

# Diet and the environment: does what you eat matter?<sup>1-4</sup>

Harold J Marlow, William K Hayes, Samuel Soret, Ronald L Carter, Ernest R Schwab, and Joan Sabaté

## ABSTRACT

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 was to compare the environmental effect of a vegetarian and nonvegetarian diet in California in terms of agricultural production inputs, including pesticides and fertilizers, water, and energy used to produce commodities. The working assumption was that a greater number and amount of inputs were associated with a greater environmental effect. The literature supported this notion. To accomplish this goal, dietary preferences were quantified with the Adventist Health Study, and California state agricultural data were collected and applied to state commodity production statistics. These data were used to calculate different dietary consumption patterns and indexes to compare the environmental effect associated with dietary preference. Results show that, for the combined differential production of 11 food items for which consumption differs among vegetarians and nonvegetarians, the nonvegetarian diet required 2.9 times more water, 2.5 times more primary energy, 13 times more fertilizer, and 1.4 times more pesticides than did the vegetarian diet. The greatest contribution to the differences came from the consumption of beef in the diet. We found that a nonvegetarian diet exacts a higher cost on the environment relative to a vegetarian diet. From an environmental perspective, what a person chooses to eat makes a difference. *Am J Clin Nutr* 2009;89(suppl):1699S–703S.

## INTRODUCTION

In developed countries, and throughout the world, there exists a link between agricultural production and environmental degradation (1–4). Public awareness of diverse global environmental issues, such as climate change (5–7), toxic residues in food (8), soil erosion (9, 10), and species endangerment (9, 11), has brought about a call for sustainable food production practices (12) and responsible stewardship of our finite resources (13). Particular skepticism has been aimed at supporting the increased demand for animal products in the diet of the economically advantaged persons of the world (4, 14).

To address concerns about the increased demand for animal consumption, we can begin by asking a series of pertinent questions. Do dietary choices really have an effect on the environment? More specifically, does animal consumption create a heavier footprint than a vegetarian diet? If so, what are some of the major environmental effects of an animal-based diet, and how might these be measured?

In this article, we first identify and briefly review 6 major effects that dietary choices may have on the environment and then

describe a research program undertaken at Loma Linda University to quantify the environmental effects of vegetarian and nonvegetarian diets.

## MODERN AGRICULTURE'S EFFECT ON THE ENVIRONMENT

The environmental effect of modern agriculture has increased with the implementation of technologies designed to increase crop yield and commodity production (15). Technologic advances in mechanization, irrigation, fertilization, and chemical control of pests have facilitated substantial increases in agricultural output since the 1940s (16). Simultaneously, there has been an increase in total energy expenditure (17), depletion of natural resources (12, 18), and generation of waste products (16) associated with increased agricultural output. In fact, the point has been reached where scientists and policymakers have begun to seriously doubt the sustainability of these trends (19). In the remainder of this section, we identify and briefly review 6 major effects that dietary choices may have on the environment: water resources, energy consumption, chemical fertilizer application, pesticide application, waste generation, and land degradation.

### Water resources

Most cropland in the United States is rain fed (20). Despite this fact, agricultural production requires  $\leq 80\%$  of the water consumed in the United States (15, 21) to irrigate  $\approx 10\text{--}15\%$  of cropland (15, 20, 22) and to water livestock (20). Critical water issues exacerbated by agricultural practices include the pollution of surface and groundwater sources (23), overdrafting of aquifers (20), waterlogging and salinization of soils (12, 13), wetlands loss (24), and runoff, evaporation, and leakage from

<sup>1</sup> From the Departments of Environmental Health (HJM and SS) and Nutrition (JS), School of Public Health, Department of Earth and Biological Sciences, School of Science and Technology (WKH and RLC), Department of Allied Health Studies, School of Allied Health Professions (ERS), Loma Linda University, Loma Linda, CA.

