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LOMA LINDA UNIVERSITY
School of Science and Technology
in conjunction with the
Faculty of Graduate Studies

The Environmental Impact of Dietary Choice and Agriculture in California

by

Harold J. Marlow, Jr.

A Dissertation submitted in partial satisfaction of
the requirements for the degree of
Doctor of Philosophy in Biology

June 2006

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Each person whose signature appears below certifies that this dissertation in his/her opinion is adequate, in scope and quality, as a dissertation for the degree Doctor of Philosophy.

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DEDICATION

What a long strange trip it's been. To quote Sir Winston Churchill "If you're going through Hell, keep on going!" I would first and foremost like to thank God for the courage, willingness, and strength to persevere and see this research to its completion.

This process has given me a new understanding of trusting and leaning on Him. My Grandpa Marlow had a favorite saying, "I do the best I can with what I've got."

Considering what I had to work with, I think my grandpa would be proud. I would like to thank my parents and family for their encouragement, love and support through out the process. Most importantly, I would like to thank my wife for her love and the grace she extended to me during the difficult culmination of this manuscript.

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ABSTRACT OF THE DISSERTATION

The Environmental Impact of Dietary Choice and Agriculture in California

by

Harold J. Marlow Jr.

Doctor of Philosophy, Graduate Program in Biology

Loma Linda University, June 2006

Dr. Samuel Soret, Chairperson

Food demand influences agricultural production. Modern agricultural practices have resulted in polluted soil, air and water, eroded soil, dependence on imported oil, and loss of biodiversity. The goal of this research is to investigate the environmental impact of pesticide and fertilizer application, water consumption, and energy used to produce commodities for a vegetarian and nonvegetarian diet in California. The working assumption is that greater number and amount of inputs are associated with greater environmental impact. The literature supports this notion. To accomplish this goal, dietary preferences were quantified using the Adventist Health Study and state agricultural data were collected and applied to commodity production statistics. These data were used to calculate the difference in consumption patterns between the two diets and indices to compare the environmental impact associated with inputs for the two dietary patterns. In addition, the results for the Adventist vegetarian and nonvegetarian diets were compared to the production inputs for the production of an average American diet. Results show the Adventist vegetarian diet required 5.41 times less water, 2.48 times less primary energy, 12.9 times less fertilizer, and 1.4 times less pesticides than did the Adventist nonvegetarian diet. The Adventist nonvegetarian diet required 1.99 times less water, 1.82 times less primary energy, 2.10 times less fertilizer, and 1.43 times less

pesticides than did the average American diet. It is clear that the production of a SDA nonvegetarian or average American diet requires the inputs of significantly greater amounts of water, primary energy, fertilizers and pesticides when compared to the SDA vegetarian diet. The greatest contribution to the differences came from the consumption of animal products, eggs, broilers, and beef in the diet. From an environmental perspective, what a person chooses to eat makes a difference. Viewed from the individual lens, the difference in the dietary choices of the SDA vegetarian, nonvegetarian and average American do not appear to support profound conclusions. However, with the added perspective of time and numbers the differences become quite pronounced and may have the potential for tremendously different impacts to the environment.

CHAPTER ONE

INTRODUCTION

In developed countries, and throughout the world, there is a direct link between dietary preference, agricultural production, and environmental degradation (Gussow and Clancy, 1986; Goodland, 1997; Carlsson-Kanyama, 1998). If industrialized agriculture is placing a burden on the environment it is essential for researchers, educators, and policy makers to have a method to quantify the environmental impact of modern agricultural practices.

This research has been developed to explore the relationship between dietary preference and environmental impact. The main purpose of this program is to quantify the environmental impact of agricultural practices used to produce commodities for a vegetarian and nonvegetarian diet. The state of California is used as a model to identify and quantify the association between dietary preference and ecological degradation. Several potential impacts, the use of energy, water, pesticides, and inorganic fertilizers, have been identified. The goal of this research is to investigate the environmental impact of pesticide and fertilizer application, water consumption, and energy used to produce commodities for a vegetarian and nonvegetarian diet in California. The working assumption is that greater number and amount of inputs are associated with greater environmental impact.

To accomplish this goal state agricultural data were collected and applied to commodity production statistics. These data were used to calculate indices to compare the environmental impact associated with the two dietary patterns.

This dissertation is divided into six sections: LITERATURE REVIEW, RESEARCH DESIGN & METHODS, RESULTS, DISCUSSION and, REFERENCES. The significance and timeliness of this research is presented along with previous work related to this topic in the LITERATURE REVIEW. Research methodology including a description of statistical methods, data sources and the validity and reliability of measuring instruments is presented in RESEARCH DESIGN & METHODS. Research results are presented in the RESULTS section. A discussion of the results and suggestions for further research are included in the DISCUSSION. A list of literature cited is presented in the REFERENCES.

CHAPTER TWO

LITERATURE REVIEW

The environmental impact of modern agriculture has increased with the implementation of technologies designed to increase crop yield and commodity production (Brown, 1970; Pimentel and Pimentel, 1983; Aldy, Hrubovcak, and Vasavada, 1998; Bennett, 2000). Technological advances in mechanization, irrigation, fertilization and chemical control of pests have allowed substantial increases in agricultural output since the 1940s (Brown, 1970). Simultaneously, there has been an increase in total energy expenditure, (Lockeretz, 1983; Cleveland, 1995; Conforti and Giampietro, 1997), depletion of natural resources (Schaaf, 1983; Pimentel and Pimentel, 1997; Pinstруп-Andersen and Pandya-Lorch, 1998), and generation of waste products (Brown, 1970; Gussow, 1994; Harkin, 1997). In fact, the point has been reached where scientists and policy makers have begun to seriously doubt the sustainability of these trends (Friend, 1983; Pal, 1984; Robertson, Parks, and English, 1998). Particular skepticism has been aimed at supporting the increased demand for animal products in the diet of the economically advantaged persons of the world (Heitschmidt, Short, and Grings, 1995; Rerat and Kaushik, 1995; Spedding, 1995).

The majority of cropland in the US is rain fed (Tanji and Enos, 1994). Despite this fact, agricultural production requires 80% of the water consumed in the US and California (Pimentel and Pimentel, 1983; Snyder, Hanson, and Coppock, 1986; Zilberman, et al., 2002) to irrigate approximately 10-15 % of cropland (Pimentel and Pimentel, 1983; Plaut and Meiri, 1994; Tanji and Enos, 1994; Howell, 2001; Pimentel et al., 2004) and to water livestock (Tanji and Enos, 1994; Yaron and Frenkel, 1994).

Critical water issues exacerbated by agricultural practices include pollution of surface and groundwater sources (Aldy, Hrubovcak, and Vasavada, 1998; Pimentel, 1999; Sampat, 2000; Klohn and Applegren, 2002; Anderson, et al., 2003), overdrafting of aquifers (Tanji and Enos, 1994; Aldy, Hrubovcak, and Vasavada, 1998), waterlogging and salinization of soils (Pinstrup-Andersen and Pandya-Lorch, 1998; Abu-Amrieh, Sabbah, and Isaac, 1999; Pimentel, 1999), wetlands loss (Lemly, Kingsford and Thompson, 2000) and runoff, evaporation and leakage from irrigation systems (Wallace, 2000; Usmanova, 2003). These impacts may have greater significance during times of seasonal or extended drought (Zilberman, et al., 2002; Woods, 2000). Federal subsidies and the failure of pricing practices to reflect the true value of water lead to devaluation of the resource and disincentivize conservation measures (Lemly, Kingsford and Thompson, 2000; Usmanova, 2003).

Increased use of fossil fuels and concurrent technological advances has allowed humans to increase the production of natural systems by manipulating the environment (Lockertz, 1983; Le Pape and Mercier, 1983; Uri and Gill, 1992; Cleveland, 1995; Pimentel, 1999; Millian, 2002). The energy intensiveness of agricultural production varies with the type of crop produced, amount of chemical inputs, and the geographical location (Lockhertz, 1983; Pimentel and Pimentel, 1997). With market globalization and convenient transportation choices food will be available during seasons that they were typically absent and the increased energy requirements partially borne by consumers and driven by market demand (Pirog et al., 2001). In the US, fossil fuel consumption has doubled in the last 20 years while the caloric return per calorie of input on most crops has diminished (Pimentel and Pimentel, 1983). Cheap sources of fossil fuels will allow for

massive energy inputs to agricultural systems but as prices increase and supplies dwindle this practice is likely to change (Heitschmidt, Short, and Grings, 1995). Conservation and optimization of energy use will certainly be in the future of agriculture (Meadows, 2001). A positive return of 2-3 nutrient calories per calorie of primary energy input is characteristic for most cereal grains and legumes (Horrigan, Lawrence, and Walker, 2002). Most fruits and vegetables return about 0.5 calories, and animal products about 0.01-0.05 calories (Pimentel and Pimentel, 1983; Giampietro, Bukkens, and Pimentel, 1994). According to Reijnders and Soret (2003), the energy inputs for animal products may be 2.5-5.0 times greater than for plant products. One of the major challenges for agriculture in the future will be to reduce the dependence on non-renewable sources of energy, negative environmental impacts associated with fossil fuel use (Lansink, van Ierland and Best, 2002; Pretty, et al., 2002) and increase the energy use efficiency of agricultural systems (de Koeijer, et al., 2002; Nonhebel, 2002).

The natural fertility of the soil in the US has been depleted and replaced by application of chemical fertilizers that has increased approximately 10% per year since the 1950s (Pimentel and Pimentel, 1983). Potassium and phosphate are produced from non-renewable resources and the production of nitrogen fertilizer relies directly on petroleum (Viglizzo, et al., 2003). The use of fertilizers represents the single greatest energy input for many crops (Pimentel, 1983) and the over use of fertilizers has resulted in surface and groundwater contamination (Pimentel and Pimentel, 1997; Hossain and Singh, 1999; Singh, 2000; Spalding, et al., 2001; Adler, 2002; Cavero, Beltran, and Aragues, 2003), air pollution (Parris, 1998; Galloway et al., 2001) and a decrease in biodiversity (McLaughlin and Mineau, 1995).

Pesticide use has increased as much as 33 times in the US since the 1940s (Brown, 1970; Pimentel et al., 1992). Annually, approximately 2.5 million tons of pesticides are applied to crops worldwide (van der Werf, 1996; Paoletti and Pimentel, 2000). In spite of this increase in the use of pesticides, an estimated 37% of all crop production is lost annually to pests (Pimentel et al., 1992; Pimentel et al., 1993, Paoletti and Pimentel, 2000). Increased monoculture cultivation (Conforti and Giampietro, 1997; Pretty, Vorley, and Keeney, 1998; Thies and Tschamtkke, 1999), positive cost-benefit ratios (Paoletti and Pimentel, 2000; Falconer, 2002) and neglect of the environmental or social cost of application (Roush, 1997; Foster et al., 1998; Pearce and Tinch, 1998; Osteen and Pagitt, 2002) have lead to unrestricted increases pesticide usage. Concerns over the environmental consequences of pesticide use include: residues on food (Lee, 1992; Pimentel et al., 1993), ground and surface water contamination (Lee, 1992; Levitan, Merwin and Kovach, 1995;), persistence in the environment (Kiraly, 1996; Foster et al., 1998), damage to non-targeted species (Levitan, Merwin and Kovach, 1995; Kiraly, 1996; Hamer, 2000; Osteen and Pagitt, 2002), increased resistance in pests (Pimentel et al., 1993; Foster et al., 1998), and worker safety (Kishi and Ladou, 2001, Osteen and Padgitt, 2002). Some environmental effects may be difficult to measure or assess accurately (Burn, 2003). A host of acute and chronic human health effects have been reported and include, endocrine disruption, immune dysfunction, neurological disorders, and cancer (van der Werf, 1996; Pretty, Vorley and Keeney, 1998, Paoletti and Pimentel, 2000; Kishi and Ladou, 2001). Regulations aimed at protecting public health and limiting environmental impact from pesticide usage began in 1910 with the Federal Insecticide Act and have advanced through a series of legislation and promulgation

ending most recently with the 1996 Food Quality Protection Act which uses a risk assessment approach to set tolerances for pesticide residues in foods (Reed, 2002; Seiber, 2002)

Public awareness of diverse global environmental issues such as toxic residues in food (Clarkson, 1995; Falconer 1998), soil erosion (Huston, 1993; Trimbel and Crosson, 2000) and species endangerment (Huston, 1993; Tisdell, 1997) has brought about a call for sustainable food production practices (Rosenberg et al., 1993; Pinstруп-Andersen and Pandya-Lorch, 1998; Jackson, 2002) and responsible stewardship of our finite resources (Alper, 1993; Worrell and Appleby, 2000). There have been attempts to identify and quantify the ecological concerns associated with intensive farming (Pimentel and Pimentel, 1983; Giampietro, Bukkens and Pimentel, 1994; Halberg, 1999; Pimentel, 1999; Bennett, 2000). Gussow (1995) issued a call for research permitting a direct comparison of the ecological consequences of different diets. Although several associations have been suggested (Giampietro, Bukkens and Pimentel, 1994; Carlsson-Kayama, 1998; Pimentel, 1998) no direct comparisons have been published to date.

There exists a direct link between dietary preference, agricultural production, and environmental degradation (Gussow and Clancy, 1986; Goodland, 1997; Carlsson-Kanyama, 1998). Human health and the health of the environment are also inextricably linked (World Health Organization, 1997). The link is so clear for Fowler and Hobbs (2003) that they conclude that “humanity is not sustainable.” It is clear that understanding the associations is essential.

The goal of this research is to investigate the environmental impact of pesticide and fertilizer application, water consumption, and energy used to produce commodities

for a vegetarian and nonvegetarian diet in California. Pesticide and fertilizer use has been linked to environmental contamination and degradation of California's natural resources. In addition, water and energy resources demand primary consideration in California. The results of this research may enable further understanding of the impact of diet on the environment and resource allocations.

CHAPTER THREE

RESEARCH DESIGN AND METHODS

The state of California was used as a model to identify and quantify the association between dietary preference and ecological degradation. Several potential impacts, the use of energy, water, pesticides, and inorganic fertilizers, were identified.

The goal of this research was to investigate the environmental impact of pesticide and fertilizer application, water consumption, and energy used to produce commodities for a vegetarian and nonvegetarian diet in California. To accomplish this goal state agricultural data were collected and applied to commodity production statistics. These data were used to calculate indices to compare the environmental impact associated with the two dietary patterns. The working assumption is that greater number and amount of inputs are associated with greater environmental impact.

This chapter is divided into five sections: Dietary Patterns, Data Collection, Production Statistics, Data Analysis, and Statistical Analysis.

Dietary Patterns

There are many vegetarian diets, many with a sample of one. To make this project relevant, we selected the largest vegetarian group in California, the Seventh-day Adventists. Among them there are about 50% nonvegetarians. Even though the nonvegetarians perhaps do not eat like the general population, from a methodological point of view, they are the best comparison. The Adventist Health Study (AHS; Beeson, et al., 1989) began in 1973 with a preliminary identification of the study population. Between 1974 and 1976 the study population was identified and enumerated. The study population completed detailed census, lifestyle and dietary questionnaires as a part of

participation in the study. As a result 34,198 non-Hispanic white Seventh-day Adventists were enrolled in the study.

The AHS has been used as a tool to study the relationship between diet and other lifestyle characteristics and chronic disease incidence in a group of California Seventh-day Adventists. The data have been extensively utilized and have resulted in the publication of over 200 scientific articles. The utility of the data was extended and applied to environmental health research.

Dietary Preference

The AHS was used to identify and quantify the dietary preferences of a group of Seventh-day Adventists in the state of California. Two dietary patterns, vegetarian and nonvegetarian, were chosen based on the frequency of consumption of meat, poultry, and fish. Dietary preference was defined by using existing conventions (Beeson et al., 1989; Fraser, 1999; Myint, et al., 2000):

- vegetarian - eats < 1 serving of meat per week
- nonvegetarian - eats ≥ 1 serving of meat per week

The Independent-sample t -test and the Mann-Whitney (Norusis, 1998) test were used to identify statistically significant differences in the consumption pattern, between vegetarians and nonvegetarians, for 31 of the 50 items found on the AHS food frequency questionnaire. The remaining 19 items were not included in the research because they were beverages or consisted of complex mixtures of commodities, such as doughnuts. The items in the food frequency questionnaire and included in the statistical comparison are shown in Table 3.1. Statistically significant differences in the number of servings per week were found for 22 of the 31 food items or groups and are shown in Table 3.2.

Table 3.1 Food and Beverage Items Listed on the Adventist
Health Study Food Frequency Questionnaire

Questionnaire Item	Questionnaire Item
Whole milk	Low fat (2%) milk
Nonfat (skim milk)	Buttermilk
Sweets and desserts*	Fruit drinks*
Black tea*	Hot chocolate*
Other hot drinks*	Cola beverages*
Other soft drinks*	Beer or wine*
Hard liquor*	Beef – steak
Beef – hamburger	Other beef or veal
Fish	Poultry
Pork products	Eggs
Cheese	Margarine*
Meat Analogues	Dried or canned beans
Nuts	Green salads
Cottage cheese	Cooked green vegetables
Canned or frozen fruit	Tomatoes
Dried fruit	Citrus fruit
Winter fruit	Seasonal fruit
White rice	Brown rice
Doughnuts and sweet rolls*	Crackers*
Chips*	Pancakes or waffles*
Salad dressing or mayonnaise*	Whipping cream*

*items not included in analysis because they are beverage or complex mixtures of items.

