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Replacement of meat and dairy by plant-derived foods: estimated effects on land use, iron and SFA intakes in young Dutch adult females

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Abstract

Objective: Reduction in the current high levels of meat and dairy consumption may contribute to environmental as well as human health. Since meat is a major source of Fe, effects on Fe intake need to be evaluated, especially in groups vulnerable to negative Fe status. In the present study we evaluated the effects of replacing meat and dairy foods with plant-based products on environmental sustainability (land requirement) and health (SFA and Fe intakes) in women.
Design: Data on land requirements were derived from existing calculation methods. Food composition data were derived from the Dutch Food Composition Table 2006. Data were linked to the food consumption of young Dutch women. Land requirements and nutrient intakes were evaluated at baseline and in two scenarios in which 30 % (Scenario_30 %) or 100 % (Scenario_100 %) of the dairy and meat consumption was randomly replaced by the same amount of plant-based dairy- and meat-replacing foods.
Setting: The Netherlands.
Subjects: Three hundred and ninety-eight young Dutch females.
Results: Replacement of meat and dairy by plant-based foods benefited the environment by decreasing land use. The intake of SFA decreased considerably compared with the baseline situation. On average, total Fe intake increased by 2·5 mg/d, although most of the Fe intake was from a less bioavailable source.
Conclusions: Replacement of meat and dairy foods by plant-based foods reduced land use for consumption and SFA intake of young Dutch females and did not compromise total Fe intake.

Keywords
Sustainable food consumption
Land requirement
Iron
SFA
Scenario analyses

On a global scale the production of animal products, for meat and dairy, has a negative impact on the environment. Major environmental problems related to livestock production are land use change, consequent loss of biodiversity, and the emission of greenhouse gases (GHG) and nitrogen in various forms[1]. The livestock sector accounts for 70 % of all agricultural land usage[2]. Globally, the demand for meat and dairy is increasing rapidly[2]. To reduce the environmental damage, it is recommended that the current high consumption of meat (especially ruminant red meat) and dairy should be reduced[1]. Further, meat and dairy foods are the main source of SFA. On the other hand, however, they are also important sources of certain vitamins and minerals, such as vitamin B_{12}, vitamin B_2, Ca and Fe[3]. The recommended intakes of these nutrients are difficult to obtain[4]. In the present study we focused on the intakes of SFA and Fe in adult women. Intakes of SFA are above the recommended maximum 10 % of total energy intake in adults[5,6]. Lowering of dietary saturated fat intake is associated with a reduced risk of IHD[7]. Conversely, Fe intake in children and women of childbearing age is in most countries below recommendations[5,8]. A low Fe intake is among the major risk factors for Fe deficiency[9]. Fe deficiency is estimated to be the most common cause of anaemia worldwide and is also prevalent in developed countries[10]. In the Netherlands it is estimated that 14·2 % of non-pregnant women of childbearing age are anaemic[11]. A lowering of meat consumption would specifically lower the intake of haem-Fe, the best source of bioavailable Fe. Before a reduction of meat and dairy products can be recommended, the nutritional impact of meat and dairy reductions needs to be evaluated, especially in women.

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In the present study we estimated the effects of replacement of meat and dairy foods by plant-derived dairy- and meat-replacing foods on the environment as measured by land use and on health as measured by the intakes of Fe and SFA.

Methods

Land use and nutritional composition of foods

In the present study we relied on land use as the environmental parameter. The starting point of the research was the conversion model[12] developed from a food safety perspective to convert foods as consumed into primary agricultural products. With this model, the amount of primary agricultural products consumed is linked to concentrations of e.g. contaminants or residues measured in primary agricultural products. In the current study, the conversion model was applied in the opposite direction to determine land use of foods as consumed from land use of primary agricultural products; we did not take into account the land used for packaging the foods.

In the last decade, methods have been developed to quantify the land required for food[13–16]. These methods work as follows: for food products the agricultural product that forms the basis is determined (so for sugar this can be sugar beet or sugar cane). Then the amount of agricultural product that is needed for 1 kg of food product (sugar) is determined (in the case of sugar beet, 7 kg of sugar beet is needed for 1 kg of sugar). This value is combined with the yield of the crop (kg/ha) leading to the area required to produce the food product. For animal products, the amount and type of feed (wheat, soyabeans, maize, etc.) needed for the production of milk/meat/eggs is determined. Again, this value is combined with the crop yields of the crops used as feed, resulting in the area required for the production of animal products. For most agricultural products information is available. Data show large variations due to differences in crop yields in different parts of the world. For all primary agricultural products in the conversion model, the land requirements were determined based on the requirements mentioned in Elferink and Nonhebel[13] and Gerbens-Leenes *et al.*[15] for the Dutch situation. Through using the conversion model, it was possible to quantify the land required for producing 200 g of cake on the basis of the land required to produce 1 kg of wheat, 1 kg of sugar, 1 kg of eggs and 1 kg of butter.

