Regional effects of climate change on California animal agriculture and options for farmers to respond through husbandry adaptation and greenhouse gas mitigation

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Abstract

Climate change will pose challenges for the world's food supply in the coming decades. As a leading agricultural state with a diverse agricultural portfolio, California will face its own unique regional challenges due to its complex agricultural inter-dependencies. As veterinarians and animal scientists with livestock and poultry clientele in the Central Valley of California, we are starting to observe changes in food safety, production efficiency, welfare and disease that can be linked to the effects of climate change. For example, in California drought has reduced access to rice hulls which are commonly used as bedding for poultry which have necessitated the use for recycling rice hulls. Our results have shown an 11.08 × greater risk ($P < 0.5$) of Salmonella in poultry raised on litter recycled more than 3 × versus poultry raised on fresh litter material. While these types of challenges can be mitigated through adapting husbandry, it is also important to recognize that there are opportunities for the farmers to focus on mitigation of greenhouse gases via the alternative usage of agricultural 'waste' products with a focus on increasing baseload renewable energy from anaerobic digestion (AD). Specifically, the further targeted integration of methane digesters in the Central Valley of California could play a significant role in renewable energy production from carbon-based agricultural 'waste' material. To that point, geographic information system-based maps were made showing the spatial location of major livestock and crop production areas laid over the current natural gas pipeline network for Fresno County (the most productive agricultural county in the USA). Refinement and further development of these types of maps are integral in order to visualize and develop a robust and commercially viable AD network into our current energy infrastructure. This review aims to describe current scenarios spanning food safety, welfare and the connection between animal disease and production efficiency in California livestock and poultry production with respect to how climate change affects California livestock and poultry.

Keywords: Climate change, California, Livestock, Poultry, Energy

Review Methodology: The present paper constitutes a detailed literature review using the on-line subscription-based citation indexing database, Web of Science (keyword search terms used: Climate Change and/or California and Livestock. Climate Change and/or California and Poultry, Food Safety or Welfare or Production and Climate Change. Bluetongue Virus or Salmonella and Climate Change. Methane Digesters and/or Anaerobic Digestion and/or Climate Change). References from the articles obtained by this method were evaluated for additional relevant material. The authors also obtained expert opinions from colleagues and checked for any upcoming studies not yet published. In addition, original maps of agriculture and gas line infrastructure were assembled using ArcGIS 10.6. Data was obtained from the USDAs National Agricultural Statistical Service (NASS), the state of California and the National Pipeline Mapping System.
Methane Digesters, Anaerobic Digestion and Energy

Review Text

The impacts of climate change on temperature, snow depth, albedo, precipitation, evapotranspiration and runoff will result in unintended agricultural changes across the globe. While climate change is a global phenomenon, a regional understanding of the effects of climate change is essential to better understand the downstream effects on agricultural production [1]. This regional-specific approach is particularly important for the state of California, which is the most productive agricultural state in the USA [2].

In 2016, annual revenues for California agriculture topped US$46 billion with US$20 billion of that total sold as exports [2]. In California, commercial livestock, poultry and their products account for over US$10.4 billion of that revenue [2]. The national and international prominence of California's livestock and poultry sector makes it a high priority for climate change adaption research. This is especially relevant when considering that not only will the world's population grow to over 9 billion people by 2050 but the global middle class, which consumes the majority of the world's animal-based proteins, is estimated to grow from 450 million people in 2005 to 2.1 billion by 2050, as well [3]. Yet, the majority of peer-reviewed publications focused on the effects of climate change on agriculture in California have primarily focused on crop production and have focused less on livestock and poultry production [4–7]. Because California agriculture is so diverse from both an ecosystem and crop perspective and because California is integral to domestic and international food supplies, understanding how climate change affects livestock and poultry production in terms of food safety, production efficiency, animal welfare and disease may offer insights to agricultural planners around the world.

The present review is divided into two parts. The first part summarizes and connects the literature on the effects of climate change in California on:

- Food safety associated with poultry production.
- Welfare of poultry under extreme temperatures associated with public demand for poultry raised outdoors.
- Losses in production efficiency of livestock as a result of epi-zoonotic vector-borne diseases such as Bluetongue Virus (BTV) in cattle.

