified farming practices as reduction in GHG emissions and other co-benefits may have a more potent effect on associated co-benefits than single farms alone.

Dairy & Intensive Livestock

State policies that encourage reductions of GHG emissions need to account for the already high levels of resource efficiency in the California dairy sector. A recent Rabobank report on the competitive challenge of environmental regulations, comparing the dairy sectors of the Netherlands, California, and New Zealand, documents that California dairies produce more milk per cow than the Netherlands, and more than 2.6 times as much per cow as dairies in New Zealand, while operating under strict environmental regulations (Rabobank, 2014). The United Nations Food & Agriculture Organization's Livestock Environmental Assessment Performance Partnership (LEAP) provides an additional tool for environmental benchmarking of livestock supply chains (UN FAO, LEAP) globally.

Calibration of GHG models for California conditions will provide a more accurate basis for measuring progress than current IPCC values, and for assessing the potential benefits of different forage and feed practices on emissions. There are several methodologies developed in the last few years that can be adapted for use in California to provide more accurate estimates of GHG emissions (Moraes et al., 2014; Santiago-Juarez et al., 2016).

About half of California's livestock GHG emissions comes from enteric fermentation (belching) and half from manure in concentrated beef cattle and dairy operations. Thus, the largest opportunities for change in livestock practices center on feed (composition and precision feeding) and manure management. California offers a uniquely diverse range of crop by-products for use as dairy cow feeds, and research has improved our understanding of the impacts of different feeds on productivity, economics, and GHG emissions (Moate et al., 2014; Moraes et al., 2015; Niu et al., 2016; Hirstov et al., 2013). One caution: there is a risk that focusing on one climate pollutant, such as methane, could lead to practices that have negative trade-offs for other environmental pollutants, such as increased nitrogen and phosphorous impact on water quality (Niu et al., 2016).

A recent report submitted to the Air Resources Board suggests it is feasible for California to aim for 50 percent reductions in methane emissions from dairy manure management by 2030 (Kaffka et al., 2016). This would require capturing or avoiding methane generated by an estimated 60 percent of dairy cows in California, primarily from the State's 250 largest dairies (ARB, 2016). If successful, a gallon of California milk may be the least GHG intensive in the world. The report outlines a number of strategies to reduce methane emissions from alternative manure management practices and technologies (ARB, 2016). These include:

- Switching from flush water lagoon systems without methane capture to solid-scrape or dry manure management

- Covered lagoons for capture of biogas for transportation, on-farm electricity, or injection into nature gas pipelines
- Anaerobic digesters to capture and utilize methane such as CDFA's dairy digester program
- Pasture-based dairy management, in which manure is left in the field and decomposes aerobically.

A diversity of practices will likely be needed to reflect the economics of the range of scale of dairies in California. For example, a shift to solid-scrape and dry manure management have economies of scale for larger dairies to transport waste off-site for biodigester facilities. Potential trade-offs of these manure management practices on air quality, crop management, nutrient efficiency, and cost , however, bear further analysis. Pasture systems may be more suitable to coastal areas than the Central Valley where pasture would require significantly more irrigated land for feed production (ARB, 2016).

RANGELAND MANAGEMENT

Comprising just under half California's agricultural land (UC AIC, 2012), these working lands provide ecosystem services (i.e. wildlife habitat, pollinator habitat, water storage), in addition to supporting production of livestock (Huntsinger et al., 2010; Shaw et al., 2011; Byrd et al., 2015). Grasslands have higher levels of total soil carbon, nitrogen, and biomass compared to cultivated lands (Steenwerth et al., 2005). Practices such as improved grazing management, moderate stocking rates, compost application and management of plant biodiversity offer additional benefits for carbon sequestration. Given the considerable sequestration potential, research is needed to identify socioeconomic opportunities and barriers to greater participation in range management incentive programs (DeLonge et al., 2013).

Restoration of rangelands often involves cultivation and re-seeding to restore native perennial grasses. A number of studies in California show that while the soil disturbance reduces soil microbial biomass and soil carbon in the short term, these begin to recover quickly, within four years. And over a longer period, native grasses may sequester carbon in slightly deeper soil levels due to perennial root systems (Potthoff et al., 2009; Steenwerth et al., 2002). Mixed planting of woody species with grasses may provide similar benefits while promoting a more resilient system in other arid regions (Barger et al., 2011; Grice, 2006), but this needs to be tested in California. The use of mixtures of native grasses and oaks in rangelands could provide the greatest positive impact, as native plants are associated with lower soil carbon losses (Koteen et al., 2011), higher nitrogen cycling rates (Parker et al., 2009) and better soil aggregation qualities (Duchicela et al., 2012).