Food composition data for foods as consumed were derived from the Dutch Food Composition Table 2006[17,18].

Food consumption

Food consumption data for young adults in 2003, taken from the Dutch Food Consumption Survey (DFCS), were used[19]. The aim of the DFCS was to assess the dietary consumption of men and women aged 19 to 30 years (n 750). In the present study we were interested only in the food consumption of women, as they are more vulnerable to Fe deficiency. In a representative sample of 398 young females, diet was assessed by two 24 h recalls conducted on independent days by trained dietitians. The women were non-pregnant and not lactating. During a 24 h recall the participants reported the types and quantities of all foods and beverages that were consumed during the preceding day. To obtain a standardised 24 h recall interview, the validated software package EPIC-SOFT was used[20].

Simultaneous nutrient intake and land use assessment

Individuals in a population differ in their dietary habits and this has an influence on both their intake of nutrients and the land requirements connected with their consumption pattern. In the present study we quantified nutrient intake and land requirements related to the habitual food consumption of individuals simultaneously. Whereas individual intake is obviously relevant for individual health, individual land requirement is a new concept, which is of more psychological relevance to an individual person (comparable to the idea of the ecological footprint).

In the current study we calculated the distributions of habitual intake and land use in the population of young Dutch females. These distributions were compared with dietary recommendations and a cut-off value for land use, resulting in estimated proportions of this population that conforms to these guidelines. Dietary reference intake of total Fe for young women, as set by the Health Council of the Netherlands, is 15 mg/d. The value is based on an adequate intake. The recommendation for SFA content of the diet is ≤10 % of total daily energy intake[21]. For individual land use no recommendations exist as this is a new concept. In the present study, for illustrative purposes, we applied a tentative limit value of 4 m^2 year/d, which was an amount of land use not exceeded by the majority of the population.

The nutrient intake or individual land use associated with consumption on a particular day was estimated by multiplying nutrient concentration and consumption per person-day for each food, and then summing over all relevant foods in the diet. In more detail, y_{ij}, the intake or land use by individual i on day j (in mg/d for Fe, g/d for SFA or m^2 year/d for land use), was estimated as the sum over foods of x_{ijk}, the consumed amount of a food k by individual i on day j (g/d), multiplied by c_k, the nutrient concentration in or land use of food k (mg/kg for Fe, g/kg for SFA or m^2 year/kg for land use). To calculate the percentage of total energy (E%) from SFA, daily intakes of SFA (in g/d) were converted into kJ/d (1 g of fat is 38 kJ) and then divided by the individual's daily intake of energy and multiplied by 100.

The habitual intake and land use distribution were estimated from the daily values with a bivariate lognormal

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distribution variance components model[22]. In short, the data were logarithmically transformed to achieve a better normality and stabilise the variance. Subsequently, between-person and within-person variance components were estimated for land requirement (A), nutrient intake (B) and the sum of these two variables (A + B). From the variance components estimated with the three models it was then possible to estimate the correlation between land requirement and nutrient intake[22]. Together with the means and variances for the logarithms of land requirement and nutrient intake, this defines a bivariate normal distribution. A large number of samples from this distribution were then classified into the four quadrants determined by the limit values for land use and nutrient intake to derive the number of the population that did or did not conform to desired food policies.

Scenario analyses

A list of dairy and meat consumptions as well as the frequency of consumption was derived from the DFCS 2003. Exchange tables were devised for two replacement scenarios. Consumed foods other than meat and dairy were not replaced and assumed not to change. In the intermediate scenario (Scenario_30 %), 30 % of dairy and meat consumption was randomly replaced by the same amount of a plant-based dairy- or meat-replacing food. In the maximum scenario (Scenario_100 %) all dairy and meat consumption was replaced by the same amount of a similar plant-based dairy- or meat-replacing food.

