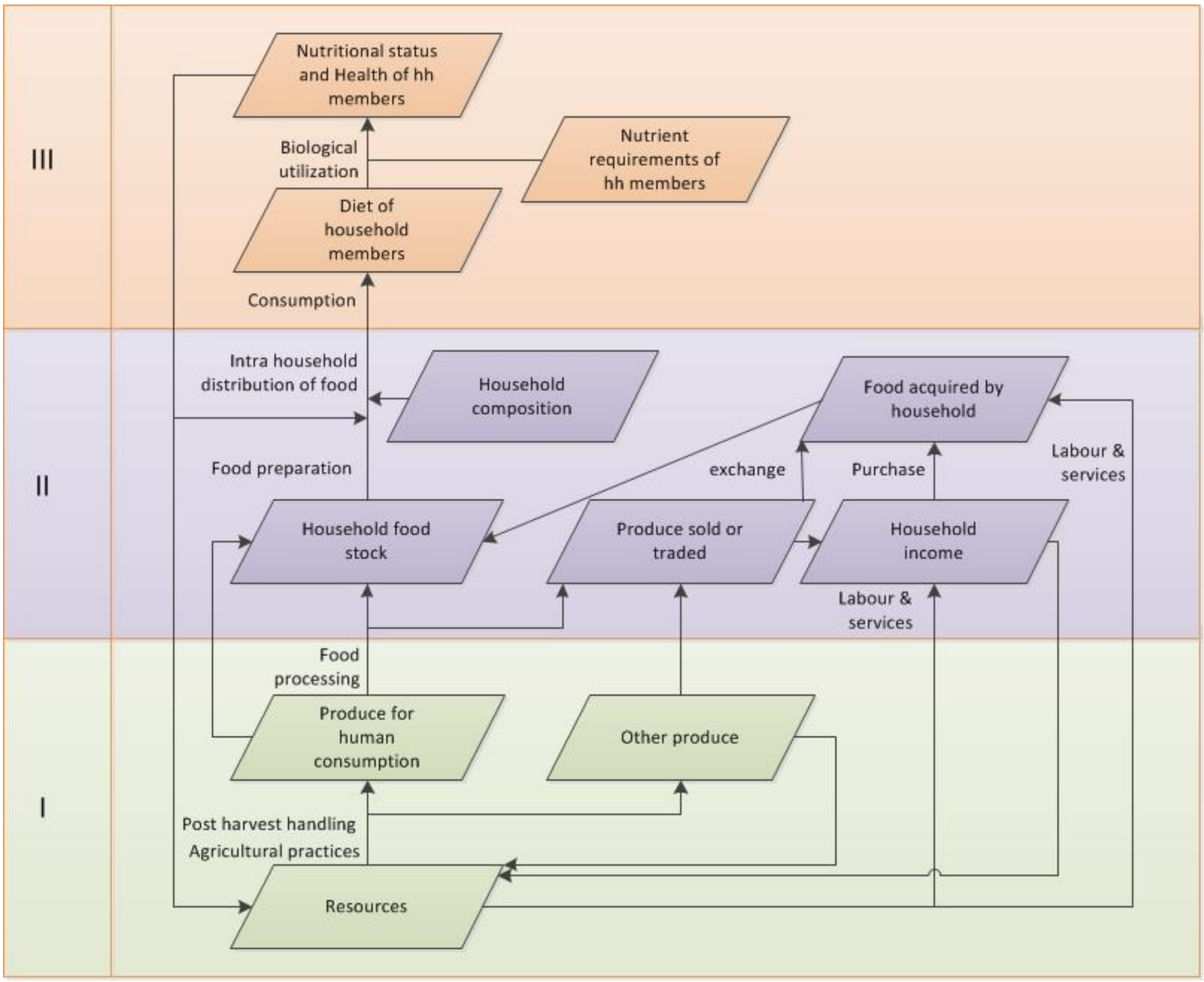
Incorporating household dietary and nutritional needs in quantitative farming systems analysis



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Last but not least I am utmost thankful and proud that at the end of this period I can say I have learned a lot, was inspired and motivated through the whole, was able to finalize this report and still have my two little angels tell me they love me every single day.

Abstract

Good nutrition is essential for human survival, development, health and wellbeing. Still a large proportion of global population is currently suffering from a lack of calories and/or (micro-) nutrients in their diets. The adequacy of diets depends on within-household processes, priorities and food habits and on the supply of foods from agricultural systems, landscapes and markets. This complexity with multiple components and interactions warrants a systems approach to better match food supply and demand for improved nutrition. This research investigates different options for integrating knowledge from these originally very separate research fields. A conceptual framework of agriculture-nutrition linkages is constructed based on a systematic literature review showing the complexity of pathways from agricultural production to nutrition within a household. Several options for integrating a household nutrition component in farming systems analysis are identified, differing in level of complexity. These options include nutrient-based approaches, dietary pattern-based approaches and proxies like dietary diversity indicators. The identified options are flexible to enable adjustment to case-specific demands, and are able to use inputs from existing models and approaches for either diet formulation or farm configuration. Implementation methodologies are described for three different options for integration of a household nutrition component in the whole farm model FarmDESIGN. After technological implementation, the resulting module will be tested in case studies of the Nutrition-Sensitive-Landscape approach in Humidtropics action sites in Kenya and Vietnam.

Table of Contents

List of Figures

1. Introduction

Despite the fact that the right to food has been recognized as a human right since 1948, around 870 million people in the world are currently chronically undernourished, meaning that their daily caloric intake falls below 1,800 kilocalories per day (von Grebmer et al., 2013). In addition, more than 2 billion people suffer from one or more micronutrient deficiencies, which can have detrimental effects such as impaired mental and physical development in children, increased morbidity and increased mortality rates (Black et al., 2013). Improving this situation is an important development outcome of many development agencies and projects.

Since the approximately 500 million smallholder farmers in the world produce 80% of the food supply in developing countries, increasing their productivity is likely to be a crucial component of the pursuit to achieve the Millennium Development Goal to eradicate extreme hunger and poverty by 2015 (FAO, 2011). Quantitative farming systems analysis could play a significant role in the sustainable intensification of smallholder farming systems through enabling the assessment of relations between farm performance indicators (e.g. soil nitrogen losses and operating profit) and of how changes in farming system configuration could impact these indicators.

In the process of intensifying smallholder farming systems, the impact on household nutrition should not be overlooked. Not only do smallholder farmers (partly) depend on their production for the food of their household (Graham et al., 2007), the health and capacities of the people in the farm household are influenced by their nutrition. This in turn can have an impact on farm productivity (Demment, Young, & Sensenig, 2003; Victora et al., 2008). In addition, human health and capacities and farm productivity can influence household nutrition by influencing the possibilities for off-farm food acquisition, through exchange of produce or labour for food with or without money to aid the exchange. These relations are illustrated in Figure 1.

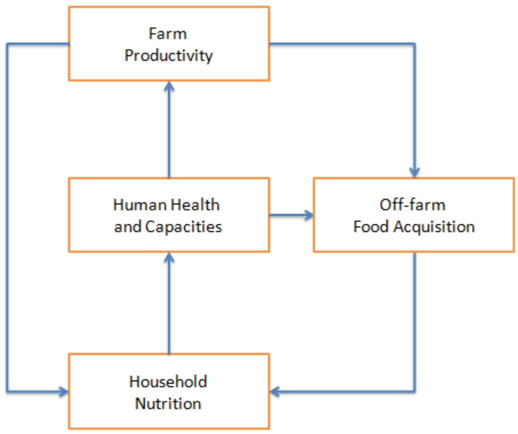

Figure 1: Visual representation of the relations between household nutrition, human health and capacities, farm productivity and off-farm food acquisition.
Arrows indicate impact pathways.

Earlier attempts to support development projects that aim to improve human nutrition aided by quantitative farming systems analysis were able to theoretically improve nutrient budgets of households under study (T. Amede & Delve, 2008; Amede, Stroud, & Aune, 2004; McIntyre, Bouldin, Urey, & Kizito, 2001). However, the incorporation of knowledge on human nutrition in these studies was not complete. Factors such as realistic food portion size, number of servings from a certain food group and acceptable foods, which can play an important role in the adoption and impact of proposed diets(WHO/FAO, 1996), were not taken into account.

The adequacy of the diets of household members depends on a complex combination of components and interactions. The shortcomings of previous approaches demonstrate the need for a systems approach, exploring which concepts are involved and how they relate, so that future attempts to improve human nutrition aided by quantitative farming system analysis will better match reality. This study focuses on the development of a conceptual framework based on a systematic literature review, followed by the identification of options for integrating a household nutrition component in farming systems analysis. Finally, methodologies are developed for implementation of these different options in the whole farm model FarmDESIGN, a tool used to analyse and re-design farming systems using multi-objective optimization (Groot, Oomen, & Rossing, 2012).

The following research questions are addressed:

1. What is the conceptual framework for incorporation of household dietary and nutritional needs in quantitative farming system analysis?

2. What relevant dimensions for incorporation of household dietary and nutritional needs in quantitative farming systems analysis can be identified?

3. What options for incorporation of household dietary and nutritional needs in quantitative farming systems analysis can be identified?

4. What implementation methodologies for the different incorporation options can be developed for whole farm models like FarmDESIGN?

After a description of the methodology, the developed conceptual framework is presented followed by a description of options for integration that have been identified. Subsequently, after a short description of the FarmDESIGN model, methodologies for implementation of the different options in that model are described. These sections are succeeded by a discussion and conclusion, with a list of references to complete the report.

2. Methodology

After building the conceptual framework for incorporation of household dietary and nutritional needs in quantitative farming system analysis, different incorporation options could be identified. Subsequently, methodologies for implementation in the whole farm model FarmDESIGN were developed for these options. The different phases of the research methodology are described below.

2.1 Development of a conceptual framework

Following the concept of nutrition-sensitive agriculture, which aims to "*deliver nutrient-rich, diversified and balanced diets to all consumers throughout the year*" (Jaenicke & Virchow, 2013), a systems approach was used, looking at components of the pathways from resources to human nutrition. In addition, the concept of human health was included in this review. The focus during conceptual framework development was on smallholder farming systems in general.

Relevant literature from several disciplines was collected from databases recommended by the Wageningen UR library. These databases are listed in Table 1.

Table 1: List of databases used for data collection within the different disciplines

Discipline	Databases
Agriculture	AGRICOLA, AGRIS, CAB abstracts, Scopus, Web of Science, Tropaq & rural, Wageningen UR library
Food science	CAB abstracts, Scopus, Web of Science, Biological abstracts, Scifinder, Wageningen UR library
Human nutrition	CAB abstracts, Scopus, Web of Science, Wageningen UR library

Keyword combinations such as 'nutrition sensitive agriculture' and 'agriculture AND nutrition', were used to discover relevant articles. The initial focus was on interdisciplinary review articles providing a good overview of relevant concepts. Subsequently, more in depth articles from the different relevant disciplines were reviewed to provide more insight in the relevant concepts and relations related to that discipline. The reference list of selected articles was reviewed to find other relevant articles, and when available, the option ´cited by´ was used to find the most up to date information. In addition, the websites of relevant organizations (e.g., FAO, CGIAR institutes, and IFAD) were searched for relevant information. Judgment on appropriateness and reliability were done by checking the references and source of the information, the purpose of the publication and the suitability for this research. Only information in Dutch or English was used. The reference management software Endnote® was used to store relevant resources.

