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A method to determine land requirements relating to food consumption patterns

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Abstract

Food production requires agricultural land. The area needed to feed a population depends on the one hand on production systems (e.g. yields per hectare), and on the other hand on the consumption (pattern) of this population. The amount of land available for food production is declining due to various reasons. Several studies on the food security item focussing on the production side of the question have been published over the last decade. However, food consumption patterns also have large effects on total land requirements and are probably in the same order of magnitude than changing production levels or the growth of the world population. Available studies estimated that an affluent diet requires more than three times as much land as a vegetarian diet.

In this paper, attention is paid to the impact of consumption patterns on land requirements for food. A method is developed to calculate the land required to produce individual food items. In combination with data on household consumption, total requirements for food can be determined. The method is applied for the Dutch situation in 1990 and resulted in an overview of land requirements for over a hundred individual food items. Large differences between requirements for food items were observed. Especially the consumption of livestock products, oils and fats, and beverages have large effects on total land requirements.

The data obtained with this method can be used to study the impact of relative small changes in consumption patterns. However, results are typical for the Dutch situation and cannot be used to derive land requirements for other populations, but the method can be applied for all countries from which the required data are available. In this way, the study can give a valuable contribution to the discussion on future land use. Available studies on food security have shown that future generations can be fed. The method presented in this study can be used to assess the possibility to do so in a way that not only physical but also cultural and emotional requirements are met. © 2002 Elsevier Science B.V. All rights reserved.

Keywords: Agricultural land; Household food consumption; Land requirement for food; Ecological footprint; The Netherlands

1. Introduction

The agricultural studies on land use done up to now were focussed on food security (e.g. Penning de Vries et al., 1995; Bouma et al., 1998a; Groot et al., 1998). History has shown that technological developments and increased global food trade were the reason that the agricultural sector was so far capable to keep up with population growth (Ivens et al., 1992). According to the medium-fertility scenario of the United Nations, the world population will grow from 5.7 billion persons in 1995 to 9.4 billion in 2050 (United Nations, 1998). When high external input farming (HEI) is practised, simulations of agricultural production

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potentials for the year 2040 indicated that future world populations can be fed (Penning de Vries et al., 1995; Bouma et al., 1998a; Groot et al., 1998).

However, agricultural land is becoming more and more a scarce resource due to ongoing industrialization, urbanization, infrastructural development, land degradation and desertification. Total potential agricultural land in the world is decreasing at a rate of 7% per decade (Oldeman et al., 1991). Between 1950 and 1984, the world grain harvest per person increased from 247 to 342 kg (Brown et al., 1997), but the available agricultural area dropped from 1.5 ha per person in 1961 to 0.8 ha in 1998 (FAO-site Internet, 2001). Continuing degradation of the land, increasing food demand on the world market and the impact of environmental awareness of consumers puts a strain on the ability to produce enough food in the next decades (Bouma et al., 1998b).

On the one hand land requirements for food are determined by the production system, e.g. yields per hectare and efficiency in the food industry, on the other hand by consumption patterns. Food consumption patterns are repeated arrangements that can be observed in the consumption of food by a population group. They have to do with types and quantities of foods and their combinations into different dishes or meals. Tradition and religious rules are often important (Ivens et al., 1992; Whitney and Rolfes, 1999). Food consumption patterns depend on several factors: e.g. personal preference, habit, availability, economy, convenience, ethnic heritage, tradition or other cultural and nutritional requirements (Wijn de and Weits, 1971; Braun von, 1988; Wandel, 1988; Musaiger, 1989; Braun von and Paulino, 1990; Vringer and Blok, 1995; Boom-Binkhorst van der et al., 1997; Whitney and Rolfes, 1999). Consumption patterns differ between communities and between generations (Jobse-van Putten, 1995).

To provide enough energy to stay alive, food has to supply about 10 MJ per capita per day (Voedingscentrum, 1998). However, as soon as welfare rises above the subsistence level, people put other demands on food than ‘enough to stay alive’. Features like taste, day-to-day variety and convenience also become important. In Dutch environmental studies, it has been shown that in the past decades, increasing incomes resulted in a higher use of natural resources such as water (Achtienribbe, 1993) and energy (Vringer and Blok, 1995). Despite the physiological limits of food intake, there could well be a relationship between increasing affluence in society, and hence more affluent food consumption patterns, and higher claims on agricultural land. Available studies estimated that an affluent diet requires more than three times as much land as a vegetarian diet (Penning de Vries et al., 1995; Bouma et al., 1998a; Groot et al., 1998). This implies that the impact of food consumption patterns on land required probably is in the same order of magnitude than changing production levels and the growing world population, but up to now this impact has not been studied in a quantitative manner.