Table 3.2 Seventh-day Adventist Consumption Patterns According to Vegetarian Status¹

Food Item	Vegetarian	Nonvegetarian	Food Item	Vegetarian	Nonvegetarian
<u>servings per week</u>			<u>servings per week</u>		
Dry Fruit	2.66	1.51	Cheese	1.76	2.49
Canned Fruit	2.77	1.92	Cottage Cheese	2.32	1.91
Winter Fruit	5.23	4.18	Milk	12.66	12.03
Citrus Fruit	2.61	2.23	Beef	0.13	3.49
Fruit Juice	4.58	4.24	Pork	0.00	0.15
Seasonal Fruit	3.88	3.11	Poultry	0.05	0.72
Tomatoes	3.68	3.42	Fish	0.06	0.63
Green Vegetables	5.21	5.07	Eggs	1.42	2.18
Nuts	3.32	1.90	Beans	2.12	1.16
White Rice	0.34	0.42	Soy Milk	0.91	0.18
Brown Rice	0.60	0.35	Meat Analogs	3.34	1.28

¹ All differences were significant at $P < 0.05$. Vegetarians ate meat, fish, or poultry less than one time per week; nonvegetarians ate these foods greater than or equal to 1 time per week.

Given the large population size ($n=34,191$) of the AHS almost any difference in was statistically significant at the level of $p < 0.05$ so the items included in the study were determined on the basis of practical relevance. From the 22 food items with statistically significant differences we included only those with practical relevance in this research. We defined practical relevance in consumption pattern differences as a consumption frequency difference between the diet groups of > 0.25 servings per week (1 serving per month). All servings of dairy products were combined for the analysis. All servings of rice were combined for the analysis. Fish, soymilk and meat analogs were excluded because they are not produced in California. Such differences in the number of servings per week were found for 11 of the 31 food items or food groups. Table 3.3 shows the food items or food groups used in this research.

Table 3.3 Practically Relevant Seventh-day Adventist Consumption Patterns According to Vegetarian Status¹

Food Item	Vegetarian	Nonvegetarian	Food Item	Vegetarian	Nonvegetarian
<u>servings per week</u>			<u>servings per week</u>		
Dry Fruit	2.66	1.51	Nuts	3.32	1.90
Canned Fruit	2.77	1.92	Beans	2.12	1.16
Winter Fruit	5.23	4.18	Eggs	1.42	2.18
Seasonal Fruit	3.88	3.11	Poultry	0.05	0.72
Citrus Fruit	2.61	2.23	Beef	0.13	3.49
Fruit Juice	4.58	4.24			

¹ All differences were significant at $P < 0.05$ and are considered practically relevant differences. Vegetarians ate meat, fish, or poultry less than one time per week; nonvegetarians ate these foods greater than or equal to 1 time per week.

Portion Size

The Special Nutrition Sub-Study of the AHS (SNSS; Fraser, et al., 1998) was used to determine portion size for each food item used in this research and enabled the calculation of weekly consumption amounts for the food items included in the study. I wish to acknowledge Jay Tanzman from Loma Linda University, School of Public Health for his assistance in determining portion size weighting and contributions to this section. Portion size data from the SNSS were used to estimate mean portion sizes for vegetarians and non-vegetarians in the AHS. Because the gender distributions of vegetarians and non-vegetarians in the SNSS differed from those of the AHS (Table 3.4) and because gender is a potential confounder of the relation between vegetarian status and portion size, the SNSS data were weighted to reflect the gender distribution of the AHS.

Table 3.4 Population Demographics: Gender and Vegetarian Status

Diet	Gender	AHS	SNSS
		<u>percent</u>	
Vegetarian	Female	62.00	68.89
	Male	38.00	31.11
Nonvegetarian	Female	54.90	77.78
	Male	45.10	22.22

Not all subjects in either the SNSS or the AHS ate each food. Because this resulted in each food having a unique gender distribution of consumers, separate sets of weights were computed for each food for each of the two vegetarian status groups. The weight w_{ijk} for the portion size of the i -th food for each SNSS subject (who consumed that food) in vegetarian status group j having gender k was calculated as the ratio of the proportions P_{ijk} / p_{ijk} , where:

$$P_{ijk} = N_{ijk} / M_{ij} \text{ and,}$$

N_{ijk} = the number of AHS subjects who ate food i and belonged to vegetarian status group j and were of gender k , M_{ij} = the number of AHS subjects who ate food i and belonged to vegetarian status group j , and where p_{ijk} is defined for SNSS subjects in a manner analogous to P_{ijk} . The weights applied to the SNSS portion size data are shown in Table 3.5.

Table 3.5 Weights Applied to SNSS Portion Size Data

Food Item	Diet	Gender	Weight	Food Item	Diet	Gender	Weight
Dry Fruit	vegetarian	Female	0.88	Nuts	vegetarian	Female	0.94
		Male	1.30			Male	1.12
	nonvegetarian	Female	0.72		nonvegetarian	Female	0.66
		Male	1.94			Male	2.65
Canned Fruit	vegetarian	Female	0.92	Beans	vegetarian	Female	0.89
		Male	1.16			Male	1.24
	nonvegetarian	Female	0.72		nonvegetarian	Female	0.70
		Male	1.87			Male	2.07
Winter Fruit	vegetarian	Female	0.91	Eggs	vegetarian	Female	0.88
		Male	1.20			Male	1.28
	nonvegetarian	Female	0.65		nonvegetarian	Female	0.68
		Male	2.84			Male	2.27
Seasonal Fruit	vegetarian	Female	0.91	Poultry	vegetarian	Female	0.86
		Male	1.20			Male	1.42
	nonvegetarian	Female	0.60		nonvegetarian	Female	0.70
		Male	6.26			Male	2.14
Citrus Fruit	vegetarian	Female	0.93	Beef	vegetarian	Female	0.88
		Male	1.14			Male	1.26
	nonvegetarian	Female	0.73		nonvegetarian	Female	0.74
		Male	1.86			Male	1.77
Fruit Juice	vegetarian	Female	0.89				
		Male	1.25				
	nonvegetarian	Female	0.69				
		Male	2.37				

Weighted mean portion sizes Y were then calculated as follows:

$$Y_{ij} = \sum_l w_{ijk} x_{ijkl} / \sum_{k,l} w_{ij}$$

Where l indexes subjects, the other subscripts are defined as above, and the x_{ijkl} 's are the portion sizes reported by each SNSS subject who consumed the i -th food. Weighted and unweighted mean portion sizes are shown in Table 3.6.

Table 3.6 Unweighted and Weighted Portion Size From the SNSS Study and Used for this Research¹

Food Item	Diet	Unweighted Portion Size	Weighted Portion Size
		<u>grams consumed</u>	
Dry Fruit	vegetarian	33.08	33.00
	nonvegetarian	48.10	59.77
Canned Fruit	vegetarian	116.45	119.77
	nonvegetarian	96.03	96.42
Winter Fruit	vegetarian	120.93	122.69
	nonvegetarian	100.93	108.76
Seasonal Fruit	vegetarian	110.85	111.81
	nonvegetarian	88.95	88.73
Citrus Fruit	vegetarian	139.50	140.31
	nonvegetarian	101.90	102.05
Fruit Juice	vegetarian	154.52	156.08
	nonvegetarian	165.18	172.84
Nuts	vegetarian	19.41	19.75
	nonvegetarian	16.52	14.59
Beans	vegetarian	120.64	121.29
	nonvegetarian	150.95	145.52
Eggs	vegetarian	42.72	42.42
	nonvegetarian	57.44	63.08
Poultry	vegetarian	65.35	72.07
	nonvegetarian	126.96	123.79
Beef	vegetarian	82.67	79.20
	nonvegetarian	91.24	94.57

¹ All differences were significant at $P < 0.05$ and are considered practically relevant differences. Vegetarians ate meat, fish, or poultry less than one time per week; nonvegetarians ate these foods greater than or equal to 1 time per week.

Representative Food Items

Representative food items were chosen for each food group identified above using the U.S. Department of Agriculture Food Consumption, Prices, and Expenditures, 1970-97 (Putnam and Allshouse, 1999). A representative food item was defined as the most frequently consumed food item from each food group. The results are shown in Table 3.7. The items included were raisins, canned peaches, apples, watermelon, oranges, orange juice, almonds, dried beans, eggs, chicken and beef. For practical purposes, orange juice consumption was converted to an equivalent orange consumption by dividing the grams of orange juice consumed by 53, the grams of juice in a medium orange. Grape production statistics were used for calculations involving raisins.

Annual Food Consumption

The dietary habit of the average Adventist vegetarian does not dramatically differ from the average Adventist nonvegetarian. Accordingly, the environmental impact of those differences may be more difficult to determine. The average Adventist nonvegetarian appears not to consume food items in the same amount as an average American. The annual consumption (AC) of each individual food item from the study was calculated to allow a comparison of the average Adventist nonvegetarian diet with the average American diet.

The AC was calculated as follows:

$$AC = 52 (SW Y)$$

Where SW = weekly number of servings and Y = weighted portion size.

Table 3.7 Representative Food Items Included in the Research¹

Food Group	1° Consumed	2° Consumed	3° Consumed
<u>Per capita consumption (kg)</u>			
Dried Fruit	Raisins (0.7)	Prunes (0.2)	Figs (0.1)
Canned Fruit	Peaches (2.6)	Apples(1.9)	Pineapples (1.5) ²
Winter Fruit	Bananas (10.3) ²	Apples (8.3)	Pears (1.3)
Seasonal Fruit	Melons (10.3)	Peaches (2.6)	Strawberries (1.3)
Melons ³	Watermelon (6.0)	Cantaloupe (3.5)	Honeydew (0.8)
Citrus Fruit	Oranges (6.1)	Grapefruit (3.2)	Tangerines (0.9)
Fruit Juice ⁴	Orange (2.2)	Apple (0.5)	Grapefruit (0.3)
Nuts	Almonds (0.25)	Pecans (0.20)	Walnuts (0.20)
Beans Dry	Beans (3.0)		
Eggs	Eggs (261) ⁵		
Chicken	Chicken (26.1)		
Beef	Beef (48.1)		

¹ Most frequently consumed food items consumed for each food group. Source: U.S. Department of Agriculture Food Consumption, Prices, and Expenditures, 1970-97.

² Item not produced in California in any appreciable quantity and not included in research

³ Melons were most frequently consumed seasonal fruit. Melon consumption data shown.

⁴ Orange juice consumption converted to equivalent orange consumption for calculations.

⁵ Egg consumption shown in number of eggs.

The annual consumption values for the 11 commodities under investigation were compiled from the U.S. Department of Agriculture Food Consumption, Prices, and Expenditures, 1970-97 (Putnam and Allshouse, 1999) for the year 1985. All reported values were converted to metric units. Beef and chicken were reported as ready to eat portions (retail cut equivalent). Egg consumption was reported in numbers of eggs and the weight was calculated by multiplying the number times 50 g per egg. Fruits, nuts and beans were reported as ready to eat portions.

The annual consumption of individual food items is shown in Table 3.8.

Table 3.8 Consumption Values Used for this Research ¹

Food Item	Diet	Servings per week	Weighted Portion Size grams	Weekly Consumption grams	Annual Consumption kg
Dry Fruit	vegetarian	2.66	33.00	87.78	4.56
	nonvegetarian	1.51	59.77	90.25	4.69
	American			26.05	1.35
Canned Fruit	vegetarian	2.77	119.77	331.76	17.25
	nonvegetarian	1.92	96.42	185.13	9.63
	American			184.53	9.59
Winter Fruit	vegetarian	5.23	122.69	641.67	33.37
	nonvegetarian	4.18	108.76	454.62	23.64
	American			381.12	19.82
Seasonal Fruit	vegetarian	3.88	111.81	433.82	22.56
	nonvegetarian	3.11	88.73	275.95	14.35
	American			381.99	19.86
Citrus Fruit	vegetarian	2.61	140.31	366.21	19.04
	nonvegetarian	2.23	102.05	227.57	11.83
	American			187.94	9.77
Fruit Juice	vegetarian	4.58	156.08	714.85	37.17
	nonvegetarian	4.24	172.84	732.84	38.11
	American			612.00	31.83
Nuts	vegetarian	3.32	19.75	65.57	3.41
	nonvegetarian	1.90	14.59	27.72	1.44
	American			20.98	1.09
Beans	vegetarian	2.12	121.29	257.13	13.37
	nonvegetarian	1.16	145.52	168.80	8.78
	American			66.43	3.45
Eggs	vegetarian	1.42	42.42	60.24	3.13
	nonvegetarian	2.18	63.08	137.51	7.15
	American			244.90	12.74
Poultry	vegetarian	0.05	72.07	3.60	0.19
	nonvegetarian	0.72	123.79	89.13	4.63
	American			458.04	23.82
Beef	vegetarian	0.13	79.20	10.30	0.54
	nonvegetarian	3.49	94.57	330.05	17.16
	American			691.35	35.95

1) Vegetarian and Nonvegetarian values calculated from the Adventist Health Study. American values calculated from U.S. Department of Agriculture Food Consumption, Prices, and Expenditures, 1970-97.

Data Collection

The goal of this research was to investigate the environmental impact of agricultural inputs of pesticide and fertilizer applications, water consumption, and primary energy used to produce commodities for a vegetarian and nonvegetarian diet in California. Statistics and data compiled by other researchers and local, state, and federal agencies were used to assess the environmental impact associated with the production of food items identified above.

For ease and coherence of presentation, data collection and analysis were divided into two sections describing production of 1) Plant Products; almonds, apples, dried beans, grapes, oranges, peaches, and watermelon and 2) Animal Products; alfalfa and corn used for animal feed, chicken, eggs, and beef.

Research Location

This research was limited to agricultural production in the state of California. A number of factors make California an ideal place to study. California has historically been the largest producer of agricultural and food products in the US and hosts a wide range of operations (Weick, 2001). California produced more than 70% of the top five fruits consumed in the US and was the second producer of the remaining two (Duxbury and Welch, 1999). Over half of the US supply of fresh and processed vegetables was produced in the state (Duxbury and Welch, 1999). Agricultural activities in California have resulted in air and water contamination, aquifer overdraft, pesticide poisonings, species endangerment and other environmental impacts. California leads the nation in research and policy in the areas of environmental protection, natural resource conservation and sustainable agriculture (Clark et al., 1999).

The San Joaquin Valley in central California has been the leading region for agricultural production in the state of California. In 1998 the San Joaquin Valley was home to four of California's top five leading agricultural counties with total value of production over \$13.7 billion (California Statistical Abstract, 2000). A San Joaquin Valley County ranks in the top three producers, based on gross weight of production, for each of the commodities chosen for inclusion in this research (Table 3.9, USDA, 1999A). Consequently, this research effort was focused on three top producing counties in the San Joaquin Valley; San Joaquin in the north, Fresno in the middle, and Kern in the south thus maximizing the geographical representation in the region. The geographical extent of the San Joaquin Valley and the location of the counties included in the research are shown on Figure 3.1.

Figure 3.1 Study Area

Production Practices

Beef Production

California's great geographical diversity with extreme climatic and environmental conditions has resulted in a varied cattle production industry. Beef production practices in California vary greatly and are primarily influenced by the region where production occurs and the type of operation. Additional influences include breed of cattle produced, husbandry practices, and herd nutritional demands.

According to the 1997 Census of Agriculture (USDA, 1999A), California had an inventory of approximately two and one half million beef cattle on approximately twelve thousand farms. In that same year approximately one and one quarter million cattle and calves were slaughtered (USDA 1999) at 10 facilities in the state (Anderson et al, 2002). According to Anderson et al. (2002) the vast majority of cattle production in California occurs in the Central Valley and the southeastern part of the state. A small portion of the cattle and almost all of the calves slaughtered were from dairy herds (dairy beef) and were produced in the southeastern portion of the state.

In general California beef cattle enterprises consist of Cow-Calf, Stocker, and Feedlot phases of production (Jesen and Oltjen, 1996). In addition, seed stock operations produce purebred or registered cattle with superior genetics marketed as herd sires and replacement females (Jesen and Oltjen, 1996). Calves are born throughout the year however, the majority are usually born in the spring and weaned in the fall. Calves are weaned between 6 and 10 months, weighing 136-318 kg (300-700 lbs, Taylor and Field, 1999). After they have been weaned, calves go directly to the range as stockers or, depending on grain prices and pasture availability, to the feedlot to be fed. The stocker

calves are grazed on pasture for 6-8 months, by which time they weigh an average of 273-364 kg (600-800 lbs) (Jesen and Oltjen, 1996; Ensminger, Oldfield, and Heinemann, 1990) and are sent to feedlots for finishing. During the finishing phase, feeder cattle are fed in a feedlot for 120-150 days and to reach a market weight of 523-568 kg (1,150-1,250 lbs) (Jesen and Oltjen, 1996)

The focus of this research was on California's beef production. The requirements for production and maintenance of replacement heifers and seed stock were beyond the scope of this research because the contribution of each is minimal and difficult to amortize in the production of an individual animal. The production of dairy beef occurs primarily in the southeastern part of California and not in the Central Valley and was not included in this research. Assumptions used and requirements for beef production are described below.

Husbandry and Feedstuffs

Cow-Calf production. The cow-calf phase begins with fertilization and lasts until the calf is weaned. The gestation period for a cow is slightly more than 9 months. Beef cows remain in production for 5-8 years and are bred to produce a calf every 12 months. The cow-calf phase was assumed to last 16 months resulting in the production of a calf with an average weaning weight of 227 kg (500 lbs) at 7 months (Jesen and Oltjen, 1996).