The literature resources were categorized by discipline and concept names, descriptions, relations to other concepts, source and page number were extracted. Subsequently, concepts which had great similarity were integrated and grouped.

Using the information gathered and filling information gaps with additional literature research, a version of the conceptual framework depicting the relations between key concepts was constructed and described.

2.2 Identification of relevant dimensions for incorporation in quantitative farming systems analysis

The conceptual framework constructed in research phase 2.1 was used to identify implications for the incorporation of household dietary and nutritional needs in quantitative farming systems analysis. Different dimensions that can be taken into account were identified and a few possible selection criteria were outlined based on scientific literature.

2.3 Identification of options for incorporation in quantitative farming systems analysis

Based on the previous steps, three distinct options for incorporation of household dietary and nutritional needs in quantitative farming systems analysis were identified and described.

2.4 Development of methodologies for implementation in FarmDESIGN

The conceptual and technical infrastructure of the FarmDESIGN model was explored by reading the manual, experimenting with the model in the user interface and consultation with one of the developers, Dr.ir. J.C.J. Groot.
Based on the purpose of the model extension, the availability of relevant data and the conceptual and technical infrastructure of the model implementation methodologies for the 3 options identified in research phase 2.3 were developed, following best practice as described by Burnham and Anderson in the citation below;

"The ideal model would be appropriately simple, based on concepts of parsimony. Furthermore, precise, unbiased estimators of parameters would be ideal, as would accurate estimators of precision. (...) Finally, one would like as good an approximation of the structure of the system as the information permits." (Burnham & Anderson, 2002)

Model components were defined in consultation with Dr. ir. J.C.J. Groot and Dr. ir. I.D. Brouwer.

3. Results

3.1 Conceptual framework

The developed conceptual framework for incorporating household dietary and nutritional needs in quantitative farming systems analysis is shown in Figure 2. The conceptual framework was divided into several components which are explained separately. These components are production (I), household (II) and individual household member (III). Produce and resources from the production component (I) can be utilized by the household (II) to compose the household food stock. Subsequently, the diets of individual household members (III) are based on foods selected from this food stock. In the following sections the different concepts and processes will be explained. Unless mentioned otherwise the activities discussed are at farm and/or household level.

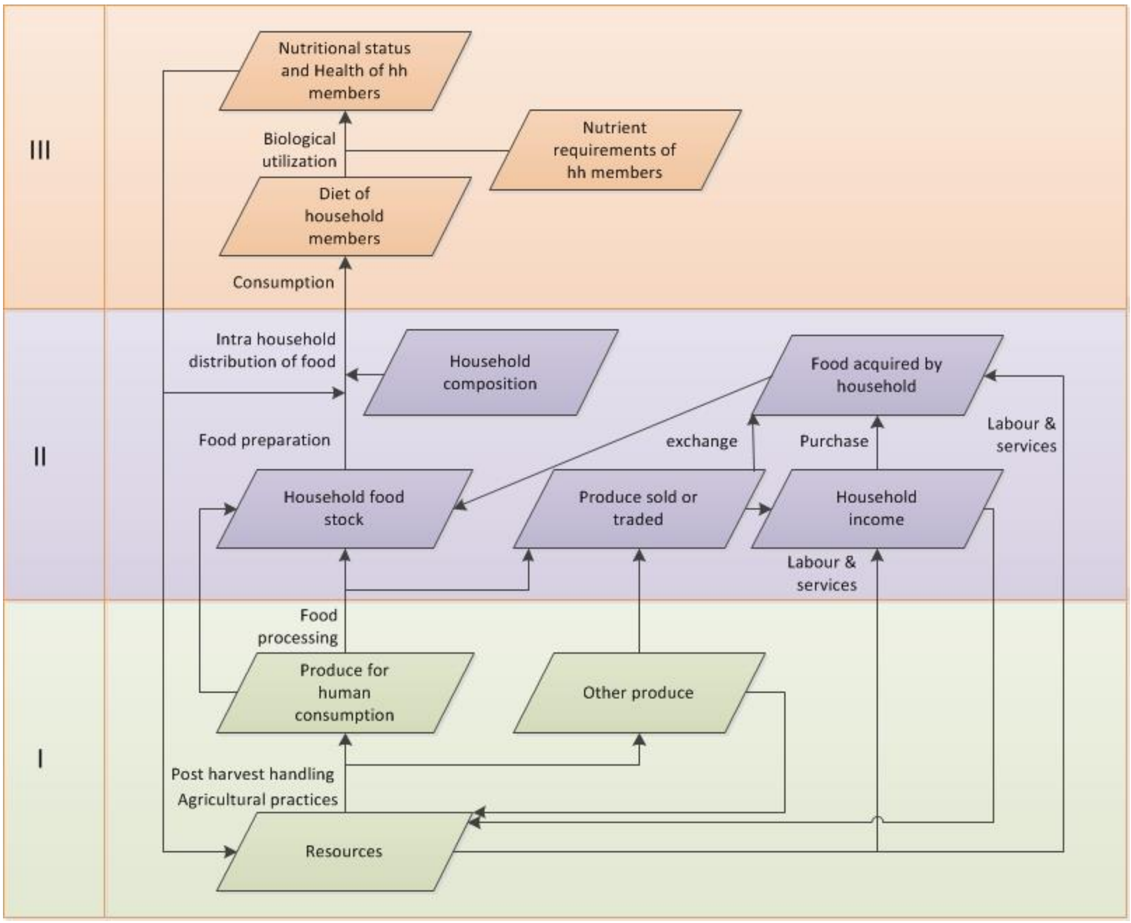

Figure 2: Visual representation of the conceptual framework.
Colours and numbers on the left side of the figure indicate the different components. Component I (green) encompasses production, component II (purple) household and component III (orange) the individual household members. Boxes indicate states; arrows between states indicate a possible impact pathway. For some arrows, processes involved in the impact pathway are described in text on the left side of the arrow. Not indicated in the figure are losses occurring during production, post-harvest handling and processing, and food waste at the household and individual level.

Losses occur during production, post-harvest handling and processing, and food is wasted at the household and individual level. For simplification purposes, these losses were not included in the figure. This does not mean they can be disregarded, as they can diminish the amount of food available.

Production

The production component of the conceptual framework is shown in Figure 3. For relations to the other components please refer to Figure 2.

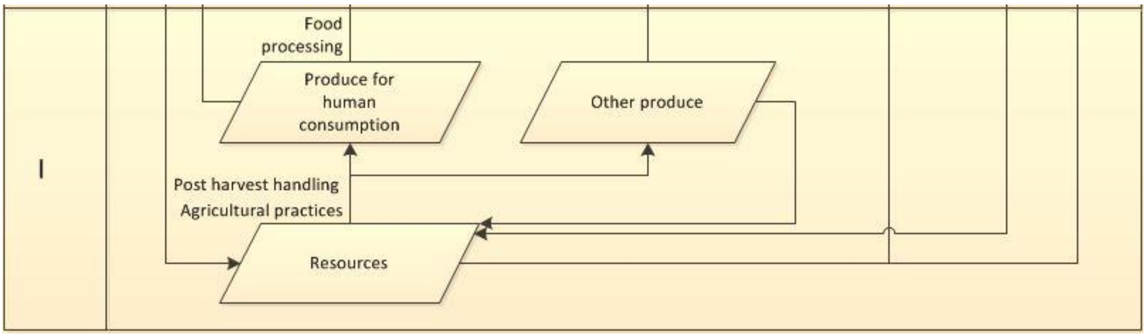

Figure 3: Visual representation of the production component of the conceptual framework
Boxes indicate states; arrows between states indicate possible impact pathways. For some arrows, processes involved in the impact pathway are described in text on the left side of the arrow.

The production level of the conceptual framework encompasses resources, produce for human consumption and other produce. The processes discusses *are agricultural practices, post-harvest handling (including storage) and processing of produce.*

Resources relevant to agricultural production are time and various types of capital. Time refers to the availability of physical labour for work. Capital can be of biophysical nature (e.g. land, water, tools, energy, livestock, materials and bio-plasma), but also human capital (human health, nutritional status, schooling and knowledge), social capital and economic capital play a role (Fan & Pandya-Lorch, 2012; Sobal, Kettel Khan, & Bisogni, 1998). Resources can be individually or collectively owned and allocated to a variety of activities. These activities include using labour or services for the generation of income (Fan & Pandya-Lorch, 2012), food acquisition and the production of produce for human consumption and other produce through agricultural practices and post-harvest handling.

Agricultural practices turn resources into produce (for human consumption or other purposes). There are numerable agricultural practices which can influence the quantity (kg edible yield) and quality (nutrient content/kg edible yield and bioavailability of these nutrients) of the produce for human consumption within a farming system. An overview of a number of these practices is given in Table 2.

Table 2: Agricultural practices affecting quantity and quality of crops and animal produce
Adapted from Miller & Welch (2013)

Crop produce	Animal produce
Crop selection	Species selection
Cropland allocation	Breed selection
Plant breeding (biofortification)	Number of animals kept
Soil quality management	Animal diets
Fertilization	Animal husbandry practices
Irrigation	
Crop protection	

Post-harvest handling includes handling, transportation and storage of produce. Storage of food can help overcome seasonal food gaps, and is aimed at preserving the quality and quantity of the food (Sobal et al., 1998). However, some nutrients are lost during storage, and the impact of storage on the quantity and quality of produce is influenced by the preservation and storage methods used and storage time. Losses can occur during handling and transportation of the produce or e.g. by infestation by microbes, fungi or pests. Improving harvest, transportation and storage technologies can help reduce damaging and spoiling of food after harvest (Keding, Schneider, & Jordan, 2013). At this point, a separation can be made between produce for human consumption and other produce.

<u>Produce for human consumption</u> encompasses raw produce which is suitable for human consumption or can be made suitable for human consumption using food processing. Produce suitable for human consumption can become part of the household food stock for home consumption or sold or traded.

<u>Other produce</u> encompasses produce not suitable or destined for human consumption, such as animal feed, green manure and building material or fuel.

Food processing can be applied for preservation purposes, but also to increase the safety, palatability and convenience (Keding et al., 2013; Miller & Welch, 2013). Processing can alter the digestibility and appeal of foods. It can lead to a loss of nutrients, but it can also increase bioavailability of nutrients for utilization by the human body. Processing methods include e.g. pasteurization, canning, drying, freezing, cleaning, milling, cooking, fermentation, germination, pounding, grinding, and roasting. The methods differ in labour intensity and cost of time (Haddad, 2000; Keding et al., 2013; Wiegers, Dorp, & Torgerson, 2011).