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<sup>4</sup> Reprints not available. Address correspondence to HJ Marlow, Department of Environmental Health, School of Public Health, Loma Linda University, Loma Linda, CA 92350. E-mail: hmarlow@llu.edu.

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irrigation systems (25). These effects may have greater significance during times of seasonal or extended drought (21).

### Energy consumption

Increased use of fossil fuels and concurrent technologic advances have allowed humans to increase the productivity of natural systems by manipulating the environment (17, 23). The energy intensiveness of agricultural production varies with type of crop produced, amount of chemical inputs, and geographic location (18). With market globalization and convenient transportation choices, food has become available during seasons when they were typically absent, and the increased energy requirements are largely borne by consumers and driven by market demand. In the United States, fossil fuel consumption doubled during a 20-y span while the caloric return per calorie of input on most crops diminished (15). Cheap sources of fossil fuels will continue to allow for massive energy inputs to agricultural systems, but, as prices increase and supplies dwindle, this practice is likely to change (14). Conservation and optimization of energy use will certainly be in the future of agriculture.

A positive return of 2–3 nutrient calories per calorie of primary energy input is characteristic for most cereal grains and legumes (26). Most fruit and vegetables return  $\approx 0.5$  calories, and animal products return  $\approx 0.01$ – $0.05$  calories (15). The energy inputs for animal products may be 2.5–5.0 times greater than for plant products (27).

### Chemical fertilizer application

The natural fertility of soil in the United States has been depleted and has been replaced by application of chemical fertilizers at rates that, for a time, increased  $\approx 10\%/y$  since the 1950s (15). Potassium and phosphate are produced from nonrenewable resources, and the production of nitrogen fertilizer relies directly on petroleum (28). The use of fertilizers represents the single greatest energy input for many crops (15), and the overuse of fertilizers has resulted in surface and groundwater contamination (18, 19, 29), air pollution (30), and a decrease in biodiversity (31).

### Pesticide application

Pesticide use has increased as much as 33-fold in the United States since the 1940s (16, 32). At the turn of the century,  $\approx 2.5$  million tons of pesticides were applied annually to crops worldwide (33). Despite this increase in the use of pesticides, an estimated 37% of all crop production is lost annually to pests (32–34). Increased monoculture cultivation, positive cost-benefit ratios (8, 33), and neglect of the environmental or social cost of application (35) have led to unrestricted increases in pesticide usage.

Concerns over the environmental consequences of pesticide use include: residues on food (34), ground and surface water contamination (36), persistence in the environment and bioamplification (35), damage to nontargeted species (36), increased chemical resistance in pests (34, 35), and worker safety (37). Many of the environmental effects are difficult to measure or assess accurately (38).

In addition to direct and indirect environmental effects, a host of acute and chronic human health effects have also been associated with pesticides. These include endocrine disruption, immune dysfunction, neurological disorders, and cancer (39).

### Waste generation

In addition to the previously identified pollution problems, wastes generated by intensified animal production often result in significant water, soil, and air pollution (40). In the United States, 7 billion livestock generate 130 times more waste than produced by 300 million humans (41). These wastes, most of which go untreated, contain high concentrations of nitrogen, phosphorous, and potassium compounds and traces of metals and antibiotics; these represent a serious public health problem according to the World Health Organization and US Department of Agriculture (4, 23, 40, 41). Concentrated livestock operations and livestock waste also produce gases. Some, such as ammonia, have a more local effect and are generally regarded as nuisance odors (40). Others such as carbon dioxide, methane, and nitrous oxide exert a global effect and have been implicated in climate change (4, 26, 40, 42).

### Land degradation

Livestock production exacts a significant toll on natural habitats. According to a recent report from the Food and Agriculture Organization of the United Nations, the livestock sector is by far the single largest anthropogenic user of land, accounting for 70% of all agricultural land and 30% of the land surface of the planet (4). Livestock production, and its continuing expansion and intensification, is a key driver of many destructive ecosystem changes, including deforestation; replacement of herbaceous plants by woody plant cover; desertification; and soil compaction, erosion, and subsequent sedimentation of waterways, wetlands, and coastal areas (4, 43, 44). Animal production also facilitates the establishment and spread of invasive plants and animals, as well as zoonotic diseases. The poultry industry, for example, has been linked to the transmission of highly pathogenic avian influenza (45).