In this article, the relationship between food consumption patterns and land requirements is studied. The article presents a method for assessing land requirements for food. Therefore, detailed microlevel information on land requirements for individual food items and household consumption is required. The analysis is complicated by the large inter-generational and regional differences between food consumption patterns as well as by yield differences between regions. For example, large differences exists between the consumption of specific food items in the countries of the European Union (LEI-DLO/CBS, 1998; FAO-site Internet, 2001). Another complication is that the factors that determine land requirements are interrelated. Systems provide the availability of commodities, but demand determines what and how much is produced and the waste streams that are generated. This implies that the calculation of land requirements can only be performed for a clearly defined situation. In this study, the method is used to assess requirements for Dutch households. Land requirements (m^2 year kg^{-1}) for over a hundred commonly used food items in The Netherlands are calculated. In order to assess household land requirements for food these data are combined with data on household consumption (kg per year).

Information obtained at the bottom of the food system, the household level, can represent a major improvement in the quality of the analyses on the land requirement for food. This type of information provides a valuable link to how food consumption patterns can be related to aggregate demand of resources. The results of this method can be used to study the impact of changes in consumption patterns on land requirements and can contribute to the discussion on future land requirements.

2. System description

Agricultural production provides the availability of food commodities. These commodities are processed in various ways for the production of an enormous variety of food and non-food items. Food items or foodstuffs are products of animal or vegetable origin that are available for consumers. They form the end of the food production chain. In this chain, several basic materials, originating from different food production systems and with different land requirements, are needed. To make a cake, for instance, basic ingredients such as sugar, flour, eggs and butter are needed, and these all have different land requirements. Therefore, land requirements for individual food items can differ considerably. Per capita available amounts of food, like grain or soyabeans, are well known (Brown et al., 1997). However, what is done with this food in production systems remains uncertain. Consumers do not eat grain, they eat bread, pasta or meat. Grain or soyabeans (Glycine max L. Merr.) can directly be processed to produce food items, like bread or oil. They can also be used for livestock fodders, so that basic materials are used indirectly to produce livestock products like meat, milk or eggs. Therefore, consumption patterns, and so demand for food items on a household scale, determines what is done with the available food in production systems. In this way the demand for specific foods strongly influences the size of the agricultural area required.

Food production systems are quite complex. A rough division can be made between primary and secondary production systems. In primary production, crops are grown. These crops form the basis for the secondary or livestock production. Land requirements for commodities originating in primary production systems depend on yields and therefore on crop characteristics and countries of origin. Yields depend heavily on the production system applied. Primary production systems range from systems with high external input and high yields and systems with low external input and relatively low yields. In livestock production systems large amounts of wastes originating in the food industry are used. The production of soya oil for example generates large amounts of oil cakes that are used for livestock fodders. Land requirements for basic materials originating in secondary production therefore depend on: (1) supply of plant materials and waste streams; (2) animal species and (3) characteristics of the production system. Basic materials for food or food items can either be imported or produced in the country itself, while other basic materials or food items are exported.

3. Materials and methods

Several approaches can be applied to assess the total land requirement for food. However, every method must combine data on food consumption with data on production. In the environmental research, a method is developed to calculate energy requirements for household purchases (Engelenburg van et al., 1994) and for food items (Kok et al., 1993). This method uses items of consumption as its basic unit of measurement. The assessment of per household consumption is based on household expenditure and on prices of consumption items. The results are combined with calculations on energy requirements for consumption items. This method is adopted for the assessment of land requirements for food (Gerbens-Leenes, 1999). What is finally arrived at by combining household consumption (kg) with land requirements per food item (m^2 year kg^{-1}) is the land requirement for food at a household level.

The study considers over a hundred food items divided into nine main consumption categories: (1) meat; (2) milk products and eggs; (3) beverages; (4) cakes and pastries; (5) potatoes (Solanum tuberasum L.), vegetables and fruits; (6) oils and fats; (7) bread; (8) flour products and (9) 'other food products'.

To determine land requirements for food items, information on yields, imports, food industry recipes and proportions of crops grown in the open air and in glasshouses are needed. For The Netherlands information on yields is available on different levels of scale (FAO, CBS, IKC-AG). Information on imports is available from the Dutch Bureau of Statistics (CBS). Information on recipes in the food industry and data on the proportion of crops grown in the open air and in glasshouses are derived from knowledge obtained in energy studies (Kramer and Moll, 1995).