Household

The household component of the conceptual framework is shown in Figure 4. For relations to the other components please refer to Figure 2.

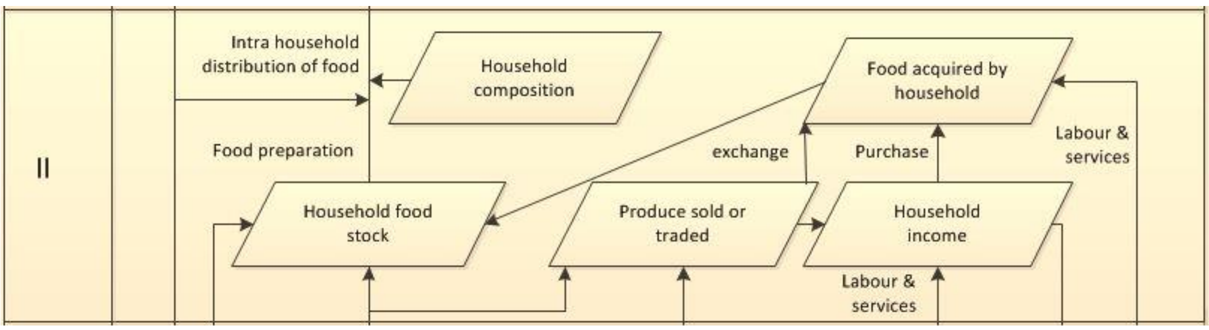

Figure 4: Visual representation of the household component of the conceptual framework
Boxes indicate states; arrows between states indicate possible impact pathways. For some arrows, processes involved in the impact pathway are described in text on the left side of the arrow.

The household level of the conceptual framework encompasses <u>household food stock; food acquired by the household; produce sold or traded</u>, <u>household income</u> and <u>household</u>

composition. The processes involved that will be described below are *exchange, purchase, labour and services, food preparation* and *intra-household distribution of food*.

The household food stock encompasses all food acquired or produced by the household which is destined for consumption by household members and guests. This food is available for immediate consumption or stored for later use. Food waste can diminish the amount food available for consumption(Miller & Welch, 2013).

Food acquired by the household encompasses all food acquired by the household from other sources than own production. This can entail food items acquired through purchase or exchange, but also food items acquired from the environment by food gathering, hunting and fishing (Sobal et al., 1998). In addition, gifts and food aid could play a role.

Produce sold or traded can contribute to household food acquisition through the generation of income or exchange for food products (Fan & Pandya-Lorch, 2012).

Household income, an amount of money or its equivalent received by the household, can be generated through produce sold and labour and services. Income can be used for food acquisition by the purchase of food items. However, an increased income does not always lead to increased food acquisition. Often, the money is used to buy non-food items (Haddad, 2000; C. Hawkes & Ruel, 2006; Wiegers et al., 2011). Since women are often responsible for feeding their family, income under their control is more likely to have a positive impact on household nutrition. Additionally, it appears that small regular cash flows (often earned by women) are more likely to be spent on food items, while larger sporadic income (often earned by men) are often spent on non-food items (Wiegers et al., 2011). Methods of income generation (e.g. trade or labour) use resources (time and/or capital).

Labour and services in this framework encompasses all forms of (non-)agricultural labour or services which generate cash or in-kind income, not represented by the amount of produce sold or traded. Labour and services use resources (time and/or capital).

Food preparation can influence the amount and quality of food consumed by individual household members. Although some foods are consumed raw, food preparation techniques are used for many foods before consumption. Preparation (e.g. cooking, fermentation, germination), like processing, can change the physical, chemical and water content of the food (Sobal et al., 1998). It can promote or reduce the levels of bio-available micronutrients and anti-nutrients (Welch & Graham, 2004). The preparation of food by a household is influenced by culture and requires resources (time and capital) (Sobal et al., 1998).

Intra-household distribution of food is another factor which can influence the amount and quality of food consumed by individual household members (Wiegers et al., 2011). Food destined for consumption by the household is distributed among its members. Wiegers (2011) describes the distribution processes to be context specific, complex and dynamic. Rights, responsibilities and power relations (influenced by culture) and knowledge on nutrient requirements of different family members are suggested to play a role. There are reports of differences in the food distribution behaviour of care givers influenced by the health, perceived vulnerability and weight of a child (Hartog, Staveren, & Brouwer, 2006).

Household composition is an important factor in the determination of total household nutritional needs. In addition, it can influence intra-household distribution of food by influencing e.g. responsibilities and power relations. Besides the household members living on the farm, other people (family, neighbours and labourers) might be fed on farm. In addition, off farm consumption can play a role, for example by a wife that is domiciled away from the farm (McIntyre et al., 2001).

Individual household members

The individual household member component of the conceptual framework is shown in Figure 5. For relations to the other components please refer to Figure 2.

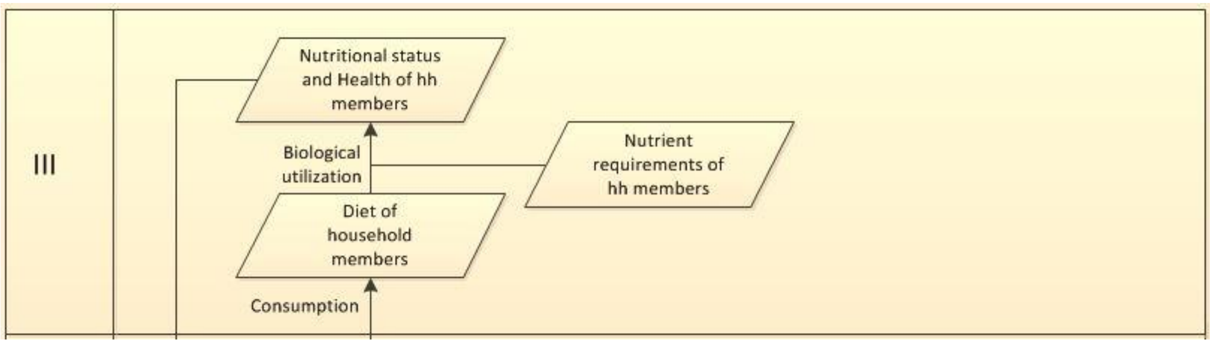

Figure 5: Visual representation of the individual household member component of the conceptual framework
Boxes indicate states; arrows between states indicate possible impact pathways. For some arrows, processes involved in the impact pathway are described in text on the left side of the arrow.

The individual household member level encompasses nutrient requirements of household members; diet of household members; nutritional status and health of household members. The processes discussed in this section are *food consumption* and *biological utilization*.

Food consumption encompasses selection, serving and ingestion of food items (Sobal et al., 1998). Individual food selection is influenced by culture (e.g. food taboos (Hartog et al., 2006)), food availability, climate, education, socioeconomic status and tradition(Keding et al., 2013). Religion can also influence food selection (Hartog et al., 2006). Serving patterns differ among individuals, influenced by the process of intra-household food distribution. Factors such as realistic food portion size, number of servings from a certain food group and acceptable foods can play an important role (WHO/FAO, 1996). Ingestion, the action of taking food into the body, is the final stage of food consumption and influenced by appetite (the desire to satisfy the bodily need for food)(Hartog et al., 2006).

Diet of household members is described as the sum of food consumed by each individual household member. Food consumption patterns (or; dietary patterns) contain a number of cycles; yearly (through food events), through days (meals and snacks), meals (courses) and through courses (bites or sips) (Sobal et al., 1998).

Ample research shows nutrition and health benefits of a diverse diet. The benefits might come from an increased likelihood that a more diverse diet will provide the necessary nutrients and energy. This could be due to the fact that people tend to eat more, when a greater food variety is available (buffet effect), or due to the fact that low-diversity diets often consist mainly of staples with low nutrient density(Fanzo, Hunter, Borelli, & Mattei, 2013). Keding (2013) stated that *'the consumption of a variety of foods across and within food groups almost guarantees adequate intake of essential nutrients and important non nutrient factors'* and dietary diversity scoring can be used as a proxy for nutrient adequacy of the diet of individuals, although the validity if this method depends on the types and numbers of food groups used for scoring, whether or not a minimum intake cut-off is applied and the overall adequacy of the nutrient supply of the existing diet (Arimond et al., 2010).

The biological utilization of nutrients is described by den Hartog et al. (2006) as '*the ability of the human body to take food and to convert it into nutrients that can be used by the body to maintain health*'. The bioavailability of nutrients depends on the individual characteristics of the person consuming the food, the type (matrix) of the food, the combination of foods consumed (food synergy (Jacobs Jr & Tapsell, 2007)), processing and preparation, the total nutrient content of the foods consumed (Welch & Graham, 2004) and the presence of non-nutrient food components influencing digestion and absorption(Fanzo et al., 2013).

Nutritional requirements of household members depend on age, physiological status, level of physical activity and sex, and even then there are individual differences.
To avoid malnutrition, a person should not only have an adequate intake of dietary energy, fat and protein, but also adequate amounts of relevant micro-nutrients. In addition, overweight and obesity should be avoided(Gómez et al., 2013).
At least 51 nutrients are needed to fulfil a person's nutritional needs, in different amounts (Graham et al., 2007). Macronutrients (protein, fat and carbohydrates), the main providers of energy, are needed in larger quantities than micronutrients (vitamins, minerals and trace elements).
Recommended dietary allowance (RDA) describes the intake level meeting the nutrient requirements of 97.5% of a population, while the Estimated Average Requirement (EAR) describes the average intake level meeting the nutrient requirements of half of a population. The Tolerable Upper Intake Level (UL) indicates the highest level of continuing daily intake of a nutrient which is likely to yield no adverse health effects for almost all members of a population(Corinna Hawkes & Ruel, 2008).
Nutritional requirements of household members influence the impact of the diet consumed on their nutritional status and health.

The nutritional status of household members is viewed in this conceptual framework according to the definition of nutritional status as given by UNICEF; *"the internal state of an individual as it relates to the availability and utilisation of nutrients at the cellular level" (UNICEF).* The health of household members is viewed as "*a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity*" (WHO, 2003).
Diet and the biological utilization of nutrients can influence the nutritional status of household members (depending on their nutrient requirements), which consequently impacts their health. However, there are many more pathways through which the food

system can impact human health (Fan & Pandya-Lorch, 2012; Fanzo et al., 2013; Haddad, 2000; Keding et al., 2013). Pinstrup-Andersen developed an overview showing different impact pathways, which can be found in Figure 6.