The plant-based foods that replaced meat and dairy foods and their composition are shown in the lower part of Table 1. Liquid dairy foods were replaced by similar soya-based dairy foods, e.g. milk by soya milk without sugar, yoghurt drink by sweetened soya milk and vanilla custard by a soya dessert. Meat products and cheese to be used as sandwich fillings were replaced by a variety of other sandwich fillings/toppings. The replacements of sandwich filling meat products and cheese were made with a probability proportional to frequency of consumption of these toppings in the baseline situation (see Table 1). Thus, the main substitutes for meat and cheese as sandwich filling were peanut butter, chocolate nut spread, jam and chocolate sprinklers. Meat products to be used in hot meals were replaced by a variety of meat replacers. Preferred meat substitutes were obtained on the advice of the Dutch Nutrition Centre[23] and included vegetarian meat substitutes, tofu, pulses and eggs. Replacements were made as follows. First, a category of replacement was chosen according to fixed probabilities: vegetarian meat substitutes (43 %, three times weekly), egg dishes (29 %, twice weekly), pulses (14 %, once weekly) or tofu/tempeh (14 %, once weekly). Subsequently, within the chosen category a vegetarian product was chosen with a probability proportional to the frequency of consumption of the products in this category in the baseline situation (Table 1). Finally, soft cheese, usually consumed in the Netherlands as a snack, was replaced by popcorn. The scenarios chosen enabled us to evaluate the reduction in meat and dairy consumption while staying as close as possible to habitual eating habits. For all foods, replacements were based on the quantity of the food originally consumed, i.e. the amount (in grams) of the original food consumed was replaced by exactly the same amount of the replacement food. The normal serving sizes for sandwich fillings are similar for meat (15–20 g/sandwich) compared with the plant-based substitution food such as jam or peanut butter (15–20 g/sandwich).

Results

Table 1 shows land requirements, SFA and total Fe content of the three most consumed meat or dairy foods. The composition of all replacement foods is also given in this table. Land requirements vary according to the type of meat, with a higher land use for beef than for pork and the lowest for chicken. SFA as well as total Fe contents are high in pork or beef sausages and lower in chicken fillet. The proportion of haem-Fe varies from 80 % in pork or beef meat to 35 % in chicken (data not shown). The total Fe content of the meat substitutes (variety of sandwich toppings and vegetarian dishes) is, in general, higher than in the original meats but it is 100 % non haem-Fe, which is less bioavailable. Cheese is especially high in SFA content and low in Fe content.

The land use is similar for all types of liquid dairy food. The amount of SFA depends on the extent of skimming and the Fe content of dairy foods is low. The total fat content of the replacement soya milk and desserts is between that for full-fat and semi-skimmed milk (data not shown), but the SFA content of the soya milk and desserts is low and similar to the content in buttermilk. The Fe content of the soya replacement foods is slightly higher than that of the liquid dairy products, except for the dairy drinks with chocolate.

Land use by consumption, habitual intakes of Fe and SFA

In Table 2, the average land use for consumption and habitual intakes of Fe and SFA are given. Figure 1 presents the contribution of food groups to land requirements, Fe and SFA intakes at baseline. The average land use in this population of young females was 3·7 (SD 1·0) m^2 year/d. The most important contributor to land use was meat (39 %), of which minced meat was the food with the highest contribution to land used for consumption. Dairy products contributed 16 % to land use and semi-skimmed milk was the food contributing most in this category. Drinks, of which brewed coffee was the most important source, contributed 10 % to land use. Expressed as primary agricultural products, beef (21 %), cow's milk (17 %), oils

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Table 1 Average consumption, land requirement and nutritional composition of meat and dairy foods (three most consumed foods) and replacement foods