Taylor and Field (1999) estimate that 60-70% of calf weaning weight is accounted for by the milk production of the cow and the remaining 30-40% comes from forage and feed that the calf consumes directly. On good quality forage, a 455 kg (1000 lbs) dry pregnant cow will consume 2.0-2.5% of her body weight in dry matter daily. That equals

9.1-11.4 kg (20-25) lbs dry weight or 11.0-12.7 (22-28 lbs) as fed (Maas, 1994; Ensminger, Oldfield, and Heinemann, 1990). Assuming good quality roughage, an estimate of 2.25% body weight or 11.3 kg (24.8 lbs) as fed was used to calculate the daily grazed intake for a cow to sustain her condition. A 455 kg (1000 lbs) pregnant lactating cow will consume 2.8-3.0% of her body weight in dry matter daily. That equals 12.7-13.6 kg (28-30) lbs dry weight or 14.1-15.0 kg (31-33 lbs) as fed. Assuming good quality roughage, an estimate of 2.9% body weight or 14.5 kg (31.9 lbs) was used to calculate the daily grazed intake for a cow to produce milk for her calf and sustain her condition. Cow-calf grazing forage intake was calculated for a 455 kg (1000 lbs) lactating cow and her calf. Assuming good quality roughage, an estimate of 3.2 kg (7.1 lbs) daily of grazed forage was required to provide milk for the calf (Table 3.9). Using the same assumption, an estimate of 1.50% body weight or 2.25 kg (5.0 lbs) daily was used to calculate the portion of grazed intake in the diet for a 136 kg (300 lbs) calf (Table 3.9). Cow-calf operations are significantly more cost effective when cows graze more days during the year and are fed less harvested feed (Taylor and Field, 1999). It was assumed that the nutritional needs of the cow-calf unit were mostly met by grazing with a supplementation of 151 kg (333 lbs) of alfalfa (Forero et al., 2004). This equals a net feed usage of approximately 0.83 kg (0.38 lb) of alfalfa per kg (2.2 pounds) of live weight calf produced.

Accordingly, when calculating inputs of water, pesticide, fertilizer, and energy into cow-calf production (below), the inputs for producing 151 kg (330 lbs) of alfalfa were added. Values used for cow-calf production are presented in Table 3.9.

Table 3.9 Daily Feed Requirements for Cattle

Class of Cattle	<u>Daily Consumption</u>		Dry Matter (kg)	As-Fed (kg)	Days on Feed	Total Consumption (kg)
	Weight (kg)	Feed				
Dry	454.55	Pasture	10.85	11.27	200	2254.55
Pregnant Cow						
Nursing	454.55	Pasture	13.18	14.5	200	2900.00
Pregnant Cow						
Milk Production (a)	NA	Pasture	2.93	3.23	200	645.45
Calf	136.36	Pasture	2.05	2.25	200	450.00
Stocker (b)	318.18	Pasture	6.2	6.85	200	1636.64
Feeder (c)	522.73	Concentrates			150	
		Corn	6.95	7.64		1146.14
		Alfalfa	1.74	1.91		286.36
		Total	8.68	9.55		1432.50

(a) Milk production was calculated by subtracting the daily requirements of a nursing cow from that of a dry cow. Milk production was supplemented by feeding 151 kg (333 lbs) of alfalfa.

(b) Grass fed stocker assumed to gain 0.45 kg/day (1 lb/da) during 200 days of grazing.

(c) Feeder assumed to gain 1.36 kg/day (3lbs/da) on concentrates consisting of 80% corn and 20% alfalfa.

Stocker production. Stocker operations feed and manage cattle, typically steers and heifers, for growth prior to going to a feedlot for finishing. In stocker cattle average daily gain is affected by genetics, health, body condition, and nutrition of cattle (Taylor and Field, 1999). It was assumed that in California stocker cattle remain on rangelands or pastures 7 months until they weigh on average 318 kg (700 lbs, Jesen and Oltjen, 1996). According to Ensminger, Oldfield, and Heinemann (1990), stockers grazed on pasture need to consume on average 6.8 kg (15 lbs) of grass-legume mixed hay to gain on average 0.45 kg (1 lb) per day. During periods of inadequate rangeland production,

producers meet herd nutritional need through *in situ* supplementation (Maas, 2000) or by transporting cattle to a location where sufficient feed is available. It was assumed that the nutritional needs of the stocker were mostly met by grazing with a supplementation of 39.5 kg (87 lbs) of alfalfa (Nader, 2005). Accordingly, when calculating inputs of water, pesticide, fertilizer, and energy into stocker production (below), the inputs for producing 39.5 kg (87 lbs) of alfalfa were added. This equals a net feed usage of approximately 0.43 kg (0.20 lb) of alfalfa per kilogram (2.2 pounds) of live weight stocker beef produced. In addition, the distance to move stockers from the cow-calf production site to the stocking site was assumed to be 209 km (130 miles) one-way (Larry Forero personal communication) and this figure was used to calculate energy input into stocker production (below). Values used for stocker production are presented in Table 3.9.

Feeder production. The terms finishing or finished cattle and the related term fed cattle refer to cattle that have been fed feed grains or concentrates (Taylor and Field, 1999). Feeding programs are influenced by the age, weight, and sex of cattle, price and availability of feedstuffs, feedlot management practices, and length of feeding time (Taylor and Field, 1999). Typical cattle performance measurements of interest include dry matter feed consumption, feed conversion efficiency, average daily weight gain, and cost of weight gain. Feed conversion efficiencies for beef range from 4-10 kg of feed per kg of live weight gain (4-10 lbs/lb) (Ensminger, Oldfield, and Heinemann, 1990; Taylor and Field, 1999).

Feedlot rations used for calculations assumed a 318 kg (700 lbs) medium frame steer expected to gain 1.4 kg (3 lbs) per day during a 150-day finishing period and weighing 523 kg (1150 lbs) at slaughter. The rations were assumed to have been

balanced for net energy, protein, minerals and vitamins. The requirements for this steer are 9.6 kg as-fed (8.7 dry matter, 21.01 lbs as-fed/19.1 lb dry matter) including 1.0 kg (2.2 lbs) crude protein (Taylor and Field, 1999) yielding average conversion efficiency of 3.2kg (7.0 lbs) of feed per 0.45 kg (pound) of live weight gain.

The cost of gains in feeder cattle is directly related to grain prices. Corn is the most common grain used in feeding cattle (Ensminger, Oldfield, and Heinemann, 1990). In general, the price of corn represents 70-80% of the total cost of gain (Taylor and Field, 1999). Hay is the most common harvested roughage for feedlot cattle (Ensminger, Oldfield, and Heinemann, 1990). The daily feed ration for a steer was estimated using a formula of 80% concentrates from corn and 20% roughage from alfalfa hay (Taylor and Field, 1999) and is as follows: 7.6 kg corn and 1.9 kg alfalfa (16.81 lb corn and 4.20 lb alfalfa, Table 3.9). This equals a net feed usage of approximately 5.6 kg of corn and 1.40 kg of alfalfa per kg of live weight feedlot beef produced (5.60 lbs of corn and 1.40 lbs of alfalfa/ lb).

According to Ensminger, Oldfield, and Heinemann (1990), the most commonly used protein supplements for finishing cattle are soybean meal, cottonseed meal, linseed meal, urea, and other nonprotein nitrogen sources. In California, beef cattle are fed by-products produced in the processing of agricultural products for human consumption. Examples include sugar beet tops and pulp, cull citrus and citrus pulp, cannery refuse, corncobs, cottonseed and almond hulls, and milling commodities (Ensminger, Oldfield, and Heinemann, 1990; Jensen and Oltjen, 1999). It was assumed that the unmet protein need from the diet above would be met by feeding by-products.

Water, pesticide, fertilizer, and energy input to feedlot production will be discussed below. Total net feed consumption for beef production equals the sum of feed required cow-calf production (0.83 kg alfalfa/kg weight gain), stocker production (0.43 kg alfalfa/kg weight gain), and feeder production (5.60 kg corn and 1.4 kg alfalfa / kg gain). Values used for feeder production are presented in Table 3.9.

Water

Water requirements. Adequate hydration is essential for proper digestion and absorption of nutrients, removal of waste, and regulation of body temperature (Ensminger, Oldfield, and Heinemann, 1990). Water requirements depend on temperature, humidity, animal weight, type of feed consumed, and phase and type of production (Ensminger, Oldfield, and Heinemann, 1990). Guidelines suggest that water requirements may range from 1.82-20.4 L (4 to 45 gallons) per animal per day (Jensen and Oltjen, 1999). The daily water requirement is met by drinking water and moisture in feeds and for a given class of cattle is dependent on ambient temperature and intake of dry matter.

The average annual temperature in the study area was calculated from data compiled by the National Oceanic and Atmospheric Administration and published as Climatology of the United States No. 81 (2002). Monthly mean temperatures for Stockton, Merced, and Bakersfield were used to determine the mean annual temperature for the Central Valley. The mean annual temperature was calculated to be 75.5 °F (24.2 °C) but, for ease of calculation the temperature used was 75°F (23.9 °C). The original data from the NRC Nutrient Requirements for Beef Cattle (2000, Table 3.10) listed water

consumption for various classes of cattle at 70 °F (21.1 °C) and 80 °F (26.7 °C) and consumption data for 75°F (23.9 °C) were interpolated using these data.

Table 3.10 Approximate Total Daily Water Intake of Beef Cattle¹

Weight		Temperature in °F (°C) ²											
		40	(4.4)	50	(10.0)	60	(14.4)	70	(21.1)	80	(26.6)	90	(32.2)
kg	lb	Liter	Gal	Liter	Gal	Liter	Gal	Liter	Gal	Liter	Gal	Liter	Gal
Growing heifers, steers, and bulls													
182	400	15.1	4.0	16.3	4.3	18.9	5.0	22.0	5.8	25.4	6.7	36.0	9.5
273	600	20.1	5.3	22.0	5.8	25.0	6.6	29.5	7.8	33.7	8.9	48.1	12.7
364	800	23.0	6.3	25.7	6.8	29.9	7.9	34.8	9.2	40.1	10.6	56.8	15.0
Finishing Cattle													
273	600	22.7	6.0	24.6	6.5	28.0	7.4	32.9	8.7	37.9	10.0	54.1	14.3
264	800	27.6	7.3	29.9	7.9	34.4	9.1	40.5	10.7	46.6	12.3	65.9	17.4
454	1,000	32.9	8.7	35.6	9.4	40.9	10.8	47.7	12.6	54.9	14.5	78.0	20.6
Wintering Pregnant Cows													
409	900	25.4	6.7	27.3	7.2	31.4	8.3	36.7	9.7	-	-	-	-
500	1,100	22.7	6.0	24.6	6.5	28.0	7.4	32.9	8.7	-	-	-	-
Lactating Cows													
409	900	43.1	11.4	47.7	12.6	54.9	14.5	64.0	16.9	67.8	17.9	61.3	16.2
Mature Bulls													
636	1,400	30.3	8.0	32.6	8.6	37.5	9.9	44.3	11.7	50.7	13.4	71.9	19.0
727	1,600+	32.9	8.7	35.6	9.4	40.9	10.8	47.7	12.6	54.9	14.5	78.0	20.6

¹Source Nutrient Requirements of Beef Cattle, Seventh Revised Edition National research Council-National Academy of Science, 2000.

²Water intake of a given class of cattle in a specific management regime is a function of dry matter intake and ambient temperature. Water intake is quite constant up to 40 °F (4.4°C).

For calculations conducted for this research, approximate daily water intake for a 454 kg (1000 lbs) nursing cow was 17.4 gallons (65.95 l) and for a pregnant wintering cow was 10.6 gallons (40.17 l). The net difference between a nursing and dry cow, 6.8 gallons (25.7 l) was assumed to be the amount of water consumed for milk production. Furthermore, the approximate daily water intake for a 182 kg (400 lbs) calf was 5.8 gallons (22.0 l), for a 273 kg (600 lbs) stocker 8.4 gallons (31.8 l), and for a 409 kg (900 lbs) finishing steer 12.6 gallons (47.8 l, Table 3.11). Total direct consumption for beef production equals the sum of water required for milk production and calf, stocker, and feeder consumption (25,468.80 l) was divided by the total weight of beef produced (477.27 kg) to arrive at a yield of 53.36 l/kg beef produced. Total indirect consumption

for beef production equals the water required to produce consumed feedstuffs (5.62 kg corn and 2.66 kg alfalfa/ kg beef) and will be discussed below.

Table 3.11 Daily Water Requirements for Cattle at 75°F¹

Class of Cattle	Daily Consumption		Days	Total Consumption (L)
	Weight (kg)	Daily Consumption (L)		
Dry Pregnant Cow	454.55	40.17	200	8034.80
Nursing Pregnant Cow	454.55	65.95	200	13189.20
Milk Production (a)	na	25.77	200	5154.40
Calf	181.82	21.98	200	4396.40
Stocker	272.73	31.84	200	6367.20
Feeder	409.09	47.75	150	9550.8

¹Data interpolated from data obtained from Source Nutrient Requirements of Beef Cattle, Seventh Revised Edition National research Council-National Academy of Science, 2000.

(a)Milk production was calculated by subtracting the daily requirements of a nursing cow from that of a dry cow.

Broiler and Egg Production

Chicken enterprises in California raise birds for meat production (broilers), egg production, and replacement stock. In 1998 the California Poultry Workgroup (Bell, et al., 1998) reported that there were 200 commercial egg production facilities in the state maintaining approximately 25 million layers and generating an estimated \$300 to \$400 million in gross revenue. The Workgroup (Ernst, et al., 1998) also reported \$457 million in receipts from the production of 234 million broilers in 1996. The vast majority of broilers were produced on farms located in the San Joaquin Valley.

The focus of this research was on California's broiler and egg production for direct human consumption. Assumptions used and requirements for production of broiler and eggs are described below.

Broiler production

A few giant integrated companies control the broiler production in California (Ernst, 1995). These companies direct production of broilers via independently contracted operators in segments ranging from egg production to marketing of the adult birds (Ernst, 1995). These chickens may be marketed as game hens, broilers, or roasters depending on age and weight. This research focused on the contracted production of broilers in a closed environmental facility assumed to reach an average live weight of 2.27 kg (5 pounds) at 49 days (7 weeks) of age (Bell and Weaver, 2002; Ernst, 1995; National Research Council, 1994).

Feed. Most poultry rations fed today provide a precise formulation of energy, amino acids, vitamins and minerals. Such rations are known as complete rations (Bell and Weaver, 2002; National Research Council, 1994; Ensminger, Oldfield, and Heinemann, 1990). Broilers have nutrition requirements distinct from layers and are bred to produce rapid and economical gains for producers. After genetic differences, temperature and relative humidity have the greatest effect on poultry nutrition requirements (Ensminger, Oldfield, and Heinemann, 1990). Corn provides the primary source of energy for most broiler rations and usually amounts to 55-70% of the ration (Bell and Weaver, 2002; National Research Council, 1994; Ensminger, Oldfield, and Heinemann, 1990). Broilers have no minimum requirement for crude protein and as such the established minimums, approximately 20-30%, fulfill the need for amino acids in the

diet (National Research Council, 1994). The bulk of the broiler ration consists of fats (2-5%), vitamins, minerals and antibiotics (Bell and Weaver, 2002; National Research Council, 1994; Ensminger, Oldfield, and Heinemann, 1990). Modern broiler dietary regimes utilized in the industry consist of separate starter, grower, and finisher ration formulations (Bell and Weaver, 2002). For the purpose of this research, an average broiler ration that consisted of 68.5% corn, 21.9% soy meal, 6.24% meat and bone meal, and 2.10% fat was calculated from data provided by Bell and Weaver (2002). Typical feed conversion efficiencies rang from 1.9-2.5 kilograms of feed per kilogram of broiler live weight gain (Bell and Weaver, 2002; National Research Council, 1994; Ensminger, Oldfield, and Heinemann, 1990). A feed conversion efficiency of 2.0 was used for calculations performed during this research (Bell and Weaver, 2002). The production of a 2.27 kg (5 pounds) broiler in 49 days (7 weeks) would require approximately 3.11 kg (6.84 lb) of corn, 0.99 kg (2.19 lb) soybean meal, 0.28 kg (0.62 lb) meat and bone meal, and 0.095 kg (0.21 lb) fat. This equals a net feed usage of approximately 1.37 kg (3.01 lb) of corn, 0.44 kg (0.96 lb) of soy bean meal, 0.12 kg (0.26 lb) of meat and bone meal, and 0.042 kg (0.092 lb) of fat per kilogram (2.2 pounds) of live weight chicken produced. Water, pesticide, fertilizer, and energy input to feedstuffs for broiler production will be discussed below. Values used for broiler production are presented in Table 3.12.

