Diet and the environment: does what you eat matter?[1–4]

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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 ≤80% of the water consumed in the United States (15, 21) to irrigate ≈10–15% 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

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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 ≈0.5 calories, and animal products return ≈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 ≈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, ≈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 lead 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 nonvegetarian 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, ≈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[1]

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

[1] Food composition of vegetarian and nonvegetarian diets was calculated from the Adventist Health Study (50).
[2] Expressed as ratio of vegetarian to nonvegetarian diet.
[3] 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.
[4] 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 ≈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[1]

Input[2]	Ratio[3]
Water (L)	2.9
Primary energy (kJ)	2.5
Fertilizer (g)	13
Pesticides (g)	1.4

[1] 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).
[2] Expressed as cumulative requirements.
[3] Expressed as ratio of nonvegetarian to vegetarian input quantities.

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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.)

The authors' responsibilities were as follows—HJM: was the principal author of the manuscript and was primarily responsible for the design of the experiment, collection and analysis of data, and writing of the manuscript; WKH, SS, and JS: contributed to the writing and editing of the manuscript; And RLC and ERS: provided significant advice and consultation during the data analysis and manuscript preparation. None of the authors declared a conflict of interest.

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