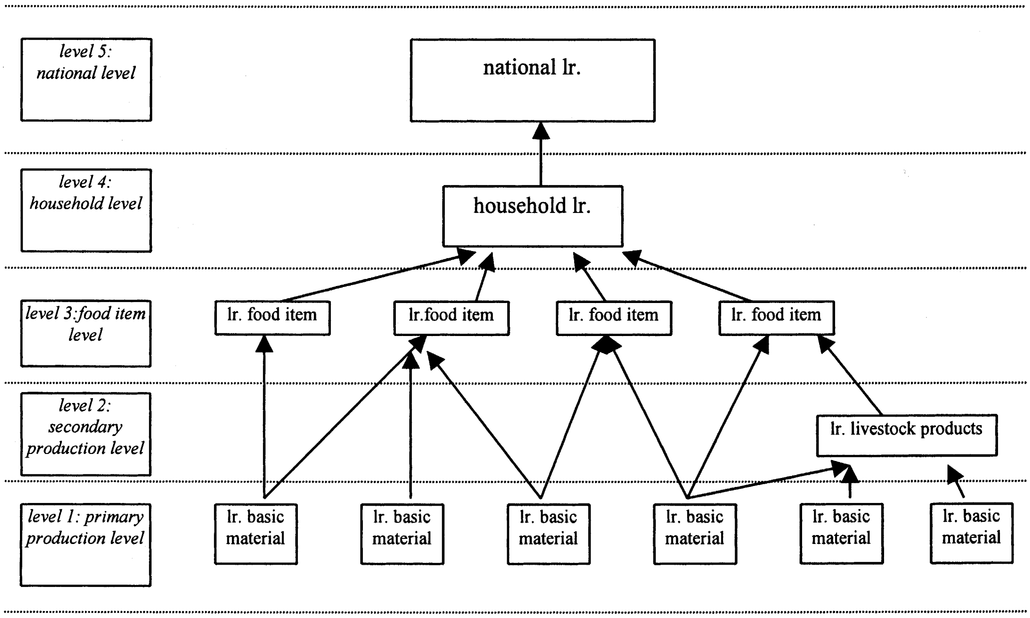

Fig. 1. Schematic representation of the five levels of scale for the land requirements for food. Level 1: the primary production level; level 2: the secondary producton level; level 3: the food item level; level 4: the household level and level 5: the national level. For the assessment of level 4, data from level 3 are coupled with data on household consumption (lr: land requirement).

3.1. Scale levels for land requirements for food

Five levels of scale for the land requirement for food can be distinguished. This is shown in Fig. 1. These levels are: (1) the primary production level; (2) the secondary production level; (3) the food item level; (4) the household level and (5) the national level. Data from a lower level form the input data for a higher level. The land requirement for the household (level 4) is calculated using data from level 3 and data on household consumption. This land requirement can be scaled up to the national level by multiplying the household land requirement by the total number of Dutch households (level 5).

3.2. Flow chart of calculations and input

The total land requirement for food in The Netherlands was determined by a step-by-step approach in which the output of one step formed the input of the next one (Gerbens-Leenes, 1999). The flow chart and necessary inputs are shown in Fig. 2.

In step 1 the prices of food items in 1990 were assessed using national statistical data (CBS, 1980, 1986, 1991) or derived from the study on energy requirements for food (Kramer and Moll, 1995).

In step 2, the amount of food items bought by an average Dutch household was determined by combining prices of food items along with household expenditure. Data were obtained from the Dutch Household Expenditure Survey (CBS, 1990) which is based on a representative sample of households.

In step 3, a calculation of land requirements for Dutch crops was made. Land requirements for crops are inversely proportional to the yield. It is expressed as area per kg crop year (m^2 year kg^{-1}). The land requirements for agricultural crops were calculated by dividing the total Dutch cultivated area (m^2) by the total Dutch yield per year (kg per year) for each crop. Data were obtained from CBS-inventories (CBS, 1990, 1993). Vegetables and fruits are cultivated either in the open air or in glasshouses. The land requirements for open air vegetables and fruits, and for tomatoes (Lycopersicon esculentum L.), capsicums and cucumbers (Cucumis Sativus L.) in glasshouses were calculated by dividing the total cultivated area per crop by the Dutch yields of 1990. For the latter assessment, data were taken from CBS-inventories (CBS,

