Chapter 5: Ecosystem services and human well-being

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Contents

5.1 Boxes:

5.1 Figures:

5.1 Tables:

5.1 Appendix:

5.2 Clean drinking water

5.2 Figures:

5.2.14 Classification of susceptible water systems and populations based on estimated vulnerability and water quality data in the Tulare Lake Basin and Salinas Valley study area

5.2 Tables:

5.2.1 Data sources with the total number of samples recorded, total number of sampled wells, location of wells, type of wells, and for the last decade (2000-2010) in the Tulare Lake Basin and Salinas Valley

5.2.2 Estimated capital, service and annualized costs for single self-supplied households using alternative nitrate treatment and avoidance strategies

5.2.3 Cost of community water supply projects proposed to California Department of Public Health and US Department of Agriculture during 2005-2009 where nitrate contamination was identified as the sole problem

5.2.4 Cost of community water supply projects funded by California Department of Public Health and US Department of Agriculture during 2005-2009 where nitrate contamination was identified as one of several problems addressed

5.2 Appendices:

5.2.1 Glossary for section 5.2

5.2.2 Reserve wording and data table for section 5.2

5.3 Clean air

5.3.1. Relationship between nitrogen and air pollutants

5.3.1.1 Emissions of NO_x and NH_3

5.3 Figures:

5.3 Tables:

5.4 Boxes:

5.4 Figures:

5.4 Tables:

5.4.2 Processes altered by reactive N that have radiative forcing effects. The size of the short-term (20yr) and long-term (100yr) effect is relative to other processes altered by reactive N

5.4.3 California greenhouse gases and percent of annual total emitted in 1990, 2000 and 2009

5.4.4 Estimated emissions of N_2O, NO_x and NH_3 by source and fate in California during 2005

5.5.5 Default values and uncertainty range for IPCC emission factors used to calculate direct and indirect N_2O emissions from agricultural soils in the California Greenhouse Gas Emissions Inventory

5.5 Cultural services

- 5.5.0 Introduction
- 5.5.1 Effects of nitrogen on land use and biodiversity
    - 5.5.1.1 Land use and agrobiodiversity
    - 5.5.1.2 Aquatic biodiversity
    - 5.5.1.3 Terrestrial biodiversity
- 5.5.2 Aesthetic value
- 5.5.3 Recreational value
- 5.5.4 Cultural heritage values
- 5.5.5 Spiritual and religious values

5.5.6 Cultural and spiritual values as motivators for addressing N issues

5.5 Boxes:

5.5.1 Poem depicting the use of legume cover crops entitled *Enriching the Earth* by Wendell Berry (1985)

5.5 Figures:

5.5 Tables:

What is this chapter about?

Changes in nitrogen (N) levels in soils, air, and water affect the benefits people derive from ecosystems. These benefits, known as ecosystem services, fall into the four categories of *provisioning*, *regulating*, *cultural*, and *supporting* services. In this chapter we examined ecosystem services that are known to be affected by nitrogen levels and management activities, with a focus on those that are relevant to

California. The five sections of this chapter address the central role of N in food production and agriculture (Section 5.1); how N affects the ecosystem goods of clean drinking water and clean air (Sections 5.2 and 5.3); the regulating service that N provides in maintaining a stable climate (Section 5.4); and the cultural and spiritual values that N affects, most notably how excess N alters biodiversity in terrestrial and aquatic ecosystems, changing the way humans interact with and enjoy nature (Section 5.5).

Main Messages

Production of California livestock and agricultural crops has increased since 1980, accompanied by greater N fertilizer application. Between 1980 and 2007, production of vegetables and melons and fruits and nuts increased 128% and 17% respectively, reflecting shifts in the diet composition of the US population. To meet increasing demands for animal protein, feed crops was also one of the highest crop production categories, almost tripling over this period. Correspondingly, livestock production was on an increasing trend, with the average annual milk cow and heifer population doubling.

While N is indispensable in increasing the production of agricultural systems, much of the N applied is lost to the environment, resulting in a variety of impacts on atmospheric, terrestrial, and aquatic ecosystems. The difference between the tonnes of N fertilizer applied and N harvested is on a decreasing trend for cotton since 1980. However, the estimated amount of N that is not taken up by crops is on a slightly increasing trend for vegetables, fruits and nuts. This corresponds to the amount of fertilizer applied by crop, with estimated application rates on many vegetable and fruit and nut crops having increased in recent decades, at the same time as the total acreage for these crops has also increased.

California's agricultural sector is important to the state's economy and also contributes significantly to the provision of food security for the US and globally. California's agricultural economy is the largest in the US with over $37.5 billion in earnings in 2010, producing 21% of the nation's dairy commodities and more than 50% of the fruits and vegetables. The state is also the largest producer of ornamental horticultural goods in the US with $2.3 billion in wholesale sales and $235 million in retail sales in 2009. From a global perspective, California ranks 5th in terms of agricultural value added based on GDP market exchange rates.

Stakeholder Questions

The California Nitrogen Assessment engaged with industry groups, policy makers, non-profit organizations, farmers, farm advisors, scientists, and government agencies. This outreach generated more than 100 N-related questions, which were then synthesized into five overarching research areas to guide the assessment (Figure 1.4). Stakeholder generated questions addressed in this chapter include:

- What is the state of knowledge on how nitrogen influences air and water quality and impacts human health?
- What is the cost of N management –to growers and to society in terms of public health costs, and costs related to environmental contamination?

5.0 Introduction

This chapter outlines the impacts that changes in the nitrogen (N) cycle have on the environment and human-well-being. On the one hand, perturbation of the N cycle facilitates greater production of food (e.g., crops and livestock) and fiber, greatly benefiting the economy of California and the health of people worldwide. On the other hand, excessive reactive N in the environment from agricultural and urban activities is polluting the soils, air, and water and is linked to environmental damage including: acidification, invasive species, particulate matter and ground-level ozone formation, depletion of the stratospheric ozone layer, climate change, endangered species decline, eutrophication, and changes in the composition of terrestrial and aquatic biotic communities. Changes in N levels in these resource stocks affect the goods and services Californians derive from their surroundings, such as clean drinking water, clean air, and recreational activities.

In this assessment we examined how changes in ecosystem services affect human well-being, including food security, human health, and a healthy environment. Ecosystem services are the benefits people obtain from ecosystems. These include provisioning, regulating, and cultural services that directly affect people, as well as supporting services needed to maintain other services (MA 2005). Provisioning services are the products obtained from ecosystems (e.g., food, fuel, clean water, clean air). Regulating services are the benefits obtained from regulation of ecosystem processes (e.g., climate regulation). Cultural services are nonmaterial benefits obtained from ecosystems through spiritual enrichment, recreation, and aesthetic experiences (e.g., swimming, fishing, wildlife viewing, and ceremonial uses of particular plant and animal species). Supporting services are necessary for the production of all other ecosystem services. They include processes such as soil formation and production of atmospheric oxygen. Supporting services differ from the above in that their impacts on people are often indirect or occur over a long time period, whereas changes in the other categories have relatively direct and short-term impacts. Building on Compton et al (2011), we examined ecosystem services that are known to be affected by nitrogen levels and management activities (Table 5.0.1), and refined this list to focus on those that are relevant in the California context. Trends and impacts on the environment and human health in California are synthesized within this framework, providing an assessment of the qualitative effects of nitrogen on ecosystem services and processes.

[Table 5.0.1 – click to jump]

This chapter is divided into five main sections. Section 5.1 describes the central role of N in food production and other agricultural products in California. Food production in this context includes crop and animal products. It shows the temporal trend of different groups of crop and livestock production in California. Furthermore, it details the direct and indirect effects California agricultural production has on the economy of California, as well as the important role California agriculture has in the food system of the United States and worldwide. Section 5.2 and Section 5.3 discuss how N affects ecosystem goods - clean drinking water and clean air respectively. Section 5.2 shows the spatial and temporal trend of nitrate concentration levels in groundwater in California, and explains the human health consequences of drinking water contaminated with high levels of nitrate. Section 5.3 explains how N affects air quality and illustrates trends in air quality in California. Furthermore, it details the different respiratory illnesses, cancer cases, birth outcomes, and mortality associated with exposure to nitrogen dioxide (NO_2), ozone (O_3), and particulate matter (PM). The assessment of impacts on human well-being is discussed in detail in sections 5.2 and 5.3 as this was an important issue identified by the research team as well as through ongoing stakeholder comments; it is also a topic for which a comprehensive accounting for California was lacking. Section 5.4 details the regulating service that N provides in maintaining a stable climate. It discusses briefly how different forms of N influence the formation of greenhouse gases (GHGs) and how it contributes directly and indirectly to global warming as well as cooling. Section 5.5 discusses cultural and spiritual values that N affects, notably how excess N alters biodiversity in both terrestrial and aquatic ecosystems – e.g., swimming, fishing, and/or other human use of aquatic systems, changes in the way humans interact with and enjoy nature, and reduction in the cultural and aesthetic values these different ecosystems provide for human well-being.