Table 3.12 Requirements for Producing Broilers and Eggs

Class of Chicken	Product	Product Weight (kg)	Feed (kg)		Water (L)
Broiler	Meat	1	Corn	1.37	9.69
			Soy	0.44	
			Bone Meal	0.12	
			Fat	0.042	
Layer	Eggs	1	Corn	1.37	9.65
			Soy	0.34	
			Bone Meal	0.10	
			Limestone	0.18	

Water. Water required for the production of broilers was consumed directly by the birds and indirectly used by the closed environmental production facility for evaporative cooling, facility sanitation, and fire protection (Bell and Weaver, 2002). The amount of water consumed depends on temperature and relative humidity, energy content of the feed consumed, age of birds, and type of watering system (Bell and Weaver, 2002; National Research Council, 1994). Water is essential and acts as a solvent and a lubricant, and allows efficient thermoregulation (Ensminger, Oldfield, and Heinemann, 1990). Water is provided *ad libitum* and as general rule chickens consume about two times as much water by weight as they do feed (Bell and Weaver, 2002; National Research Council, 1994; Ensminger, Oldfield, and Heinemann, 1990). For calculation purposes, an estimated 0.23 kg (0.50 lb) of water was consumed per bird per day, which equaled an average direct consumptive use of 227.12 liters (60 gallons) of water per 1000 birds per day (Bell and Weaver, 2002; National Research Council, 1994; Ensminger, Oldfield, and Heinemann, 1990). An average estimated indirect consumptive use of 227.12 liters (60 gallons) of water per 1000 birds per day (Bell and Weaver, 2002) for evaporative cooling and facility sanitation was assumed. A total consumptive water use

value of 454.24 liters (120 gallons) of water per 1000 birds per day or 0.45 liters (0.12 gallons) of water per bird per day was used for calculations in this research. The production of a 2.27 kg (5 pounds) broiler in 49 days (7 weeks) would require approximately 22.0 liters (5.81 gallons) of water and equal a net water usage of approximately 9.69 liters (2.56 gallons) of water per kilogram (2.2 pounds) of live weight chicken produced. Values used for broiler production are presented in Table 3.12.

Chicken egg production

In 1998 the California Poultry Workgroup (Bell, et al., 1998) reported that there were 200 commercial egg production facilities in the state maintaining approximately 25 million layers. In 1998 6.6 billion eggs were produced (California Statistical Abstract, 2000). For the calculations used in this research, an average white-shell egg laying chicken was assumed to be productive for a total of 59 weeks, from 19 to 78 weeks of age, produced an average of 333 eggs and consumed an average of 1.46 kg (3.21 pounds) of feed per dozen eggs produced (Bell and Weaver, 2002).

Feed. Layers have nutrition requirements distinct from meat producing chickens and are a smaller bird designed for efficient and economical egg production. Rations must meet the minimum requirements for body growth and maintenance and provide nutrients for egg production. Corn provides the primary source of energy for most layer rations and usually amounts to 65-75% of the ration (Bell and Weaver, 2002; National Research Council, 1994; Ensminger, Oldfield, and Heinemann, 1990). Layers have no minimum requirement for crude protein and as such the established minimums, approximately 15-25%, fulfill the need for amino acids in the diet (National Research Council, 1994). The bulk of the layer ration consists of limestone (5-15%), fats,

vitamins, and minerals. (Bell and Weaver, 2002; National Research Council, 1994; Ensminger, Oldfield, and Heinemann, 1990). For the purpose of this research, an average broiler ration that consisted of 68.4% corn, 16.8% soybean meal, 9.00% limestone, and 5.00% meat and bone meal was calculated from data provided by Bell and Weaver (2002). Typical feed conversion efficiencies rang from 1.9-2.5 kilograms of feed per kilogram of egg produced (Bell and Weaver, 2002; National Research Council, 1994; Ensminger, Oldfield, and Heinemann, 1990). For the purpose of calculations performed for this research, a feed conversion efficiency of 2.0 was used (Bell and Weaver, 2002). Therefore, the production of 1.00 kg (2.2 pounds) of egg would require approximately 1.37 kg (3.01 lb) of corn, 0.34 kg (0.74 lb) soybean meal, 0.18 kg (0.40lb) limestone, and 0.10 kg (0.22 lb) meat and bone meal. This equals a net feed usage of approximately 1.37 kg (3.01 lb) of corn, 0.34 kg (0.74 lb) soybean meal, 0.18 kg (0.40lb) limestone, and 0.10 kg (0.22 lb) meat and bone meal per kilogram (2.2 pounds) of egg produced. Water, pesticide, fertilizer, and energy input to feedstuffs for broiler production will be discussed below. Values used for egg production are presented in Table 3.12.

Water. For calculation purposes, an estimated 0.23 kg (0.50 lb) of water was consumed per bird per day, which equaled an average direct consumptive use of 227.12 liters (60 gallons) of water per 1000 birds per day (Bell and Weaver, 2002; National Research Council, 1994; Ensminger, Oldfield, and Heinemann, 1990). In addition, an estimated average indirect consumptive use was 238.48 liters (63 gallons) of water per 1000 birds per day (Bell and Weaver, 2002) for evaporative cooling, egg washing, and facility sanitation. The total consumptive water volume calculation used for this research was 465.60 liters (123 gallons) of water per 1000 birds per day or 0.47 liters (0.12

gallons) of water per bird per day. Assuming an average 80.6% hen-day egg production rate and 60.4 grams average individual egg weight, the average hen produces 48.7 grams of egg per day (Bell and Weaver, 2002). The production of 1.00 kg (2.2 pounds) eggs required approximately 9.65 liters (2.55 gallons) of water for a net water usage of approximately 9.65 liters (2.55 gallons) of water per kilogram (2.2 pounds) of egg produced. Values used for egg production are presented in Table 3.12.

Production Statistics

The 1997 Census of Agriculture was published by the U.S. Department of Agriculture, National Agricultural Statistics Service and is the primary source of agricultural production statistics and considered the only source of consistent, comparable data in the country (USDA, 1999a). Census data are used to develop, fund, and administer a variety of State and Federal farm programs and conduct public and private agricultural research and were used to identify production statistics for the specific foods identified above. All production values were converted to metric units. In addition, data from the 1997 Agricultural Commissioners' Data published by the California Department of Food and Agriculture, California Agricultural Statistics Service (California, 1998) was used for production statistics for eggs.

Plant Products

Production statistics for almonds, apples, dried beans, grapes, oranges, peaches, and watermelon were compiled from the 1997 Census of Agriculture (USDA, 1999a). Table 3.13 shows the quantity of each commodity produced in 1997 by county. Orange production data for San Joaquin County were withheld to avoid disclosing data for individual farms.

Table 3.13: Plant Products Commodity Statistics by County

Commodity	County		
	San Joaquin kg	Fresno	Kern
Almonds	27,636,120	44,436,081	55,875,735
Apples	44,774,750	33,829,350	91,606,272
Dried Beans	19,557,455	15,539,364	3,162,364
Grapes	464,949,233	2,123,418,929	692,493,229
Oranges	1555	302,215,280	42,391,972
Peaches	34,216,580	108,382,205	13,150,737
Watermelons	35,454,546	41,818,182	86,818,182

Animal Products

Production statistics for alfalfa and corn used for animal feed were obtained from the 1997 Census of Agriculture (USDA, 1999a). Production figures for corn were reported as bushels per acre. A value of 25.45 kilograms (56 pounds) per bushel (USDA, 1999a) was used in converting production figures from bushels per acre to kilograms per hectare. Production statistics for chicken and beef were compiled from the 1997 Census of Agriculture (USDA, 1999a). Production statistics for eggs were compiled from the 1997 Agricultural Commissioners' Data (California, 1998). Data for Kern County were withheld to avoid disclosing data for individual farms.

Table 3.14 shows the quantity of each commodity produced in 1997 by county.

Table 3.14 Production Statistics for Animal Products Including Fodder

Commodity	County		
	San Joaquin	Fresno	Kern
Alfalfa and Hay (kg)	396,279,091	468,932,727	718,992,727
Corn (kg)	239,973,134	24,947,822	12,261,276
Eggs (dozen)	35,787,000	978,000	(a)
Broiler (head)	1,150,000	9,818,303	564,000
Beef Cattle (Head)	87,197	455,291	141,347

(a) Data not disclosed due to limited number of producers.

Water Use Statistics

Plant Products

Water use data for the production of almonds (Klonsky et al., 1997; Hendricks 1998a; Hendricks, 1998b), apples (Caprile, et al., 2001), dried beans (Long, et al., 1999; Frate, Klonsky, and DeMoura, 2001a, Frate, Klonsky, and DeMoura, 2001b), grapes (Klonsky, et al., 1997; Vasquez, et al., 2003), oranges (O'Connell, et al., 1999; Fake, Klonsky, and DeMoura, 2002), peaches (Day, et al., 2000; Frost, Klonsky, and DeMoura, 2000; Hasey, et al., 1998), and watermelon (Mayberry, 2000) were obtained from Cost and Return Studies (CRS) published by the University of California Cooperative Extension Service and the University of California Davis Department of Agriculture and Resource Economics. Table 3.15 shows water use data for each commodity included in the research.

Table 3.15 Water Used for Plant Products

Commodity	Irrigation Rate		Yield (kg/hectare)
	(acft/yr)	(1/yr)	
Almonds	3.6	593,613	2,242
Apples	3.0	494,677	6,7251
Dried Beans	2.2	362,763	2,653
Grapes	3.5	577,124	4,483
Oranges	2.7	445,210	22,991
Peaches	3.6	593,613	33,999
Watermelons	3.0	494,677	56,042

Animal Products

Water use data for the production of alfalfa (Mathews, et al., 1998; Vargas, et al., 1998) and corn (Vargas, et al., 1999; Brittan, et al., 2004) used for animal feed were obtained from CRS. Table 3.16 shows water use data for the production of alfalfa and corn used for animal feed.

Table 3.16 Water Used for Animal Fodder

Commodity	Irrigation Rate		Yield (kg/hector)
	(acft/yr)	(1/yr)	
Alfalfa and Hay	5.0	824,462	15,692
Corn	3.7	610,102	11,208

Primary Energy Use Statistics

Plant Products

Primary energy use data for the production of almonds, apples, dried beans, grapes, oranges, peaches, and watermelon were obtained from CRS (cited above). Original data for primary energy usage were reported for usage of gasoline and diesel fuel in units of gallons per acre and were converted to units of joules of energy used per kilogram of commodity produced. An energy value of 34,839,537 joules per liter was used for gasoline and 38,6000,000 joules per liter was used for diesel fuel (USDOT, 2006).

Table 3.17 shows primary energy use data calculated for each commodity included in the research.

Animal Products

Primary energy use data for the production of alfalfa and corn used for animal feed were obtained from CRS (cited above). Table 3.18 shows energy use data for the production of animal feed.

Table 3.17 Primary Energy Used For Plant Products

Commodity	Fuel Requirement (L/hectare)	Energy Supplied (a) (J/hectare)	Yield (kg/hectare)
Almonds	Gasoline	79.16	2,242
	Diesel	198.13	
Apples	Gasoline	219.26	67,251
	Diesel	346.40	
Dried Beans	Gasoline	41.32	2,653
	Diesel	159.16	
Grapes	Gasoline	68.55	4,483
	Diesel	169.68	
Oranges	Gasoline	189.11	22,991
	Diesel	124.70	
Peaches	Gasoline	53.52	33,999
	Diesel	254.47	
Watermelons	Gasoline	155.31	56,042
	Diesel	889.70	

(a) Energy supplied in joules per liter of gasoline 34,828,427 and per liter of diesel 38,657,950 (US Bureau of Transportation website)

Table 3.18 Primary Energy Used For Animal Fodder

Commodity	Fuel Requirement (L/hectare)	Energy Supplied (a) (J/hectare)	Yield (kg/hectare)
Alfalfa and Hay	Gasoline	0.95	15692
	Diesel	26.12	
	TOTAL	9,792,287,352	
Corn	Gasoline	0.83	11208
	Diesel	26.29	
	TOTAL	9,814,739,824	

Fertilizer Use Statistics

Plant Products

Fertilizer use data for the production of almonds, apples, grapes, oranges, peaches, were obtained from the USDA Agricultural Chemical Usage 1999 Fruit and Nut Summary (USDA, 2000a). Fertilizer use data for the production of dried beans and

watermelon were obtained from the USDA Agricultural Chemical Usage 1998 Vegetable Summary (USDA, 1999b). The USDA Summaries listed average fertilizer application rates for each crop produced in California.

Table 3.19 shows fertilizer use data for each commodity included in the research.

Table 3.19 Fertilizer Used For Plant Products

Commodity	Fertilizer Rate (a)		Yield
	(kg/hectare)		(kg/hectare)
Almonds	Nitrogen	138	2,242
	Phosphorous	22	
	Potassium	40	
Apples	Nitrogen	30	67,251
	Phosphorous	12	
	Potassium	18	
Dried Beans	Nitrogen	76	2,653
	Phosphorous	18	
	Potassium	9	
Grapes	Nitrogen	62	4,483
	Phosphorous	13	
	Potassium	18	
Oranges	Nitrogen	82	22,991
	Phosphorous	19	
	Potassium	20	
Peaches	Nitrogen	85	33,999
	Phosphorous	8	
	Potassium	26	
Watermelons	Nitrogen	119	56,042
	Phosphorous	52	
	Potassium	36	

(a) Fertilizer rate standardized by the percent acreage applied because not all acres received fertilizer.

Animal Products

Fertilizer use data for the production of alfalfa and corn used for animal feed were obtained from CRS (cited above). Table 3.20 shows fertilizer use data for the production of animal feed.

Table 3.20 Fertilizer Used For Animal Fodder

Commodity	Fertilizer Rate (a)		Yield
	(kg/hectare)		(kg/hectare)
Alfalfa and	Nitrogen	0	15692
Hay	Phosphorous	0	
	Potassium	75	
Corn	Nitrogen	270	11208
	Phosphorous	0	
	Potassium	0	

(a) Fertilizer rate standardized by the percent acreage applied because not all acres received fertilizer.

Pesticide Use Statistics

Plant Products

Pesticide use data for the production of almonds, apples, dried beans, grapes, oranges, peaches, and watermelon were obtained from the Summary of Pesticide Use Report Data 1997 published by the State of California Environmental Protection Agency, Department of Pesticide Regulation (California, 1999b). California specifically tracks use trends of pesticides in five different categories (California, 1999b). The pesticides listed in these categories are referred to as listed pesticides for the purposes of this research and represent the focus of this research activity. The quantities of listed pesticides rather than total pesticides were used for calculations because the listed pesticides are of special concern due to threat from environmental contamination and human health risk. In other words these are the pesticides that pose the greatest risk. From California (1999b) the categories are:

1. currently registered active ingredients listed on the State's Proposition 65 list of chemicals "known to cause reproductive toxicity";
2. currently registered active ingredients listed by U.S. EPA as B2 carcinogens or on the State's Proposition 65 list of chemicals "known to cause cancers";

3. pesticides that are cholinesterase inhibitors, that is, organophosphate and carbamate chemicals;
4. pesticides on the groundwater protection list [California Code of Regulations, Title 3, Division 6, Chapter 4, Subchapter 1, Article 1, Section 6800(a)] and norflurazon, which DPR is recommending be listed as a restricted material;
5. pesticides from the toxic air contaminants list (California Code of Regulations, Title 3, Division 6, Chapter 4, Subchapter 1, Article 1, Section 6860).

All pesticide use data were converted to metric units. The reported number of pounds applied represents the number of pounds of an active ingredient applied. Table 3.21 shows the total quantity of pesticides used and quantity of listed pesticides of applied for each commodity included in the research.

The environmental impact of pesticides was estimated for their effect on farm workers, consumers, and the environment. These estimates were combined in a single ordinal value, the environmental impact quotient of pesticides (EIQ, Kovach et al., 1992). Kovach et al. (1992) published a list of EIQ for various pesticides used in agriculture. EIQ were available for all listed pesticides except calcium hydroxide, metam-sodium, methyl bromide, and sodium chlorate. The average EIQ value, 29.6, was used for these missing values (Joe Kovach personal communication).

Animal Products

Pesticide use data for the production of alfalfa and corn used for animal feed were obtained from the Summary of Pesticide Use Report Data 1997 (California, 1999b). As described above, the listed pesticides represent the focus of this research activity. All pesticide use data were converted to metric units. The reported number of pounds applied represents the number of pounds of an active ingredient applied

Table 3.21 Pesticides Used For Plant Products

Commodity	County	Total Pesticides Applied (kg)	Listed Pesticides Applied (a) (kg)
Almonds	Fresno	796,630	761,176
	Kern	1,858,700	1,759,255
	San Joaquin	493,185	465,085
Apples	Fresno	89,331	83,615
	Kern	111,902	103,681
	San Joaquin	76,228	70,590
Dried Beans	Fresno	19,260	18,530
	Kern	14,242	13,404
	San Joaquin	22,091	20,914
Grapes	Fresno	4,327,167	4,205,553
	Kern	1,967,135	1,780,224
	San Joaquin	2,725,716	2,620,110
Oranges	Fresno	643,377	618,868
	Kern	1,183,377	1,126,786
	San Joaquin	(b)	(b)
Peaches	Fresno	351,019	340,387
	Kern	41,969	38,928
	San Joaquin	52,013	49,972
Watermelons	Fresno	15,976	15,815
	Kern	32,752	32,369
	San Joaquin	5353	4971

(a) Pesticides listed by the State of California Environmental Protection Agency, Department of Pesticide Regulation as of special concern.

(b) Data not reported to preserve anonymity of individual producers

Pesticides applied to chickens for egg and meat production (Don Bell personal communication) and beef (USDA, 2000b) were considered inconsequential due to the limited quantities of listed pesticides applied per unit produced. Table 3.22 shows the total quantity of pesticides used and quantity of pesticides of interest used for the production of animal feed.

Table 3.22 Pesticides Used For Animal Fodder

Commodity	County	Total Pesticides Applied (kg)	Listed Pesticides Applied (a) (kg)
Alfalfa and Hay	Fresno	195,068	174,126
	Kern	47,864	43,785
	San Joaquin	76,204	69,500
Corn	Fresno	46,843	44,156
	Kern	18,938	17,373
	San Joaquin	77,505	71,564

(a) Pesticides listed by the State of California Environmental Protection Agency, Department of Pesticide Regulation as of special concern.

Data Analysis

Data analysis was performed to allow a direct comparison for inputs of water, energy, fertilizer, and pesticides required to produce commodities for vegetarian and nonvegetarian diets in California.