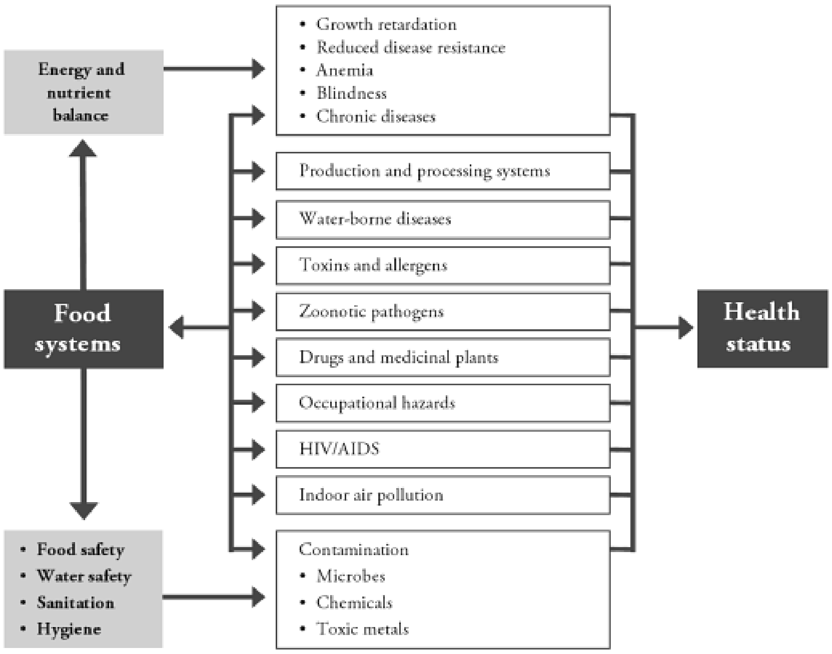

Figure 6: interactions between food systems and human health
As created by P. Pinstrup-Andersen, copied from source (Fan & Pandya-Lorch, 2012).

A persons health status can influence their consumption behaviour, through the effects of disease and/or medication on appetite (Hartog et al., 2006). This in turn can influence the diet of individual household members. The nutritional status and health of individual household members can also impact their capacities, potentially influencing intra-household distribution of food(Hartog et al., 2006) and farm productivity (Demment et al., 2003) and other activities which require the capacities of household members.

Summary

As the conceptual framework describes, production methods and circumstances influence produce quantity and quality. Between farms and fields, produce heterogeneity can be found due to differences in e.g. farm management, soil type and resource availability and allocation. Post-harvest handling (including storage) and processing can lead to losses, while processing can also increase the bioavailability of nutrients and together with good storage methods help preserve the food for extended periods of time. Preparation methods influence the nutrient content and bioavailability in a variety of ways.

Often, not all food produced on farm is consumed by household members. Food can be sold, exchanged, losses can occur and people other than on-farm household members may consume part of it. In addition, produce suitable for human consumption may be used for production purposes (e.g. as fodder) or rejected on cultural or other grounds. Food can also be acquired from outside the farm through purchase, exchange, labour, services and gathering, hunting and fishing. Food destined for consumption by the household is distributed among its members, influencing individual nutrition outcomes. Therefore, optimizing for household nutrition will not automatically optimize the nutrition of each household member.

Besides intra-household distribution, food selection and ingestion determine the diet of individual household members. Factors such as realistic food portion size, number of servings from a certain food group and acceptable foods can play an important role (WHO/FAO, 1996). Nutritional and dietary needs differ from person to person, depending on factors such as age and sex. Diet and the biological utilization of nutrients can influence the nutritional status of household members (depending on their nutrient requirements), which can consequently impact their health. This in turn can have an impact on farm productivity (Demment et al., 2003; Victora et al., 2008) and other activities which require the capacities of household members.

3.2 Relevant dimensions for incorporation in quantitative farming systems analysis

From the conceptual framework several options for incorporating household dietary and nutritional needs in quantitative farming systems analysis can be deducted, varying in level of complexity and depending on the selection criteria used. In this section some dimensions that can be taken into account are described followed by a few words on selection criteria.

Dimensions that can be taken into account

- Time dimensions
  Examples of possible time steps are day, week, month, season and year. The household members need food on a daily basis, but processing and storage methods enable the preservation of food products over longer periods of time. In many countries there is a seasonal difference in food availability (e.g. plenty versus shortage season). Yearly food events (e.g. a slaughter feast) can be important to take into account. There is a trade-off between precision on the one hand and data requirement and implementation complexity on the other hand, with the simplest and least precise option requiring the least data being the yearly time step. With smaller time steps the precision of the analysis increases, but so do the data requirement and complexity.

- Household level to individual level
  During analysis, the focus could be on the household as a whole (least complex), on household member categories (e.g. age and gender groups) or on individuals (most complex). Focussing on the household as a whole does not take into account intra-household resource distribution. Focussing on household member categories, based on e.g. age and gender, allows for inclusion of an intra-household distribution aspect by allocation certain resources for (partial) use by the relevant household member categories. Focussing on the individual level allows for integration of the impact of illness and other non-household member category related aspects influencing dietary or nutritional needs.

- Food sources
  The least complex option regarding which food sources to take into account is to only analyse the food produced by the farm under study. However, often not all food consumed by the household is produced on farm. Including a market component allows for integration of purchase and/or exchange of food. Extraction of food from the environment through hunting, gathering and fishing is another factor that can be taken into account, as well as food aid and gifts.

- Raw produce or food available for consumption

  The least complex option would be to use the edible portion of raw produce in the analysis of food produced and/or available for consumption by the household. However, post-harvest handling, processing and preparation can influence produce quantity and quality. The most accurate approximation of the quantity and quality of food produced and/or available for home consumption can be obtained by direct measurements. If this is not possible, region specific yield tables (e.g. World Bank) and food composition tables (e.g. FAO) can be used, in combination with a translation from yield to edible portion of yield. For this method the accuracy at farm level is questionable due to heterogeneity of produce nutritional quality between farms and fields.

- Food pattern or nutrients

  When focusing on the nutrient requirement of the household and/or the amount of nutrients available for consumption, information on household member nutrient requirement and/or produce nutrient content is needed and has to be included in the analysis. In this approach, dietary habits are not taken into account.

  The nutrient-based approach is more complex to implement in quantitative farming systems analysis than focusing on foot patterns, where dietary guidelines can be used as input regarding the household needs, and only the amount of different foods produced has to be known (not their nutrient content). In this case, the less complex method (the food pattern approach) is also the more complete option when dietary needs and nutritional needs were taken into account in the construction of the dietary guidelines by nutrition experts. However, in many cases these dietary guidelines still have to be developed.

- Dietary diversity

  The simplest and least complete option would be to leave out a dietary diversity proxy. A more complex but completer option is to include an individual or household dietary diversity proxy, followed by the option to include both. In addition, it could be interesting to include a 'potential dietary diversity proxy', showing the dietary diversity that could be achieved when all products suitable for human consumption within the farming system would be made available for consumption by the household (instead of e.g. bringing it to market).

- Bioavailability

  The simplest and least precise option would be not to take into account the bioavailability of nutrients during analysis. A more complex and more precise option is to take into account the effects of food type, food processing and preparation on bioavailability by using the amount of bio available nutrients in calculations instead of the total amount of nutrients in the product. A third most complex and precise option is to take into account all aspects influencing the bioavailability of nutrients, being the individual characteristics of the person consuming the food, the combination of foods consumed (food synergy (Jacobs Jr & Tapsell, 2007)), processing and preparation, the total nutrient content of the foods consumed (Welch & Graham, 2004) and the presence of non-nutrient food components influencing digestion and absorption(Fanzo et al., 2013). This would require more in depth nutritional knowledge than is currently available on this subject.

Selection criteria

The choice of which components and processes to include in a systems analysis depend on several factors. Selection criteria used can include;

- the purpose of incorporation
- the availability of relevant data
- the conceptual and technical infrastructure of the current analysis method
- the desired level of complexity
- the desired level of precision
- the communicability of outcomes

(Burnham & Anderson, 2002; Cash et al., 2003)

3.3 Options for incorporation in quantitative farming systems analysis

In the process of identifying different options for incorporation of household dietary and nutritional needs in quantitative farming systems analysis, the purpose was to describe a variety of options to enable adjustment to case-specific demands. Data availability was taken into account to some extent, including the possibilities to use output from existing models, but will have to be checked for each specific case separately. The principle of parsimony was used and within the different integration options a variety of complexity is presented, allowing for flexibility of the method used depending on the context.

3.3.1 Dietary diversity proxy

Dietary diversity can be scored by counting the number of food groups from which one or more products are consumed. Dietary diversity can be used as a proxy for nutrient adequacy of an individual's diet. With a more diverse diet, the likelihood that it will contain adequate amounts of necessary (non-)nutrients increases. At the household level, an increased household dietary diversity score is associated with household food security and socio-economic status (Kennedy, Ballard, & Dop, 2011).

The parts of the conceptual framework that are most closely related to this approach are indicated in colour in Figure 7.

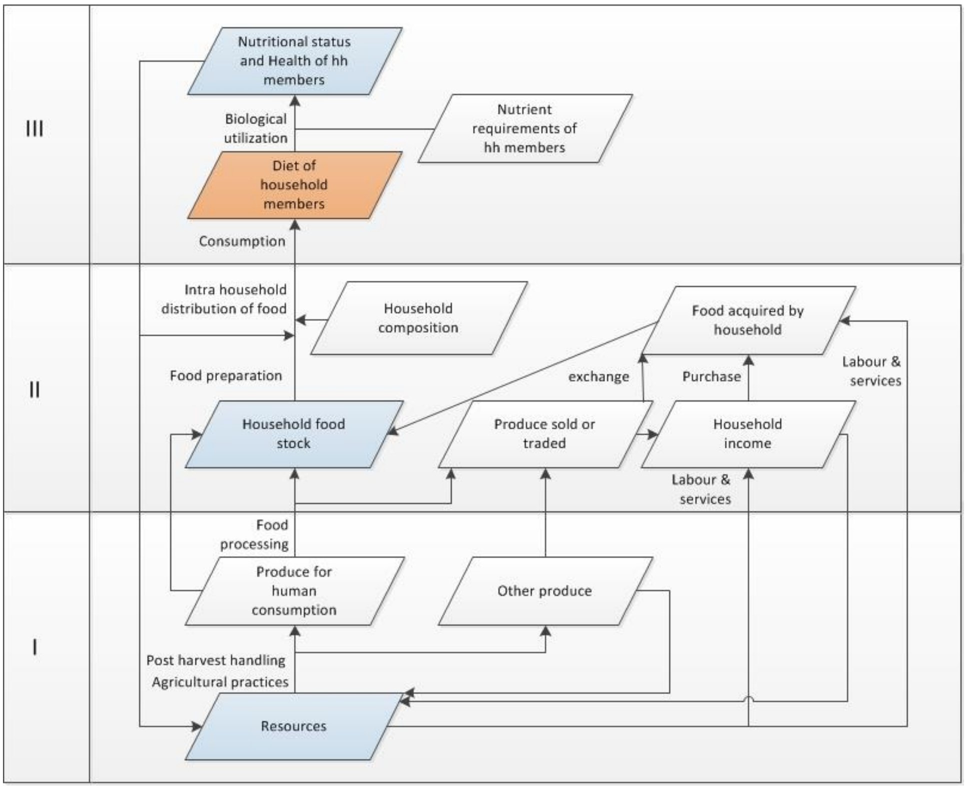

Figure 7: Relation between a dietary diversity proxy and the conceptual framework

The orange colour indicates parts of the framework that are under study, the blue colour indicated parts of the framework most closely related to elements for which more insight is gained using this approach. In this case, individual dietary diversity (related to 'Diet of household members') is used as a proxy for the nutrient adequacy of an individual's diet (related to 'Nutritional status and Health of hh members). When applied at the household level, dietary diversity can be used as a proxy for household food security (related to 'Household food stock') and socio-economic status (related to 'Resources').