5.1 Healthy food and other agricultural products

Nitrogen is an essential component of food. As a building block of proteins, DNA, and chlorophyll, N is a critical requirement for the growth and development of plants and animals (Marshner 1995, Epstein and Bloom 2008). In most agricultural systems globally, and in virtually all the agricultural systems in California, N is often the most limiting nutrient (Vitousek et al. 1997, Hirel et al. 2008). Hence, application of fertilizer N or the importation of high protein feeds results in greater food production (Bottoms and Hartz 2010, Letey et al. 1979, Oenema 2008, Kebreab 2001). Amendment of cropland with synthetic and organic N fertilizers and supplementation of animal diets with N-rich feedstock is a common practice across California (see Chapter 3).

Quantification of the impact of supplemental N on agricultural productivity and human well-being is challenging. Although there has been a plethora of research on N in crop and animal production systems, comparative long-term studies of the productivity effects of N are largely unavailable. Attempts to tease out the precise amount of agricultural productivity that is directly attributable to N supplementation are confounded by the complexities of agricultural production systems. Despite the multiple interacting factors, it is well established[1] there has been a substantial, globally positive effect of N on food production. Galloway et al. (2008) suggest that nearly 2 billion people are alive today because

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[1] Throughout the assessment, “reserve wording” was used to quantify areas of uncertainty in the available data and level of scientific agreement. See Supplemental Data Tables for further details.

of synthetic fertilizer, while another study estimates that N fertilizers support an additional 27 percent of the world's population than would have been possible otherwise (Erisman et al. 2008). A report summarizing global long-term studies found that widespread use of synthetic N fertilizers is responsible for as much as 60 percent of agricultural production (Stewart et al. 2005). It is therefore well established that greater availability of N has had an unquestionably positive impact on food production.

5.1.1 Role of nitrogen in agricultural production

The contribution of N to California agriculture has not been systematically analyzed. The long-term comparative data that would be necessary to provide an accurate estimate do not currently exist. The Long Term Research on Agricultural Systems (LTRAS) at the University of California, Davis' Russell Ranch Sustainable Agriculture Facility has performed some research that would be applicable but further years of data collection and analysis are needed to draw results (K. Scow, personal communication). Comparing concordant trends in N use and yield, however, provides some indication of the relationship. For example, crop yields and N content, varieties, soil N levels and fertilizer applications are closely monitored at LTRAS. While it is too early to predict either an upward or downward trend of crop yields at the LTRAS, future analysis will help determine to what degree genetic improvement or fertilizer applications influence yields.

Over the past 60 years (1946-2006), commercial sales of synthetic N fertilizer have increased twelve-fold, with the greatest increase occurring between 1950 and 1980 (see Chapter 3; Figure 3.1). Over the past five years, more than 600,000 tonnes of synthetic N, in the form of fertilizers, have been sold annually in California (CDFA 1971-2007, Alexander and Smith 1990). Yields of almost all California agricultural commodities have increased dramatically within this same time frame. For example, between 1950 and 2007, yields of almonds, processing tomatoes, and rice increased by 368, 221, and 137 percent, respectively (Figure 5.1.1) (NASS 2010).

[Figure 5.1.1]

While it is well established from historical data that a positive relationship exists between increasing N in agricultural systems and productivity, determining how much of these yield increases is attributable to N, per se, is more difficult. For many crops, the relative N application rates per ha have not increased significantly over this time period (see Section 3.1.1). Other components of the agricultural production system—water infrastructure, pest management, genetics, etc.—have undergone significant innovation simultaneously and are, at minimum, partially responsible for yield increase (Johnson and McCalla 2004).

In animal systems, the result of more N in feedstock is more proportional. It is well established that the amount of N fed to cattle results in greater quantities of meat and milk production (Kebreab et al. 2001, Castillo et al. 2000, Powell et al. 2010, Oenema et al. 2008). Dairy cows are now fed more N in absolute terms (not in percentage of intake), than they were being fed 30 years ago, to support higher per cow productivity. As discussed in Section 3.2.1, the overall efficiency of milk cows has increased, meaning that less N is used for physiological maintenance of the animal and more is used for milk production. On the other hand, poultry production has not increased the amount of N being fed to animals. Increases in production have resulted from other modifications to the production system (see Section 3.2.1). A more apparent benefit of N use in the livestock sector overall is its effect of increasing feed crop yields due to N fertilizer application.

5.1.1.1 Trends in indicators of crop production

Food and feed crops

While overall crop production (harvested yield x cropping area), N applied (N rate x cropping area), and N harvested (crop production x % N in harvested portion) have generally increased in California over the past several decades, the magnitude and direction of these trends differ considerably among major crop categories (See Appendix 5.1.1 for a list of crops in each category). For example, significant increases in statewide production were observed for vegetable and melons, other feed crops, and to a lesser extent fruit and nut crops between 1980 and 2007 (Figure 5.1.2). In contrast, from 1980-2007 there was a decline in statewide production of “other food crops”, a category which includes foods high in carbohydrates such as grains (rice, wheat), pulses (dry beans, peanuts), and root crops (potatoes, sweet potatoes, sugar beets). Over the same period, production of alfalfa, cotton and seed crops remained fairly constant.

[Figure 5.1.2]

Statewide trends in overall N applied and N harvested are driven mostly by changes in cropping area for the major crop categories, and to a certain extent by shifts in area among the dominant crops within each category. Due to the paucity of year-to year data on crop specific changes in N rate, N rates for specific crops within a category were held constant over time. Using this approach, mean N rates for a crop category can change over time if significant shifts in the relative area of each crop within a given category occur. As such, the increase in applied and harvested N for feed crops, and fruits and nuts (and the decrease in applied and harvested N in other food crops) mostly reflect the corresponding changes in cropping area for each category (Figure 5.1.3; Figure 5.1.4).

[Figure 5.1.3]

[Figure 5.1.4]

The difference between N applied and N harvested provides a useful approximation of how much of the N is lost to the environment from the various crop categories (Figure 5.1.5). Based on these calculations there has been a decline in surplus N lost to the environment from both cotton and other food crops. For both of these categories the decline in surplus N is due predominantly to a decline acreage and subsequent N fertilizer application as opposed to noteworthy improvements in N recovery efficiency by the crop. By contrast, increasing losses of N to the environment have occurred from fruits and nuts, vegetables and melons, and other field crops since 1980. Since our calculations do not vary fertilizer application rates over time for specific crops, there are two possible explanations for the increases in excess N in these cropping systems. One is that yields for the crops in these categories have declined over time, resulting in less N being harvested, an argument which is not well-supported by existing data (see Chapter 3, section 3.2). A more plausible explanation is that the mix of specific crop species within each category has shifted over time to favor crops that require higher fertilization rates relative to the amount of N in their harvested portions, and presumably resulting in lower apparent N use efficiency (NUE) for the category. Here NUE is defined in the simplest terms as the partial N balance, which is calculated as the amount of N harvested and removed from the field per unit of N applied. While estimates of NUE are available in this report for more than 20 individual crops (see Chapter 3; Table 3.1), there is a need for additional studies that establish long-term trends in NUE for specific California crops as well as the aggregate trends across broad crop categories.

[Figure 5.1.5]

5.1.1.2 Trends in indicators of livestock production

Livestock production in California has increased significantly since 1980 (see Section 3.8.3 and Figure 3.8). For example, the average annual milk cow and heifers population has doubled from 1980 to 2007; increasing from 896 thousand in 1980 to 1.8 million in year 2007 (Figure 5.1.6). Nationally, the production of animal products has gotten more efficient overtime; that is more animal products are being produced with fewer animals (USEPA 2011). In California, milk production per cow has increased from 15,153 pounds of milk per cow in 1980 to 22,440 pounds of milk per cow in year 2007. This increase in productivity is due in part to larger amounts of N being fed to dairy cows than 30 years ago (Figure 5.1.6). It should be noted that the increase in total N intake is a mostly a function of each animal consuming more feed rather than a significant increase in the fraction of N in the feed.

[Figure 5.1.6]

Dairy cattle partition N intake into milk or manure and urine, and research shows that about 20-40% of the N intake is excreted as milk, while about 60-80% of the N intake is excreted as manure (Chase 2011). This partitioning of N can be managed through improvements in dairy cow diets. For example, a dairy cow diet consisting of lower levels of crude protein has been shown to decrease N excretion as manure and to improve the efficiency of converting N to milk production (Chase 2011). Though the production of animal products has become more efficient over time, a greater amount of N is needed to produce the same amount of animal protein as plant protein, reducing the overall system-wide efficiency (Box 5.1.1) (Mosier et al. 2002). While N recovery (kg N retained in edible weight per kg N in feed) in livestock production is lower than in crops, certain animal production systems are more efficient than others (see Figure SPM.6 in ENA 2012). Poultry production, for example, results in a lower N footprint per kg food; that is, it exhibits a higher feed N recovery efficiency in edible weight compared to beef production (ENA 2012).