	Consumption at baseline		Environment	Nutrition		
	Person-days	g/d	Land requirement (m^2 year/kg)	SFA (g/100 g)	Total Fe (mg/100 g)	Replaced by
Meat and cheese						
Meat products and cheese for sandwiches						Sandwich toppings, variety*
Cheese, Gouda	364	42	10·0	20·5	0·2	
Ham, shoulder, medium fat, boiled	93	28	10·0	2·3	1·0	
Sausage, luncheon meat	61	16	19·0	9·7	1·3	
Meat, other						Meat replacer
Minced meat, beef/pork 50/50, raw	69	64	19·0	9·7	1·5	
Chicken fillet, raw	79	79	8·0	0·5	0·6	
Pork, 5–14 % fat, raw	38	35	10·0	3·6	1·0	
Dairy products, liquid						
Drinks (non-sweetened)						Soya milk, high calcium
Milk, semi-skimmed	339	316	2·0	1·0	0·0	
Buttermilk	48	336	2·0	0·3	0·0	
Milk, whole	30	277	2·0	2·0	0·0	
Drinks (sweetened)						Soya milk chocolate/strawberry
Yoghurt, flavoured drink	31	265	1·8	0·0	0·0	
Chocolate drink, semi-skimmed milk	29	257	1·9	1·0	0·3	
Chocolate drink, whole milk			1·9	1·9	0·7	
Yoghurts and desserts						Dessert soya
Yoghurt, low fat	91	176	2·0	0·0	0·1	
Custard, vanilla full fat	32	173	1·9	1·8	0·0	
Yoghurt, low fat with fruit	33	212	1·8	0·0	0·1	
Replacement foods						
Soya replacers for liquid dairy products						
Soya milk, high calcium		310	0·4	0·3	0·3	
Soya milk, chocolate/strawberry		267	0·4	0·4	0·5	
Dessert soya, chocolate/vanilla/caramel		176	0·4	0·4	0·6	
Sandwich toppings, variety*, top 10						
Peanut butter	67	25	1·4	9·8	1·4	
Chocolate nut spread	63	34	6·0	8·7	2·8	
Jam, household quality	60	26	0·6	0·0	0·4	
Sprinklers, chocolate, pure	54	16	1·2	9·4	8·1	
Sprinklers, chocolate, average	47	14	1·1	9·3	3·2	
Sprinklers, chocolate, milk	40	14	0·9	9·0	4·5	
Apple syrup	38	32	0·7	0·0	14·9	
Sprinklers, fruit	31	14	0·7	0·0	0·1	
Honey	26	31	0·1	0·0	0·8	
Chocolate, flakes, milk	20	14	1·0	8·6	4·4	
Meat replacers						
Eggs, chicken, boiled		41	4·0	2·6	1·9	
Marrowfats, canned		24	0·8	0·1	1·0	
Beans baked in tomato sauce, canned		134	1·0	0·1	1·8	
Beans, brown, canned		98	1·0	0·1	1·5	
Tofu, soya curd		78	1·1	1·0	2·2	
Peas, chick, fresh		7	1·0	0·4	1·8	
Hamburger, vegetarian, raw		100	1·9	0·8	2·1	
Quorn pieces		80	3·6	0·6	0·5	
Quorn filet		65	4·2	1·2	0·5	
Quorn, southern-style burger		72	3·9	2·0	0·6	
Vegetarian meat balls		71	3·4	0·8	2·1	
Soft cheese						
Popcorn		88	1·0	1·0	1·1	

*Soft cheese was replaced by popcorn.

and fats (10 %) and cheese (8 %) contributed the most to land use for consumption.

The average total Fe intake was 9·5 (SD 2·3) mg/d in this female population. Main sources of Fe intake were bread (23 %), meat (and products; 15 %) and drinks (such as coffee; 11 %). SFA intake was 13·2 (SD 2·7) E% in the baseline situation. Cheese (19 %), meat (and products; 18 %), fats and oils (16 %) and dairy products (14 %) contributed largely to SFA intake.

Scenario analyses

Land use for consumption and intakes of Fe and SFA in the two replacement scenarios are shown in Table 2 and Fig. 2. When all meat and dairy foods were replaced (Scenario_100 %), land use reduced from 3·7 to 1·8 (SD 0·5) m^2 year/d. In this 100 % replacement scenario the major foods contributing to land use were brewed coffee and eggs. Fe intake, in the 100 % scenario, increased from 9·5 to 12·0 (SD 3·1) mg/d. At baseline about 10 % of total Fe was from haem-Fe; in the 100 % replacement scenario almost all Fe was from non-haem sources. Major foods contributing to Fe intake were bread, eggs and soya desserts. In addition, the sandwich toppings containing chocolate and apple syrup contributed more to Fe intake in this scenario. SFA intake decreased from 13·2 to 9·2 (SD 1·5) E%. In the 100 % replacement scenario, 62 % of the women complied with the recommendation for SFA intakes compared with 20 % at baseline. As expected, in the 30 % replacement scenario (Scenario_30 %) changes were in a similar direction but were less pronounced (Table 2).

Figure 2 shows the shifts in land use and intakes of Fe and SFA in the young women. Each plot is divided into four quadrants. For land use and Fe intake, the upper left quadrant is the most beneficial, indicating low land use and higher total Fe. In the 100 % replacement scenario, 21 % of the women were in the upper left quadrant, compared with 2 % at baseline (Fig. 2(a)). For land use and SFA intake, low land use and low SFA intake are the most beneficial outcomes, shown in the lower left quadrant. In the 100 % replacement scenario, 62 % of the women were in this lower left quadrant compared with 16 % at baseline (Fig. 2(b)). In general, with the replacement scenarios the variation in land use in the population decreased, whereas the variation in intakes of Fe increased. Again, the shifts were more pronounced for the 100 % scenario than for the 30 % scenario.