Dietary diversity scoring allows for comparison between individuals, households or farming system configurations. In quantitative farming systems analysis, a dietary diversity proxy could be used in analysis of current scenarios, but also in design by including it as an objective or constraint (e.g. to retain, increase or maximize) in the process of multi-objective optimization.

The methodology for determining dietary diversity is simple and only a limited amount of data is needed. A food group (e.g. vitamin A rich fruits)) encompasses a number (n) of crop or animal products. The dietary diversity score is the number of food groups from which 1 or more products are consumed (green oval in Figure 8). A schematic representation of relevant system components for this approach is shown in Figure 8.

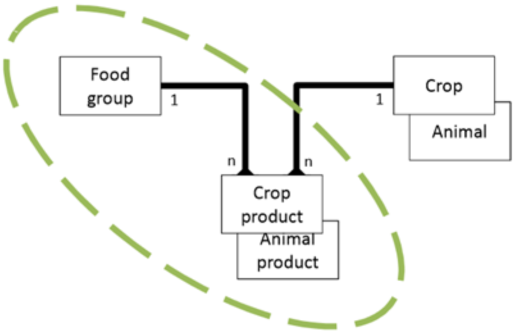

Figure 8: Schematic representation of relevant system components for the incorporation of a dietary diversity proxy
The figure shows a crop or animal yields a number (n) of crop or animal products, and a food group encompasses a number (n) of crop or animal products. The dietary diversity score is derived from the number of food groups from which 1 or more products are consumed (green oval).

The validity of this method depends on the types and numbers of food groups used for scoring, whether or not a minimum intake cut-off is applied and the overall adequacy of the nutrient supply of the existing diet(Arimond et al., 2010). The FAO developed a guideline for dietary diversity scoring, in which a list of food groups is described(Kennedy et al., 2011). This list is shown in Figure 9.

Food group	Examples
CEREALS	corn/maize, rice, wheat, sorghum, millet or any other grains or foods made from these (e.g. bread, noodles, porridge or other grain products) + *insert local foods e.g. ugali, nshima, porridge or paste*
WHITE ROOTS AND TUBERS	white potatoes, white yam, white cassava, or other foods made from roots
VITAMIN A RICH VEGETABLES AND TUBERS	pumpkin, carrot, squash, or sweet potato that are orange inside + *other locally available vitamin A rich vegetables (e.g. red sweet pepper)*
DARK GREEN LEAFY VEGETABLES	dark green leafy vegetables, including wild forms + *locally available vitamin A rich leaves such as amaranth, cassava leaves, kale, spinach*
OTHER VEGETABLES	other vegetables (e.g. tomato, onion, eggplant) + *other locally available vegetables*
VITAMIN A RICH FRUITS	ripe mango, cantaloupe, apricot (fresh or dried), ripe papaya, dried peach, and 100% fruit juice made from these + *other locally available vitamin A rich fruits*
OTHER FRUITS	other fruits, including wild fruits and 100% fruit juice made from these
ORGAN MEAT	liver, kidney, heart or other organ meats or blood-based foods
FLESH MEATS	beef, pork, lamb, goat, rabbit, game, chicken, duck, other birds, insects
EGGS	eggs from chicken, duck, guinea fowl or any other egg
FISH AND SEAFOOD	fresh or dried fish or shellfish
LEGUMES, NUTS AND SEEDS	dried beans, dried peas, lentils, nuts, seeds or foods made from these (eg. hummus, peanut butter)
MILK AND MILK PRODUCTS	milk, cheese, yogurt or other milk products
OILS AND FATS	oil, fats or butter added to food or used for cooking
SWEETS	sugar, honey, sweetened soda or sweetened juice drinks, sugary foods such as chocolates, candies, cookies and cakes
SPICES, CONDIMENTS, BEVERAGES	spices (black pepper, salt), condiments (soy sauce, hot sauce), coffee, tea, alcoholic beverages

Figure 9: List of food groups which can be used for dietary diversity scoring as defined by the FAO
For each food group some examples are given. Copied from source (Kennedy et al., 2011).

When information on the nutritional composition of the different products consumed is available, the methodology for calculating nutritional functional diversity as described by Remans or DeClerck (2011) could be used (DeClerck, Fanzo, Palm, & Remans, 2011; Remans et al., 2011) instead of a pre-defined list of food groups as proposed by e.g. the FAO. Currently there is no consensus on what is the best methodology for determining dietary diversity (Keding et al., 2013). Exploring the latest insights on this subject before implementation could aid in choosing an appropriate methodology.

As dietary diversity scores can differ greatly between consumer groups and there is no specific number of food groups that indicates an adequate dietary diversity, the FAO recommends using the mean score or distribution of scores of the populations under study for these purposes. In addition, as the dietary diversity score does not give an indication of the adequacy of nutrient supply, it is preferably used in combination with quantitative nutrition indicators (Kennedy et al., 2011).

3.3.2 Nutrient balance approach

The nutrient balance approach focusses on the balance between the nutrient requirements of the household and the amount of nutrients available for consumption.

The nutrient requirements of the household are derived from information on individual nutrient requirements and household composition. This can then be compared to the amount of nutrients available for consumption, allowing for analysis of nutritional adequacy of the available food.

The parts of the conceptual framework that are most closely related to this approach are indicated in colour in Figure 10.

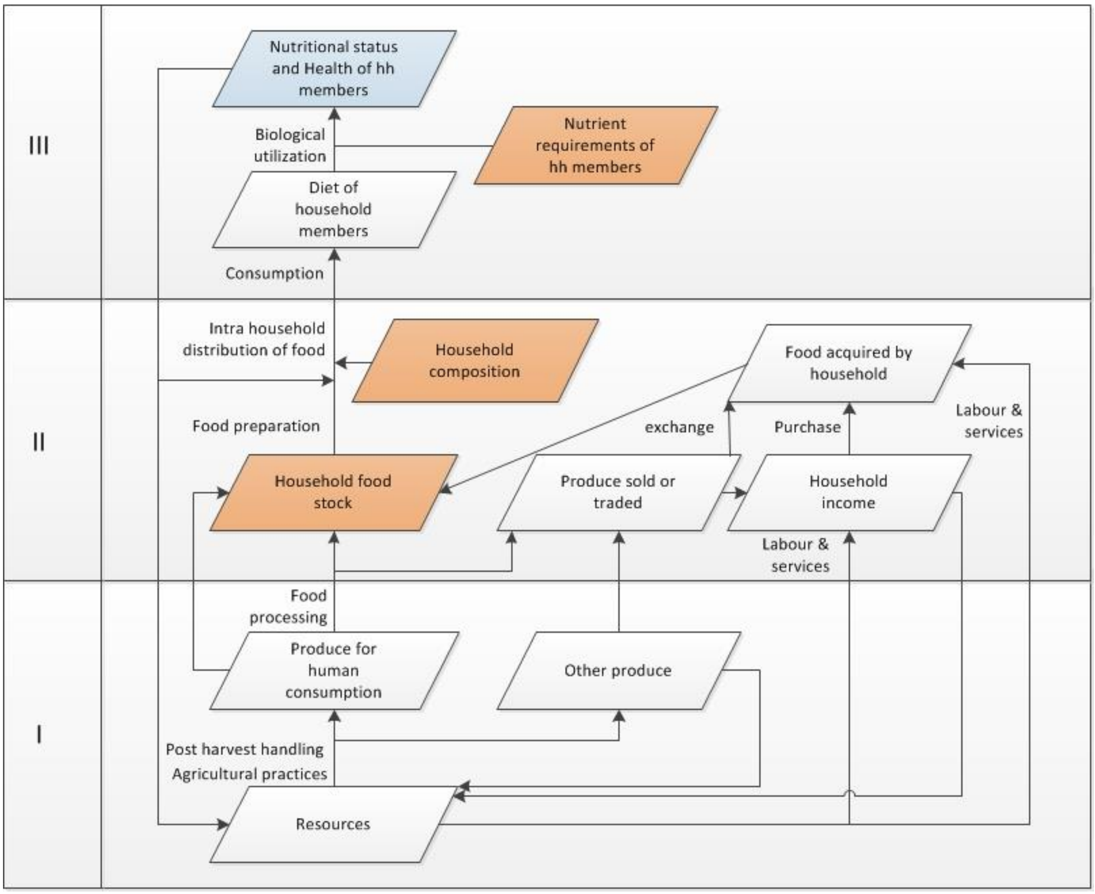

Figure 10: Relation between the nutrient balance approach and the conceptual framework

The orange colour indicates parts of the framework that are under study, the blue colour indicated parts of the framework most closely related to elements for which more insight is gained using this approach. In this case, the nutrient requirements of the household are derived from the 'Nutrient requirements of household members' and the 'Household composition'. These requirements are then compared to the amounts of nutrients available for consumption (related to 'Household food stock'), to allow for analysis of the nutritional adequacy of the available food (related to 'Nutritional status and Health of household members')

Analysing the nutrient balance allows for comparison between households or farming system configurations. In quantitative farming systems analysis, a nutrient balance could be used in analysis of current scenarios, but also in design by including nutritional adequacy as an objective or constraint in the process of multi- objective optimization.

However, as the nutrient balance approach does not take into account dietary habits, attempts to optimize or design farming systems using the nutrient-based approach potentially lead to designs which in theory fulfil the nutrient requirements of the household, but could fail in practice due to non-compliance of the resulting diet with food selection and/or serving habits.

Information on household member nutrient requirements, household composition and produce nutrient content is needed and has to be included in the analysis. A person requires a number (n) of different nutrients, in a certain amount. Crop and animal products have a certain content of a number (n) of nutrients. The nutrient balance approach balances the nutrient requirement with the availability derived from nutrient content of products (green oval in Figure 11). A schematic representation of relevant system components for this approach is shown in Figure 11.