## MEASURING ENVIRONMENTAL EFFECTS OF DIETARY PREFERENCE: VEGETARIAN COMPARED WITH NONVEGETARIAN

Human health and the health of the environment are inextricably linked. The link is so clear for Fowler and Hobbs (46) that they concluded that “humanity is not sustainable.” There have been attempts to identify and quantify the ecologic consequences associated with modern agricultural practices (15, 19, 23). At the turn of the century, Gussow (47) issued a call for research permitting a direct comparison of the ecologic consequences of different diets. Although several associations have been suggested (3, 23), what mostly appear in the literature are comparisons of discretely selected food items, not direct, quantifiable comparisons of whole diets. One notable exception is a recently published study involving the evaluation of idealized diets with the use of Life Cycle Assessment and computer modeling (19).

### Research location

At Loma Linda University we explored the relation between dietary preference and environmental effects. An approach was developed with the use of the state of California as a model to quantify the environmental effect of agricultural practices used to

produce commodities for representative vegetarian and non-vegetarian diets. California historically has been the largest producer of agricultural and food products in the United States, hosting a wide range of operations (48). The goal of our research was to compare these 2 diets in terms of the water, energy, inorganic fertilizers, and pesticides (ie, “inputs”) used to produce the commodities for each. Our working assumption was that a greater number and amount of inputs are associated with greater environmental effect. A complete description of the methods and results are available in Marlow (49).

### Quantifying vegetarian and nonvegetarian diets

There are many vegetarian diets, many unique to the individual consumer. To make this project relevant, we selected the largest vegetarian group in California, the Seventh-day Adventists (Adventists), for whom ample data are available, to specify the composition of representative vegetarian and nonvegetarian diets. Among the 34,000 California Adventists participating in the Adventist Health Study I (AHS) cohort,  $\approx 50\%$  are vegetarians and 50% nonvegetarians by dietary preference. The AHS was designed to investigate the relation between lifestyle, in particular dietary choice, and health outcomes (50). Our investigation has extended the utility of the AHS into the field of environmental health. This data set provided a means for quantifying practically relevant consumption pattern differences for specific food items or food groups in the 2 diets. Among 31 food items or food groups in the AHS questionnaire, 11 were consumed at substantially different rates by vegetarians and nonvegetarians, whereas the remainder of 20 food items or groups was similarly consumed in both diet patterns. The food items or food groups used in this research and their relative contribution to the vegetarian or nonvegetarian diet are shown in **Table 1**. The results show that vegetarians ate slightly more plant foods and that nonvegetarians ate substantially more animal foods in their diets.

### Environmental effect analyses

Commodity production quantities and input statistics were gathered from a variety of federal, state, and county agencies in addition to industry associations. These organizations provided information mostly in the form of published reports, databases, technical assistance, and professional advice. Production and input statistics were used to calculate overall variables generally referred to as “use efficiencies” (49). There were corresponding use efficiencies calculated for water consumption (water use efficiency), energy used (energy use efficiency), pesticides applied (pesticide use efficiency), and fertilizers applied (fertilizer use efficiency).

The outcome of our studies provided evidence for the much higher ecologic cost of an animal-based diet. The approximated effect ratios for water use efficiency, energy use efficiency, pesticide use efficiency, and fertilizer use efficiency are presented in **Table 2**. Our analyses further showed that these differences resulted primarily from the inclusion of beef in the diet of the nonvegetarian. This finding is similar to those published by groups in Europe (4, 19), Japan (51), the United States (27, 52), and Australia (6, 53).