Table 2 Land use for consumption and habitual intakes of iron and SFA in young Dutch females (*n* 398) aged 19–30 years in the different scenarios of replacing meat and dairy foods with plant-based products

	Mean	SD	95th percentile
Land use (m^2 year/d)			
Baseline	3·7	1·0	5·5
Scenario_30 %	3·1*	0·8	4·6
Scenario_100 %	1·8*	0·5	2·6
SFA (E%/d)			
Baseline	13·2	2·7	18·1
Scenario_30 %	12·1*	2·3	16·4
Scenario_100 %	9·2*	1·5	11·9
Total Fe intake (mg/d)			
Baseline	9·5	2·3	13·6
Scenario_30 %	10·2*	2·3	14·4
Scenario_100 %	12·0*	3·1	17·8

E%, percentage of total energy.
In Scenario_30 % and Scenario_100 %, respectively 30 % and 100 % of the dairy and meat consumption was randomly replaced by the same amount of plant-based dairy- and meat-replacing foods.
Mean values were significantly different from those of the baseline scenario (tested in a pairwise *t* test on the log values per person-day): $*P < 0·001$.

Discussion

The present modelling study showed that replacement of meats and dairy foods by plant-based alternatives leads to considerable changes in land use for consumption and in nutritional intakes. In the 100 % scenario, land use was halved and estimated SFA intake decreased by 4 E%. With the replacements, total Fe intake increased by 2·5 mg/d compared with the baseline situation.

To our knowledge, the present study is one of the first to assess environmental as well as nutritional aspects of food intake simultaneously. Recently, studies have focused on the environmental aspects of the adoption of healthy diet recommendations[24,25]. Adopting healthy diet recommendations reduces the environmental (GHG emissions and land use) impact compared with current dietary patterns[24,25]. Dietary shifts from dairy products and red meats to cereals may lower the personal nitrogen

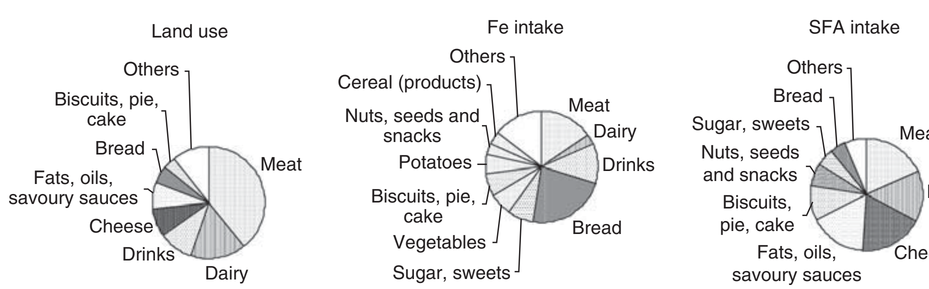

Fig. 1 Main contributors to land use for consumption, SFA intake and iron intake at baseline among young Dutch females (*n* 398) aged 19–30 years

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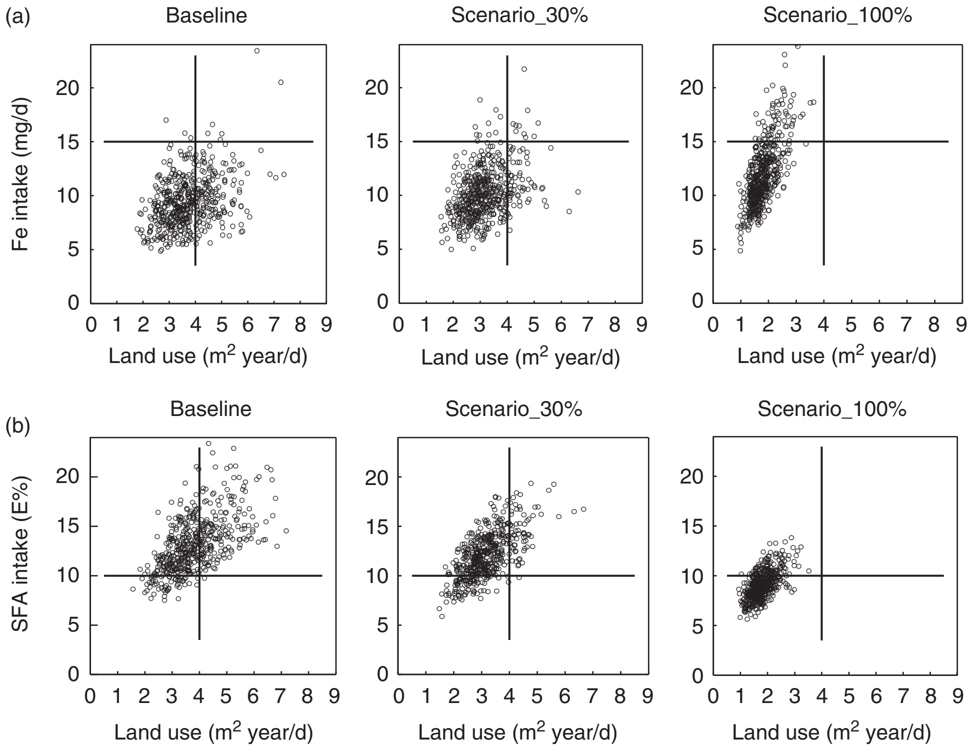