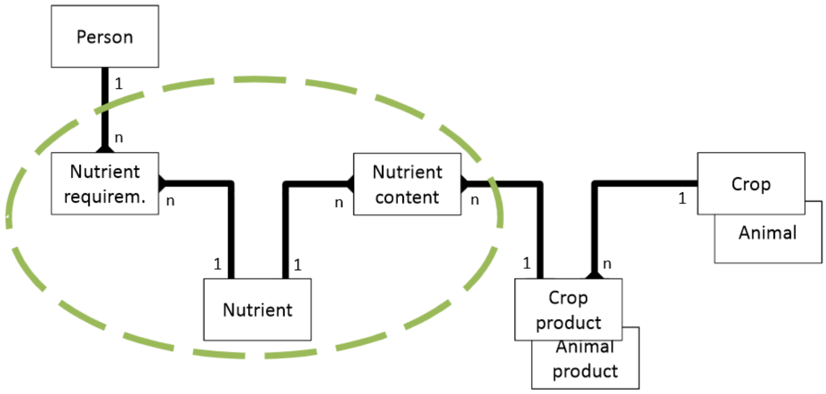

Figure 11: Schematic representation of relevant system components for the nutrient balance approach
The figure shows a person requires a number (n) of different nutrients, in a certain amount as defined in "Nutrient requirement". Crop and animal products have a certain content of a number (n) of nutrients, as defined in "Nutrient content". The nutrient balance approach balances the nutrient requirement with the availability derived from nutrient content of products (green oval).

The nutrient-based approach brings along several considerations. First of all, which nutrients to take into account. This decision will be case specific, depending on the goals and available information.

Secondly, the nutrient content of produce has to either be measured or estimated using existing food composition tables. Due to heterogeneity of crop nutrient content between varieties, farms and fields, direct measurements will give the most accurate results, followed by region specific food composition tables. The suitability of food composition tables from other regions is questionable and such a table should only be used after careful consideration. In addition, since processing and preparation of food can alter its nutrient content, careful consideration should be given to choosing to use raw or prepared products as calculation units.

A third consideration is how to take into account the nutrient requirements of the target group. There is a choice to make between using the recommended dietary allowance (RDA) or the estimated average requirement (EAR), and whether or not to include the tolerable upper intake level (UL).

Summation of the individual requirements of household members will reveal the household total requirement. In many cases food will not be distributed equally among household members, leading to possible over and underestimation of nutrient consumption for certain household members. If it is known that a proportion of a specific product is consumed by a subgroup (e.g. adult males) this could be taken into account in calculations.

A final consideration is whether or not it is necessary to take the selling or acquisition of food (from market or the environment) into account in the analysis. Often, not all food produced is consumed by the target group, and not all food consumed by the target group is produced by the farm under study.

3.3.3 Food pattern approach

The food pattern approach focusses on the balance between the food required by the household and the food available for consumption by the household. The food required by the household is derived from food based dietary guidelines (indicating what a person should be eating in terms of food, rather than nutrients) of individual household members and household composition.

The parts of the conceptual framework that are most closely related to this approach are indicated in colour in Figure 12.

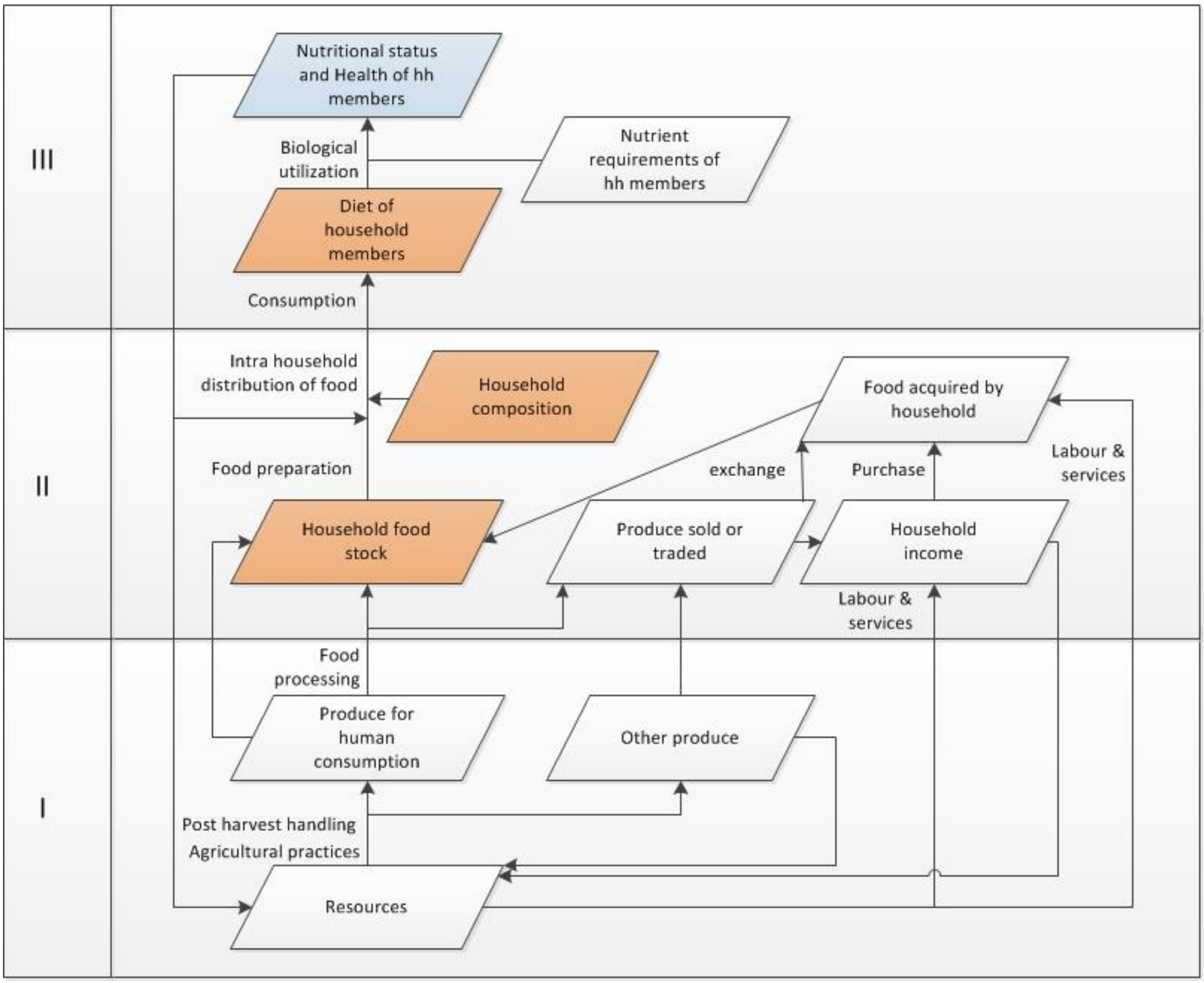

Figure 12: Relation between the food pattern approach and the conceptual framework
The orange colour indicates parts of the framework that are under study, the blue colour indicated parts of the framework most closely related to elements for which more insight is gained using this approach. In this case, dietary guidelines of household members (related to 'Diet of household members') in combination with information on household composition are used to determine the food required by the household. Subsequently, this is compared to the food available for consumption by the household (related to 'Household food stock').

An advantage of this food-based approach, compared to a nutrient-based approach, is that food habits are taken into account. This does not only allow for analysis of the balance between the produce available for consumption and household requirements, but also for optimizing or designing cropping systems to fulfil the requirements of the household. A disadvantage is that in most cases, food based dietary guidelines still have to be developed by nutrition specialists.
An example of a food-based dietary guideline can be seen in Figure 13.

The final food-based dietary guidelines derived for 3- to 6-y-old rural Malawian children using linear programming analysis

Food-plenty season	Food-shortage season
1. A 1-d portion[1] of maize flour (≥205 g/d) every day, which should be 95% extraction flour	1. A 1-d portion of maize flour (≥230 g/d) every day, which should be 95% extraction flour
2. A large 1-d portion (≥20 g/d) of fish relish every day, which must be small dry fish	2. A large 1-d portion (≥20 g/d) of fish relish every day, which must be small dry fish
3. A 1-d portion (≥70 g/d) of leaf relish at least twice every 3 d	3. A 1-d portion (≥70 g/d) of leaf relish at least once every 3 d
4. At least 2 snacks every day, which should include a 1-d portion of pumpkin (≥180 g/d) at least once every 3 d	4. A 1-d portion of legume relish (>30 g/d of dry beans) at least once every 3 d
	5. At least 3 snacks every day, which should include a 1-d portion of mangoes (≥120 g/d) every day

[1] A 1-d portion refers to a mean-sized daily portion not a meal-based one.

Figure 13: An example of food-based dietary guidelines developed using linear programming analysis
Copied from source (Ferguson, Darmon, Briend, & Premachandra, 2004)

Summation of the individual food product requirements of household members will reveal the household total requirement for that food product. Crop and animal products can be assigned to different food categories which are created based on the food-based dietary guidelines. These food categories can encompass one (e.g. the category 'pumpkin') or several products (as is the case for e.g. 'leafy vegetables'). The requirements per food category can then be balanced with the availability (green oval in Figure 14).

A schematic representation of the food-pattern approach is shown in Figure 14.

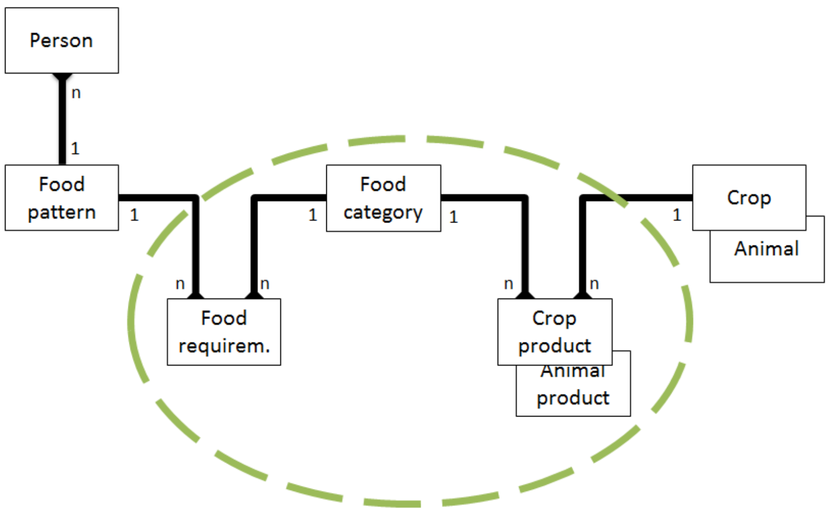

Figure 14: Schematic representation of relevant system components for the food-pattern approach
The figure shows crop and animal products belong to a food category (e.g. leafy vegetables). Each person has a food pattern, that dictates requirements of amount of foods from different categories. The food pattern approach balances the requirements per food category with the availability derived from amount of products in the different food categories (green oval).

To include the food pattern approach in quantitative farming systems analysis, food based dietary guidelines have to be known for the individual household members. In some cases existing dietary guidelines can be used, in other cases they will still have to be developed by nutrition specialists. In the development of these dietary guidelines knowledge on food habits and nutritional needs are combined. In addition, the effects of processing and preparation on food quality could be taken into account in the process.
Recently created modelling tools for developing food-based dietary guidelines such as Optifood (Daelmans et al., 2013) can be useful in this process.

In many cases food will not be distributed equally among household members, leading to possible over and underestimation of food consumption for certain household members. If it is known that a proportion of a specific product is consumed by a subgroup (e.g. adult males) this could be taken into account in calculations.