[Box 5.1.1]

The state-wide mass balance presented in Chapter 4 suggests that livestock production is an important driver of N imported into the state and contributes significantly to the N flows between many of the major sub-systems (e.g. cropland, groundwater, atmosphere, etc.). Feed crops accounted for almost two-thirds of the 543 Gg N harvested from cropland. Alfalfa, which obtains a significant fraction of its N from biological fixation, supplied almost 40% of the N harvested statewide. Even considering the large amount of feed crops grown in the state, there is still a need to import 200 Gg N to meet the dietary needs of livestock. The 537 Gg N in livestock feed is converted to 141 Gg N in food products and 416 Gg N in manure. Some of this manure is volatilized or leaches directly from the livestock facilities while 307 Gg N from manure is applied to cropland, almost 30% of the total N inputs to cropland. From the mass balance approach we can't determine the particular fate of manure applied to cropland. However, based on the modeling results in van der Schans (2004), a large fraction of the N applied as dairy manure would likely leach from cropland soils to groundwater. Results of the mass balance also indicate that livestock systems are also important sources of gaseous N emissions, accounting for approximately 53% of NH3 and 5% of N2O emitted in California each year.

5.1.2 Human well-being and agricultural production

According to multiple cohort studies (He et al. 2006, 2007, Dauchet et al. 2006), fruit and vegetable consumption is positively associated with reduced risk of leading causes of death including stroke and coronary heart disease. Thus, these studies suggest that adults should increase their fruit and vegetable consumption to more than five servings per day. Additionally, since more than one-third of children and two-thirds of adults are overweight or obese, the 7th edition of the *Dietary Guidelines for Americans* places even more emphasis on reducing calories, increasing fruits and vegetables in the diet (e.g., it advises that half the plate should be fruits and vegetables), and increasing physical activity (USDA and HHS, 2010).

5.1.2.1 Food and health

It is well established that eating a diet high in nutrient-dense foods, e.g., vegetables, fruits, whole grains, low-fat milk dairy products, seafood, lean meats and poultry, eggs, beans and peas and nuts and seeds, contributes to long-term health outcomes. Since California produces much of the nation's fruits, vegetables, and nuts (see Section 5.1.3.2), this section will review the nutritional implications of these products.

The Dietary Guidelines for Americans, 2010 suggests that all people increase the amount and variety of their fruit and vegetable intake, focusing on dark green, red and orange vegetables, beans and peas. Most contribute substantially to under-consumed nutrients such as folate, magnesium, potassium, dietary fiber and vitamins A, C and K. The recommended amount is 2 ½ cups of vegetables and 2 cups of fruit per day, which moderate evidence suggests protects against some forms of heart disease and cancer. The most recent studies using data from the Behavioral Risk Factor Surveillance System (BRFSS) show that only about one-third of adults consume fruit 2 or more times per day and only about a quarter of adults consume vegetables 3 or more times per day, far short of the national target (Grimm et al. 2010). Additionally, eaters should choose a variety of protein foods including unsalted nuts and seeds. Since nuts are also relatively high in calories, they should substitute for other protein servings (one serving is ½ oz.) instead of adding to them. Some evidence suggests that eating peanuts and some tree nuts (walnuts, almonds and pistachios) reduces risk factors for heart disease as long as they are consumed as part of a balanced diet and within calorie limitations (O'Neil et al. 2011, Kris-Etherton et al. 2008).

California also produces a significant amount of dairy products (see Section 5.1.3.2), especially for Californians. Milk products contribute significantly to calcium, vitamin D (if fortified) and potassium in the diet. Adequate milk product intake is linked to bone health, especially in children and adolescents, and reduced risk of cardiovascular disease, type II diabetes and lower blood pressure in adults. For those who may be lactose intolerant, other foods, including soy beverages, can provide a similar complement of nutrients. Choosing lower fat milk products (especially cheese) can help decrease the intake of unnecessary sodium and saturated fat. In any case, moderation is the key when consuming dairy products. The greater variety one can incorporate into one's diet - i.e., choosing seasonally available foods - the easier it is to create and sustain a well-balanced diet.

5.1.2.2 N management and food quality: the tradeoff between quantity and quality

While fertilization of crops have increased crop yield, it is provisionally agreed by most that it can also decrease the nutrient composition of plants. Higher yields that result from nutrient application (not always N) tend to be inversely related with the concentration of vitamins and minerals in plant tissues (Jarrell and Beverly 1981). This dilution effect has been described in crops ranging from grains to berries (Davis 2009). For example, a decrease in nitrate (NO_3) due to a decrease in N fertilizer use has been shown to increase the vitamin C content in fruits and leafy vegetables (Mozafar 1996).

The effect of using organic versus inorganic sources of N on the mineral composition of food is debated (Lairon 2010). It is provisionally agreed by most that food produced within organic farming systems is packed more densely with minerals and thus contains greater nutrition (Brandt and Mogaard 2001, Williams 2002, Magkos et al. 2003, Rembialkowska 2007, Benbrook et al. 2008) while others find the opposite (Bourn and Prescott 2002, Dangour et al. 2009). Benbrook et al. (2008) found that in 61% of 236 paired comparisons, organic foods were nutritionally superior while only 37% of the comparisons favored conventional foods. In contrast, Dangour et al. (2009) examined the same question and found that for 8 nutrients and other nutritionally relevant substances ranging from nitrogen to copper there was no difference between organic and conventionally produced food. Conventional crops contained higher levels of nitrogen while organic crops contained higher levels of phosphorus and titratable acidity. Part of the difference in findings may result from which studies were selected for inclusion or the methods of analyzing comparisons.

The debate over nutritional quality of organic versus conventionally grown crops has also focused on California crops. In one study, it was found that the mineral concentration of tomatoes was greater in organic but only after 7 years of organic cultivation practices (Mitchell et al. 2008). Another study demonstrated that California strawberries when grown organically have higher antioxidant activity (Reganold et al. 2010). While more recent reviews survey a wider range of data, much of the results suggest that there is no definitive answer on how organic and inorganic N will affect nutrient composition of plants because of the confounding factors in the production systems.

Regardless of the source of N, it is generally accepted that the quality of California crops is sensitive to the amount of N applied. There are negative consequences for crop production if too much or too little N is available. Effects include increased pest pressures, harvest and postharvest issues, and a lack of marketable yield (Daane, et al. 1995, Hartz et al. 2005, Linquist et al. 2008). Crop sensitivity is largely a function of growth habit, plant tissues and post-harvest storage conditions, and market pressure.

5.1.3 Economic benefit of agricultural production

California is one of the leading agricultural producers in the world and plays an important role in ensuring food security within the US and internationally. In addition, the agricultural sector in California contributes to the Gross State Product (GSP) and provides employment for the state’s population. The use of N in agroecosystems has enabled California to sustain and increase crop as well as livestock production since WWII, which has contributed tremendously to the economic well-being of Californians and the rest of the US.

5.1.3.1 The importance of food production to California's economy and society

While the agricultural sector, forestry, fishing, hunting, and supporting services account for about 1.45% of California's Gross State Product (MOCA 2009), when associated industries are included, the value of the agricultural sector to California is much greater. In year 2002, there were a total of 89,774 agriculture-related establishments in California employing over 1.6 million employees compared to a state-wide total of 820,997 establishments (not including farming, government, railroad, and employed sectors) employing over 12.8 million employees (Table 5.1.1) (MOCA 2009). Food, beverages, and tobacco manufacturing alone accounted for $61 billion in sales in year 2002 and employed nearly 200,000 employees in California. Nationwide, California establishments accounted for 15.1% of the US food, beverages, and tobacco manufacturing establishments and employed 11.8% of US employees working within the industry in year 2002 (MOCA 2009).

[Table 5.1.1]

The University of California Agricultural Issues Center (AIC) calculated the direct and multiplier effects (i.e., indirect and induced effects) of California's agricultural sector on jobs, labor income, and value added across economic sectors in the State using the IMPLAN Pro version 2.0 software and 2002 datasets from the US Department of Commerce. In year 2002, California's economy as a whole generated a total of $2.28 trillion in sales, employed almost 20 million, paid close to $915 billion in labor income, and created about $1.4 trillion of value added[2] (MOCA 2009). Accounting for direct effects[3] alone, the model shows that agricultural production and processing in California contributed 4.28% of the total sales, 3.76% of the total employment, 2.47 % of the total labor income, and 2.85% of the total value added in the State of California (Table 5.1.2) (MOCA 2009). When taking into account total effects, which include direct, indirect[4], and induced[5] effects, the contribution of California's agricultural production and processing sector to the State's total employment, labor income, and value added increased to 7.29%, 5.60%, and 6.49% respectively (Table 5.1.2) (MOCA 2009). Accounting for the total effects of farming in California, MOCA (2009) showed that 2.6% of employment (nearly 514 thousand jobs) in California, 1.6% ($14.3 billion) of labor income, and 2% ($27.2 billion) of value added is attributed to farming.

[Table 5.1.2]

The production (Figure 5.1.2) and value added (Figure 5.1.7) of vegetable and melon crops, as well as of fruit and nut crops are on an increasing trend. Vegetables, fruits, and nuts represent the highest valued subgroup within farming. The growth and production of these cropping activities has important economic and societal implications. Based on MOCA's (2009) analysis, vegetables, fruits, and nuts accounted for about 1.5% (about 299 thousand) of California's total employment and 0.97% ($8.8 billion) of total labor income in year 2002 (Table 5.1.2) (MOCA 2009). Although the production of fruits and nuts has not increased as much compared to vegetables and melons from 1980 to 2010, the

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[2] Value added is equal to the sum of compensation to employees, taxes on production of inputs, and gross operating surplus (MOCA 2009).