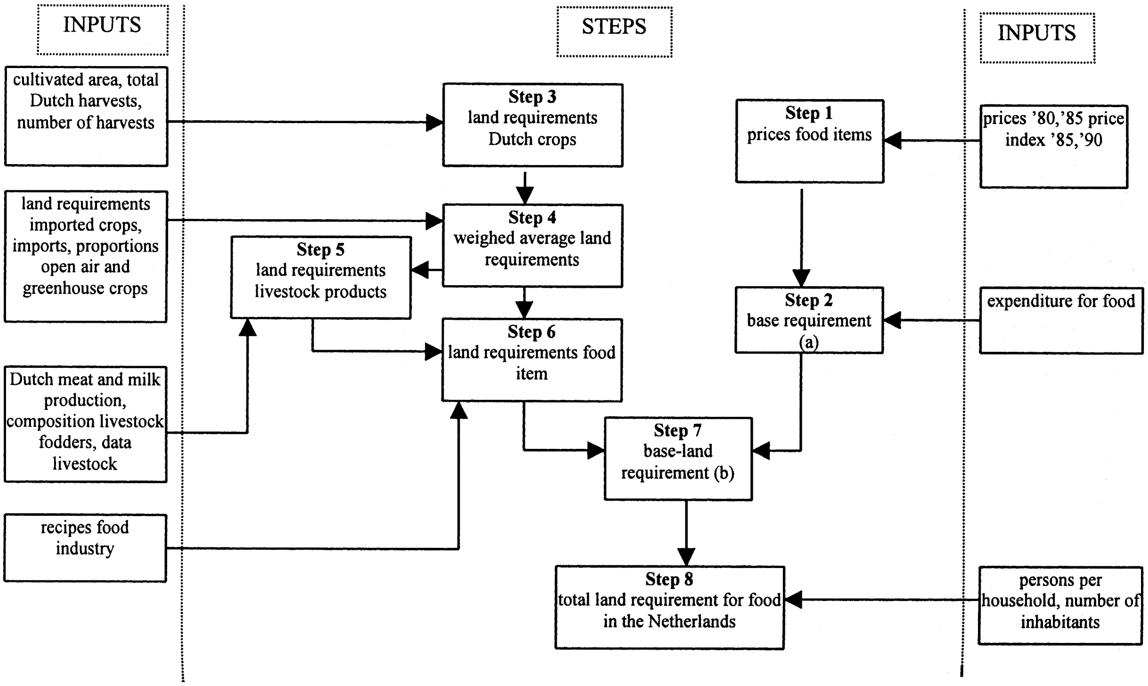

Fig. 2. Schematic representation of steps and inputs (1990) for the assessment of the total land requirement for food in The Netherlands in which the output of one step forms the input of the next one. (a) The base-requirement = food items bought by an average Dutch household in 1990; (b) the base-land requirement = the area needed to produce the amount of food for the base-requirement.

1993) and from inventories of the Informatie- en Kenniscentrum voor de Akkerbouw en de Groenteteelt in de Vollegrond (IKC-AG, 1993). Vegetables and fruits that are grown in glasshouses have several yields per year. Total yields ($kg\,m^{-2}\,year^{-1}$) were assessed by multiplying yields per production round (Ekkes et al., 1994) by the estimated number of production rounds per year. From these yields, land requirements could be calculated. Finally weighted averages of land requirements for Dutch vegetables and fruits grown in the open air, and in greenhouses were calculated.

In step 4 the weighted average land requirement for Dutch and imported crops was calculated. The calculation of land requirements for crops available in The Netherlands was done in two phases. In step 4a the weighted average land requirements for imported crops were assessed. The estimated amount and origin of foreign crops derive from inventories of the LEI-DLO and the CBS (LEI-DLO/CBS, 1991). The yields per year of imported crops derive from FAO-inventories (FAO, 1990 and FAO-site Internet, 2001). In step 4b the weighted average land requirements for crops available in The Netherlands were calculated. Using the land requirements for Dutch crops from step 3, this was done by assessing the weighted average of the Dutch and the imported crops.