Water Use Data

Plant Products

Water use efficiency (WUE), simply defined as crop yield per unit of water used (Howell 2001), was calculated for each commodity by dividing the amount of water applied (l/hectare) by the commodity yield (kg/hectare). For example, using values found in Table 3.15 the WUE for almonds was calculated:

$$WUE_{\text{almond}} = \text{water applied}_{\text{almond}} / \text{yield}_{\text{almond}}$$

Calculated WUE values for almonds, apples, dried beans, grapes, oranges, peaches, and watermelon are found in Table 3.23.

Table 3.23 Water Use Efficiency for Plant Products

Commodity	Irrigation Rate(a)		Yield	Water Use Efficiency
	(acft/yr)	(L/yr)	(kg/hectare)	(L/kg)
Almonds	3.6	593,613	2,242	264.81
Apples	3.0	494,677	6,7251	7.36
Dried Beans	2.2	362,763	2,653	136.75
Grapes	3.5	577,124	4,483	128.72
Oranges	2.7	445,210	22,991	19.36
Peaches	3.6	593,613	33,999	17.46
Watermelons	3.0	494,677	56,042	8.83

(a) acft stands for acre-foot, the amount of water required to cover 1 acre 1 foot deep.

Animal Products

WUE for data for production of alfalfa and corn used for animal feed was calculated from data in Table 3.16 in the same manner as above.

Beef

Water use data for the production of beef are reported above in Table 3.11 and described in the section on Beef Production above. Total direct water consumption for beef production equals the sum of consumed water required for milk production and calf, stocker, and feeder production (53.36 l/kg beef). Total indirect consumption for beef production equals the water required to produce feedstuffs. Total net feed consumption for beef production (5.62 kg corn / kg beef and 2.66 kg alfalfa/ kg beef) equals the sum of feed required cow-calf production (0.83 kg alfalfa/lb weight gain), stocker production (0.43 kg alfalfa/kg weight gain), and feeder production (5.62 kg corn and 1.40 kg alfalfa / kg gain). As reported above, a feed conversion efficiency of 7.0 was used for beef production. WUE for beef production was calculated by multiplying the WUE for corn and alfalfa by the net feed consumption for beef production (5.62 kg corn / kg beef and 2.66 kg alfalfa/ kg beef) and adding the WUE for direct water consumption (53.36 l/kg beef).

Broilers and Eggs

Water use data for the production of eggs and chickens are reported above in Table 3.12 and described in the section on chicken and egg production above. For the purpose of this research all water associated with the facility producing eggs or broilers (consumptive and non-consumptive) was considered direct consumption for broiler and egg production (9.65 and 9.69 l/kg respectively). Total indirect consumption for broiler and egg production equals the water required to produce feedstuffs. Of the estimated diet only the production of corn was considered. Feeding corn resulted in a net feed usage of approximately 1.37 kg (3.01 lb) of corn per kilogram (2.2 pounds) of broiler or egg produced. As reported above, a feed conversion efficiency of 2.0 kg/kg was used for broiler and egg production. WUE for broiler and egg production was calculated by multiplying the WUE for corn by the net feed consumption for broiler and egg production (1.37 kg corn / kg broiler or eggs) and adding the WUE for direct water consumption (9.65 and 9.69 l/kg respectively).

WUE values for corn, alfalfa, eggs, broilers and beef are reported in Table 3.24.

Table 3.24 Water Use Efficiency for Animal Products and Fodder

Commodity	Irrigation Rate (a) (acft/yr)	(L/yr)	Yield (kg/hectare)	Water Use Efficiency (L/kg)
Alfalfa and Hay	5.0	824,462	15,692	131.35
Corn	3.7	610,102	11,208	136.08
Eggs	na	na	na	196.08 (b)
Broiler	na	na	na	196.12 (b)
Beef Cattle	na	na	na	1167.52 (c)

(a) acft stands for acre-foot, the amount of water required to cover 1 acre 1 foot deep

(b) Water use calculated by adding the product of corn water use (136.08 l/kg) times net feed ratio of 1.37 kg/kg of broiler or egg produced and direct consumption for broiler and egg production (9.69 and 9.65 l/kg respectively).

(c) Water use calculated by adding the product of corn water use (136.08 l/kg) times net feed ratio of 5.62 kg corn/kg of beef produced and the product of alfalfa water use (131.35 l/kg) times net feed ratio of 2.66 kg alfalfa/kg of beef produced and direct consumption for beef (53.36l/kg).

The resulting WUE values from Table 3.24 were multiplied by the diet-specific weekly consumption of each commodity found in Table 3.9 to calculate a commodity diet specific water usage for vegetarian or nonvegetarian consumption (vwu or nvwu respectively). These diet specific water usage figures were added to produce a cumulative water requirement (CWR) for each diet. The CWR for the vegetarian diet was calculated:

$$CWR_{\text{vegetarian}} = \sum vwu_i$$

Where $i = i\text{-th}$ commodity, e.g., almonds, apples, etc.

The CWR for the nonvegetarian diet was calculated in a similar manner.

Primary Energy Use Data

Plant Products

Using the established convention established above for WUE, primary energy use efficiency (EUE) was defined as crop yield per unit of primary energy used and was calculated for each commodity by dividing the amount of energy applied (J/hectare) by the commodity yield (kg/ hectare). Primary energy was defined as the energy directly applied to commodity production (e.g.: diesel fuel to power a tractor). Using values found in Table 3.17 the EUE for almonds was calculated:

$$EUE_{\text{almond}} = \text{primary energy applied}_{\text{almond}} / \text{yield}_{\text{almond}}$$

Calculated EUE values for almonds, apples, dried beans, grapes, oranges, peaches, and watermelon are found in Table 3.25.

Table 3.25 Primary Energy Use Efficiency for Plant Products

	Fuel Requirement		Energy Supplied (a)	Yield	Energy Use Efficiency
Commodity	(L/hectare)		(J/hectare)	(kg/hectare)	(J/kg)
Almonds	Gasoline	79.16	2,757,814,681	2,242	4,646,328.06
	Diesel	198.13	7,659,252,819		
	TOTAL		10,417,067,500		
Apples	Gasoline	219.26	7,638,786,809	67,251	312,705.75
	Diesel	346.40	13,390,987,511		
	TOTAL		21029774320		
Dried Beans	Gasoline	41.32	1,439,428,778	2,653	2,861,756.83
	Diesel	159.16	6,152,812,098		
	TOTAL		7592240876		
Grapes	Gasoline	68.55	2,388,143,199	4,483	1,995,876.15
	Diesel	169.68	6,559,369,594		
	TOTAL		8947512793		
Oranges	Gasoline	189.11	6,588,658,087	22,991	496,249.33
	Diesel	124.70	4,820,610,305		
	TOTAL		11409268392		
Peaches	Gasoline	53.52	1,864,714,553	33,999	344,185.24
	Diesel	254.47	9,837,239,402		
	TOTAL		11701953955		
Watermelons	Gasoline	155.31	5,410,943,633	56,042	710,270.54
	Diesel	889.70	34,394,038,131		
	TOTAL		39804981764		

a) Energy supplied in joules per liter of gasoline 34,828,427 and per liter of diesel 38,657,950 (literature site)

Animal Products

EUE for data for production of alfalfa and corn used for animal feed was calculated from data in Table 3.18 in the same manner as above.

Beef

Primary energy use data for the production are divided into direct and indirect inputs. Direct inputs include fuel used in the operation of the cattle enterprise. These include fuel for vehicles used to transport animals and personnel. Primary energy use data for cow-calf (Foreno, et al., 2004) and stocker (Nader, et al., 2005) operations were

obtained from CRS. The assumptions of Forerno et al. (2004) for a 300-head cow-calf operation indicate annual pickup mileage of 15,000 miles (24,140 km) and All Terrain Vehicle (ATV) mileage of 3450 miles (5552 km). Assuming mileage of 15 miles per gallon of gasoline for each vehicle, 18,450 miles would require approximately 1230 gallons (4662 l) of gasoline or 4.1 gallons per head. Nader et al. (2005) estimate for a 300-head stocker operation 3000 annual pickup miles and 1530 annual ATV miles. Using the above assumptions 4530 miles would require approximately 302 gallons of gas or 1 gallon per head. In addition Nader et al (2005) assume that stockers would be trucked 130 miles (209 km) one-way from the cow-calf facility to the stocking grounds. Assuming truck mileage of 10 miles per gallon and 90 cattle per load each head of stock would require 0.28 gallons of fuel for round-trip transportation. Primary energy use data for feeder operations were assumed to be the same as those for stocker operations and result from moving the cattle from the stocking range to the feedlot. Based on these calculations and estimates the production of 1 head of beef, 477 kg (1050 lbs), would require a total of 6.1 gallons (23.1 l) of gasoline (1,202,383 joules/kg beef) and 0.56 gallons (1.2 l) of diesel (97253 joules/kg beef) for a total direct energy of 1,299,636 joules/kg beef. Total indirect primary energy consumption for beef production equals the primary energy required to produce feedstuffs. Total net feed consumption for beef production (5.62 kg corn/kg beef and 2.66 kg alfalfa/kg beef) equals the sum of feed required cow-calf production (0.83 kg alfalfa/lb weight gain), stocker production (0.43 kg alfalfa/kg weight gain), and feeder production (5.62 kg corn and 1.40 kg alfalfa/kg gain). As stated above, a feed conversion efficiency of 7.0 was used for beef production. EUE for beef production was calculated by multiplying the EUE for corn and alfalfa by the net

feed consumption for beef production (5.62 kg corn/kg beef and 2.66 kg alfalfa/kg beef) and adding the EUE for direct primary energy consumption (1,299,636 joules/kg beef).

Broilers and Eggs

Direct primary energy use data for the production of eggs and chickens were obtained from Ernst (1995). Adding direct energy costs for electricity of 195,334 joules/kg eggs or broiler produced and costs for natural gas of 1,407,912 joules/kg eggs or broiler produced gives a total direct energy cost of 1,603,246 joules/kg eggs or broiler produced. Total indirect energy consumption for broiler and egg production equals the primary energy required to produce feedstuffs. Of the estimated diet only the production of corn was considered. Feeding corn resulted in a net feed usage of approximately 1.37 kg (3.01 lb) of corn per kilogram (2.2 pounds) of broiler or egg produced. As stated above, a feed conversion efficiency of 2.0 kg/kg was used for broiler and egg production. EUE for broiler and egg production was calculated by multiplying the WUE for corn by the net feed consumption for broiler and egg production (1.37 kg corn/kg broiler or eggs) and adding the EUE for direct energy consumption (1,603,246 joules/kg eggs or broiler).

EUE values for corn, alfalfa, eggs, broilers and beef are reported in Table 3.26.

Table 3.26 Primary Energy Use Efficiency for Animal Products and Fodder

Commodity	Fuel Requirement (L/hectare)		Energy Supplied (a) (J/hectare)	Yield (kg/hectare)	Energy Use Efficiency (J/kg)
Alfalfa and Hay	Gasoline	0.95	310,785,759	15692	
	Diesel	26.12	9,481,501,594		
	TOTAL		9,792,287,352		624,031
Corn	Gasoline	0.83	271,528,610	11208	
	Diesel	26.29	9,543,211,213		
	TOTAL		9,814,739,824		875,691
Eggs	TOTAL	na	na	na	2,802,943 (b)
Broilers	TOTAL	na	na	na	2,802,943 (b)
Beef Cattle	TOTAL	na	na	na	7,880,941 (c)

a) Energy supplied in joules per liter of gasoline 34,828,427 and per liter of diesel 38,657,950 (US Bureau of Transportation website)

b) Energy use calculated by adding the product of corn energy use (875,691 J/kg) times net feed ratio of 1.37 kg/kg of broiler or egg produced and direct consumption for broiler and egg production (1,603,246 joules/kg).

c) Energy use calculated by adding the product of corn energy use (875,691 J/kg) times net feed ratio of 5.62 kg corn/kg of beef produced and the product of alfalfa water use (624,031 J/kg) times net feed ratio of 2.66 kg alfalfa/kg of beef produced and direct expenditure for beef (1,299,636 joules/kg beef).

The resulting EUE values from Table 3.26 were multiplied by the diet-specific weekly consumption of each commodity found in Table 3.9 to calculate a commodity diet specific primary energy usage for vegetarian or nonvegetarian consumption (veu or nveu respectively). These diet specific water usage figures were added to produce a cumulative primary energy requirement (CER) for each diet. The CER for the vegetarian diet was calculated:

$$CER_{\text{vegetarian}} = \sum veu_i$$

Where $i = i\text{-th}$ commodity, e.g., almonds, apples, etc.

The CER for the nonvegetarian diet was calculated in a similar manner.

Fertilizer Use Data

Plant Products

Using the convention established above, fertilizer use efficiency (FUE) was defined as crop yield per unit of fertilizer used. FUE was calculated for each commodity by dividing the amount of fertilizer applied (kg/hectare) by the commodity yield (kg/hectare). Using values found in Table 3.19 the FUE for almonds was calculated:

$$\text{FUE}_{\text{almond}} = \text{fertilizer applied}_{\text{almond}} / \text{yield}_{\text{almond}}$$

Calculated FUE values for almonds, apples, dried beans, grapes, oranges, peaches, and watermelon are found in Table 3.27.

Animal Products

FUE for data for the production of alfalfa and corn used for animal feed was calculated from values in Table 3.20 in the same manner as above.

Beef

Fertilizer used to produce the total net feed consumption for beef production (5.62 kg corn/kg beef and 2.66 kg alfalfa/kg beef) equals the sum of feed required cow-calf production (0.83 kg alfalfa/lb weight gain), stocker production (0.43 kg alfalfa/kg weight gain), and feeder production (5.62 kg corn and 1.40 kg alfalfa/kg gain). As stated above, a feed conversion efficiency of 7.0 was used for beef production. FUE for beef production was calculated by multiplying the FUE for corn and alfalfa by the net feed consumption for beef production (5.62 kg corn/kg beef and 2.66 kg alfalfa/ kg beef).

Broilers and eggs

Fertilizer to produce the corn for a net feed usage of approximately 1.37 kg (3.01 lb) of corn per kilogram (2.2 pounds) of broiler or egg produced is reported. As stated

above, a feed conversion efficiency of 2.0 kg/kg was used for broiler and egg production. FUE for beef production was calculated by multiplying the FUE for corn by the net feed consumption for broiler or egg production (1.37 kg corn/kg broiler or eggs).

Table 3.27 Fertilizer Use Efficiency for Plant Products Production

Commodity	Fertilizer Rate (a) (kg/hectare)		Yield (kg/hectare)	Fertilizer Use Efficiency (kg/kg)
Almonds	Nitrogen	138	2,242	0.0062
	Phosphorous	22		0.0010
	Potassium	40		0.0018
	TOTAL	180		0.0090
Apples	Nitrogen	30	67,251	0.000045
	Phosphorous	12		0.000018
	Potassium	18		0.000027
	TOTAL	60		0.000090
Dried Beans	Nitrogen	76	2,653	0.0029
	Phosphorous	18		0.00068
	Potassium	9		0.00034
	TOTAL	93		0.0039
Grapes	Nitrogen	62	4,483	0.0014
	Phosphorous	13		0.00030
	Potassium	18		0.00040
	TOTAL	93		0.0021
Oranges	Nitrogen	82	22,991	0.00036
	Phosphorous	19		0.000083
	Potassium	20		0.000088
	TOTAL	121		0.00053
Peaches	Nitrogen	85	33,999	0.00025
	Phosphorous	8		0.000023
	Potassium	26		0.000076
	TOTAL	119		0.00035
Watermelons	Nitrogen	119	56,042	0.00021
	Phosphorous	52		0.000092
	Potassium	36		0.000064
	TOTAL	197		0.00037

a) Fertilizer rate standardized by the percent acreage applied because not all acres received fertilizer.

FUE values for corn, alfalfa, eggs, broilers and beef are reported in Table 3.28.

The resulting FUE values from Table 3.27 were multiplied by the diet-specific weekly consumption of each commodity found in Table 3.9 to calculate a commodity diet specific fertilizer usage for vegetarian or nonvegetarian consumption (vfu or nvfu respectively). These diet specific fertilizer usage figures were added to produce a cumulative fertilizer requirement (CFR) for each diet. The CFR for the vegetarian diet was calculated:

$$CFR_{\text{vegetarian}} = \sum vfu_i$$

Where $i = i\text{-th}$ commodity, e.g., almonds, apples, etc.

The CFR for the nonvegetarian diet was calculated in a similar manner.

Table 3.28 Fertilizer Used For Animal Products and Fodder

Commodity	Fertilizer Rate (a)		Yield	Fertilizer Use Efficiency
	(kg/hectare)		(kg/hectare)	(kg/kg)
Alfalfa and Hay	Nitrogen	0	15692	0
	Phosphorous	0		0
	Potassium	75		0.0048
	TOTAL	75		0.0048
Corn	Nitrogen	270	11208	0.024
	Phosphorous	0		0
	Potassium	0		0
	TOTAL	270		0.024
Eggs	Nitrogen	na	na	0.033
	Phosphorous	na	na	0
	Potassium	na	na	0
	TOTAL	na	na	0.033(b)
Broilers	Nitrogen	na	na	0.033
	Phosphorous	na	na	0
	Potassium	na	na	0
	TOTAL	na	na	0.033(b)
Beef Cattle	Nitrogen	na	na	0.13
	Phosphorous	na	na	0
	Potassium	na	na	0.013
	TOTAL	na	na	0.14(c)

a) Fertilizer rate standardized by the percent acreage applied because not all acres received fertilizer.

b) Fertilizer use calculated by adding the product of corn fertilizer use (N-0.024,P-0, K-0 kg/hectare) times net feed ratio of 1.37 kg/kg of broiler or egg produced.

c) Fertilizer use calculated by adding the product of corn fertilizer use (N-0.024,P-0, K-0 kg/hectare) times net feed ratio of 5.62 kg corn/kg of beef produced and the product of alfalfa fertilizer use (N-0,P-0,K-0.0048 kg/hectare) times net feed ratio of 2.66 kg alfalfa/kg of beef produced.