[3] Direct effects measure the direct outputs of a particular industry and thus are determined directly by that industry's inputs (MOCA 2009).

[4] Indirect effects are the secondary inter-industry effects that one industry has on another (MOCA 2009).

[5] Induced effects are the changes in household consumption of goods and services measured in employment, income, and value-added (MOCA 2009).

California net value added for fruits and nuts has more than doubled within the same period of time (Figure 5.1.7).

[Figure 5.1.7]

The second highest valued subgroup within farming—the beef and dairy industry—accounted for 0.53% (about 105 thousand) of the State's total employment, 0.2 % ($1.8 billion) of labor income, and 0.24% ($3.3 billion) of value added (Table 5.1.2). However, the net value added for dairy products has tripled, from $2 billion in 1980 to about $6 billion in year 2010. The rapid and dramatic change in net value added for dairy products around 2007 can be explained by the amount of milk equivalent that the US was exporting and the currency value of the US dollar (personal communication, Professor Leslie Butler)[6]. On the other hand, the net value added[7] of poultry and eggs and other meat products has stayed relatively constant from 1980-2010 (Figure 5.1.8). Overall, the total net value added as well as the rate of increase of net value added for crop production far exceeds that of livestock production in California (Figure 5.1.9).

[Figure 5.1.8]

[Figure 5.1.9]

The importance of agriculture as an economic enterprise differs depending on region, with the Central Valley and Central Coast areas dominating in terms of total state output (Table 5.1.3), as well as in the relative importance of agriculture within their respective economies. Agricultural production

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[6] In 2004-2007, there was an increase in exports of dairy products. Similarly, the value per unit of milk increased from $11.58/Cwt in year 2006 to $18.05/CWt in year 2007 and then decreased slightly to $16.82/Cwt in year 2008 (USDA NASS). The strengthening (increase) of the US dollar in the beginning of July 2008, on the other hand, caused a huge loss to the dairy export market, which in turn caused the price of milk to decrease by almost 50% in 2009. Hence, the dramatic decrease in the net value added of dairy products in year 2009.

[7] Net value-added is the sector's contribution to the National economy and is the sum of the income from production earned by all factors-of-production, regardless of ownership (USDA ERS).

and processing represented 9.2, 7.8, and 2.8 percent of the regional output for the San Joaquin Valley, Sacramento Valley, and Central Coast, respectively (MOCA 2009).

[Table 5.1.3]

5.1.3.2 The importance of California agriculture to US and global food systems

California agriculture is critical to the long-term security of the US food system. California's agricultural economy is the largest in terms of cash receipts (37.5 billion dollars in 2010) in the United States and nearly twice as big as that of the third largest agricultural producing state of Texas (19.9 billion dollars in 2010) (USDA NASS 2011). California produces 21% of the nation's dairy commodities and more than 50% of the nation's fruits and vegetables. California is not only one of the major producers of many crop and livestock commodities; in some cases it is the only producer in the nation (Table 5.1.4). For example, in 2010, California was the sole producer (99 percent or more) of 14 commodities (USDA NASS 2011). Many of these commodities also belong in the list of California's top ten agricultural exports between years 2007-2009 (USDA NASS 2011).

[Table 5.1.4]

California is also the largest producer of environmental horticultural goods in the US in terms of both wholesale sales ($2.3 billion in year 2009) and retail sales ($235 million in year 2009) (USDA NASS 2010). Its wholesale sales of $2.3 billion in year 2009 are almost twice as much as those of the second largest horticultural producing state, Florida. In 2010, flowers and foliage, valued at about $1 billion, was one of the top 20 commodities in California. The nursery, greenhouse and floriculture commodity group comprised about 9.2% of the state's cash income, and Christmas trees showed an 83% increase in cash receipts (USDA NASS 2011).

From a global perspective, California is also one of the leading agricultural producers in the world. According to the World Bank's ranking of agricultural value added based on GDP purchasing power parity exchange rates for more than 200 countries, California ranks 9th ($27.6 billion), which is only slightly below countries like Brazil ($27.7 billion), Indonesia ($28.5 billion), and Italy ($29.7 billion). Based on the same ranking, China ranks 1st ($191 billion), the US ranks 2nd ($148.6 billion), and India ranks 3rd ($110.6 billion). When the ranking of agricultural value added is based on GDP market exchange rates, California ranks 5th ($28.4 billion), which is tied with Italy, the US ranks 1st ($153.9 billion), Japan 2nd ($71.1 billion), and China ranks 3rd (42.5 billion) (MOCA 2009). When examining specific crops, the US is the world's largest producer of almonds, strawberries, and dairy products, where California's share of the US production for these three top commodities is 19 percent, 100 percent, and 61 percent respectively (see Table 2.3).

Appendix 5.1.1 California crop categories used in the assessment

[Table A5.1.1]

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Box 5.1.1. Animal production requires more N. [Return to text]

The agricultural sector has been identified as the largest driver of change in the nitrogen cycle on Earth over the past few decades (Howarth 2004). This is because nitrogen inputs serve human needs especially in agricultural production. Worldwide, N fertilizer accounts for about 40% of the increase in per capita food production in the past 50 years (Mosier et al., 2001). In addition to the increase in fertilizer N use, animal protein consumption in both developed and developing countries are also on the rise (Mosier et al. 2002).

The increase in worldwide demand for animal protein has led to significant changes in livestock and crop production that has contributed to increases in N loss. First, intensification of meat production increases the pressure of increasing N fertilizer into food production. This is because more N is needed to produce the same amount of animal protein as plant protein (Mosier et al. 2002). For example, Bleken and Bakken (1997) found that 3g N must be supplied to soil to produce wheat flour containing approximately 6.3 grams of protein whereas a total of 21g N must be supplied to soil to produce the same amount of animal protein. Further, when considering the efficiency of the whole system, estimates suggest that four to eleven units of feed N are required to create one unit of animal protein (Integrated Nitrogen Committee 2011). The increased N requirements result from compounded inefficiencies as N is transferred through the supply chain. Tracing the N back in the food chain, Galloway and Cowling (2004) estimate that only 4% of N applied to corn is eventually consumed in beef. Although other animal production systems are typically more efficient than beef cattle on feed, this example highlights the systemic N inefficiencies when producing animal protein for human consumption.

Second, it has been observed that another contribution to the increase in N losses is due to the decoupling of livestock and crop production (Mosier et al. 2002). As a result, instead of treating animal manure as plant nutrient it is simply treated as a waste. This might have contributed to the increased use of synthetic N fertilizer in agricultural production.

Third, in addition to the decoupling of livestock and crop production, the level of animal production has exceeded that of crop production and this pattern is observed especially in China (Mosier et al. 2002). The excess manure N that is not used for crop production is simply dumped into aquatic systems contributing to myriad ecological consequences.

Figure 5.1.1 Yield increase of processing tomato, rice, and almond in California, 1950 – 2007. Source: NASS 2009 [Return to text]