In step 5 land requirements for livestock products were determined (fish was excluded). The Dutch livestock production system can roughly be divided into intensive animal husbandry and dairy farming. Livestock is fed with roughage and/or feed-concentrates. In intensive animal husbandry, the production of livestock fodder does not take place at the farm itself, while in dairy farming domestic animals are mostly fed with roughage obtained from the farmers own agricultural production system. Roughage is fresh or dried fibrous fodder, such as grass, silage, fodderbeets (Beta sp.), potatoes and straw. Feed-concentrates are made of crops (mainly grains, pulses, lupines and tapioca) and by-products and wastes originating in the food industry. The composition of feed-concentrates depends heavily on the prices of commodities on the world market and is therefore constantly changing (Kingmans, 1998). Land requirements for livestock products were calculated by dividing the areas needed for fodders (m^2 year) by the yearly production of meat, raw milk and eggs (kg). In this study, land is assigned to the main product, no land requirements were assigned to by-products and wastes from the food industry that are used in the fodders of domestic animals. Data on livestock, livestock fodders and livestock products were derived from the "Yearly statistics of livestock fodders of 1990/1991 and 1991/1992" (Bolhuis et al., 1995), from announcements of the Marketing Board for Livestock, Meat and Eggs and from CBS-inventories (CBS, 1993).

In some livestock production systems only one food product is made, while in other systems two food items are produced. Pig keeping results in the production of only pork, whereas dairy farming results in raw milk and beef. When more products are made in a production system, the total land requirements were divided over the products proportional to their energy output (kJ) (Gerbens-Leenes, 1999).

Raw milk is the basic material for the production of various food items, like semi-skimmed milk, yoghurt, cheese or butter. In order to calculate land requirements for these products, land requirements for the components milk-carbohydrate, -fat and -protein were assessed. This was done by dividing the land requirement for raw milk (m^2 year kg^{-1}) over carbohydrates, fats and proteins according to their energy content (kJ kg^{-1}). Land requirements for milk products were assessed according to their composition.

In step 6 land requirements for food items were assessed. In the food industry, basic materials are used to produce food items. The land requirement for a specific food item was calculated by multiplying land requirements for basic materials (m^2 year kg^{-1}) by the amounts of basic materials (kg kg^{-1}) needed to produce the food item and summing these results. The amounts of basic materials needed for the manufacturing of food items were derived from Kramer and Moll (1995). Data on the basic materials used in the food oil industry were taken from inventories of the Marketing Board for Margarines, Fats and Oils (Produktschap Margarine and Vetten en Oliën, 1993). Data on the composition of food items were taken from the 'Dutch food items table' (Voorlichtingsbureau voor de Voeding, 1984, 1990).

In step 7 the land requirement for food for an average Dutch household was determined by combining data on the amount of food items bought by an average Dutch household in 1990 from step 2 with per category assessed land requirements for food items from step 6.

In step 8 the total land requirement for food in The Netherlands was determined by multiplying the base-land requirement calculated in step 7 by the total number of households in The Netherlands in 1990 (CBS, 1993).

4. Results and discussion

4.1. Land requirements

The results that were obtained are on several levels. From the calculations, the amounts of food items bought by an average Dutch household in 1990 and land requirements per food item are derived (Gerbens-Leenes, 1999). Some of these results are shown in Table 1. Large differences existed between household consumption per food item and between land requirements for individual food items. In general, more expensive food items had larger land requirements. For example, in 1990 the price of beef was f17.00 kg^{-1}, of pork only f11.00 kg^{-1} (Kramer and Moll, 1995). The land requirement for beef was 20.9 m^2 kg^{-1} year, more than twice the land requirement for pork (8.9 m^2 year kg^{-1}). This was partly due to a higher conversion efficiency of swine (energy in produce/energy in feed $= 0.35$), while the conversion efficiency of beef was only 0.06 (Spedding, 1988). The second reason is that 47% of the energy content of pigfodders was provided by wastes and by-products originating in the food industry, while for beef this amount was only 27% of the total energy content (Gerbens-Leenes, 1999). As mentioned before no land requirements were assigned to these wastes and by-products.

The household land requirement for a specific type of food item was determined by the amounts bought by a household and by the individual land requirement for that type. Some food items showed high individual land requirements but low consumption resulting in relatively low land requirements per household (e.g. tea). Other food items showed low individual land

Table 1
Specific land requirements per food item (m^2 year kg^{-1}) based on local yields and the Dutch production situation in 1990, and household food consumption in The Netherlands (kg per year) based on the CBS Household Expenditure Survey of 1990[a]

Food item	Specific land requirement (m^2 year kg^{-1})	Household consumption (kg per year)
Beverages		
Beer	0.5	77.3
Wine	1.5	29.3
Coffee	15.8	8.9
Tea	35.2	1.8
Fats		
Fats for frying	21.5	8.0
Margarine	21.5	20.6
Low fat spread	10.3	9.8
Meat		
Beef	20.9	8.4
Pork	8.9	15.1
Minced meat	16.0	16.0
Sausages	12.1	14.9
Milk products and eggs		
Whole milk	1.2	34.6
Semi-skimmed milk	0.9	116.1
Cheese	10.2	27.6
Eggs	3.5	13.4
Cereals, sugar, potatoes, vegetables and fruits		
Flour	1.6	9.4
Sugar	1.2	22.3
Potatoes	0.2	153.6
Vegetables (average)	0.3	162.0
Fruits (average)	0.5	154.0

[a] Source: Gerbens-Leenes (1999).