Pesticide Use Data

Plant Products

Using the convention established above, pesticide use efficiency (PUE) was defined as crop yield per unit of pesticide used. As described above the listed pesticides were used for calculations of PUE. PUE was calculated for each commodity by dividing the amount of pesticide applied (kg/hectare) by the commodity yield (kg/hectare). Using values found in Table 3.21 the PUE for almonds was calculated:

$$PUE_{\text{almond}} = \text{pesticides applied}_{\text{almond}} / \text{yield}_{\text{almond}}$$

Calculated PUE values for almonds, apples, dried beans, grapes, oranges, peaches, and watermelon are found in Table 3.29.

Animal Products

PUE for data for the production of alfalfa and corn used for animal feed was calculated from values in Table 3.22 in the same manner as above.

Beef

Pesticides applied to produce the total net feed consumption for beef production (5.62 kg corn/kg beef and 2.66 kg alfalfa/kg beef) equals the sum of feed required cow-calf production (0.83 kg alfalfa/kg weight gain), stocker production (0.43 kg alfalfa/kg weight gain), and feeder production (5.62 kg corn and 1.40 kg alfalfa/kg gain). As stated above, a feed conversion efficiency of 7.0 was used for beef production. PUE for beef production was calculated by multiplying the PUE for corn and alfalfa by the net feed consumption for beef production (5.62 kg corn/kg beef and 2.66 kg alfalfa/ kg beef).

Table 3.29 Pesticides Use Efficiency for Plant Products

Commodity	County	Total Pesticides Applied (kg)	Listed Pesticides Applied (a) (kg)	Pesticide Use Efficiency (kg/kg)
Almonds	Fresno	796,630	761,176	0.017
	Kern	1,858,700	1,759,255	0.031
	San Joaquin	493,185	465,085	0.017
				0.022 (c)
Apples	Fresno	89,331	83,615	0.0025
	Kern	111,902	103,681	0.0011
	San Joaquin	76,228	70,590	0.0016
				0.0017 (c)
Dried Beans	Fresno	19,260	18,530	0.0012
	Kern	14,242	13,404	0.0042
	San Joaquin	22,091	20,914	0.0011
				0.0022 (c)
Grapes	Fresno	4,327,167	4,205,553	0.0020
	Kern	1,967,135	1,780,224	0.0026
	San Joaquin	2,725,716	2,620,110	0.0056
				0.0034 (c)
Oranges	Fresno	643,377	618,868	0.0020
	Kern	1,183,377	1,126,786	0.0027
	San Joaquin	(b)	(b)	(b)
				0.0024 (c)
Peaches	Fresno	351,019	340,387	0.0031
	Kern	41,969	38,928	0.0030
	San Joaquin	52,013	49,972	0.0015
				0.0025 (c)
Watermelons	Fresno	15,976	15,815	0.00038
	Kern	32,752	32,369	0.00037
	San Joaquin	5353	4971	0.00051
				0.00042 (c)

(a) Pesticides listed by the State of California Environmental Protection Agency, Department of Pesticide Regulation as of special concern.

(b) Data not reported to preserve anonymity of individual producers

(c) Average of the data points.

Broilers and eggs

Pesticides applied to produce the corn for a net feed usage of approximately 1.37 kg (3.01 lb) of corn per kilogram (2.2 pounds) of broiler or egg produced is reported. As stated above, a feed conversion efficiency of 2.0 kg/kg was used for broiler and egg

production. PUE for beef production was calculated by multiplying the PUE for corn by the net feed consumption for broiler or egg production (1.37 kg corn/kg broiler or eggs). PUE values for corn, alfalfa, eggs, broilers and beef are reported in Table 3.28.

The resulting PUE values from Table 3.25 were multiplied by the diet-specific weekly consumption of each commodity found in Table 3.9 to calculate a commodity diet specific fertilizer usage for vegetarian or nonvegetarian consumption (VPU or NVPU respectively). These diet specific fertilizer usage figures were added to produce a cumulative pesticide requirement (CPR) for each diet. The CPR for the vegetarian diet was calculated:

$$CPR_{\text{vegetarian}} = \sum vfu_i$$

Where $i = i\text{-th}$ commodity, e.g., almonds, apples, etc.

The CPR for the nonvegetarian diet was calculated in a similar manner.

The diet-specific values for CWR, CER, CFR, and CPR values were statistically compared, using a procedure described below, to assess the difference in the inputs of water, primary energy, fertilizer, and pesticides for each diet.

Table 3.30 Pesticides Used For Animal Products and Fodder

Commodity	County	Total Pesticides Applied (kg)	Listed Pesticides Applied (a) (kg)	Pesticide Use Efficiency (kg/kg)
Alfalfa and Hay	Fresno	195,068	174126	0.00037
	Kern	47,864	43,785	0.000061
	San Joaquin	76,204	69,500	0.00018
				0.00020 (d)
Corn	Fresno	46,843	44,156	0.0018
	Kern	18,938	17,373	0.0014
	San Joaquin	77,505	71,564	0.00030
				0.0012 (d)
Eggs (b)	Fresno	na	na	0.0025
	Kern	na	na	0.0019
	San Joaquin	na	na	0.00041
				0.0016 (d)
Broilers (b)	Fresno	na	na	0.0025
	Kern	na	na	0.0019
	San Joaquin	na	na	0.00041
				0.0016 (d)
Beef (c)	Fresno	na	na	0.011
	Kern	na	na	0.0080
	San Joaquin	na	na	0.0022
				0.0071 (d)

a) Pesticides listed by the State of California Environmental Protection Agency, Department of Pesticide Regulation as of special concern.

b) Pesticide use calculated by adding the product of corn pesticide yield ratio (F-0.0018,K-0.0014,SJ-0.00030) times net feed ratio of 1.37 kg/kg of broiler or egg produced.

c) Pesticide use calculated by adding the product of corn pesticide yield ratio (F-0.0018,K-0.0014,SJ-0.00030) times net feed ratio of 5.62 kg corn/kg of beef produced and the product of alfalfa pesticide yield ratio (F-0.00037,K-0.000061,SJ-0.00018) times net feed ratio of 2.66 kg alfalfa/kg of beef produced.

d) Average of the data points.

Environmental impact calculations

Kovach et al (1992) estimated the environmental impact of pesticides by their effect on farm workers, consumers, and the environment. These estimates were combined in a single ordinal value, the environmental impact quotient of pesticides (EIQ, Kovach et al., 1992). The EIQ value was used to estimate the impact of pesticide

application in the Central Valley. The EIQ was multiplied by the amount of pesticide used to produce each commodity to calculate an environmental hazard quotient (EHQ) for each pesticide. The EHQ was calculated:

$$EHQ = \text{kg pesticide} \times \text{EIQ}$$

The summation of pesticide specific EHQs resulted in a commodity-specific commodity hazard index (CHI). The CHI for pesticides applied to a commodity was calculated:

$$CHI = \sum EQH_i$$

Where $i = i\text{-th}$ pesticide applied.

CHI values are listed on Table 3.31 and Table 3.32. The commodity specific CHI was multiplied by the vegetarian specific weekly consumption of each commodity found in Table 3.9 to calculate a commodity diet specific CHI for vegetarian consumption called the diet commodity hazard index (DCHI). A dietary hazard index (DHI) for each diet was calculated by summing the DCHI for each commodity. The DHI for the vegetarian diet was calculated by summing the DCHI for vegetarian consumption:

$$DHI_{\text{vegetarian}} = \sum DCHI_i$$

Where $i = i\text{-th}$ commodity, e.g., almonds, apples, etc.

The DHI for the nonvegetarian diet was calculated in a similar manner. The DHIs were used to evaluate the environmental impact of pesticides for each diet.

Table 3.31 Environmental Hazard Index for Plant Products

Commodity	County	Total Pesticides Applied (kg)	Listed Pesticides Applied (a) (kg)	Commodity Hazard Index (b)
Almonds	Fresno	796,630	761,176	0.58
	Kern	1,858,700	1,759,255	1.02
	San Joaquin	493,185	465,085	0.56
				0.72 (d)
Apples	Fresno	89,331	83,615	0.078
	Kern	111,902	103,681	0.036
	San Joaquin	76,228	70,590	0.049
				0.054 (d)
Dried Beans	Fresno	19,260	18,530	0.038
	Kern	14,242	13,404	0.15
	San Joaquin	22,091	20,914	0.034
				0.074 (d)
Grapes	Fresno	4,327,167	4,205,553	0.083
	Kern	1,967,135	1,780,224	0.11
	San Joaquin	2,725,716	2,620,110	0.25
				0.15 (d)
Oranges	Fresno	643,377	618,868	0.062
	Kern	1,183,377	1,126,786	0.08
	San Joaquin	(c)	(c)	(c)
				0.071 (d)
Peaches	Fresno	351,019	340,387	0.099
	Kern	41,969	38,928	0.091
	San Joaquin	52,013	49,972	0.058
				0.083 (d)
Watermelons	Fresno	15,976	15,815	0.014
	Kern	32,752	32,369	0.011
	San Joaquin	5353	4971	0.0052
				0.0102 (d)

(a) Pesticides listed by the State of California Environmental Protection Agency, Department of Pesticide Regulation as of special concern.

(b) Commodity-specific commodity hazard index, CHI

(c) Data not reported to preserve anonymity of individual producers

(d) Average of the data points.

Table 3.32 Environmental Hazard Index For Animal Products and Fodder

Commodity	County	Total Pesticides Applied (kg)	Listed Pesticides Applied (a) (kg)	CHI (b)
Alfalfa and Hay	Fresno	195,068	174,126	0.014
	Kern	47,864	43,785	0.0023
	San Joaquin	76,204	69,500	0.0059
				0.0074 (e)
Corn	Fresno	46,843	44,156	0.067
	Kern	18,938	17,373	0.044
	San Joaquin	77,505	71,564	0.010
				0.041 (e)
Eggs (c)	Fresno	na	na	0.092
	Kern	na	na	0.061
	San Joaquin	na	na	0.014
				0.056 (e)
Broilers (c)	Fresno	na	na	0.092
	Kern	na	na	0.061
	San Joaquin	na	na	0.014
				0.056 (e)
Beef (d)	Fresno	na	na	0.414
	Kern	na	na	0.26
	San Joaquin	na	na	0.072
				0.25 (e)

(a) Pesticides listed by the State of California Environmental Protection Agency, Department of Pesticide Regulation as of special concern.

(b) CHI the commodity-specific commodity hazard index

(c) Pesticide use calculated by adding the product of corn pesticide yield ratio (F-0.0018,K-0.0014,SJ-0.00030) times net feed ratio of 1.37 kg/kg of broiler or egg produced.

(d) Pesticide use calculated by adding the product of corn pesticide yield ratio (F-0.0018,K-0.0014,SJ-0.00030) times net feed ratio of 5.62 kg corn/kg of beef produced and the product of alfalfa pesticide yield ratio (F-0.00037,K-0.000061,SJ-0.00018) times net feed ratio of 2.66 kg alfalfa/kg of beef produced.

(e) Average of the data points.

Statistical Analysis

When carrying out mathematical functions, such as addition and multiplication, on the values used for the calculations above a method was needed to determine the statistical uncertainties in the results of the functions. Taylor (1997) suggests a method to calculate independent uncertainties in functions assuming the uncertainties are independent and random.

For uncertainty in sums and differences suppose that e , f , g , and h are measures with uncertainties de , df , dg , and dh and used to calculate:

$$z = e + f + g + h.$$

The uncertainty in z is expressed by the quadratic sum:

$$dz = [(de)^2 + (df)^2 + (dg)^2 + (dh)^2]^{1/2}$$

For uncertainty in products and quotients suppose that e , f , g , and h are measures with uncertainties de , df , dg , and dh and used to calculate:

$$z = e f g h.$$

The fractional uncertainty in z is expressed by the sum in quadrature of the original fractional uncertainties:

$$dz/z = [(de/e)^2 + (df/f)^2 + (dg/g)^2 + (dh/h)^2]^{1/2}$$

The fractional uncertainty is then multiplied by z to calculate the uncertainty.

To compare the mean values for an individual commodity consumed a statistic to compare the difference between means was used. The Satterwaite approximation was used instead of the t -test because the standard deviations of the two distributions, in most cases, were not similar violating one of the assumptions of the t -test (Armitage and Berry, 1994).

The test stastic used:

$$d = (xv-xnv)/SE(xv-xnv)$$

Where xv is the mean weekly consumption of a commodity by a vegetarian, xnv represents the mean weekly consumption of a commodity by a nonvegetarian and $SE(xv-xnv)$ is the standard error of the difference between two means. Instead of using a pooled estimate of the variance, the standard error of the difference was calculated:

$$SE(xv-xnv) = (s_v^2/n_v + s_{nv}^2/n_{nv})^{1/2}$$

Where s_v represents the standard deviation of the mean vegetarian consumption, s_{nv} the standard deviation of the mean nonvegetarian consumption, n_v the vegetarian sample size, and n_{nv} the nonvegetarian sample size. The degrees of freedom were calculated:

$$df = (s_v^2/n_v + s_{nv}^2/n_{nv})^2 / [(s_v^2/n_v)^2 / (n_v - 1)] + [(s_{nv}^2/n_{nv})^2 / (n_{nv} - 1)]$$

The test statistic d was tested using the t -distribution. Using a t -table the degrees of freedom were used to look up an a value corresponding to $P = 0.05$.

The results of the calculations and statistics will be presented and discussed in the following chapters.

CHAPTER FOUR

RESULTS

Many of the tables in the preceding chapter, Research Design and Methods present results of calculations that describe dietary patterns, commodity production, and statistical analysis. Most of those results are self-explanatory or were tabulated for operational ease. If the data were used in subsequent operations, they were presented in Chapter 3 and for the most part will remain embodied in that chapter. Results presented in this section appear because they need further explanation and comment or present the results of terminal calculations described above.

The first 4 sections of this chapter; Water Use, Primary Energy Use, Fertilizer Use, and Pesticide Use, will compare these inputs for the AHS vegetarian and nonvegetarian cohorts. The final section of the chapter will compare the inputs for the average Adventist nonvegetarian diet with the average American diet (Putnam and Allshouse, 1999).

Water Use

Water use efficiency (WUE) was described above as crop yield per unit of water used (Howell 2001). The WUE is a measure of the utility of water used for irrigation. With respect to water use, a higher WUE indicates a more efficient use of water resources or less water applied per unit weight of commodity produced.

The WUE presented in Table 4.1 are transferred from Tables 3.23 and 3.24 above. Results showed a range of WUE from 8.83 L/kg for watermelons to a high of 1168 L/kg for beef production. With the exception of almonds (265 L/kg) the production of plant products uniformly resulted in higher WUE than that for animal products. It is

interesting to note that the WUE for almonds was lower than either eggs or broilers (196.12 L/kg).

Table 4.1 Water Use Efficiencies for Commodities

Commodity	Irrigation Rate (a) (L/yr)	Yield (Kg/hectare)	Water Use Efficiency (L/kg)
Almonds	593,613	2,242	265
Apples	494,677	6,7251	7.36
Dried Beans	362,763	2,653	137
Grapes	577,124	4,483	129
Oranges	445,210	22,991	19.4
Peaches	593,613	33,999	17.5
Watermelons	494,677	56,042	8.83
Eggs	na	na	196 (b)
Broiler	na	na	196 (b)
Beef Cattle	na	na	1168 (c)

(a) acft stands for acre-foot, the amount of water required to cover 1 acre 1 foot deep.

(b) Water use calculated by adding the product of corn water use (136.08 l/kg) times net feed ratio of 1.37 kg/kg of broiler or egg produced and direct consumption for broiler and egg production (9.69 and 9.65 l/kg respectively).

(c) Water use calculated by adding the product of corn water use (136.08 l/kg) times net feed ratio of 5.62 kg corn/kg of beef produced and the product of alfalfa water use (131.35 l/kg) times net feed ratio of 2.66 kg alfalfa/kg of beef produced and direct consumption for beef (53.36l/kg).

The cumulative water requirement (CWR) for each diet represents the total amount of water used to produce the commodities consumed. Results indicate that the vegetarian diet required the application of approximately 5 ½ times (5.42) less water than did the nonvegetarian diet (Table 4.2). The greatest contribution to the difference came from the consumption of beef in the diet of the nonvegetarian.

Table 4.2 Comparison of Water Use Efficiencies between the Vegetarian and Nonvegetarian Diets ¹

Food Item	Diet	Weekly Consumption (g)	Water Use Efficiency (L/kg)	Water Used (L)
Almond	vegetarian	65.55	265	17.4
	nonvegetarian	27.76	265	7.35
Apples	vegetarian	658.95	7.36	4.85
	nonvegetarian	466.22	7.36	3.43
Beans	vegetarian	256.55	137	35.1
	nonvegetarian	169.48	137	23.2
Grapes	vegetarian	375.79	129	48.4
	nonvegetarian	385.88	129	49.7
Oranges	vegetarian	1813.91	19.4	35.1
	nonvegetarian	1704.82	19.4	33.0
Peaches	vegetarian	383.16	17.5	6.69
	nonvegetarian	213.97	17.5	3.74
Watermelon	vegetarian	468.08	8.83	4.13
	nonvegetarian	298.28	8.83	2.63
Eggs	vegetarian	66.79	196	13.1
	nonvegetarian	137.56	196	27.0
Chicken	vegetarian	5.59	196	1.10
	nonvegetarian	136.46	196	26.8
Beef	vegetarian	23.17	1168	27.0
	Nonvegetarian	743.32	1168	868
CWR (a)	vegetarian			193
	nonvegetarian			1237

(1) Vegetarian and Nonvegetarian values calculated from the Adventist Health Study.