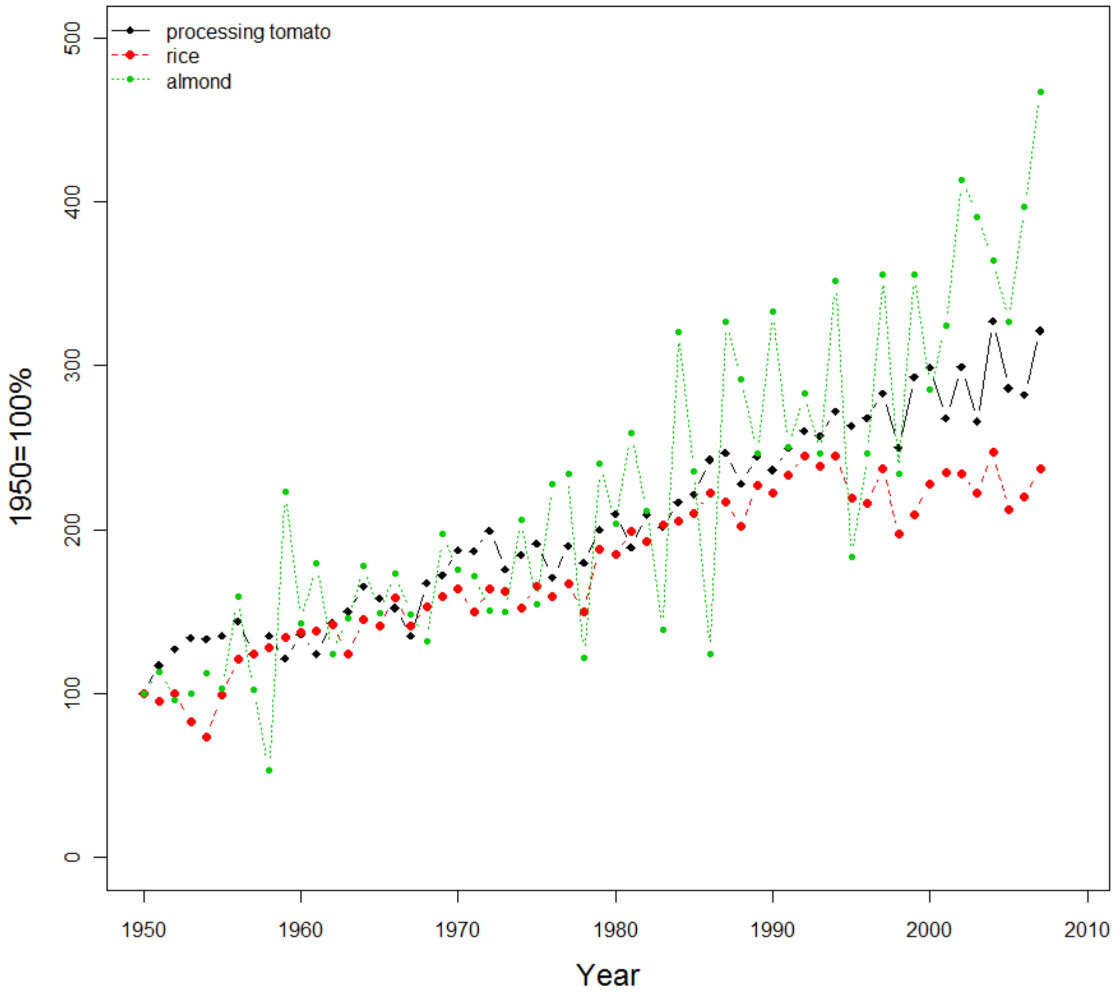

Figure 5.1.2 Production of major crops in California, 1980-2007. The groupings of crop categories mostly follow the categorization of the California Agricultural Statistics, Crop Year 2010 published by the USDA, NASS, California Field Office. For the list of crops that typically fall under the "Field Crops" category of the California Agricultural Statistics publication, we have further divided this into several categories taking into consideration the type of nutrition and function a specific type of crop provides. "Alfalfa" is an N-fixing crop and is therefore omitted. "Seed crops" are not directly harvested for human consumption and hence has its own category. "Other food crops" consists of crops that typically provide carbohydrates for human nutrition, and "Other feed crops" are crops that are typically used for livestock production. For further details on the specific crops in each crop category see Appendix 5.1.1.

Source: USDA, NASS, 1980-2007 [Return to text]

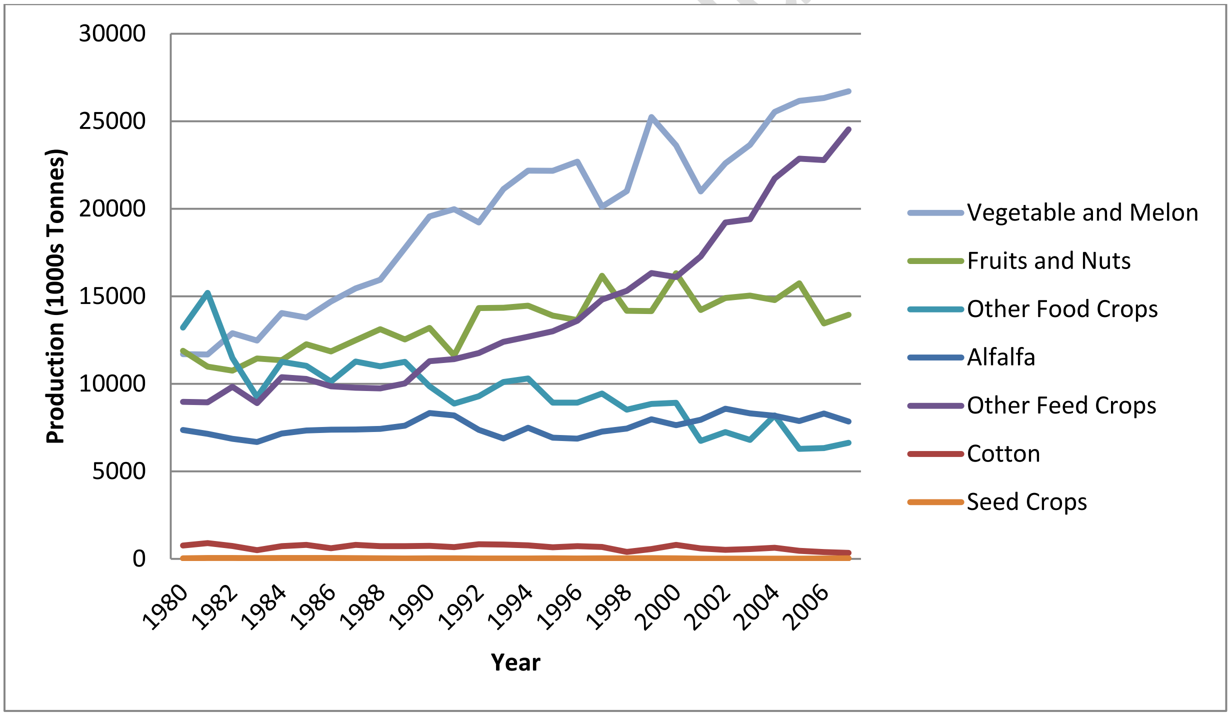

Figure 5.1.3: Tonnes of N fertilizer applied to various crop categories in California, 1980-2007. The change in N applied by crop category over time was calculated by multiplying the acreage of land devoted to each crop type by an average N fertilizer rate for each crop type. Source: USDA, NASS, California County Agricultural Commissioners' Data (2002-2007); UC Davis Cost Studies, 1999-2010, USDA Chemical Use Surveys (1995-2007). [Return to text]

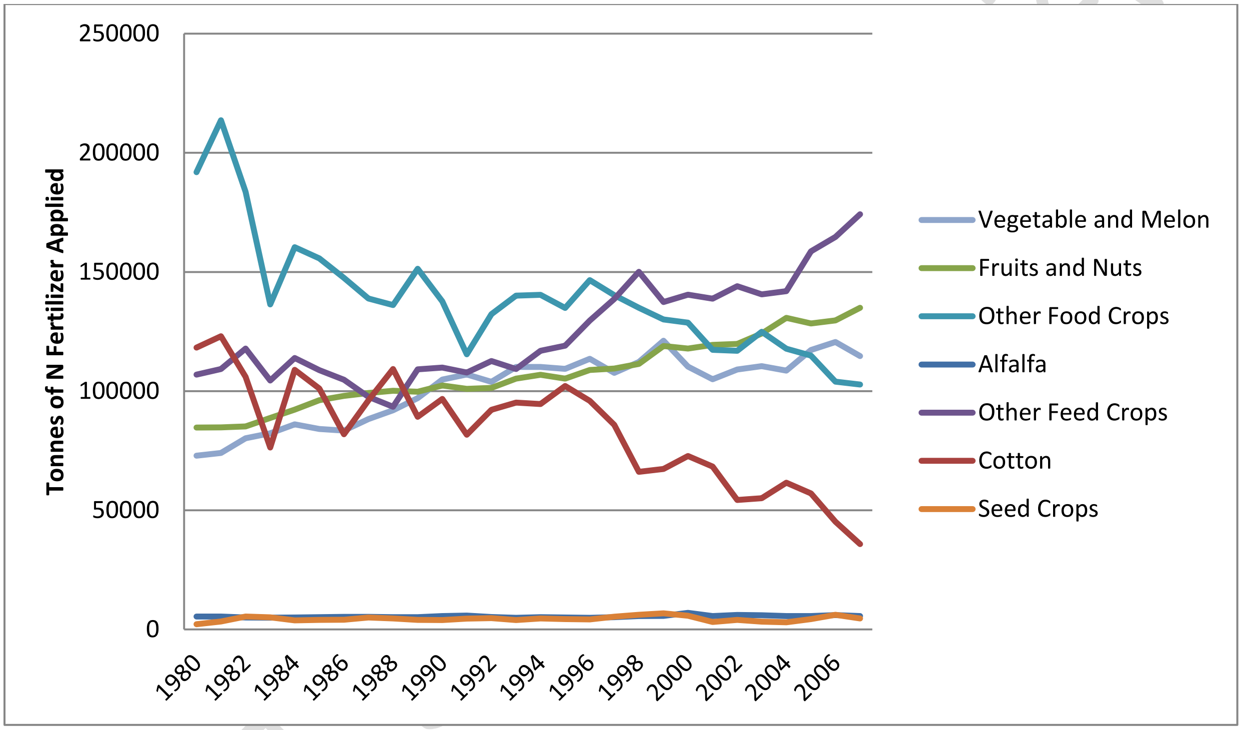

Figure 5.1.4: California imputed tonnes of N harvested, 1980-2007. Tonnes of N harvested for each crop category is calculated by: tonnes of crop produced*%Dry Matter*%N. The crop categorization of crops used here is consistent with the crop groupings used in Figure 5.1.2. Source: USDA, NASS, California County Agricultural Commissioners' Data (2002-2007); UC Davis Cost Studies, 1999-2010, USDA Chemical Use Surveys (1995-2007). [Return to text]