**TABLE 1**

Ratios of consumption of the 11 food items or groups that were significantly different between the diets of vegetarians and nonvegetarians<sup>1</sup>

	Ratio <sup>2</sup>
Plant foods	
Dry fruit	1.1
Canned fruit	1.8
Winter fruit <sup>3</sup>	1.4
Seasonal fruit <sup>3</sup>	1.6
Citrus fruit	1.6
Fruit juice	1.1
Nuts	2.4
Beans	1.5
Animal foods <sup>4</sup>	
Eggs	0.43
Poultry	0.04
Beef	0.03

<sup>1</sup> Food composition of vegetarian and nonvegetarian diets was calculated from the Adventist Health Study (50).

<sup>2</sup> Expressed as ratio of vegetarian to nonvegetarian diet.

<sup>3</sup> Winter fruit was referred to in the food-frequency questionnaire as fruit, such as an apple, for which availability was not seasonally limited. Seasonal fruit, such as watermelon, was fruit that was limited to seasonal availability.

<sup>4</sup> Corresponding figures for the inverse ratio (nonvegetarian/vegetarian) are 2.3 for eggs, 25 for poultry, and 32 for beef.

### DISCUSSION AND CONCLUSIONS

It is important to remember that these efficiency ratios are based on the differences between the diets that we chose to analyze, each of which had a limited number of food items. If, for example, the inputs from the remainder of the diet were added, the ratios would be reduced, but the absolute differences would remain unchanged.

For purposes of comparison, the absolute data are highly illustrative. When comparing water, for instance, the difference in water use for the vegetarian and nonvegetarian diet was  $\approx 1000$  L (264 gallons)/wk. These results are consistent with those reported by others (18, 22, 26, 52, 54–56). According to the American Water Works Association (57), the average weekly per capita indoor water consumption for a home with no water-conserving appliances is 1835 L (485 gallons), although this may be a conservative estimate (58). With the use of this figure, the

**TABLE 2**

Comparisons of environmentally relevant inputs for the combined production of the 11 food items or groups in which California Adventist vegetarian and nonvegetarian diets differ<sup>1</sup>

Input <sup>2</sup>	Ratio <sup>3</sup>
Water (L)	2.9
Primary energy (kJ)	2.5
Fertilizer (g)	13
Pesticides (g)	1.4

<sup>1</sup> Food composition of vegetarian and nonvegetarian diets was calculated from the Adventist Health Study (50); inputs were estimated from a variety of federal, state, and county agencies in addition to industry associations (49).

<sup>2</sup> Expressed as cumulative requirements.

<sup>3</sup> Expressed as ratio of nonvegetarian to vegetarian input quantities.

Adventist vegetarian diet conserves the equivalent of 54% of the average weekly per capita indoor water consumption. This can be compared with a savings of 35%, estimated by the American Water Works Association, by installing more-efficient water fixtures and regularly checking for leaks. From this comparison it is apparent that a plant-based diet provides a significant water conservation benefit. A similar ecologic cost effectiveness can be determined for each of the other inputs in the study.

Considering the surmounting ecologic pressures that a burgeoning human civilization exerts on our planet, there is a need to make hard decisions. Among these hard decisions, many societies, and governments in particular, will have to reconsider the increasing demand for an animal-based diet. Many governments, including both the European Union and the US government, may need to reassess agricultural subsidies (59, 60) and divert some of the funding to support additional research, development, and application of sustainable methods of food production. Outreach programs may be necessary to educate and inform people about the health and environmental benefits of a vegetarian diet. (Other articles in this supplement to the Journal include references 61–87.)