(a) Differences were significant at $P < 0.05$.

Primary Energy Use

Energy use efficiency (EUE) was described above as crop yield per unit of primary energy used. Primary energy was defined as the energy directly applied to commodity production (e.g.: diesel fuel to power a tractor). The EUE is a measure of the utility of primary energy used for commodity production. With respect to primary energy use, a higher WUE indicates a more efficient use of primary energy resources or less primary energy applied per unit weight of commodity produced.

The EUE presented in Table 4.3 are transferred from Tables 3.25 and 3.26 above. Results showed a range of EUE from 313 kJ/kg for apples to a high of 7880 kJ/kg for beef production. With the exception of almonds (4646 kJ/kg) and dried beans (2862 kJ/kg) the production of plant products resulted in higher EUE than that for animal products. Both almonds and dried beans required the input of more primary energy than either eggs or broilers (2803 kJ/kg) to produce.

The cumulative energy requirement (CER) for each diet represents the total amount of energy used to produce the commodities consumed. Results indicate that the vegetarian diet required the application of approximately 2 ½ times (2.48) less energy than did the nonvegetarian diet (Table 4.4). The greatest contribution to the difference came from the consumption of beef in the diet of the nonvegetarian.

Table 4.3 Primary Energy Use Efficiency for Commodities

Commodity	Energy Supplied (a) (J/hectare)	Yield (kg/hectare)	Energy Use Efficiencies (kJ/kg)
Almonds	10,417,067,500	2,242	4646
Apples	21,029,774,320	67,251	313
Dried Beans	7,592,240,876	2,653	2862
Grapes	8,947,512,793	4,483	1996
Oranges	11,409,268,392	22,991	496
Peaches	11701953955	33,999	344
Watermelons	39,804,981,764	56,042	710
Eggs	na	na	2803 (b)
Broilers	na	na	2803 (b)
Beef Cattle	na	na	7881 (c)

(a)Energy supplied in joules per liter of gasoline 34,828,427 and per liter of diesel 38,657,950 (literature site)

(b) Energy use calculated by adding the product of corn energy use (875,691 J/kg) times net feed ratio of 1.37 kg/kg of broiler or egg produced and direct consumption for broiler and egg production (1,603,246 joules/kg).

(c)Energy use calculated by adding the product of corn energy use (875,691 J/kg) times net feed ratio of 5.62 kg corn/kg of beef produced and the product of alfalfa water use (624,031 J/kg) times net feed ratio of 2.66 kg alfalfa/kg of beef produced and direct expenditure for beef (1,299,636 joules/kg beef).

Table 4.4 Comparison of Primary Energy Use Efficiencies between the Vegetarian and Nonvegetarian Diets ¹

Food Item	Diet	Weekly Consumption (g)	Energy Use Efficiency (kJ/kg)	Energy Used (kJ)
Almond	vegetarian	65.55	4646	305
	nonvegetarian	27.76	4646	129
Apples	vegetarian	658.95	313	207
	nonvegetarian	466.22	313	146
Beans	vegetarian	256.55	2862	734
	nonvegetarian	169.50	2862	485
Grapes	vegetarian	375.79	1996	750
	nonvegetarian	385.88	1996	770
Oranges	vegetarian	1813.91	496	900
	nonvegetarian	1704.82	496	846
Peaches	vegetarian	383.16	344	132
	nonvegetarian	213.97	344	73.6
Watermelon	vegetarian	468.08	710	332
	nonvegetarian	298.28	710	212
Eggs	vegetarian	66.79	2803	187
	nonvegetarian	137.56	2803	386
Chicken	vegetarian	5.59	2803	15.7
	nonvegetarian	136.46	2803	382
Beef	vegetarian	23.17	7881	183
	nonvegetarian	743.32	7881	5858
CER (a)	vegetarian			3745
	nonvegetarian			9288

1) Vegetarian and Nonvegetarian values calculated from the Adventist Health Study.

(a) Differences were significant at $P < 0.05$.

Fertilizer Use

Fertilizer use efficiency (FUE) was described above as crop yield per unit of fertilizer used. Fertilizer inputs of nitrogen, phosphorous, and potassium were combined to give a value for total fertilizer input. The FUE is a measure of the utility of fertilizer applied for commodity production. With respect to fertilizer use, a higher FUE indicates a more efficient use of applied fertilizer or less total fertilizer applied per unit weight of commodity produced.

The FUE presented in Table 4.5 are transferred from Tables 3.27 and 3.28 above. Results showed a range of FUE from 0.090 g/kg for apples to a high of 140 g/kg for beef production. The production of plant products uniformly resulted in higher FUE than that for animal products.

The CFR for each diet represents the total amount of fertilizer applied to produce the commodities consumed. Results indicate that the vegetarian diet required the application of approximately 13 times (12.9) less fertilizer than did the nonvegetarian diet (Table 4.6). The greatest contribution to the difference came from the consumption of beef in the diet of the nonvegetarian.

Table 4.5 Fertilizer Use Efficiency for Commodities

Commodity	Fertilizer Rate (a) (kg/hectare)	Yield (kg/hectare)	Fertilizer Use Efficiencies (g/kg)
Almonds	180	2,242	9.0
Apples	60	67,251	0.090
Dried Beans	93	2,653	3.9
Grapes	93	4,483	2.1
Oranges	121	22,991	0.53
Peaches	119	33,999	0.35
Watermelons	197	56,042	0.37
Eggs	na	na	33 (b)
Broilers	na	na	33 (b)
Beef Cattle	na	na	140 (c)

(a)Fertilizer rate standardized by the percent acreage applied because not all acres received fertilizer.

(b)Fertilizer use calculated by adding the product of corn fertilizer use (N-0.024,P-0, K-0 kg/hectare) times net feed ratio of 1.37 kg/kg of broiler or egg produced.

(c)Fertilizer use calculated by adding the product of corn fertilizer use (N-0.024,P-0, K-0 kg/hectare) times net feed ratio of 5.62 kg corn/kg of beef produced and the product of alfalfa fertilizer use (N-0,P-0,K-0.0048 kg/hectare) times net feed ratio of 2.66 kg alfalfa/kg of beef produced.

Table 4.6 Comparison of Fertilizer Use Efficiencies between the Vegetarian and Nonvegetarian Diets¹

Food Item	Diet	Weekly Consumption (g)	Fertilizer Use Efficiency (kg/kg)	Fertilizer Used (g)
Almond	vegetarian	65.55	9.0	0.59
	nonvegetarian	27.76	9.0	0.25
Apples	vegetarian	658.95	0.09	0.060
	nonvegetarian	466.21	0.09	42
Beans	vegetarian	256.55	3.9	1.0
	nonvegetarian	169.50	3.9	0.66
Grapes	vegetarian	375.79	2.1	0.79
	nonvegetarian	385.88	2.1	0.81
Oranges	vegetarian	1813.91	0.53	0.96
	nonvegetarian	1704.82	0.53	0.90
Peaches	vegetarian	383.16	0.35	0.13
	nonvegetarian	213.97	0.35	0.075
Watermelon	vegetarian	468.08	0.37	0.17
	nonvegetarian	298.28	0.37	0.11
Eggs	vegetarian	66.79	33	2.2
	nonvegetarian	137.56	33	4.5
Chicken	vegetarian	5.59	33	0.18
	nonvegetarian	136.46	33	4.5
Beef	vegetarian	23.17	140	3.2
	nonvegetarian	743.32	140	100
CFR (a)	vegetarian			9.3
	nonvegetarian			120

1) Vegetarian and Nonvegetarian values calculated from the Adventist Health Study.

(a) Differences were significant at $P < 0.05$.

Pesticide Use

Pesticide use efficiency (PUE) was described above as crop yield per unit of pesticides used. All pesticide inputs were combined to give a value for total fertilizer input. The total value for each commodity produced in each county was added and an average value computed to use in the PUE calculations. The PUE is a measure of the utility of pesticides applied for commodity production. With respect to pesticide use, a

higher PUE indicates a more efficient use of applied pesticides or a lower quantity of pesticides applied per unit weight of commodity produced.

The PUE presented in Table 4.7 are transferred from Tables 3.29 and 3.30 above. Results showed a range of PUE from 0.42 g/kg for watermelons to a high of 22 g/kg for almond production. It is interesting to note that the PUE for either eggs or broilers (1.6 g/kg) was higher than all of the plant products except watermelons.

The CPR for each diet represents the total quantity of pesticide used to produce the commodities consumed. Results indicate that the vegetarian diet required the application of approximately 1 ½ times (1.4) less water than did the nonvegetarian diet (Table 4.8). The greatest contribution to the difference came from the consumption of beef in the diet of the nonvegetarian.

Table 4.7 Pesticides Use Efficiency for Commodities

Commodity	County	Total Pesticides Applied (kg)	Listed Pesticides Applied (a) (kg)	Pesticide Use Efficiency (g/kg)
Almonds	total	1,574,258	995,172	22 (b)
Apples	total	92,487	85,962	1.7 (b)
Dried Beans	total	18,531	17616	2.2 (b)
Grapes	total	3,006,667	2868629	3.4 (b)
Oranges	total	913,377	872,827	2.4 (b)
Peaches	total	148,334	143,096	2.5 (b)
Watermelons	total	18,027	17,718	0.42 (b)
Eggs (b)	total	na	na	1.6 (b,c)
Broilers (b)	total	na	na	1.6 (b,c)
Beef (c)	total	na	na	7.1 (b,d)

(a) Pesticides listed by the State of California Environmental Protection Agency, Department of Pesticide Regulation as of special concern.

(b) Average of the data points.

(c) Pesticide use calculated by adding the product of corn pesticide yield ratio (F-0.0018,K-0.0014,SJ-0.00030) times net feed ratio of 1.37 kg/kg of broiler or egg produced.

(d) Pesticide use calculated by adding the product of corn pesticide yield ratio (F-0.0018,K-0.0014,SJ-0.00030) times net feed ratio of 5.62 kg corn/kg of beef produced and the product of alfalfa pesticide yield ratio (F-0.00037,K-0.000061,SJ-0.00018) times net feed ratio of 2.66 kg alfalfa/kg of beef produced.

Table 4.8 Comparison of Pesticide Use Efficiencies between the Vegetarian and Nonvegetarian Diets ¹

Food Item	Diet	Weekly Consumption (g)	Pesticide Use Efficiency (g/kg)	Pesticide Used (g)
Almond	vegetarian	65.55	22	1.4
	nonvegetarian	27.76	22	0.61
Apples	vegetarian	658.95	1.7	1.1
	nonvegetarian	466.22	1.7	0.79
Beans	vegetarian	256.55	2.2	0.56
	nonvegetarian	169.50	2.2	0.37
Grapes	vegetarian	375.79	3.4	1.3
	nonvegetarian	385.88	3.4	1.3
Oranges	vegetarian	1813.91	2.4	4.4
	nonvegetarian	1704.82	2.4	4.1
Peaches	vegetarian	383.16	2.5	0.96
	nonvegetarian	213.97	2.5	0.53
Watermelon	vegetarian	468.08	0.42	0.20
	nonvegetarian	298.28	0.42	0.13
Eggs	vegetarian	66.79	1.6	0.11
	nonvegetarian	137.56	1.6	0.22
Chicken	vegetarian	5.59	1.6	0.0089
	nonvegetarian	136.46	1.6	0.22
Beef	vegetarian	23.17	7.1	0.16
	nonvegetarian	743.32	7.1	5.3
CPR(a)	nonvegetarian			10
	vegetarian			14

1) Vegetarian and Nonvegetarian values calculated from the Adventist Health Study.

(a) Differences were significant at $P < 0.05$.

Environmental impact calculations

The environmental impact quotient (EIQ) value (Kovach et al., 1992) was used to estimate the impact of pesticide application in the Central Valley. The EIQ and environmental hazard quotient (EHQ) were calculated for each pesticide and commodity. The resulting value, the commodity hazard index (CHI) for each commodity produced in each county was added and averaged to give the value used in DCHI and dietary hazard index (DHI) calculations. With respect to environmental toxicity, higher EIQ, EHQ, and

CHI values indicate a greater potential for observing toxic effects and environmental impact.

The results presented in Table 4.9 are transferred from Tables 3.31 and 3.32 above. Results showed a range of CHI from 0.0102 for watermelons to a high of 0.72 for the production of almonds (Table 4.9). With the exception of apples and watermelons, the production of plant products resulted in higher CHI than either eggs or broilers (0.056g)

The DHI for each diet represents the combined toxicity rating for pesticides used to produce the commodities consumed. Results indicate that the vegetarian resulted in approximately 1 ½ times (1.52) less environmental impact than did the nonvegetarian diet (Table 4.10). The greatest contribution to the difference came from the consumption of beef in the diet of the nonvegetarian.

Table 4.9 Environmental Hazard Index for Commodities

Commodity	County	Total Pesticides Applied (kg)	Listed Pesticides Applied (a) (kg)	Environmental Hazard Index
Almonds	total	1,574,258	995,172	0.72 (b)
Apples	total	92,487	85,962	0.054 (b)
Dried Beans	total	18,531	17616	0.074 (b)
Grapes	total	3,006,667	2868629	0.15 (b)
Oranges	total	913,377	872,827	0.071 (b)
Peaches	total	148,334	143,096	0.083 (b)
Watermelons	total	18,027	17,718	0.0102 (b)
Eggs (b)	total	na	na	0.056 (b,c)
Broilers (b)	total	na	na	0.056 (b,c)
Beef (c)	total	na	na	0.25 (b,d)

(a) Pesticides listed by the State of California Environmental Protection Agency, Department of Pesticide Regulation as of special concern.

(b) Average of the data points

(c) Pesticide use calculated by adding the product of corn pesticide yield ratio (F-0.0018,K-0.0014,SJ-0.00030) times net feed ratio of 1.37 kg/kg of broiler or egg produced.

(d) Pesticide use calculated by adding the product of corn pesticide yield ratio (F-0.0018,K-0.0014,SJ-0.00030) times net feed ratio of 5.62 kg corn/kg of beef produced and the product of alfalfa pesticide yield ratio (F-0.00037,K-0.000061,SJ-0.00018) times net feed ratio of 2.66 kg alfalfa/kg of beef produced.

Table 4.10 Comparison of Dietary Hazard Indices Between the Vegetarian and Nonvegetarian Diets ¹

Food Item	Diet	Weekly Consumption (g)	Environmental Hazard Index	Commodity Hazard Index
Almond	vegetarian	65.55	0.0721	0.0047
	nonvegetarian	27.76	0.0721	0.0020
Apples	vegetarian	658.95	0.0544	0.036
	nonvegetarian	466.22	0.0544	0.025
Beans	vegetarian	256.55	0.0741	0.019
	nonvegetarian	169.50	0.0741	0.013
Grapes	vegetarian	375.80	0.147	0.055
	nonvegetarian	385.88	0.147	0.057
Oranges	vegetarian	1813.91	0.0709	0.13
	nonvegetarian	1704.82	0.0709	0.12
Peaches	vegetarian	383.16	0.083	0.032
	nonvegetarian	213.97	0.083	0.018
Watermelon	vegetarian	468.08	0.0102	0.0048
	nonvegetarian	298.28	0.0102	0.0030
Eggs	vegetarian	66.79	0.0556	0.0037
	nonvegetarian	137.56	0.0556	0.0076
Chicken	vegetarian	5.59	0.0556	0.00031
	nonvegetarian	136.46	0.0556	0.0076
Beef	vegetarian	23.17	0.248	0.0057
	nonvegetarian	743.32	0.248	0.18
DHI	vegetarian			0.29
	nonvegetarian			0.44

1) Vegetarian and Nonvegetarian values calculated from the Adventist Health Study.

Comparison of the Vegetarian and Nonvegetarian Diet

For ease of comparison, the compiled results for CWR, CER, CFR, CPR, and DHI are presented in Table 4.11. All differences between vegetarian and nonvegetarian were significant at $p < 0.05$ for the combined plant products and animal product intake as well as plant products and animal product considered individually. The vegetarian diet required 5.41 times less water, 2.48 times less primary energy, 12.9 times less fertilizer, and 1.4 times less pesticides than did the nonvegetarian diet. This difference is primarily due to the larger quantity of animal products, specifically beef, in the diet of the

nonvegetarian. In addition the environmental impact of pesticides, as measured by the

DHI indicated a 1.52 times greater impact for the nonvegetarian diet.

Table 4.11 Input Comparison for the Vegetarian and Nonvegetarian Diet ¹

Input	Diet	Value	Ratio
Water (L) CWR	vegetarian	193	5.41
	nonvegetarian	1045	
Primary Energy (kJ) CER	vegetarian	3745	2.48
	nonvegetarian	9288	
Fertilizer (g) CFR	vegetarian	9.3	12.9
	nonvegetarian	120	
Pesticides (g) CPR	vegetarian	10	1.4
	nonvegetarian	14	
Environmental Impact of Pesticides	vegetarian	0.29	1.52
	nonvegetarian	0.44	

(1) Vegetarian and Nonvegetarian values calculated from the Adventist Health Study. All differences were significant at $P < 0.05$.