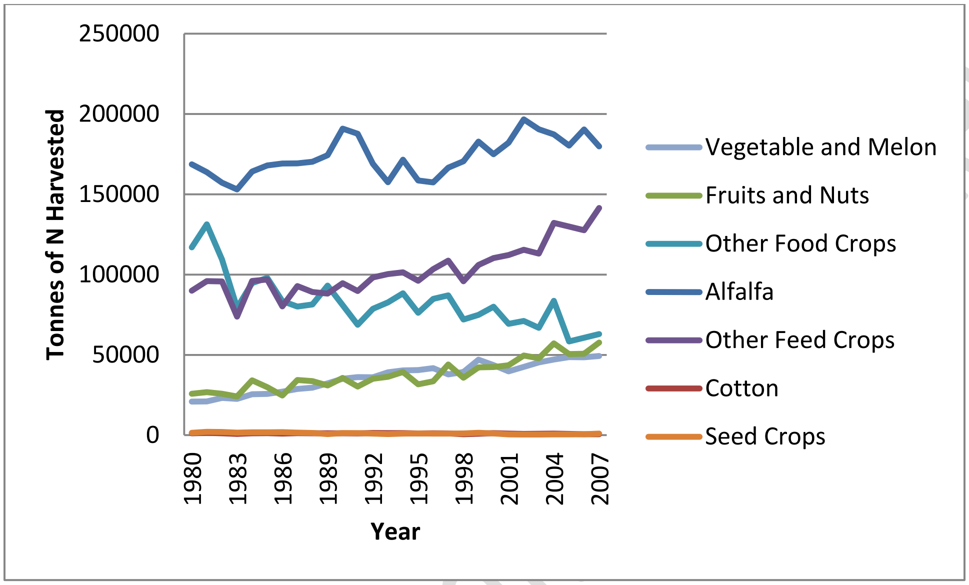

Figure 5.1.5: California estimated difference in tonnes of N applied in fertilizer and N harvested, 1980-2007. The estimated difference between total tonnes of N applied (crop area x average N application rate) and tonnes of N harvested provide a rough approximation of how much of the N applied is lost to the environment. The crop categorization of crops used here is consistent with the crop groupings used in Figure 5.1.2. Alfalfa is omitted since it is an N-fixing crop and very little synthetic N is applied (e.g., 13 kg N/ha) for the cultivation of alfalfa. Source: USDA, NASS, California County Agricultural Commissioners' Data (2002-2007); UC Davis Cost Studies, 1999-2010, USDA Chemical Use Surveys (1995-2007). [Return to text]

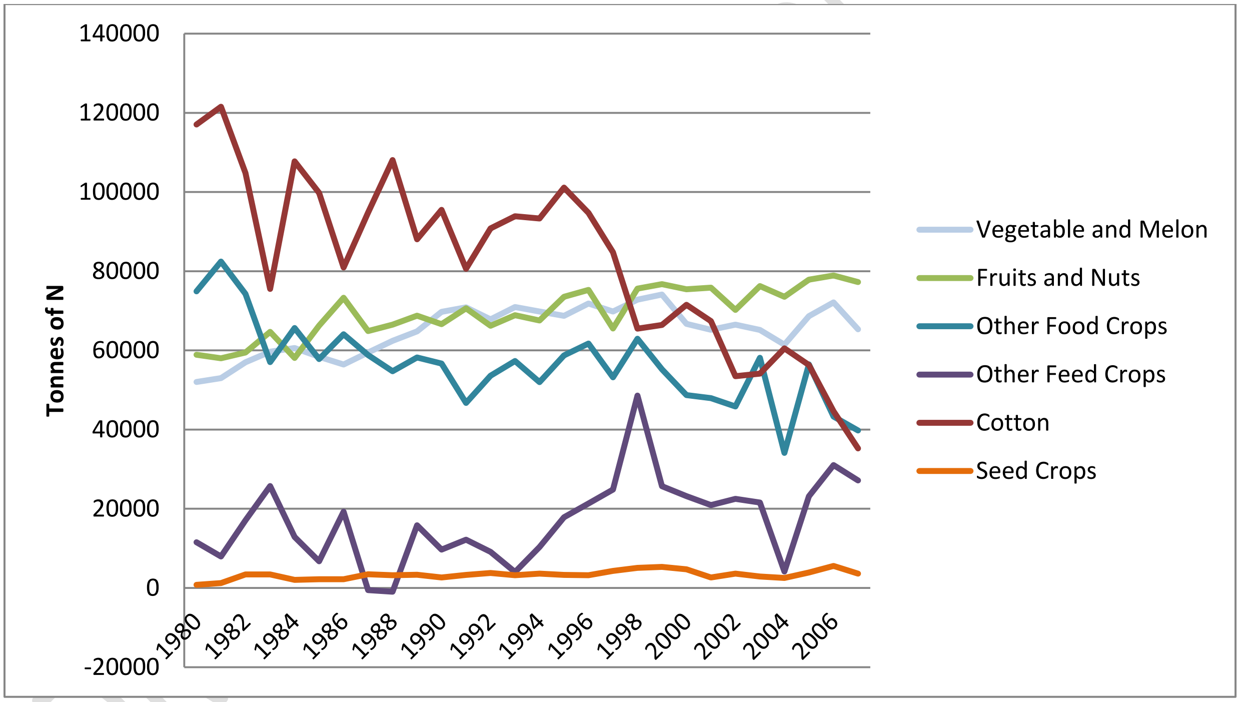

Figure 5.1.6: California population of milk cows and heifers and production per milk cow, 1980-2007. California has gotten more efficient in milk production overtime as the production of milk per cow has increased from 15,000 pounds per milk cow in year 1980 to about 22,500 pounds per milk cow in year 2007. Source: USDA, NASS, 1935-2009. **[Return to text]**

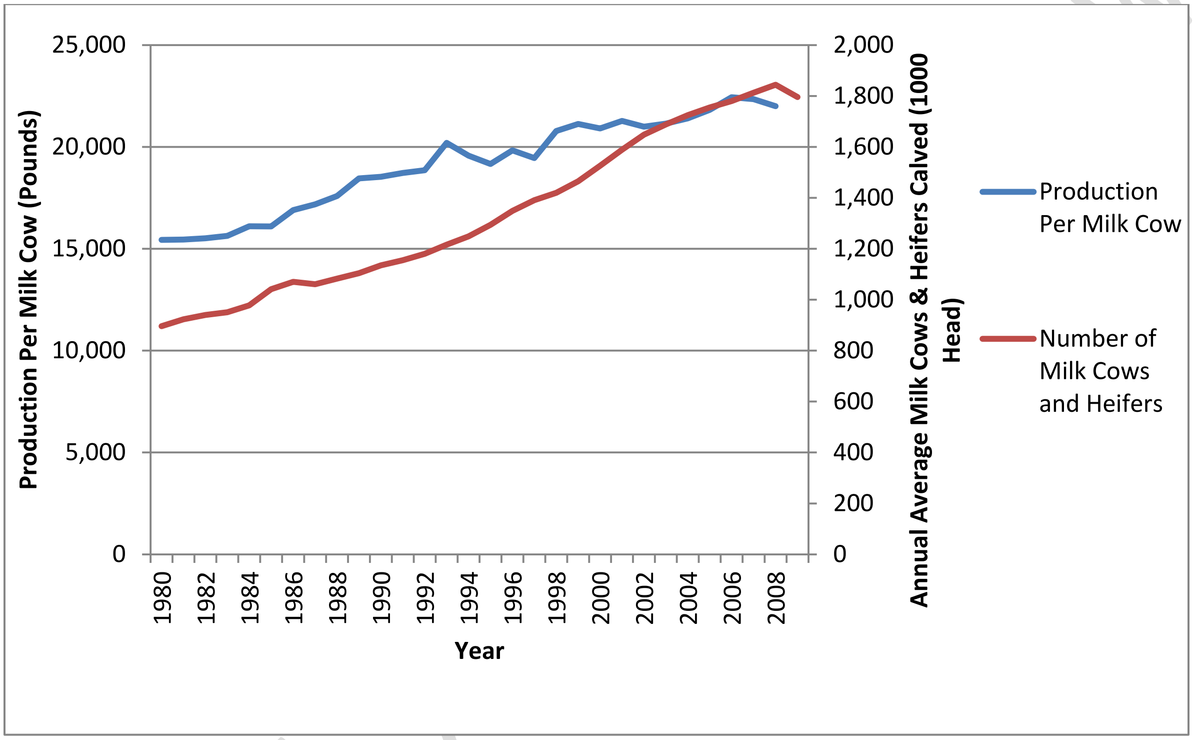

Figure 5.1.7: California net value added from crop production, 1980-2010. Net value-added is the sector's contribution to the national economy and is the sum of the income from production earned by all factors-of-production, regardless of ownership (USDA ERS). The "Other" category shown in the figure below includes oil crops, tobacco, home consumption, 'value of inventory adjustment', and other miscellaneous values as reported in the USDA ERS database. The net value added for fruits and tree nuts has more than tripled from 1980-2010. Crop groupings follow that of the USDA ERS and are not the same as those used in Figures 5.1.2 – 5.1.5. Source: USDA, ERS, 1980-2010. **[Return to text]**