These less studied downstream effects of climate change are important to understand at both the farm and regional level. The second part summarizes the potential role agriculture can play on mitigation of greenhouse gases (GHG) via the adoption of anaerobic digesters. Specifically, the utilization of geographic information system (GIS) as a tool to identify farm-scale digestible material in addition to integrating AD systems into our current natural gas distribution system is discussed from a spatial perspective. Both parts integrate novel research from our studies in California and reflect our observations as faculty from a land-grant school with appointments that include research and extension in animal agriculture and GHG mitigation from animal agriculture.

Part I: How Climate Change is Affecting Food Safety, Production Efficiency, Animal Welfare and Disease in California

Food safety

In the USA the economic burden of foodborne illness is estimated to be approximately US$14 billion/yr with viruses (norovirus), bacteria (*Salmonella*, *Campylobacter, E.coli* and *Listeria*) and parasites (*Cryptosporidium parvum*) being the primary culprits [1, 8]. In response to climate change, foodborne outbreaks are expected to increase [1, 9, 10]. This is primarily attributed to the effect of increased ambient temperatures on the growth of bacteria at various points along the food chain in addition to the increased environmental loading and transmission of foodborne pathogens due to flooding [10, 11]. While the connection between crop production, available pasture land and livestock and poultry production is well established with respect to feed production [12], the connection between crops and food safety with respect to non-edible plant material used in livestock and poultry production (i.e. poultry and cattle) primarily as a substrate or bedding material is not as well established. For example, while there is literature demonstrating the presence of *Salmonella* in almond hulls [13] and in waterfowl and rodents that use rice fields as habitat [14, 15], there is a lack of literature on how climate change can impact food safety of production animals.

In California, non-edible rice hulls (byproducts of rice production) are the most commonly used substrate (i.e. bedding) in commercial poultry production facilities. While California is the leading rice-producing state in the USA with annual production of long, medium and short grains combined routinely over 40 million cwt planted on over 400,000 acres of land [2], rice production has been volatile over the last 5 years. Specifically, the amount of planted rice land ranged between 429,000 acres in 2015 and 567,000 acres in 2013 [2]. This variability in total acres of plant rice is primarily due to drought and limited water availability. In turn, this has led to a decrease in the availability of rice hulls, which are commonly used as poultry litter in California broiler production. Consequently, the ability to replace rice hulls regularly to mitigate *Salmonella* loads in the litter is affected resulting in potential food safety challenges.

Our research (i.e. boot swabs (Hardy Diagnostics, EB100) of 10 broiler farms owned by a single company) has showed that recycling rice hulls (i.e. taking rice hulls and composting them after a flock has been depopulated and then using that material for the following flock) more than three times results in 4.49 × ($P < 0.05$) greater risk for the presence of *Salmonella* in rice hulls versus using rice hulls only once (unpublished results). Similarly, we identified a 11.08 × ($P < 0.05$) increased risk of *Salmonella* in the poultry processing plant versus birds raised on fresh litter material when the rice hulls were recycled three times. While these data suggest that companies should stop recycling rice hulls more than three times, the decreased access to fresh rice hulls associated with drought has led to less material being available. This scenario could be exacerbated under warmer ambient conditions with respect to the total load of *Salmonella* present [16, 17]. As organic free-range and pastured poultry production systems become more popular commercially, the potential for further risk should be considered due to the increased exposure to wildlife which can carry disease and ambient temperatures.