In addition, since often not all food produced is consumed by the target group, and not all food consumed by the target group is produced by the farm(s) under study, selling or acquisition of food (from market or the environment) could be taken into account in the analysis.

Summary of the 3 incorporation options

An overview of the different qualities of the three incorporation options is given in Table 3.

Table 3: Overview of the different qualities of the three incorporation options

	Dietary Diversity Proxy	Nutrient Balance approach	Food Pattern approach
Focus	Dietary diversity is used as a proxy for nutrient adequacy of an individual's diet. At the household level, an increased household dietary diversity score is associated with household food security and socio-economic status.	Balance between the nutrient requirements of the household (members) and the amount of nutrients available for consumption.	Balance between the food required by the household and the food available for consumption by the household.
Specific information requirements	A list of food groups used for scoring and the number of food groups from which one or more products are consumed.	Information on household member nutrient requirements, household composition and produce nutrient content.	Dietary guidelines for the different household members and information on household composition
Use	Comparison between individuals, households or farming system configurations. In design by including it as an objective or constraint (e.g. to retain, increase or maximize) in the process of multi-objective optimization.	Analysis of nutritional adequacy of the food available for consumption in a scenario. In design by including nutritional adequacy as an objective or constraint in the process of multi- objective optimization.	Analysis of adequacy of the amounts of foods available for consumption in a scenario. In design by including adequacy of the supply of the relevant food items as an objective or constraint in the process of multi-objective optimization.
Nutritional needs taken into account	By means of a proxy	Yes	Yes
Dietary needs taken into account	Only diversity of diet	No	Yes

3.4 Implementation methodologies for FarmDesign

As a part of the Nutrition-Sensitive-Landscape approach in the Humidtropics project, the goal was to include a household nutrition component in the whole farm model FarmDESIGN. In the following sections a description of FarmDESIGN will be given, followed by implementation methodologies for the different incorporation options for this model.

3.4.1 Description of FarmDESIGN

FarmDESIGN is a bio-economical farm model that uses a multi-objective optimization algorithm to generate Pareto-optimal alternative (mixed-) farm configurations (Groot et al., 2012). The different entities within the model and their relationships are described by variables stored in the model database. A schematic representation of the FarmDESIGN model, as created by Groot et al. (2012) is shown in Figure 15.

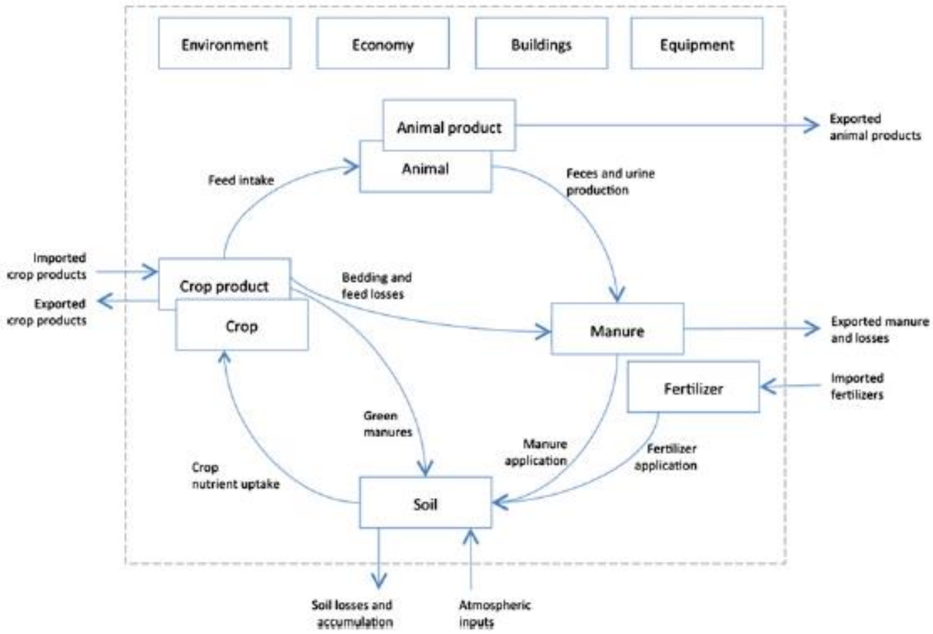

Figure 15: Schematic representation of the farm model and data within FarmDESIGN

The boxes indicate components included as entities in the model, the arrows represent material flows quantified by the model. The dashed lines denote the farming system boundary with the external environment(Groot et al., 2012).

The model supports iterative learning and adaptation cycles, where the system is first described, after which the results are determined in terms of agronomic, environmental and economic indicators. Subsequently, the results are evaluated and new options for farming system configuration are explored, after which the design phase is started by choosing a new configuration from the multiple options identified. This chosen configuration can be then used as a starting point for a new cycle to fine tune the design.

3.4.2 General additions to FarmDESIGN

Incorporating household dietary and nutritional needs in FarmDESIGN using either one of the previously identified options requires the addition of a household component to the model. This would allow for designation of produce for consumption (or other use) by the household. If the household is the unit of focus during analysis, this could suffice. However, if individual household members are the unit of focus, a person component would have to be added. This could enable taking into account effect of intra-household distribution of food by including an option to designate produce for consumption by specific consumers within the household (e.g. adult men).

If different food seasons exist (e.g. plenty and lean season), an option could be included to designate (a proportion of) produce for consumption in the lean and/or plenty season to allow for analysis of how well the needs are met in the different seasons.

In addition, import of animal products is likely to play a role, but is not yet included in the model.

An overview of the above-mentioned proposed additions to the FarmDESIGN model is illustrated in Figure 16 below.

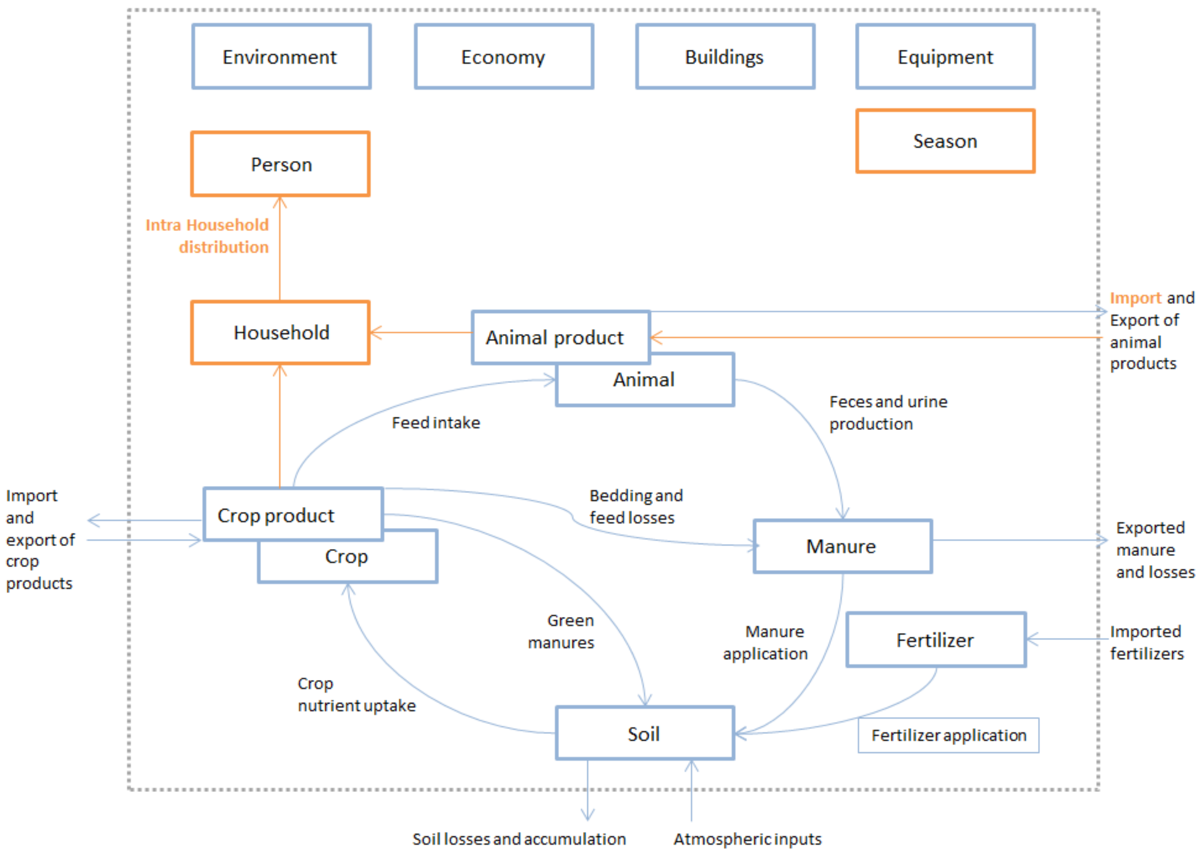

Figure 16: Proposed additions to the FarmDESIGN model

The boxes indicate components included as entities in the model, the arrows represent material flows quantified by the model. The dashed lines denote the farming system boundary with the external environment. Orange boxes, arrows and text represent proposed additions. Modified from source (Groot et al., 2012).

3.4.3 Dietary diversity proxy

When incorporating a dietary diversity proxy in FarmDESIGN, an option is to store a list of the (human) food groups (HFG) that will be used for dietary diversity scoring in the database. Crop and animal products (PRD and APR) could then be assigned to the food group to which they belong, for example by using a selection pane in the product window.

The relevant model components regarding assigning produce to human food groups including some examples are shown in Figure 17. This figure is based on the relevant system components as identified earlier in Figure 8.

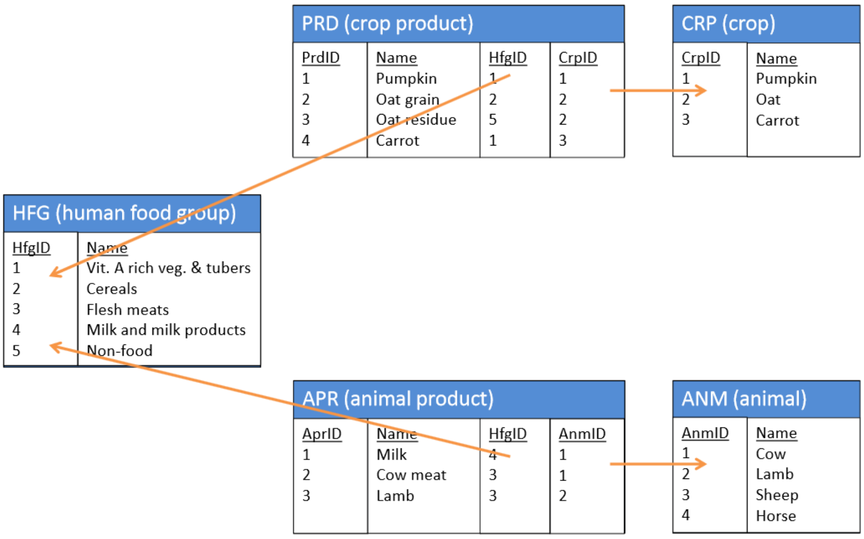

Figure 17: Overview of relevant model components for inclusion of a dietary diversity proxy
Different tables represent different components, arrows indicate relations between components. Each entity has a unique identification (ID). Several crop products (PRD) can come from one crop (CRP), and several crop products (PRD) can belong to the same human food group (HFG). The same logic applies to animal products (APR). For example, a cow (Animal ID 1) can produce cow milk (Animal product ID 1) and cow meat (Animal product ID 2), which belong to human food groups 4 (milk and milk products) and 3 (flesh meats) respectively.