Comparison of the Average American and Adventist Nonvegetarian Diet

The dietary values presented in Table 4.12 are transferred from Tables 3.8 above.

The average American annual consumption values for the 11 commodities under investigation were compiled from the U.S. Department of Agriculture Food

Consumption, Prices, and Expenditures, 1970-97 (Putnam and Allshouse, 1999) for the year 1985. The values reported represent mean per capita consumption. No statistical

values were available so the reported means were compared to the average Adventist nonvegetarian consumption in a semi-quantitative manner. In general the Adventist nonvegetarian consumed more plant products and less animal products than their American counterparts. The only exception to this trend was for seasonal fruit and here the average American consumed about 1.4 times as much as the Adventist nonvegetarian. The Adventist nonvegetarian eats, on average, 1.16 times as much plant products as does the average American. The average American consumed, on average, approximately 2.51 times the animal products including 1.8 times as many eggs, 5.1 times as much poultry, and 2.1 times as much beef as the Adventist nonvegetarian.

The same methodological procedures, with the exception of statistical tests, described above were applied to determine the CER, CER, CFR, CPR, and DHI values to compare the average American diet and the Adventist nonvegetarian diet (Table 4.12). Across the board the results indicate greater total inputs of water, primary energy, fertilizer and pesticides, as measured by the CER, CER, CFR, CPR, and DHI, for the average American diet. The Adventist nonvegetarian diet required 1.99 times less water, 1.82 times less primary energy, 2.10 times less fertilizer, and 1.43 times less pesticides than did the average American diet. Figures that more or less mirror the additional quantity of animal products in the diet of the average American. The greatest contribution to the difference came from the consumption of animal products, eggs, broilers, and beef in the diet of the average American

Table 4.12 Average American and Adventist Nonvegetarian Consumption Values Used for this Research ¹

Food Item	Diet	Weekly Consumption grams	Annual Consumption kg
Dry Fruit	American	26.05	1.35
	nonvegetarian	90.25	4.69
Canned Fruit	American	184.53	9.59
	nonvegetarian	185.13	9.63
Winter Fruit	American	381.12	19.82
	nonvegetarian	454.62	23.64
Seasonal Fruit	American	381.99	19.86
	nonvegetarian	275.95	14.35
Citrus Fruit	American	187.94	9.77
	nonvegetarian	227.57	11.83
Fruit Juice	American	612.00	31.83
	nonvegetarian	732.84	38.11
Nuts	American	20.98	1.09
	nonvegetarian	27.72	1.44
Beans	American	66.43	3.45
	nonvegetarian	168.80	8.78
Eggs	American	244.90	12.74
	nonvegetarian	137.51	7.15
Poultry	American	458.04	23.82
	nonvegetarian	89.13	4.63
Beef	American	691.35	35.95
	nonvegetarian	330.05	17.16

1) Vegetarian and Nonvegetarian values calculated from the Adventist Health Study. American values calculated from U.S. Department of Agriculture Food Consumption, Prices, and Expenditures, 1970-97.

Table 4.13 Input Comparison for the American and Nonvegetarian Diet ¹

Input	Diet	Value	Ratio
Water (L) CWR	American	2081	1.99
	nonvegetarian	1045	
Primary Energy (kJ) CER	American	16,867	1.82
	nonvegetarian	9288	
Fertilizer (g) CFR	American	252	2.10
	nonvegetarian	120	
Pesticides (g) CPR	American	20	1.43
	nonvegetarian	14	
Environmental Impact of Pesticides	American	0.65	1.48
	nonvegetarian	0.44	

1) Nonvegetarian values calculated from the Adventist Health Study and American values from (Putnam and Allshouse, 1999).

These results presented in Chapter 3 above and in this section will be discussed in the following chapter.

CHAPTER FIVE

DISCUSSION

The preceding chapters of this manuscript have introduced the rationale for this project, provided a review of the literature, presented the study design and methodology and the results of the analysis. A discussion of these sections, some implications of the research and findings, and recommendations for additional investigation will be presented in this chapter.

This chapter will be divided into 3 sections, with comments on research design, and methodology, results, and recommendations.

Research Design and Methodology

The intent of this research was to investigate the environmental impact of food production practices. In limiting the study to food production, the environmental impact attributable to food processing, distribution, and retailing was not considered. The literature suggests that the contribution from these activities may be considerable, though very complex.

The environmental impact of dietary choice was investigated by analyzing the dietary habits of the largest vegetarian group in California. The Seventh-day Adventist population in general contains about 50% vegetarians and 50% nonvegetarians by dietary preference. The AHS was designed as a tool to investigate the relationship between lifestyle, in particular dietary choice, and health outcomes. This investigation has extended the utility of this research into the field of environmental health. The similarities in the dietary choices of the two groups tended to obscure environmental outcomes though the large sample size gave sufficient power to detect those differences.

The original food frequency questionnaire contained a variety of food items of interest including beverages and complex mixtures of commodities (eg: doughnuts). Beverages and combination foods were excluded from the study to simplify the research design.

It is difficult to determine the percentage of the total dietary consumption that was represented in the foods selected for the food frequency questionnaire and subsequently included in this research. An analysis of caloric contribution or some other quantification may be used to determine the representative percentage. An estimate from the Food Consumption, Prices and Expenditures, 1970-97 (Putnam and Allshouse, 1999) suggests that the food groups selected could have accounted for 30-50% of the total dietary intake and their representative commodities included in the study. A similar percentage contribution was assumed for the AHS data. This estimate is difficult to quantify because of the complex classifications and segregations employed by Putnam and Allshouse (1999).

Two major food groups, dairy products and vegetables, were excluded from the study because there were no statistically significant differences in the consumption of these two items. Accordingly, the assumption was made that the environmental impact was equal for the two groups and was not used to calculate the cumulative inputs from the study. Nonetheless, the production of these commodities requires inputs of water, primary energy, fertilizer, and pesticides. The inputs have environmental consequences but, for the purpose of this research, the inputs were considered to have offset each other and were not included in calculating the impact difference between the diets.

The use of representative food items for a food group (e.g. oranges to represent citrus fruit) may have confounded the results if the associated impact from inputs used to produce another food item from the same group may have been significantly greater. If this were the case, the relative contribution of the increase would affect the calculation of the dietary input by the same magnitude for each diet.

Food items not produced in California were not included in the study. There were significant differences in the consumption of fish and soy products between the two AHS groups. These items were not included because they are not produced in any appreciable quantities in the state. Soy in the feed formulations for beef and poultry was also excluded. Furthermore, the inputs associated with production and transportation costs for fish and soy could have been estimated and added to this study but would have confounded the design to investigate California production practices and impact.

Assumptions made for beef production representative of the bulk of production for the state. The assumptions made and data collected were representative for the Central Valley, the focus of this research, where the vast majority of the cattle are produced. Approximately 25% of beef produced and consumed in the US is dairy beef (Taylor and Field, 1999). The majority of dairy beef is produced in southeastern California (Forero personal communication). The production of dairy beef requires significantly greater inputs of concentrates, and impact from their production, because the cattle are in a feedlot for approximately four times as long (Taylor and Field, 1999; Ensminger, Oldfield, and Heinemann, 1990). Not including dairy beef production lead to the effect of drawing more conservative conclusions for the inputs and impact of beef production.

If the finishing weights of cattle at each phase were incorrectly estimated the inputs to each phase would be changed accordingly. The estimated quantity that has the greatest potential impact, 400-450 lbs of gain in the feedlot, is the one that is most important to have estimated correctly (Forero personal communication), because this period of time is the most input-intensive with the feeding of concentrate rations.

Adding the inputs of production of heifers and seed stock to an individual head of beef produced would have slightly increased the overall value and impact of all inputs but the contribution would likely be minimal because of the number of animals this impact would have been allocated between.

Waste production from beef and poultry operations was initially included in the research design. A large volume of literature suggests a tremendous environmental impact from the waste stream generated by these operations. This line of research was not pursued because, in general, waste products generated are not limited to manure production and include such hard-to-quantify emissions as methane and carbon dioxide. Waste generation was not included in this research because, it would not be justifiable to include only a partial, though high profile, quantification of waste generation.

Data Analysis

Only primary water and energy inputs were included in the research. Water directly used for irrigation and primary energy used to operate machinery or power cooling fans is relatively easy to accurately represent. Secondary water use for production of machinery or manufacturing of other inputs such as pesticides is difficult to quantify and relatively ambiguous in amortizing inputs across many categories. Secondary energy inputs into fertilizer or pesticide manufacture or to run ancillary

equipment would be difficult to quantify and assign to a primary production budget.

Consequently, the contribution of these inputs was not included in the calculations. Their inclusion would have likely made a relative and uniform addition that would have been applied across the board and likely not to contribute greatly to quantifying the differences in the inputs to commodity production.

A decision was made early in the research to focus on the pesticides listed of special concern by California. Upon analyzing the results, it was determined that total pesticide use may have given a more accurate picture of pesticide use and environmental impact from pesticide application. The listed pesticides accounted for between 89-100% of the total for all commodities studied though most contributions were in the mid- to high 90% of the total. The inclusion of total pesticides could have been expected to increase the total contribution by a similar margin and would have slightly increased the amount of pesticides and impact reported in the research.

Results

The results of this research are not surprising and are in fact similar to those reported in the popular and scientific literature. However, for the most part, the popular literature is biased and prejudiced by sensationalizing or misrepresenting the data. There are few reports of environmental impact in the scientific literature that examine and contrast differences in actual diets. The majority of the scientific literature focuses on the production and contrast of relatively few commodities or idealized diets and is not representative of actual dietary habits of people. Extrapolations from these data have been made but are of limited utility. Notable exceptions were research conducted by

Gussow (1995, 1999), Carlsson-Kanyama (1998), Pimentel (1999, 2003), Reijnders and Soret (2003).

The working assumption for this research was that a greater number and amount of inputs are associated with greater environmental impact. The literature supports this notion. Critical water issues exacerbated by agricultural practices include pollution of surface and groundwater sources (Aldy, Hrubovcak, and Vasavada, 1998; Pimentel, 1999), overdrafting of aquifers (Tanji and Enos, 1994; Aldy, Hrubovcak, and Vasavada, 1998), salinization of soils (Pimentel, 1999), and runoff, evaporation and leakage from irrigation systems (Wallace, 2000). In the US, fossil fuel consumption has doubled in the last 20 years while the caloric return per calorie of input on most crops has diminished (Pimentel and Pimentel, 1983). Environmental and health impacts associated with using fossil fuels include acid rain, air pollution, respiratory and cardiovascular disease, soil and water contamination and others. Pesticide use has increased as much as 33 times in the US since the 1940s (Brown, 1970; Pimentel et al., 1992). Concerns over the environmental consequences of pesticide use include: residues on food (Lee, 1992; Pimentel et al., 1993), ground and surface water contamination (Lee, 1992; Levitan, Merwin and Kovach, 1995), persistence in the environment (Kiraly, 1996; Foster et al., 1998), damage to non-targeted species (Levitan, Merwin and Kovach, 1995; Kiraly, 1996), and increased resistance in pests (Pimentel et al., 1993; Foster et al., 1998). The natural fertility of the soil in the US has been depleted by intensive practices and replaced by application of chemical fertilizers, and the over use of fertilizers has resulted in surface and groundwater contamination (Pimentel and Pimentel, 1997) and salinification of soils.

Results show that eating a vegetarian diet or a more plant-based diet could mitigate some of the impacts described above if we assume that the amount of these inputs used is related to the extent of the impacts described. All of the inputs studied showed a clear relationship between dietary preference and the expenditure of resources input to production. The largest single contribution to a lower WUE, EUE, FUE, or PUE is the amount of beef consumed in the diet. For the vegetarian diet, the use efficiencies were from approximately 1 to 12 times greater than for the nonvegetarian diet. The Adventist nonvegetarian diet had inputs use efficiencies that averaged 1.5 to 2 times greater than for the average American diet.

It is important to remember that these efficiency ratios are based on the differences between the diets. If the inputs from the remainder of the diet were added the ratios would be reduced. For comparative purposes, the absolute data may be more illustrative. When comparing water for instance, the difference in water use for the vegetarian and nonvegetarian diet was 1044 L per week. The difference would be expected to remain constant when the remainder of the diet was included.

That the nonvegetarian diet required 1044 L per week more water than the vegetarian diet is a relatively unimpressive statistic. The figure takes on more significance when considering increased time or number of persons participating in the diet. When viewed for a period of one year, the vegetarian diet may be expected to require the input of 54,290 L less water than the nonvegetarian. Over a 70 year lifespan, that figure becomes 3,800,000 L. Producing the diet for 1000 SDA vegetarians could be expected to require 54,000,000 L less water annually than that required for the nonvegetarians. The average American diet requires 1888 L more water to produce than

does the SDA vegetarian. Were these diets contrasted in a similar manner, the SDA vegetarian diet for an individual would require the input of 98,200 L less water annually and 6,900,000 L less water over a 70 lifespan. Producing the diet for 1000 SDA vegetarians could be expected to require 98,000,000 L less water input than producing the diet for 1000 average Americans. Viewed from this vantage it is readily apparent that a significant savings could be realized by choosing a vegetarian diet. These results are consistent with those reported by Pimentel et al., (1997, 2003), Duxbury and Welch (1999) Nestle (1999), Horrigan, Lawrence and Walker (2002), and Leitzmann (2003). According to the American Water Works Association (2006), the average daily per capita indoor water consumption for a home with no water conserving appliances is 74 gallons (280 L). Using this figure, the SDA vegetarian diet annually conserves the equivalent of 194 days of water when compared to the SDA nonvegetarian diet and 351 days of water when compared to the average American diet.

A similar analysis to the one conducted above for water revealed the effect of perspective, of time and numbers, for primary energy. The SDA vegetarian diet required the weekly input of 5543 kJ less energy than the nonvegetarian diet and 13,100 kJ less energy than did the average American diet. The annual input reduction for the vegetarian diet could be expected to be 288,000 kJ less than the nonvegetarian diet and 682,000 kJ less than the average American diet. Using the conversion factors employed for this research (USDOT, 2006), this energy expenditure equals a annual savings of approximately 8.3 L of gasoline compared to the nonvegetarian diet and 19.6 L of gasoline compared to the average American diet. To gain some further perspective, over

the lifetime of 1000 SDA vegetarians the equivalent savings would be 581,000 L compared to the nonvegetarian and 1,370,000 L compared to the average American diet.

When the same calculations are accomplished for the difference in fertilizer use, the weekly input difference, compared to the vegetarian diet, of 111 g for the nonvegetarian diet and 243 g for the average American diet yields similar results. The annual fertilizer inputs for the vegetarian diet could be reduced by 5770 g compared to the nonvegetarian diet and 12,600 g compared to the average American diet. The lifetime input reduction for 1000 SDA vegetarians could be reduced by 404,000 kg and 882,000 kg, respectively compared to the nonvegetarian and average American diets.

The weekly input difference of pesticides for the diets shows the vegetarian diet produces a reduction of 4 g applied per week for the nonvegetarian diet and 10 g per week applied for the average American diet. The annual pesticide inputs for the vegetarian diet could amount to a reduction of 208 grams compared to the nonvegetarian diet and 520 g compared to the average American diet. Viewed from the lifetime input reduction of 1000 SDA vegetarians, 14,600 kg fewer pesticides could be applied compared to the nonvegetarian diet and 36,400 kg fewer pesticides could be applied compared to the average American diet.

From an environmental perspective, it is clear that what a person chooses to eat matters. Viewed from the individual lens, the difference in the dietary choices of the SDA vegetarian, nonvegetarian and average American do not appear to support profound conclusions. However, with the added perspective of time and numbers the differences become quite pronounced and may have the potential for tremendously different impacts to the environment. The working assumption for this research, supported by a vast

literature, was that a greater number and amount of inputs are associated with greater environmental impact.

It is clear that the production of a SDA nonvegetarian or average American diet requires the inputs of significantly greater amounts of water, primary energy, fertilizers and pesticides when compared to the SDA vegetarian diet and that those impacts have a more profound affect on the environment. This conclusion is supported by the popular and scientific literature and by this research. The research design and method allowed a direct comparison of the SDA vegetarian and nonvegetarian diets and a direct, but less powerful, comparison of both diets to the average American diet. Primary data collected by other researchers was analyzed and used in conjunction with meta-analysis of other data to produce values that were used to reliably calculate inputs of water, primary energy, fertilizer and pesticides and compare these inputs between diets.

Future Work

This research has revealed many interesting prospects for the future. First and foremost, the research design and methods, results, and discussion need to be published and presented. There are several papers that could result from this effort and may include:

- Beef Production in the State of California
- Chicken and Egg Production in the State of California
- The use of Primary and Meta-Data analysis in Determining Environmental Impact
- Dietary Choice and Water Use Efficiency
- Dietary Choice and Pesticide Use Efficiency

- Dietary Choice and Fertilizer Use Efficiency
- Dietary Choice and Energy Use Efficiency
- The Environmental Impact of Dietary Choice and Agriculture in California

Extramural funding should be sought after to continue the current line of inquiry, foster additional investigation, initiate and develop a research program, and attract students and research assistants.

New research activities should focus on updating and incorporating the most recent production statistics and using the most recent AHS data. If statistical data can be obtained from the USDA it could be used to determine statistical significance of the results of the comparison of the average American diet and the SDA diets.

Transportation and production costs may be calculated to include soybeans in the diet and for animal feed. Calculations could be made to include the generation of waste during food production. Additional activities could include the incorporation of secondary input data and calculations to produce more accurate estimates and possibly inclusion of agricultural or ecological economic valuation of inputs and environmental impacts.

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