Connecting heat stress to welfare, production efficiency and disease

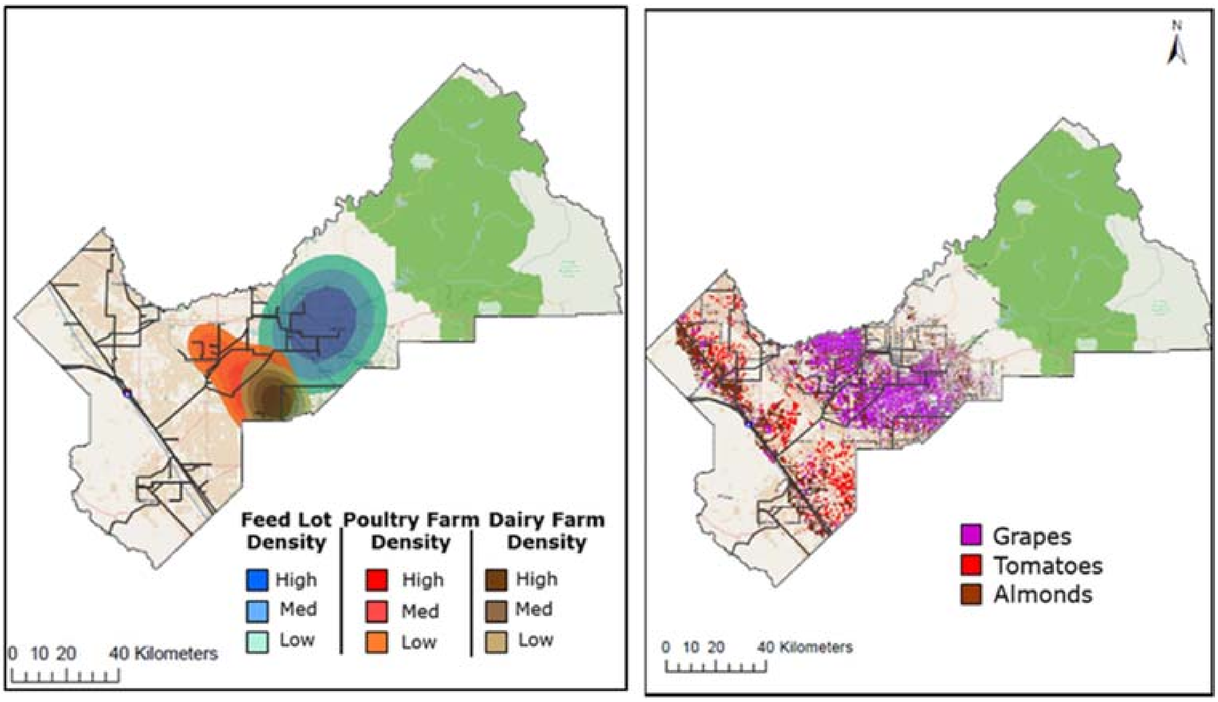
Heat stress is caused by a combination of different environmental factors including temperature, relative humidity and ventilation [18]. The connections between heat stress, welfare, and production efficiency (i.e. feed conversion ratio and reproductive efficiency) in livestock and poultry is well established [19–21]. In short, farm animals are most productive when they are healthy and raised in a thermoneutral environment [21]. While conventional layer, broiler and turkey production still dominates the USA and California market, it is important from a heat stress perspective to recognize that more poultry is being raised outdoors due largely to consumer demand [22]. For example, in the USA as of May 2018 there are 15.6 million organic layers (which are required to have outdoor access by regulation) which represent a 36.8% increase in organic layer numbers since January of 2016 [23] These data do not capture the number of free-range and pastured poultry layers that are not organic [this data is not currently recorded by the United States Department of Agriculture (USDA)].

Controlling the temperature of birds in these husbandry systems is typically not possible in the same way that one can control temperature in a conventional barn, where temperature can be managed using computer-controlled mechanical ventilation systems. As temperature extremes increase, this difference in husbandry capabilities can have a significant negative effect on both welfare and production. Specifically, the optimum effective temperature for hens in cages and in floor systems is between 20–24 and 18–22 °C, respectively. Higher temperatures over long periods of time particularly above 28 °C combined with high relative humidity can result in heat stress, loss of production and greater susceptibility to disease [24]. This is relevant for California, where average surface temperatures are estimated to increase by 2 °C by 2050 [4] and the warmest daily temperatures in the central valley are projected to increase by up to 6 °C, also by mid-century [25]. While there are strains of poultry that are heat resilient, including the Fayoumi they are generally not as productive as other genetic lines [24]. Therefore, while there is a growing body of research that is considering using genetics in livestock and poultry production to mitigate increased heat stress due to climate change, balancing those traits with production efficiency will be challenging [24, 26, 27].