Studies of both California's coastal and valley grasslands show that use of compost can boost carbon sequestration to between 0.6 to 4.1 tons CO2-eq per hectare per year (Ryals et al., 2013), and modeling using DAYCENT indicates that the impact persists for years. Research suggests that scaling this practice up to 5 percent of California rangeland could mitigate 0.7 to 4.7 million t CO_2-eq per year. Applying organic materials to rangelands in Southern California has proven to provide co-benefits such as stabilizing soil nitrogen stocks, improved plant community resilience and productivity and increased soil organic matter accumulation after one year of application (Zinc et al., 1998). However, due to the limited number of studies, long-term studies (greater than ten years) that span California rangelands are needed to further validate these results and provide long-term policy recommendations. The use of composted materials in rangelands may reduce N_2O emissions up to 50% (Ryals et al., 2013; Dalal et al. 2009, Dalal et al., 2010; Paul et al., 1993; Eghball, 2000; Sikora et al., 2001; DeLonge et al., 2014). It is will be important to ensure that any rangeland compost practices do not create negative trade-offs for water quality through nutrient run-off or leaching, and that fossil fuel use for transportation to rangeland sites do not incur large CO_2 emissions.

NRCS provides cost-share programs for range managers to split the cost of implementing improved management techniques. Currently, only 30-40% of California ranchers participate in these programs. Based on the research findings above, this points to additional opportunities using existing incentive programs to further agriculture's contributions to the state climate goals.

Biomass-based Energy Production

The most recent assessment of state biomass details the availability of resources that could support generation of three to four times the current biomass-based renewable energy being produced (California Biomass Collaborative, 2015). Biomass use for energy, however, has declined in recent years, as it is generally more expensive than alternative fuels. Federal renewable fuel standards and solar power incentives, together with low natural gas prices have created uncertainty in the market for biomass-based renewable contracts by public utilities, In addition, interconnection issues between biomass facilities and utilities complicates investment in new facilities. Research and policy actions to reduce barriers and incentivize co-benefits for greenhouse gas reductions and ecosystem services will be required to expand this sector.

Current biomass energy production from agricultural residues in California is largely based on combustion of woody biomass from orchards and vineyards, and nut shells. While a few growers have installed successful on-farm small-scale gasification systems for nut shells and wood chips, larger scale facilities are typically more than forty years old, and the power produced is more expensive than other forms of alternative energy (UC Davis California Geothermal Energy Collaborative, 2013). Many plants are now idle or closed, leaving tree and vine producers with few or more costly options for disposal of biomass.

Other significant sources of underutilized agricultural biomass are rice straw and hulls and livestock manures and anaerobic digestion technology (Kaffka et al., 2016; Kaffka et al., 2012).

Current biogas systems use to make electricity on most dairies use internal combustion. Exhaust from these systems pose air quality problems that must be remediated. Manure is not a high gas yielding feedstock. Upgrading manure with fermentable feedstocks such as crop residue, food processing residues (Amon et al., 2011), and other materials can improve the energy and economic return (UC Davis California Geothermal Energy Collaborative, 2013). There is potential for crop-based biofuels and bioenergy in California based on locally optimal feedstocks and biorefineries (Kaffka et al., 2014; Jenkins et al., 2009; Kaffka, 2009).

Research should emphasize quantifying the co-benefits of agricultural biomass use for greenhouse gas reduction and other ecosystem services as a basis for exploring policy options such as carbon credits.

Priorities for Future Research

Here we identify cross-cutting priorities that will enable scaling, and equally importantly, the integration of multiple practices to achieve more substantial progress toward mitigation and adaption of agriculture to climate change. Among the priorities we identified at the workshop are:

- Quantification of synergies from stacking multiple practices over time (i.e. crop rotation, cover cropping, compost addition, NT, microirrigation, etc.) and scale (field to region) to address efficacies surrounding carbon sequestration, emissions reductions and nitrogen use efficiencies.
- Quantification of co-benefits (water, economic, biodiversity) from soil management practices and biomass-based fuels.
- Identifying socioeconomic trade-offs or barriers to adoption of practices (improved rangeland management, NO-TILL).
- Further characterization of potential water and air quality benefits (i.e. NO-TILL and improved animal nutrition) and trade-offs from some livestock (range & intensive) management options.
- Defined and validated metrics for soil health parameters and further calibration of models for CA systems
    - Use of remote sensing-based metrics for practice adoption
    - DAYCENT, COMET FARM, livestock emission methodologies.
- Social science research on to understand how greater involvement of NGOs, marketing organizations, and businesses could spread the financial burden of innovation across the value chain.
- To develop scalable metrics, develop sampling or survey tools to measure adoption of key practices that have been demonstrated to reduce emissions.

As this report outlines, the number of practices and technologies that can assist California to meet its climate change goals is as diverse as the types of agriculture practiced across the state. Support for research has been critical to identifying these climate benefits – both mitigation and adaptation. Similarly, state incentive programs are critical to promoting adoption of these practices at scale through co-investment with the agriculture sector to achieve our mutual goal of sustaining a vibrant food system for our state and nationally.