Table 2
Land requirements (m^2 per household and % of the total agricultural area for household food consumption) for the nine main consumption categories (meat; oils and fats; milk products and eggs; beverages; bread; potatoes, vegetables and fruits; cakes and pastries; flour products and other food products) based on the Dutch production situation and household consumption in 1990, and the total land requirement per household for food consumption

Consumption category	Land requirement (m^2 per household)[a]	Land requirement (% of the total agricultural area) for household food consumption)
Meat	1022	29
Oils and fats	827	24
Milk products and eggs	598	17
Beverages	368	11
Bread	183	5
Potatoes, vegetables and fruits	168	5
Cakes and pastries	107	3
Flour products	68	2
Other food products	148	4
Total	3490	100

[a] In 1990 an average Dutch household consisted of 2.41 persons (CBS, 1993).

requirements, but relatively high household land requirements due to high consumption (e.g. semi-skimmed milk and potatoes). Only six food items accounted for 43% of the total Dutch household land requirement for food due to relatively high individual land requirements and high consumption. The items were: (1) margarine (12.6% of the total household land requirement); (2) minced meat (7.4% of the total household land requirement); (3) sausages (5.2% of the total household land requirement); (4) cheese (5.1% of the total household land requirement); (5) fats for frying (4.9% of the total household land requirement) and (6) coffee (4.0% of the total household land requirement). Staple foods, like potatoes, vegetables, fruits, bread and flour products accounted for only 12% of the total Dutch household land requirement.

Land requirements per consumption category per household are shown in Table 2. The consumption category of meat was the largest category with 1022 m^2 per household (29% of the total). Of the total land requirement for food, 827 m^2 per household was needed for oils and fats. This land requirement was based on the use of soya oil in the food oil industry. The assessment of land requirements for individual food items was often complicated by a joint production dilemma. For soyabeans, all of the land required was classified as being for soya oil, and oil cakes used for livestock fodders were merely seen as being a waste product. The consequence of assigning all the land to the main product is that land requirements for oil products were relative high, while land requirements for livestock products were low. The land requirement for the consumption category of milk products and eggs was 598 m^2 per household; 17% of the total land requirement for food in The Netherlands. Raw milk is the basic material for the production of various milk products. Because of the chosen method, the land requirement for milk-fat (16.6 m^2 kg^{-1}) was twice as high as requirements for milk-protein and -carbohydrates (7.4 m^2 kg^{-1}). As a consequence, land requirements for milk products are dominated by their fat content. Compared to meat, the land requirement for eggs was relatively low (3.5 m^2 year kg^{-1}). Of the total land requirement for a household, 368 m^2 (11%) is needed for beverages. More than half of this requirement, 203 m^2, was needed for coffee and tea. The area needed for these two beverages was even higher than land requirements for basic food items like bread, potatoes, and vegetables and fruits. In reality, the amounts of coffee consumed were even higher than the amounts calculated in this study (Gerbens-Leenes, 1999). According to the 'Association of Dutch Coffee Roasters and Tea Packers', the total amount of coffee used per capita in 1990 was 8.4 kg (Vereniging van Nederlandse koffiebranders en theepakkers, 1998). This study calculated only 3.7 kg per capita. The difference between household and average consumption indicated that most of the coffee was not consumed at home, but at work or in restaurants. In Table 2 is shown that only a relatively small area was needed for the categories of bread; potatoes, vegetables and fruits; cakes and pastries; and flour products.

Results showed that even small changes in food consumption patterns can have large impacts on the agricultural area required to produce this food. For example, in The Netherlands a hot meal mostly includes some meat; potatoes, rice or pasta; and vegetables. A slight increase of the consumption of meat by only one mouthful (10 g) per capita per day will increase the agricultural area required by 103 m^2 per household per year (+3%), whereas the same increase of potato consumption will result in an increase of only 2 m^2 per household per year (+0.05%).