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## REFERENCES

- Gussow JD, Clancy KL. Dietary guidelines for sustainability. *J Nutr Educ* 1986;18:1–5.
- Goodland R. Environmental sustainability in agriculture: diet matters. *Ecol Econ* 1997;23:189–200.
- Carlsson-Kanyama A. Climate change and dietary choices: how can emissions of greenhouse gases from food consumption be reduced? *Food Policy* 1998;3–4:277–98.
- Steinfeld H, Gerber P, Wassenaar T, Castel V, Rosales M, de Haan C. Livestock's long shadow: environmental issues and options. Rome, Italy: Food and Agriculture Organization of the United Nations, 2006.
- Johnson JM, Franzluebbers AJ, Weyers SL, Reicosky DC. Agricultural opportunities to mitigate greenhouse gas emissions. *Environ Pollut* 2007;150:107–24.
- McMichael AJ, Powles JW, Butler CD, Vauy R. Food, livestock production, energy, climate change, and health. *Lancet* 2007;370:1253–63.
- Noble BF, Christmas LM. Strategic environmental assessment of greenhouse gas mitigation options in the Canadian agricultural sector. *Environ Manage* 2008;41:64–78.
- Falconer KE. Managing diffuse environmental contamination from agricultural pesticides—an economic perspective on issues and policy options, with particular reference to Europe. *Agric Ecosyst Environ* 1998;69:37–54.
- Huston M. Biological diversity, soils, and economics. *Science* 1993;262:1676–80.
- Trimble SW, Crosson P. Land use—US soil erosion rates—myth and reality. *Science* 2000;289:248–50.
- Tisdell C. Agricultural sustainability and conservation of biodiversity: competing policies and paradigms. In: Dragun AK, Jakobsson KM, eds. Sustainability and global environmental policy. Cheltenham, United Kingdom: Edward Elgar Publishing Ltd, 1998:97–129.
- Pinstrup-Andersen P, Pandya-Lorch R. Food security and sustainable use of natural resources: a 2020 vision. *Ecol Econ* 1998;26:1–10.
- Worrell R, Appleby MC. Stewardship of natural resources: definition, ethical and practical aspects. *J Agric Environ Ethics* 2000;12:263–77.
- Heitschmidt RK, Short RE, Grings EE. Ecosystems, sustainability, and animal agriculture. *J Anim Sci* 1996;74:1395–405.
- Pimentel D, Pimentel M. The future of American agriculture. In: Knorr D, ed. Sustainable food systems. Westport, CT: Avi Publishers, 1983:3–27.
- Brown LR. Human food production as a process in the biosphere. *Sci Am* 1970;223:161–70.
- Cleveland CJ. The direct and indirect use of fossil fuels and electricity in USA agriculture, 1910–1990. *Agric Ecosyst Environ* 1995;55:111–21.
- Pimentel D, Pimentel M. US food production threatened by rapid population growth. Washington, DC: Prepared for Carrying Capacity Network, 1997.
- Baroni L, Cenci L, Tettamanti M, Berati M. Evaluating the environmental impact of various dietary patterns combined with different food production systems. *Eur J Clin Nutr* 2007;61:279–86.
- Tanji KK, Enos CA. Global water resources and agricultural use. In: Tanji KK, Yaron B, eds. Management of water use in agriculture. Berlin, Germany: Springer-Verlag, 1994:3–24.
- Zilberman D, Dunarm A, MacDougal N, Khanna M, Brown C, Castillo F. Individual and institutional responses to the drought: the case of California agriculture. *J Contemp Water Res Educ* 2002;121:17–23.
- Pimentel D, Berger B, Filiberto D, et al. Water resources: agricultural and environmental issues. *Bioscience* 2004;54:909–18.