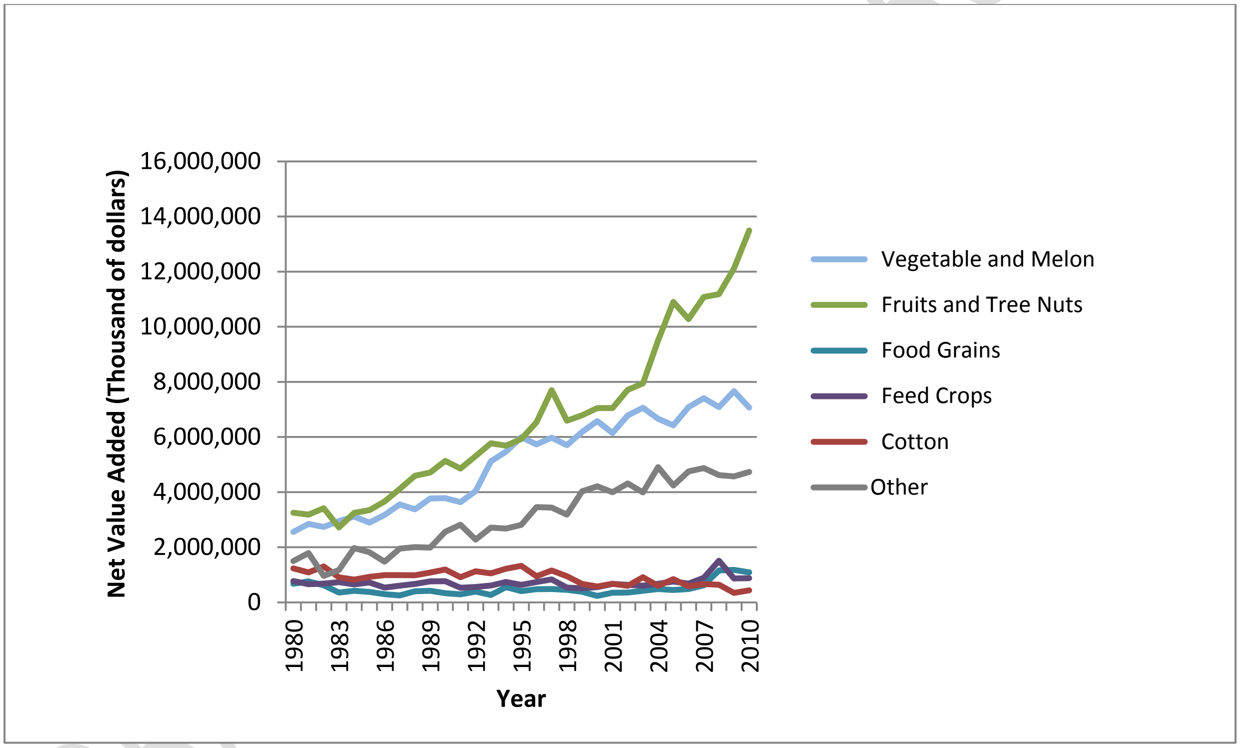

Figure 5.1.8: California net value added from livestock production, 1980-2010. Net value-added is the sector's contribution to the national economy and is the sum of the income from production earned by all factors-of-production, regardless of ownership (USDA ERS). The "Other" category shown below is a sum of the net value added from miscellaneous livestock, home consumption, and 'value of inventory adjustment' as reported in the USDA ERS database. The net value added for dairy products has tripled, from $2 billion in 1980 to about $6 billion in year 2010. Source: USDA, ERS, 2011. [Return to text]

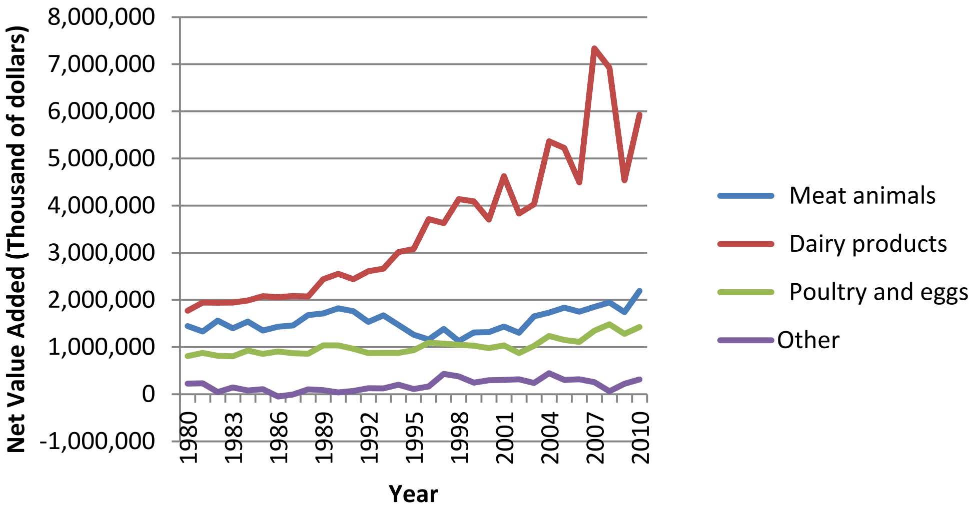

Figure 5.1.9: California total value added from crop and livestock production, 1980-2010. The value of agricultural sector production is the gross value of the commodities and services produced within a year. The value of crop production below is the sum of the total value added from the different categories of crop production minus the "other" and the "vegetables" category as published by the USDA/ERS (1980-2010) database. Similarly, the value of livestock production is the sum of the value added from the different livestock production categories minus the "other" category as shown in Figure 5.1.8. The total value added from crop production far exceeds the total value added from livestock production in California. Source: USDA, ERS, 2011. **[Return to text]**

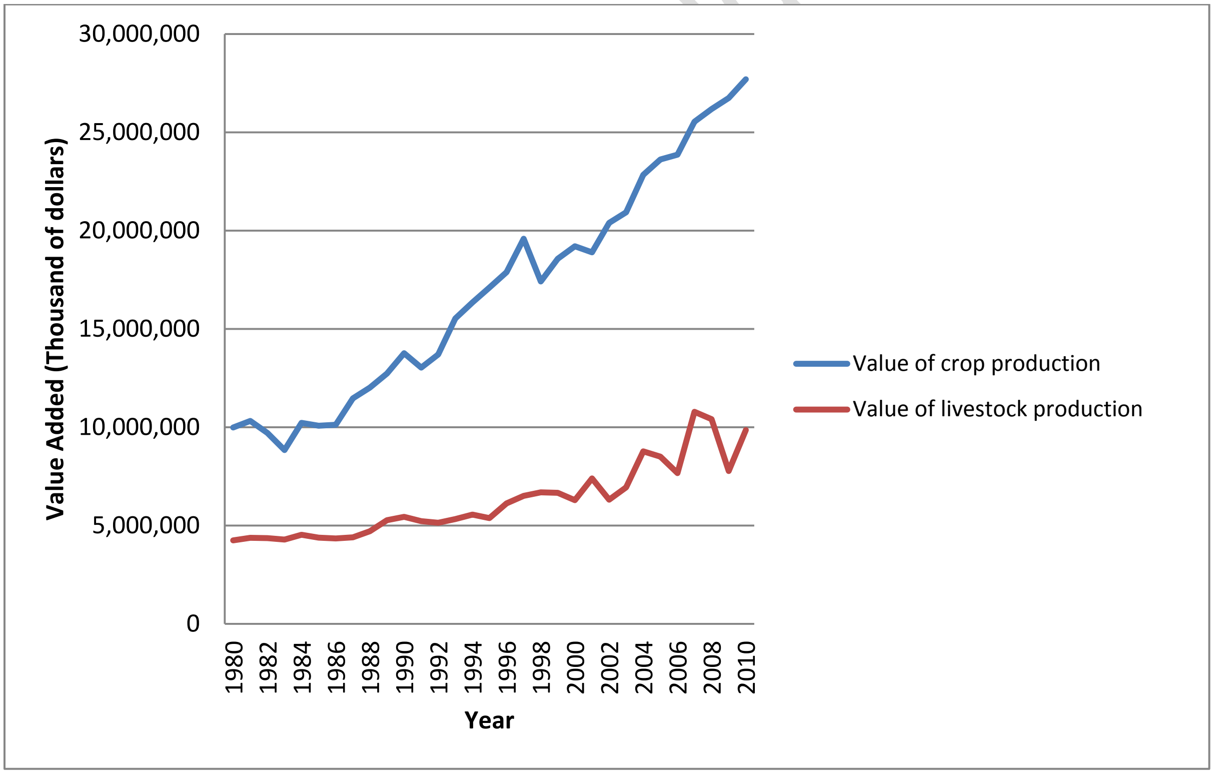

Table 5.0.1: Ecosystem services affected by increased N in the environment. Positive and negative impacts of N on various environmental and human health services are indicated using a plus or a minus. Source: Adapted from Compton et al (2011) and USEPA (2012). **[Return to text]**

Type	Ecosystem service	Beneficial or adverse impact	Mechanism of impact	N-related cause	Source
Provisioning	Production of food and materials	+	Increased production and nutritional quality of food crops	N fertilizer increases crop growth	Synthetic and organic N fertilizer
		+	Increased production of building materials and fiber for clothing or paper	N fertilizer increases crop growth	Synthetic and organic N fertilizer
		-	Soil acidification, nutrient imbalances and altered species composition	Acid deposition	Fossil fuel combustion, and agriculture
	Fuel Production	-/+	Increased N inputs required for some biofuel crops can affect other services	N fertilizer increases crop growth	Synthetic and organic N fertilizer
		+	Increased use of fossil fuels to improve human health and well-being across the globe[8]	Increase energy availability	Fossil fuel combustion
Supporting and Regulating	Drinking water	-	Increased nitrate concentrations lead to blue-baby syndrome, certain cancers	Nitrate into water	Agriculture
		-	Increased acidification and mobility of heavy metals and aluminum	Acid deposition	Fossil fuel combustion, and agriculture
	Clean Air	-	NO_x-driven increases in ozone and particulates exacerbate respiratory and cardiac conditions.	NO_x into air; $PM_{2.5}$, O_3 and related toxins	NO_y and NH_x from fossil fuel combustion, and agriculture
		-	Increased allergenic pollen production	Pollen production	Crops with airborne pollen
		-	Stimulation of ozone formation, which in turn can reduce agricultural and wood production and act as a greenhouse gas	Ozone and acid deposition	Fossil fuel combustion

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[8] This impact is not addressed in Chapter 5. Please refer to Section 3.4 for a discussion of fuel combustion as a direct driver.