Fig. 2 Shifts in land use for consumption, SFA intake and iron intake among young Dutch females (*n* 398) aged 19–30 years in the different scenarios of replacing meat and dairy foods with plant-based products: (a) land use and iron intake at baseline, Scenario_30 % and Scenario_100 %; (b) land use and SFA intake at baseline, Scenario_30 % and Scenario_100 %. In Scenario_30 % and Scenario_100 %, respectively 30 % and 100 % of the dairy and meat consumption was randomly replaced by the same amount of plant-based dairy- and meat-replacing foods (E%, percentage of total energy)

footprint[26]. Other studies show the environmental impacts of meals with similar energy or protein content but a wide span of GHG emissions owing to different protein sources[27,28]. Lock *et al.* applied an interesting broader approach and estimated the effects of a healthy sustainable diet policy on health as well as the economy in different countries[29].

The land use reduction observed in the present study, by replacing meat and dairy foods with plant-based foods, confirms previous findings. The concomitant estimates of nutritional changes for SFA and Fe intakes represent new findings. The reduced intake of SFA obtained by lowering meat and dairy consumption is worthwhile; three times the number of females met the recommendations in the 100 % scenario. This may contribute to lowering the risk of CVD[7]. Fe intake of the young Dutch women was comparable to other results of populations within Western countries, with a large number below the recommended Fe intake[11]. With the replacements made in the current study, total Fe intake did not decrease but even increased by 2·5 mg/d compared with baseline. At baseline, however, about 10 % of the total Fe intake was haem-Fe, whereas in the 100 % scenario all Fe was non-haem. This might be a concern since it is known that non haem-Fe is absorbed less efficiently than haem-Fe[30]. On the other hand, Fe absorption is tightly regulated by Fe status and body storage; if Fe storage is depleted, more Fe is absorbed[31]. Cross-sectional studies suggest that vegetarian women have similar or even higher Fe intakes[32–34] and similar Hb concentrations[34] than meat-consuming women. Serum ferritin concentrations are mostly lower in vegetarian than in meat-consuming women[33,34], but usually within the reference range. A recent report[8] considering the implications of a reduction in meat consumption on the Fe status of the UK population advised focusing on total Fe intake via a healthy balanced diet which includes a variety of foods containing Fe. Our study confirmed that a plant-based diet does not lower total Fe intake, and with the replacements chosen even increases total Fe intake slightly.

The choice of replacement foods and their nutritional composition is crucial for intake calculations in the different scenarios. In the current study we chose to replace meat and dairy foods with plant-based foods which have a similar use to the reference food. It was assumed that the replacement foods were consumed in similar amounts. The replacement of meats and cheese toppings on sandwiches by other plant-based sandwich toppings is in line with current Dutch consumption patterns. In addition, replacements for sandwich toppings were in proportion to current use, which may be the most realistic scenario. However, while the toppings are derived from