- Pimentel D. Environmental and economic benefits of sustainable agriculture. In: Kihn J, Gowdy J, Hinterberger F, van der Straaten J, eds. Sustainability in question. Cheltenham, United Kingdom: Edward Elgar Publishing Ltd, 1999:153–70.
- Lemly AD, Kingsford RT, Thompson JR. Irrigated agriculture and wildlife conservation: conflict on a global scale. *Environ Manage* 2000;25:485–512.
- Wallace JS. Increasing agricultural water use efficiency to meet future food production. *Agric Ecosyst Environ* 2000;82:105–19.
- Horrihan L, Lawrence RS, Walker P. How sustainable agriculture can address the environmental and human health harms of industrial agriculture. *Environ Health Perspect* 2002;110:445–56.
- Reijnders L, Soret S. Quantification of the environmental impact of different dietary protein choices. *Am J Clin Nutr* 2003;78(suppl):664S–8S.
- Viglizzo EF, Pordomingo AJ, Castro MG, Lertora FA. Environmental assessment of agriculture at a regional scale in the Pampas of Argentina. *Environ Monit Assess* 2003;87:169–95.
- Cavero J, Beltran A, Aragues R. Nitrate exported in drainage waters of two sprinkler-irrigated watersheds. *J Environ Qual* 2003;32:916–26.
- Cowling E, Galloway J, Furiness C, et al. Optimizing nitrogen management in food and energy production and environmental protection: summary statement from the Second International Nitrogen Conference. *ScientificWorldJournal* 2001;1:1–9.
- Mineau P, McLaughlin A. Conservation of biodiversity within Canadian agricultural landscapes: integrating habitat for wildlife. *J Agric Environ Ethics* 1996;9:93–113.
- Pimentel D, Acquay H, Biltonen M, et al. Environmental and economic costs of pesticide use. An assessment based on currently available U.S. data, although incomplete, tallies \$8 billion in annual costs. *Bioscience* 1992;42:750–60.
- Paoletti MG, Pimentel D. Environmental risks of pesticides versus genetic engineering for agricultural pest control. *J Agric Environ Ethics* 2000;12:279–303.
- Pimentel D, McLaughlin L, Zepp A, et al. Environmental and economic effects of reducing pesticide use in agriculture. *Agric Ecosyst Environ* 1993;46:273–88.
- Foster V, Mourato S, Tinch R, Ozdemiroglu E, Pearce D. Incorporation external impacts in pest management choices. In: Vorley W, Keeney D, eds. Bugs in the system. London, United Kingdom: Earthscan Publications Limited, 1998:94–106.
- Leviton L, Merwin I, Kovach J. Assessing the relative environmental impacts of agricultural pesticides: the quest for a holistic method. *Agric Ecosyst Environ* 1995;55:153–68.
- Kishi M, Ladou J. International pesticide use. Introduction. *Int J Occup Environ Health* 2001;7:259–65.
- Burn A. Pesticide buffer zones for the protection of wildlife. *Pest Manag Sci* 2003;59:583–90.
- Pretty J. Agricultural sustainability: concepts, principles and evidence. *Philos Trans R Soc Lond B Biol Sci* 2008;363:447–65.
- Delgado C, Rosegrant M, Steinfeld H, Ehui S, Courbois C. Livestock to 2020: the next food revolution. Washington, DC: International Food Policy Research Institute, 2001:27–9.
- US General Accounting Office, Committee on Agriculture Nutrition and Forestry. Animal agriculture: waste management practices: report to the Honorable Tom Harkin, Ranking Minority Member, Committee on Agriculture, Nutrition, and Forestry, U.S. Senate United States General