4.2. Effect of uncertainty and inaccuracy on final results

For the assessment of the land requirements for food information from several sources was required. On the one hand all information obtained shows uncertainties that are related to the impossibility to do an accurate description of a system. For example, uncertainties related to food consumption are caused by losses in the life cycle, outdoor consumption and non-food purposes. In the life cycle of a food item about 10% of the total amount is lost (Groenendaal, 1996). The CBS expenditure survey does not take consumption outside the house into account. For example, as mentioned before large differences were found between household coffee consumption and the availability of coffee on a national scale. Most agricultural crops are used for food purposes, but some are applied in other areas. For example, potato starch is used for foodstuffs and animal feed, but most of the starch is used for non-food purposes (LEI-DLO/CBS, 1992).

On the other hand consumption data are inaccurate, because of underreporting and price effects. The CBS concludes that households underreport their expenditure (CBS, 1994). The CBS estimates that underreporting is about 16% of the total expenditure. Some expenditures are presumed to be even more underreported. In an earlier study, on energy requirements for food items it was argued that underreporting of alcoholic beverages is about 34% of the total (Kok et al., 1993). The CBS assesses prices of food items by using a fixed package of products. In this assessment, weekly offers of supermarkets were not taken into account. This means that by using these food price data, real amounts of food items bought by households were underestimated. In this study, it is argued that the amounts of food bought by an average Dutch household were 10% higher than the amounts of the base-requirement because of this effect.

In order to calculate the sensitivity of the model, underreporting, price effects, losses in the life cycle and outdoor consumption were cumulatively taken into account. The land requirement for food for a Dutch household lied between 3490 and 5243 m^2. Uncertainty and inaccuracy in available consumption data all augment the household land requirement, so that actual requirements were probably close to the maximum of the calculated interval. This is why no average value is given. For some foods underreporting is higher than for others (e.g. alcoholic beverages), while other food items are mostly consumed outside the house (e.g. coffee). These inaccuracies and uncertainties influence the fractions of land requirements per consumption category, so that some fractions were probably higher than calculated for the household land requirement (e.g. beverages), while others were lower (e.g. bread).

4.3. Comparison with data on available food on a national level

To be able to compare the results with calculations on a national scale, land requirements at a household level have to be scaled up to the national level. Based on household consumption, the total Dutch land requirement for food lied between 2.2×10^6 and 3.2×10^6 ha. In The Netherlands, data on consumption are available from inventories on a national scale. Every year, the Dutch Agricultural Economic Institute (LEI) and the Central Bureau for Statistics (CBS) publish data on the amount of food available in The Netherlands (Landbouwcijfers). In order to study the impact of assumptions on the final result, the land requirement for the available food in The Netherlands was also calculated based on these LEI/CBS inventories. This requirement was 3.0×10^6 ha, which lies in the interval calculated above.

4.4. Application and sensitivity of the method

Results showed that the total land requirement for a populations food need was strongly determined by household consumption (Tables 1 and 2). Especially the consumption of livestock products (milk products and meat), vegetable oils and fats, and beverages had a large effect on land requirements for food. When data obtained in this study were evaluated, it was shown that Dutch land requirements for meat and milk accounted for nearly half of the total land requirement for food, while land requirements for bread, potatoes, vegetables, fruits and flour products accounted for only 12% of the total. A shift to a more luxury diet often implies the consumption of more or more luxury meat types. Expensive meat types (e.g. beef) often have larger land requirements than cheaper ones (pork). But not only in the category of meat changes take place, in all food categories shifts occur: other vegetables, more fruits, more snacks and cakes etc. All these more luxury food items require more land. For example, Dutch land requirements for beverages were large: 11% of the total land requirement for food was needed for the production of beverages, mostly for coffee. The so-called non-meat changes in the menu (oils, beverages, fruits, cakes etc.) seem to have a large impact on land requirements. The effect of these types of changes in consumption patterns on land requirements for food can only be studied via the route presented in this paper. Slight changes can be calculated using the land requirements for individual food items generated by the method, but for larger changes (e.g. a shift towards a vegetarian menu) new assessments of the system are necessary. Changes in demand for food will influenced the whole food production system. For example, if the consumption of fats rises larger waste streams are generated. These streams can be used for livestock production, so that land requirements for meat, eggs and milk will drop.

Penning de Vries et al. (1995) and Bouma et al. (1998a) estimated that a shift from a vegetarian diet to an affluent diet with meat leads to a tripling of the land requirement. Based on an average energy requirement of 10 MJ per capita per day, the consumption of wheat and data obtained in this study, the hypothetical per capita land requirement for a household at the subsistence level was 444 m^2, a factor of eight lower than the Dutch household land requirement calculated in this study. This gives an indication that the difference between a vegetarian and an affluent diet with meat could be much larger than the factor of three estimated by the authors mentioned above.