An additional consideration is the connection between climate change, welfare, and infectious disease in livestock and poultry. The effects of climate change on the geographic range and density of various insects and the bacterial and viral diseases they transmit is well understood [28–30]. Diseases including, bovine respiratory disease (BRD) bovine keratoconjunctivitis (i.e pink eye) and BTV in cattle result in both production losses and a decrease in welfare [30–32]. One arthropod vectored disease relevant to California livestock production are *culicoides* biting midges, which can transmit several diseases including BTV [28]. Historically the vast majority of BTV infections occurred during the hot and dry summer and fall months [28]. However, female *culicoides* midges have been found to 'overwinter' on dairies in Northern California [33]. This observation is consistent with models from similar studies in which BTV transmission is found to be driven by temperature and other parameters related to *culicoides* (primary vector of BTV in CA) [34]. Based on the deterministic modelling of BTV transmission, southern California and the Central Valley are predicted to have the highest basic reproduction number (R_0) in terms of the replication rate of the virus [34]. These geographic areas of California are where the greatest number of dairies currently exist. California is currently the leading dairy state in the USA producing more milk than the trailing states Wisconsin and New York combined. As the impacts of climate change continue to evolve, dairy producers will need to consider how to adapt their husbandry practices and even consider changing the location of their farm(s) to address issues related to food safety, production efficiency, animal welfare and disease. Other less drastic options include reducing heat-stress within the micro-environment of the animal which has been shown to reduce the disease incidence of BRD in calves [32]. To that point, further efforts focusing on improving ventilation, providing appropriate amounts of shade and spacing in order to moderate temperature have been shown to be effective in moderating temperature and humidity in calves [35].

Part II: Mitigation of GHG in California From Agricultural Byproducts

While Part I addressed how climate change is affecting food safety, production efficiency, animal welfare and disease in livestock and poultry production in California, it is also important to recognize the role that animal agriculture can play in mitigation of climate change. Animal manure is typically composted, and edible plant materials not used for human consumption are typically used as animal feed. Climate change models show that reducing emissions



(a) (b)

Figure 1. (a and b) Maps of Fresno County. (a) Shows the investor-owned utility gas pipeline overlaid on poultry, dairy and feedlot facilities. (b) Shows the same investor-owned utility gas pipeline overlaid on grape, tomato and almond farms.

of carbon dioxide over the next several decades could buffer the long-term impacts of climate change [36]. Therefore, mitigation of GHG via the widespread adoption of best practices on farms should be considered at a policy and scientific level. One potential area of growth for the agricultural sector in California is via the greater adoption of anaerobic digesters (AD) for mitigation of the GHG gases methane (CH_4) and nitrous oxide (N_2O) in concert with energy production [37, 38]. To that point, currently California has 26 operating on-farm anaerobic digesters converting animal manure to electricity [39]. Furthermore, in the USA there are currently approximately 239 operating anaerobic digesters on farms. However, US-EPA estimates that approximately 8000 farms have the capacity for anaerobic digestion [40]. Therefore, greater adoption rates are possible within the agricultural community.

Life cycle assessments (LCAs) have been used to analyze the overall benefits from an energy and GHG perspective for multiple agricultural byproducts including animal 'waste' materials like manure and discarded parts of vegetables (i.e. tomatoes) during processing, which are commonly produced in California [41, 42]. In addition, the engineering, infrastructure, economics and potential of this issue has been well studied in California [37, 38, 43, 44]. Several AD systems usually include a combination of organic material including animal waste and crop byproducts to produce various types of energy including compressed natural gas or combined heat and power. This is not to suggest that large scale adoption of anaerobic digestion would make livestock and poultry production 'net zero' with respect to GHG from a LCA perspective [45, 46]. However, large scale adoption of these systems in California similar to other similarly sized livestock regions like Germany, where there are over 9000 ADs could make a small but important impact on both mitigation and baseline renewable energy production [47].

To better understand what this large-scale adoption of AD systems would look like in California, GIS mapping of major crops, livestock/poultry farms as identified by the National Agricultural Statistical Service [48] and the current gas pipeline within Fresno County (the top agricultural county in California [2]) was generated (Figure 1). Specifically, we created a series of GIS-based maps using ArcGIS 10.3.1 of the top three crops (i.e. almonds, tomatoes, and grapes) grown in Fresno County as identified by the California Department of Food and Agriculture's annual report [49]. Livestock and poultry data were provided by an anonymous third party. We then used publically available information regarding the approximate location of current natural gas pipelines in Fresno County that we requested from the National Pipeline Mapping System. Figure 1a demonstrates livestock and poultry facilities separated by species (because their manure quality is different). For example, manure collected from cattle in a feedlot will have a higher percentage of solids versus dairy manure, which is typically collected as a liquid and hence has less energy per ton than solid manure. The same is true for plant material quality with respect to digestion. The energy in almond hulls is extracted differently than the energy from tomato and table grape waste.