Type	Ecosystem service	Beneficial or adverse impact	Mechanism of impact	N-related cause	Source
	Visibility	-	Increased NO_x and NH_3 in air stimulates formation of particulates, smog and regional haze	Fine particulate matter	NO_y and NH_x from fossil fuel combustion and agriculture
	Climate regulation	+/-	Variable and system-dependent impacts on net CO_2 exchange	N deposition	Fossil fuel combustion, agriculture
		-	Stimulation of N_2O production, a powerful greenhouse gas	N_2O into air	Agriculture, animal manure management, sewage treatment, fossil fuel combustion
	UV Regulation	-	Increased N_2O release, which has strong-ozone-depleting potential	N_2O into air	Agriculture, animal manure management, sewage treatment, fossil fuel combustion
Cultural	Swimming	-	Stimulation of harmful algal blooms that release neurotoxins (interaction with phosphorus)	Excess nutrient loading, eutrophication, variable freshwater runoff	Fossil fuel combustion, agriculture
		-	Increased vector-borne diseases such as West Nile virus, malaria and cholera	Excess nutrient loading, eutrophication, variable freshwater runoff	Fossil fuel combustion, agriculture
	Fishing	+	Increased fish production and catch for some very N-limited coastal waters	Nutrient loading, N deposition	Fossil fuel combustion, agriculture
		-	Increased hypoxia and harmful algal blooms in coastal zones, closing fish and shellfish harvests	Excess nutrient loading, eutrophication, variable freshwater runoff	Fossil fuel combustion, agriculture
		-	Reduced number and species of recreational fisheries from acidification and eutrophication	Atmospheric deposition of HNO_3, NH_3 and ammonium compounds	Fossil fuel combustion, agriculture
	Hiking	-	Altered biodiversity, health and stability of natural ecosystems	N deposition	Fossil fuel combustion, agriculture
	Biodiversity	-	Altered biodiversity, food webs, habitat and species composition of natural ecosystems	N deposition	Fossil fuel combustion, agriculture
	Other	-	Damage to buildings and structures from	Acid deposition	Fossil fuel combustion,

Type	Ecosystem service	Beneficial or adverse impact	Mechanism of impact	N-related cause	Source
			acids		agriculture
		+/-	Long range trans-boundary N transport and associated effects (both negative and positive)	N deposition	Fossil fuel combustion, agriculture

856

Table 5.1.1: California's agriculture-related industries, 2002. Source: MOCA 2009 **[Return to text]**

Category	Establishments	Sales ($ million)	Payroll ($ million)	Employees
Food, beverages and tobacco manufacturing	4,661	61,615	6,515	196,508
Total agriculture-related industries	89,774	264,988	33,353	1,656,316
Total California, not including farming, government, railroad and employed sectors	820,997	N/A	510,841	12,856,426

Table 5.1.2 California: Direct and total effects as share of state economy, 2002. Source: MOCA 2009

[Return to text]

	Direct Effects (percent)				Total Effects (percent)		
	Industry output (sales)	Employ.	Labor income	Value added	Employ.	Labor income	Value added
Agricultural production and processing	4.28	3.76	2.47	2.85	7.29	5.60	6.49
Farming	1.24	1.55	0.77	1.05	2.59	1.56	1.96
Vegetables, fruits, nuts	0.66	0.83	0.47	0.66	1.51	0.97	1.18
Beef and dairy cattle	0.22	0.27	0.03	0.03	0.53	0.20	0.24

Table 5.1.3 Economic importance of agriculture to selected regional economies, 2002. Source: MOCA 2009 **[Return to text]**

	Direct effects				Total effects		
Region	Industry output (sales) ($mil.)	Employ. (jobs)	Labor income ($ mil.)	Value added	Employ. (jobs)	Labor Value ($ mil.)	Value added
San Joaquin Valley	34,005	313,277	7,567	12,698	601,102	16,580	28,345
Sacramento Valley	7,958	54,422	1,592	3,318	95,517	3,056	5,977
Central Coast	14,028	110,686	3,894	6,728	183,606	7,213	12,594
California Agricultural Production and Processing	97,722	744,920	22,553	39,646	1,445,357	51,227	90,194
Total California economy	2,281,194	19,831,054	914,708	1,389,164	N/A	N/A	N/A

Table 5.1.4: Share of US production of California commodities for top 25 commodities produced in California. Source: USDA ERS: http://www.ers.usda.gov/data/FarmIncome/finfidmu.htm

[Return to text]

Commodity	Value of receipts ($1000)	Share of California receipts (%)	California share of U.S. value (%)
Almonds	2,200,055	6.9	100
Avocados	365,371	1.1	96.3
Broccoli	625,721	2	92.5
Cattle and calves	1,633,740	5.1	3.5
Celery	265,081	0.8	93.4
Cotton lint, all	666,510	2.1	14.3
Dairy products	5,365,992	16.9	19.6
Grapes	2,758,467	8.7	91.5
Greenhouse/nursery	3,328,147	10.5	21.2
Hay	603,344	1.9	13.7
Lemons	284,413	0.9	88.9
Lettuce	1,462,331	4.6	70.7
Melons, watermelons, etc.	319,027	1	45.3
Onions	313,534	1	30.6
Oranges	577,326	1.8	36.8
Peaches	251,254	0.8	54.4
Peppers, green fresh	277,120	0.9	48.1
Pistachios	444,160	1.4	100
Potatoes	217,782	0.7	9.2
Poultry/eggs	1,230,065	3.9	4.2
Spinach, fresh	199,920	0.6	76.6
Strawberries	1,218,860	3.8	82.8
Tomatoes, fresh	420,616	1.3	31.3
Tomatoes, processing	669,973	2.1	93.1
Walnuts	438,750	1.4	100

Table A5.1.1. California crop categories used in the assessment[9] [Return to text]

Alfalfa	Seed Crops	Other Food crops	Other Feed Crop
Alfalfa Hay	Alfalfa Seed	Beans, dry	Almond Hulls
	Grass seed, sudan	Beans, dry lima	Barley
	Grass seed, Bermuda Grass	Beans, green lima	Corn Grain
	Grass seed, other	Field crops, other	Corn Silage
	Legume Seed	Peanuts	Haylage, non-alfalfa
	Sunflower	Potatoes	Oats
	Vegetable seeds	Rice	Rye
		Safflower	Small Grain Hay
		Sugar Beets	Sorghum Grain
		Sweet Potatoes	Sorghum Silage
		Wheat	Sudan Hay
		Wild Rice	Tame Hay
			Triticale
			Wild Hay

Fruits and Nuts

Almonds
Apples
Apricots
Avocados
Berries, Other
Blackberries
Blueberries
Boysenberries
Cherries
Chestnuts
Dates
Deciduous, other
Figs
Grapefruit
Grapes
Guavas
Hazelnuts
Jojoba
Kiwis
Kumquats
Lemons
Limes
Macadamias
Melons,
Cantaloupe
Nectarines
Olives
Oranges
Peaches
Pears
Pecans
Persimmons
Pistachios
Plums
Pluots
Pomegranates
Prunes
Raspberries
Strawberries
Subtropical, other
Tangelos
Tangerines
Walnuts

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[9] These crop categories were used for the analysis in Figures 5.1.2, 5.1.3, 5.1.4, and 5.1.5.

Vegetable and Melon

Artichokes
Asparagus
Beans, snap
Beets
Broccoli
Brussel Sprouts
Cabbage, Chinese
Cabbage, Head
Carrots
Cauliflower
Celery
Chicory
Collards
Cucumbers
Eggplant
Escarole+Endive
Garlic
Herbs
Kale
Lettuce
Melons, Honeydew
Melons, Watermelon
Mint
Mushrooms
Mustard Greens
Mustard Seed
Okra
Onions, dry
Onions, green
Parsley
Peas, Chinese
Peas, green
Pepper, chili
Peppers, bell
Pumpkins
Radishes
Rhubarb
Spinach
Squash
Sweet Corn
Tomatoes, fresh
Tomatoes, processing
Turnips
Vegetables, other
Watercress