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plants, most toppings may contain high contents of sugar. This will lead to increased sugar intakes. Further innovations are needed to develop plant-based foods with low sugar, Na and SFA contents, as well as foods that can be consumed as a replacement to animal-based sandwich toppings and that are appealing to consumers. Meats in hot meals were replaced by vegetarian alternatives, including eggs. The choice of plant-based meat substitutes in hot meals is in line with the healthy diet recommendations[23]. For dairy foods – milk and dairy desserts – we chose for a replacement with soya-based dairy foods. We could have chosen other plant-based milks (i.e. oat, rice) as well. The soya-derived milk and dessert replacements made are probably less realistic than the meat replacements. Not many people use soya drinks and eat soya desserts, especially on a daily basis, except for medical reasons such as allergies. Whereas dairy is not a good source of Fe, soya-based milk and desserts contain more Fe and contributed significantly to Fe intake in the replacement scenarios. In general, studies suggest that a large proportion of the population is not yet ready to consume a fully plant-based diet[35,36]. In addition, the awareness of the impact on the environment of meat production is low, even among those who already believe that food-related actions are important in helping the environment[37]. Therefore it is likely that, at least in the short term, interest in plant-based diets which contain some meat will be higher. Therefore, a scenario in which some part of meat and dairy foods is replaced by plant-based foods, as in the 30 % scenario, is probably more realistic than the 100 % scenario.

In the current paper we rely on the environmental parameter land use. For this indicator the primary production phase is the most important. Another indicator of environmental impact would be GHG emissions. For this indicator, processing and packaging would contribute more to impact. The data used in our analysis for land use of different foods and food composition were the best available. The data were used to show differences between the replacement scenarios compared with the baseline situation. Land use data are very sensitive to assumptions with respect to yields, which show very large variations. To study the consequences of changes in food patterns it is essential that assumptions with respect to yields are consistent over the whole set of data. As mentioned in the Methods section, the land use data in the present study were obtained from different publications; however, calculation methods were consistently applied. The data are suitable for estimating differences between scenarios. Another aspect that needs careful future consideration is the quality of the conversion model of primary agricultural products[12], which was developed from a food safety perspective. For some foods the conversion lacks the required level of detail. For example, conversions of unspecified fats are now coded as a combination of animal and vegetal fat, whereas for some foods, such as specific types of margarines, vegetable fat is used, and some recipes may have been updated. These factors may have led to imprecise estimates of land use, but do not affect conclusions about the nutritional differences between scenarios. Data on food consumption were based on two one-day dietary assessments. It needs further evaluation whether this is good enough to assess individual assessments for environmental aspects such as land requirements or other indicators such as GHG emissions.

Conclusion

Replacement of meat and dairy foods by plant-based foods reduced land use for consumption and SFA in young Dutch females and did not compromise total Fe intake. Sugar intake will probably increase, although this was not quantified.

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References

1. McMichael AJ, Powles JW, Butler CD *et al.* (2007) Food, livestock production, energy, climate change, and health. *Lancet* **370**, 1253–1263.
2. Steinfeld H, Gerber P, Wassenaar T *et al.* (2006) *Livestock's Long Shadow, Environmental Issues and Options*. Rome: FAO.
3. Hill M (2002) Meat, cancer and dietary advice to the public. *Eur J Clin Nutr* **56**, Suppl. 1, S36–S41.
4. Millward DJ & Garnett T (2011) Food and the planet: nutritional dilemmas of greenhouse gas emission reductions through reduced intakes of meat and dairy foods. *Proc Nutr Soc* **69**, 103–118.
5. World Health Organization (2003) *Diet, Nutrition and the Prevention of Chronic Diseases. Joint WHO/FAO Expert Consultation. WHO Technical Report Series* no. 916. Geneva: WHO.
6. van Kreijl C, Knaap A & van Raaij J (2006) *Our Food, Our Health – Healthy Diet and Safe Food in the Netherlands. RIVM Rapport* no. 270555009. Bilthoven: RIVM.
7. Kromhout D, Menotti A, Kesteloot H *et al.* (2002) Prevention of coronary heart disease by diet and lifestyle: evidence from prospective cross-cultural, cohort, and intervention studies. *Circulation* **105**, 893–898.