The method presented here can only be used to assess land requirements for a clearly defined food production and consumption system. Land requirements for food items are strongly related to yields per hectare. Halving the yields leads to doubling the land requirements. The production situation in The Netherlands for example, is characterized by high yields per hectare in comparison with global average yields, but also with yields in other European countries. In 1996, the average Dutch wheat yield was 8.9 Mg ha^{-1}, while the global average was only 2.5 and wheat yields in Italy 3.3 Mg ha^{-1}. This implies that when Dutch consumption has to be met with a production based on global average yields, about three to four times as much land will be required. These yield differences are the main reason for the large variations that occur in various footprint studies. Wackernagel et al. (1997) determined the footprint for Dutch food consumption. They used global yields as input data and arrived at 33×10^6 ha (including 7×10^6 ha for fish), one order of magnitude higher than results of the current study.

Imports and exports of considerable quantities of commodities and food items on a world scale influence the statistical data of individual countries. If only imports are taken into account in assessing land requirements for food, requirements for countries with highly productive food industries and consequently high exports like The Netherlands, will be overestimated. Land requirements can be assessed using food balance sheets, determining land use due to imports, domestic land use and subtracting land use for exports. This method was used by the RIVM (Van Vuuren et al., 1999). A disadvantage is that the processes in the food industry can not be taken into account. Imported grain for example, can be used for the production of bread, but also for the production of pork for export purposes. In the current study, land requirements for individual food items were assessed, so that in combination with data on consumption only land requirements in relation to consumption patterns of the population considered were calculated and double countings were avoided.

Two Dutch studies on food security in The Netherlands (Bakker, 1984; Groenendaal, 1996) assessed land requirements based on Dutch yields and a minimum consumption. It was shown that food consumption in The Netherlands could be provided for with present yields on the available area for agriculture (2×10^6 ha) which is in the same order of magnitude as the results of this study. However, those studies were less detailed than the present one, so that the effect of slight changes could not be given.

The sensitivity of results of the method to yields per hectare and properties of the food system implies that values for food items derived in this study cannot be used to evaluate consumption patterns in other situations. Yield levels, production systems and consumption patterns change in time and vary between populations so that data obtained here are only valid for The Netherlands in 1990. In most other countries yield levels are lower, so that land requirements for food items will be larger.

It is stressed that results obtained by the method can not be used as an indicator for sustainable land use. Comparing land requirements for different systems is complicated by the fact that productivity is not only influenced by human management factors, but also by natural factors, such as climate and soil quality. Agricultural systems range from systems with high external input and high yields to systems with low external input and relatively low yields. The present Dutch agricultural system is a so-called high input system focussed on high yields per hectare, requiring large input of chemical fertilizers and biocides leading to large emissions to the environment. Increased environmental awareness might lead to the introduction of more environmentally friendly agricultural systems, often achieving lower yields per hectare. This may imply larger land requirements in the future.

Data on land requirements for individual food items and microlevel information on household consumption obtained at the bottom of the food system can give a valuable contribution to the discussion on land requirements for populations. The method presented can be used to study other combinations of consumption patterns and production systems, for example other countries or future perspectives. In that case, information on agricultural yields, consumption patterns, food production systems, etc. is required. This type of information is available for nearly all developed countries.

5. Conclusions

Results of the current study showed that an analysis of the land requirement for food based on data on food production and on household consumption obtained at the top and at the bottom of the food system provides new perspectives. When the method was used to assess requirements for Dutch households, large differences between land requirements for the nine consumption categories defined and even between individual food items of the same category were shown. Almost half of the Dutch household land requirement for food was needed for only six food items: margarine, minced meat, sausages, cheese, fats for frying and coffee. Staple foods, like potatoes, vegetables, fruits, bread and flour products accounted for only 12% of the total household land requirement.

Changes in food consumption patterns will have large effects on total land requirements for food and are in the same order of magnitude than changing production levels or the growth of the world population.

The current study described only 72% of Dutch food consumption, but microlevel information provided by this analysis can form a basis for further research into ways of changing land requirements by adding the perspective of the household and food item level. Data obtained with the method developed are only valid for

The Netherlands in 1990, but provided the necessary information is available, the method can be adopted by other countries as well. In this way the study presented here can give a contribution to the discussion on the ability to produce enough food in the next decades. Available studies on food security have shown that future generations can be fed. The method presented in this study can be used to assess the possibility to do so in a way that not only physical but also cultural and emotional requirements are met.

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