- Accounting Office. Washington, DC: US General Accounting Office, 1999.
42. Eshel G, Martin PA. Diet, energy, and global warming. *Earth Interact* 2006;10:1–17.
  43. Uri ND, Lewis JA. The dynamics of soil erosion in US agriculture. *Sci Total Environ* 1998;218:45–58.
  44. Asner GP, Elmore AJ, Olander LP, Martin RE, Harris AT. Grazing systems, ecosystem responses, and global change. *Annu Rev Environ Resour* 2004;29:261–99.
  45. Gilchrist P. Involvement of free-flying wild birds in the spread of the viruses of avian influenza, Newcastle disease and infectious bursal disease from poultry products to commercial poultry. *World's Poult Sci J* 2005;61:198–214.
  46. Fowler CW, Hobbs L. Is humanity sustainable? *Proc R Soc Lond B Biol Sci* 2003;270:2579–83.
  47. Gussow JD. Mediterranean diets: are they environmentally responsible? *Am J Clin Nutr* 1995;61:1383S–9S.
  48. Wagner-Weick CW. Agribusiness technology in 2010: directions and challenges. *Technol Soc* 2001;23:59–72.
  49. Marlow HJ. The environmental impact of dietary choice and agriculture in California. PhD dissertation. Loma Linda University, Loma Linda, CA, 2006.
  50. Beeson WL, Mills PK, Phillips RL, Andress M, Fraser GE. Chronic disease among Seventh-day Adventists, a low-risk group: rationale, methodology, and description of the population. *Cancer* 1989;64:570–81.
  51. Ogino A, Orito H, Shimada K, Hirooka H. Evaluating environmental impacts of the Japanese beef cow-calf system by the life cycle assessment method. *J Anim Sci* 2007;78:424–32.
  52. Pimentel D, Pimentel M. Sustainability of meat-based and plant-based diets and the environment. *Am J Clin Nutr* 2003;78(suppl):660S–3S.
  53. McMichael AJ. Integrating nutrition with ecology: balancing the health of humans and biosphere. *Public Health Nutr* 2005;8:706–15.
  54. Duxbury JM, Welch RM. Agriculture and dietary guidelines. *Food Policy* 1999;24:197–209.
  55. Nestle M. Animal v. plant foods in human diets and health: is the historical record unequivocal? *Proc Nutr Soc* 1999;58:211–8.
  56. Leitzmann C. Nutrition ecology: the contribution of vegetarian diets. *Am J Clin Nutr* 2003;78(suppl):657S–9S.
  57. American Water Works Association. Water use statistics. Version current 1 April 2008. Available from: <http://www.drinktap.org/consumerdnn/Default.aspx?tabid=85> (cited 1 April 2008).
  58. US Geological Survey. Water science for schools. Version current 1 April 2008. Available from: <http://ga.water.usgs.gov/edu/qahome.html#HDR3> (cited 1 April 2008).
  59. Schmitz A, Schmitz TG, Rossi F. Agricultural subsidies in developed countries: impact on global welfare. *Rev Agric Econ* 2006;28:416–25.
  60. Koo WW, Kennedy PL. The impact of agricultural subsidies on global welfare. *Am J Agric Econ* 2006;88:1219–26.
  61. Rajaram S, Sabaté J. Preface. *Am J Clin Nutr* 2009;89(suppl):1541S–2S.
  62. Jacobs DR Jr, Gross MD, Tapsell LC. Food synergy: an operational concept for understanding nutrition. *Am J Clin Nutr* 2009;89(suppl):1543S–8S.
  63. Jacobs DR Jr, Haddad EH, Lanou AJ, Messina MJ. Food, plant food, and vegetarian diets in the US dietary guidelines: conclusions of an expert panel. *Am J Clin Nutr* 2009;89(suppl):1549S–52S.
  64. Lampe JW. Interindividual differences in response to plant-based diets: implications for cancer risk. *Am J Clin Nutr* 2009;89(suppl):1553S–7S.
  65. Simon JA, Chen Y-H, Bent S. The relation of  $\alpha$ -linolenic acid to the risk of prostate cancer: a systematic review and meta-analysis. *Am J Clin Nutr* 2009;89(suppl):1558S–64S.