8. Scientific Advisory Committee on Nutrition (2010) *Iron and Health*. Norwich: Her Majesty's Stationery Office.
9. Stoltzfus RJ (2003) Iron deficiency: global prevalence and consequences. *Food Nutr Bull* **24**, 4 Suppl., S99–S103.
10. McLean E, Cogswell M, Egli I *et al.* (2009) Worldwide prevalence of anaemia, WHO Vitamin and Mineral Nutrition Information System, 1993–2005. *Public Health Nutr* **12**, 444–454.
11. Benoist B, McLean E, Cogswell M *et al*. (2008) *Worldwide Prevalence of Anaemia 1993–2005*. Geneva: WHO.
12. van Dooren MMH, Boeijen I, van Klaveren JD *et al*. (1995) *Conversie van consumeerbare voedingsmiddelen naar primaire agrarische produkten*. *RIKILT Rapport* no. 95.17. Wageningen: RIKILT-DLO.
13. Elferink EV & Nonhebel S (2007) Variations in land requirements for meat production. *J Cleaner Prod* **15**, 1778–1786.
14. Gerbens-Leenes PW & Nonhebel S (2002) Consumption patterns and their effects on land required for food. *Ecol Econ* **42**, 185–199.
15. Gerbens-Leenes PW, Nonhebel S & Ivens WPMF (2002) A method to determine land requirements relating to food consumption patterns. *Agric Ecosyst Environ* **90**, 47–58.
16. Nonhebel S (2005) Renewable energy and food supply: will there be enough land? *Renew Sustain Energy Rev* **9**, 191–201.
17. NEVO Foundation (2006) *NEVO-Table, Dutch Food Composition Table 2006*. Zeist: NEVO Foundation.
18. National Institute for Public Health and the Environment (2009) NEVO-online, version 2009/1.0. http://nevo-online.rivm.nl/ (accessed November 2010).
19. Ocke M, Hulshof K & van Rossum C (2005) The Dutch national food consumption survey 2003. Methodological issues. *Arch Public Health* **63**, 227–241.
20. Slimani N & Valsta L (2002) Perspectives of using the EPIC-SOFT programme in the context of pan-European nutritional monitoring surveys: methodological and practical implications. *Eur J Clin Nutr* **56**, Suppl. 2, S63–S74.
21. Health Council of the Netherlands (2006) *Guidelines for a Healthy Diet 2006*. *Report* no. 2006/21E. The Hague: Health Council of the Netherlands.
22. van der Voet H, de Mul A & van Klaveren JD (2007) A probabilistic model for simultaneous exposure to multiple compounds from food and its use for risk–benefit assessment. *Food Chem Toxicol* **45**, 1496–1506.
23. Voedingscentrum (2009) *Richtlijnen voedselkeuze*. Den Haag: Voedingscentrum.
24. Stehfest E, Bouwman L, van Vuuren DP *et al*. (2009) Climate benefits of changing diet. *Climatic Change* **95**, 83–102.
25. Blonk H, Kool A & Luske B (2008) *Milieueffecten van Nederlandse consumptie van eiwitrijke producten. Gevolgen van vervanging van dierlijke eiwitten anno 2008*. Gouda: Blonk Milieu Advies.
26. Xue X & Landis AE (2010) Eutrophication potential of food consumption patterns. *Environ Sci Technol* **44**, 6450–6456.
27. Carlsson-Kanyama A & Gonzalez AD (2009) Potential contributions of food consumption patterns to climate change. *Am J Clin Nutr* **89**, issue 5, S1704–S1709.
28. Davis J, Sonesson U, Baumgartner DU *et al*. (2010) Environmental impact of four meals with different protein sources: case studies in Spain and Sweden. *Food Res Int* **43**, 1874–1884.
29. Lock K, Smith RD, Dangour AD *et al*. (2010) Health, agricultural, and economic effects of adoption of healthy diet recommendations. *Lancet* **376**, 1699–1709.
30. Hallberg L & Hulthen L (2002) Perspectives on iron absorption. *Blood Cells Mol Dis* **29**, 562–573.
31. Bothwell TH & Charlton RW (1979) Current problems of iron overload. *Recent Results Cancer Res* **69**, 87–95.
32. Davey GK, Spencer EA, Appleby PN *et al*. (2003) EPIC-Oxford: lifestyle characteristics and nutrient intakes in a cohort of 33 883 meat-eaters and 31 546 non meat-eaters in the UK. *Public Health Nutr* **6**, 259–269.
33. Alexander D, Ball MJ & Mann J (1994) Nutrient intake and haematological status of vegetarians and age–sex matched omnivores. *Eur J Clin Nutr* **48**, 538–546.
34. Haddad EH, Berk LS, Kettering JD *et al*. (1999) Dietary intake and biochemical, hematologic, and immune status of vegans compared with nonvegetarians. *Am J Clin Nutr* **70**, 3 Suppl., 586S–593S.
35. Lea EJ, Crawford D & Worsley A (2006) Consumers' readiness to eat a plant-based diet. *Eur J Clin Nutr* **60**, 342–351.
36. Hoek AC, Luning PA, Stafleu A *et al*. (2004) Food-related lifestyle and health attitudes of Dutch vegetarians, non-vegetarian consumers of meat substitutes, and meat consumers. *Appetite* **42**, 265–272.
37. Lea E & Worsley A (2008) Australian consumers' food-related environmental beliefs and behaviours. *Appetite* **50**, 207–214.