The efficient utilization of 'waste materials' from both commercial cropping, livestock and poultry production could play a significant role in both renewable energy production and GHG mitigation. New co-digestion AD systems have the ability to utilize multiple types of organic material simultaneously [50]. Therefore, the maps generated in Figure 1 could be used to generate discussions not only about the location of ADs but also to discuss the type of ADs that can convert the most amount of organic material to energy. For example, because plant and organic plant material are often produced in close proximity to each other, the potential to utilize ADs that utilizes co-digestion for conversion of multiple types of organic material for energy production should be considered.

While evaluations have been conducted on the feasibility of AD [34, 51–53], to our knowledge this is the first time maps have been produced, which combine current natural gas infrastructure with crop, livestock and poultry production in Fresno county, which is consistently the most productive agricultural county in the USA. These type of maps offer a glimpse of the locations of substrate material and infrastructure that currently exists. While the size of each farm is not provided from the data, the general proximity between the pipeline and the crops and poultry and livestock farms is apparent (Figure 1). While quantifying the total potential biomass of Fresno County's major crops and livestock and poultry manure is challenging due to a lack of knowledge of each waste stream and the assumptions involved regarding calculating methane production from each waste stream, the calculation of methane from livestock manure is well understood. The California Air Resource Board estimates that on average 0.22 m^3 methane can be produced when 1 kg of manure-based volatile solid (VS) is digested under anaerobic conditions [54]. Based on USDA statistics [55], total livestock population in Fresno County is 395,000 which can produce approximately 1,975,049 kg of manure. Assuming that the average mass of livestock is 590 kg, that 8.47 kg VS/day/1000 kg livestock mass [54], and that all this manure can be digested in anaerobic digesters, there is the potential to produce 434,511 m^3 biogas per day in Fresno County alone from livestock. In order to better leverage Figure 1 in parallel with these types of calculations, further GIS-based weighted midpoint analysis utilizing the amount of potential material at each location could be used to further identify strategic locations for AD.

Interestingly, many countries within the European Union have been able to develop a large network of digesters. Germany has roughly the same dairy population as California yet it has over 9000 large scale anaerobic digesters [56]. Even a small European country like Austria has more large-scale ADs (551) than the entire USA (239) [57]. While the German and Austrian governments' policies toward biogas production may not be a viable model for the USA, both countries nevertheless demonstrate that the digester technology is viable and robust. Therefore, the question for the USA in agriculturally dense areas like the Central Valley of California where fuel stock (e.g. manure and other food animal waste) is abundant is how to move from a single farm using a digester to hundreds of different farms with different feed stocks. Economics and convenience will dictate adoption and profitability for the farmers and utilities. Policies in California associated with climate change – including Assembly Bill (AB)-32, the Low Carbon Fuel Standard, and the Renewable Portfolio Standard – are policy/regulatory mandates intended to help create incentives in order to create a regulatory and economic environment conducive to adoption of alternative low carbon energy.

Conclusion

California is the largest and most diverse agricultural state in the USA producing over 400 different commodity crops [4]. The seventy-seven thousand plus farms in California will continue to play a major role in supplying food for over 9 billion people by 2050 [3]. Putting this 2050 challenge into context, if you were born in the 1960s the world only had 3 billion mouths to feed. Animal protein (eggs, milk and meat) is currently, and will most likely in the future, play an even greater role in the world's food supply in order to meet the global caloric demands in 2050. Climate change will create challenges with respect to food safety, production efficiency, animal welfare and the temporal and spatial distribution of animal diseases. Climate change associated environmental pressures will affect global and regional agricultural food production [12, 58]. Many of these challenges will be 'downstream' affects that are hard to anticipate at a regional level. Adoption of regional specific challenges and approaches focused on adaption and mitigation are essential for planning. While climate change is an international issue, the effects will be addressed at a national, sub-national and regional level. Adaption will require commercial poultry and livestock producers in California to reconsider multiple aspects of husbandry. Mitigation will require widespread adoption of technologies like AD. Identifying a parallel approach focusing on optimization of commercial poultry and livestock production in response to climate change in addition to focusing on climate change mitigation at the farm level are essential.

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