  66. Pierce JP, Natarajan L, Caan BJ, et al. Dietary change and reduced breast cancer events among women without hot flashes after treatment of early-stage breast cancer: subgroup analysis of the Women's Healthy Eating and Living Study. *Am J Clin Nutr* 2009;89(suppl):1565S–71S.
  67. Newby PK. Plant foods and plant-based diets: protective against childhood obesity? *Am J Clin Nutr* 2009;89(suppl):1572S–87S.
  68. Barnard ND, Cohen J, Jenkins DJA, et al. A low-fat vegan diet and a conventional diabetes diet in the treatment of type 2 diabetes: a randomized, controlled, 74-wk clinical trial. *Am J Clin Nutr* 2009;89(suppl):1588S–96S.
  69. Mangat I. Do vegetarians have to eat fish for optimal cardiovascular protection? *Am J Clin Nutr* 2009;89(suppl):1597S–601S.
  70. Willis LM, Shukitt-Hale B, Joseph JA. Modulation of cognition and behavior in aged animals: role for antioxidant- and essential fatty acid-rich plant foods. *Am J Clin Nutr* 2009;89(suppl):1602S–6S.
  71. Fraser GE. Vegetarian diets: what do we know of their effects on common chronic diseases? *Am J Clin Nutr* 2009;89(suppl):1607S–12S.
  72. Key TJ, Appleby PN, Spencer EA, Travis RC, Roddam AW, Allen NE. Cancer incidence in vegetarians: results from the European Prospective Investigation into Cancer and Nutrition (EPIC-Oxford). *Am J Clin Nutr* 2009;89(suppl):1620S–6S.
  73. Key TJ, Appleby PN, Spencer EA, Travis RC, Roddam AW, Allen NE. Mortality in British vegetarians: results from the European Prospective Investigation into Cancer and Nutrition (EPIC-Oxford). *Am J Clin Nutr* 2009;89(suppl):1613S–9S.
  74. Craig WJ. Health effects of vegan diets. *Am J Clin Nutr* 2009;89(suppl):1627S–33S.
  75. Weaver CM. Should dairy be recommended as part of a healthy vegetarian diet? Point. *Am J Clin Nutr* 2009;89(suppl):1634S–7S.
  76. Lanou AJ. Should dairy be recommended as part of a healthy vegetarian diet? Counterpoint. *Am J Clin Nutr* 2009;89(suppl):1638S–42S.
  77. Sabaté J, Ang Y. Nuts and health outcomes: new epidemiologic evidence. *Am J Clin Nutr* 2009;89(suppl):1643S–8S.
  78. Ros E. Nuts and novel biomarkers of cardiovascular disease. *Am J Clin Nutr* 2009;89(suppl):1649S–56S.
  79. Rajaram S, Haddad EH, Mejia A, Sabaté J. Walnuts and fatty fish influence different serum lipid fractions in normal to mildly hyperlipidemic individuals: a randomized controlled study. *Am J Clin Nutr* 2009;89(suppl):1657S–63S.
  80. Lampe JW. Is equol the key to the efficacy of soy foods? *Am J Clin Nutr* 2009;89(suppl):1664S–7S.
  81. Badger TM, Gilchrist JM, Pivik RT, et al. The health implications of soy infant formula. *Am J Clin Nutr* 2009;89(suppl):1668S–72S.
  82. Messina M, Wu AH. Perspectives on the soy-breast cancer relation. *Am J Clin Nutr* 2009;89(suppl):1673S–9S.
  83. Lönnerdal B. Soybean ferritin: implications for iron status of vegetarians. *Am J Clin Nutr* 2009;89(suppl):1680S–5S.
  84. Chan J, Jaceldo-Siegl K, Fraser GE. Serum 25-hydroxyvitamin D status of vegetarians, partial vegetarians, and nonvegetarians, the Adventist Health Study-2. *Am J Clin Nutr* 2009;89(suppl):1686S–92S.
  85. Elmadfa I, Singer I. Vitamin B-12 and homocysteine status among vegetarians: a global perspective. *Am J Clin Nutr* 2009;89(suppl):1693S–8S.
  86. Carlsson-Kanyama A, González AD. Potential contributions of food consumption patterns to climate change. *Am J Clin Nutr* 2009;89(suppl):1704S–9S.
  87. Eshel G, Martin PA. Geophysics and nutritional science: toward a novel, unified paradigm. *Am J Clin Nutr* 2009;89(suppl):1710S–6S.