When the information on which products are destined for consumption by the household is provided, it becomes possible to count the number of different human food groups from which one or more products are consumed. Individual dietary diversity scoring would require the calculation to take into account foods that are assigned for consumption by specific members of the household. In addition, it could be interesting to make a distinction between dietary diversity in different seasons.

When including all the above-mentioned options, the addition to the user interface for products could look like Figure 18.

Figure 18: Example of elements that could be added to the user interface in the product description window to enable dietary diversity scoring
After indicating that the product is consumed by the household, the sections below become active and can be altered.

If desired, an option could be included to enable exploration of the potential dietary diversity score of the scenario. This score reflects the dietary diversity that could be achieved when all produce fit for human consumption would be made available for consumption by the household. This could be implemented by including a non-food category and requiring the end-user to always choose a food group, even when the product is not destined for home use. Produce that is not suitable for human consumption could then be placed in the category ‘non-food’, and a summation of the total number of unique food groups (excluding the ‘non-food’ category) selected then indicates the potential dietary diversity score.

In the process of multi-objective optimization, dietary diversity score could be included as an objective (e.g. maximize) or constraint (e.g. higher than or equal to the score of the current situation).

3.4.4 Nutrient balance approach

Incorporation of household nutritional needs in FarmDESIGN using a nutrient balance approach requires the inclusion of a list of the human nutrients (HNT) under study. In addition, the requirements of those nutrients (HNR) for each household member would have to be included in the database. The nutrient requirements of household members could be taken into account by setting the EAR as a goal +/- 2 standard deviations as lower and upper limit, unless the upper limit would in that case be higher than the UL.

The nutrient content (HNC) of food products would also have to be included in the database.

The relevant model components including some examples are shown in Figure 19. This figure is based on the relevant system components as identified earlier in Figure 11.

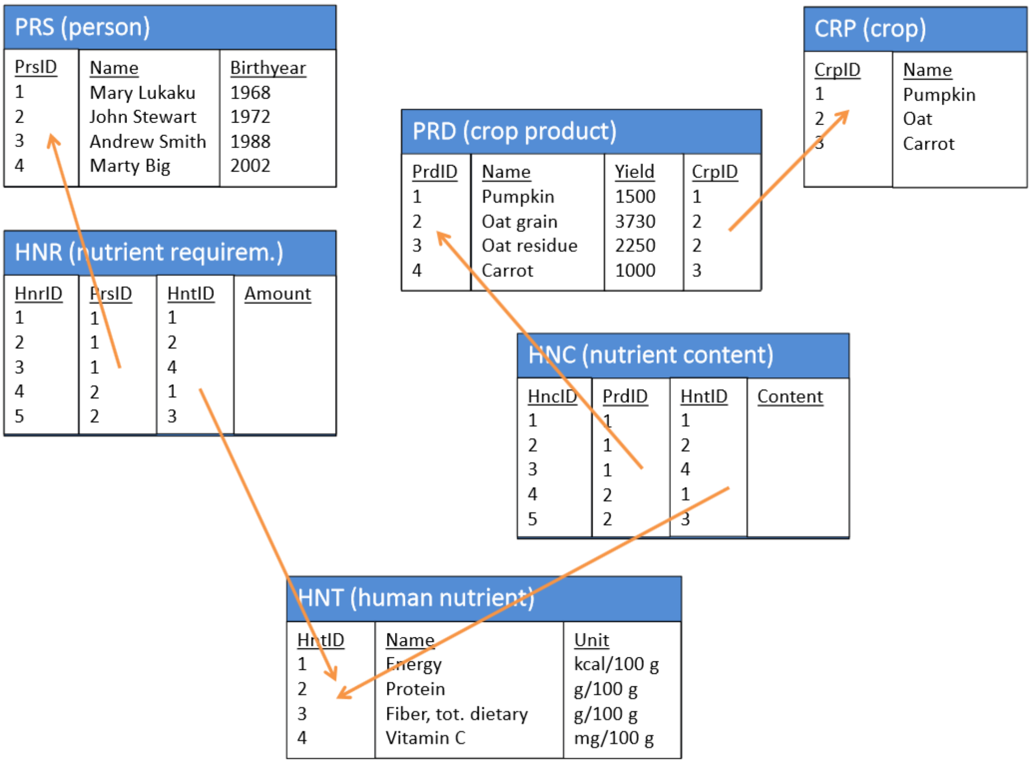

Figure 19: Overview of relevant model components for inclusion of a nutrient balance

Different tables represent different components, arrows indicate relations between components. Each entity has a unique identification (ID). As the figure shows, a person (PRS) requires a number of different nutrients (HNT), in a certain amount (HNR). Crop products (CRP) and animal products (not in the figure) have a certain content (HNC) of a number of nutrients.

For reviewing the balance between nutrients available for consumption and total household nutrient need, a summation of the individual needs (g/season) and a calculation for the total of each nutrient under study designated as food for the household (g/season) could be incorporated. The same can be done for individual needs, by calculating the nutrients available for consumption by the individual under study and comparing this to their needs.

When including all the above-mentioned options, the addition to the user interface for products could look something like Figure 20 below.

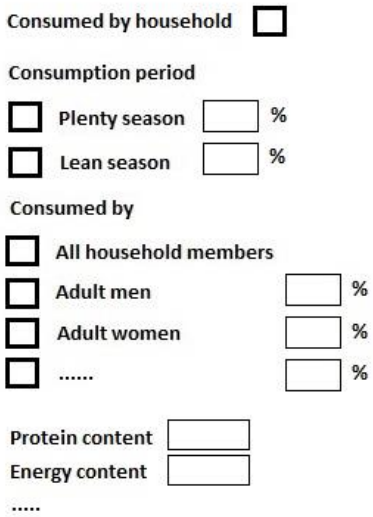

Figure 20: Example of elements that could be added to the user interface in the product description window to enable evaluation of the nutrient balance
After indicating that the product is consumed by the household, the sections below become active and can be altered. The proportion of produce consumed in a certain season and/or by specific household members can be indicated as well as the content of relevant nutrients.

Effects of processing and preparation on product nutrient content can be taken into account by including prepared and/or processed produce as a separate crop product. Residues from processing can be included as an additional product to enable use for other purposes (e.g. animal feed or soil organic matter building).

In the process of multi-objective optimization, the nutrient balance could be included as an objective (aiming to match the nutrients available with the requirements) or constraint (allowing the generation of scenarios in which availability matches the requirements only).

3.4.5 Food pattern approach

Incorporation of household dietary and nutritional needs in FarmDESIGN using a food pattern approach requires the inclusion of food-based dietary guidelines. These dietary guidelines can be stored in the database as food patterns (HFP), describing required amounts (HFR) of relevant food categories (HFC). These food patterns could then be linked to specific persons (PRS). If something in the situation of that person would change, influencing their dietary and/or nutritional needs, a different food pattern could be linked to their profile.

A list of food categories could be derived from the dietary guidelines, by including food items specifically mentioned in these guidelines as categories (e.g. leafy vegetables). A selection pane could then be included in the window of each product (PRD) destined for consumption by the household to indicate to which food category the product belongs.

The relevant model components including some examples are shown in Figure 21. This figure is based on the relevant system components as identified earlier in Figure 15.

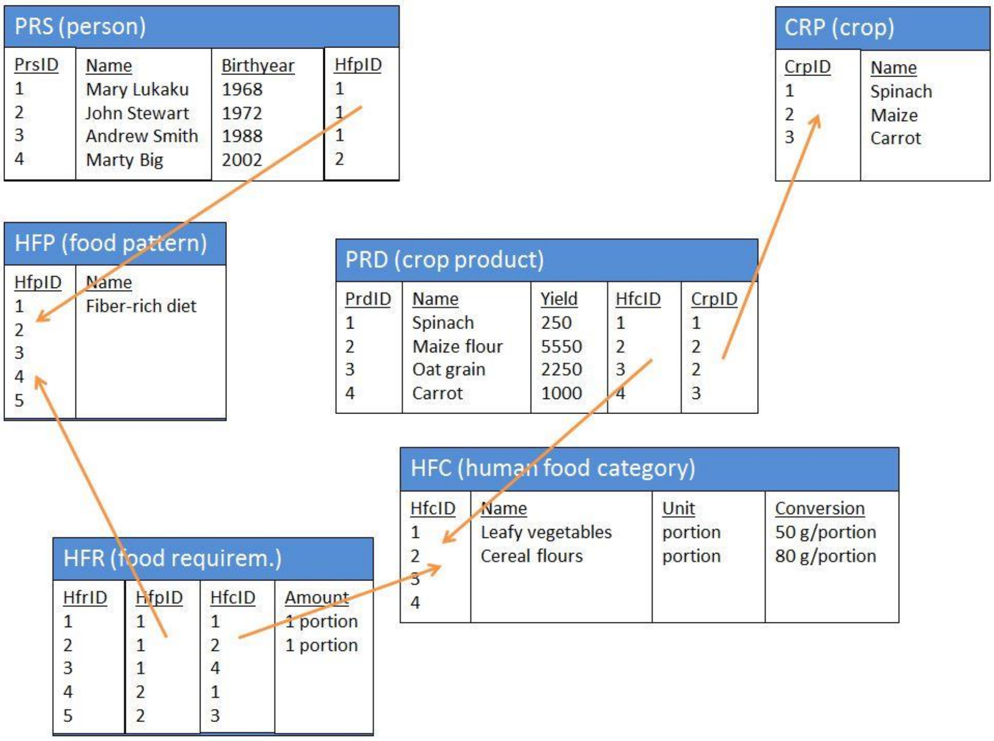

Figure 21: Overview of relevant model components for inclusion of a food pattern approach

Different tables represent different components, arrows indicate relations between components. Each entity has a unique identification (ID). Not included in this figure are the animal product (APR) and animal (ANM) component, which should also be included and relate to the human food category (HFC) component in a similar manner as crop (CRP) and crop product (PRD).

For reviewing the balance between the amount of food available for consumption and the total household needs, the total amount designated as food for the household (g/season) could be compared to the sum of the individual needs (g/season) for each product. The same can be done for individual needs, by calculating the food available for consumption by the individual under study and comparing this to their needs.

When including all the above-mentioned options, the addition to the user interface for products could look something like Figure 22 below.

Figure 22: Example of elements that could be added to the user interface in the product description window for the food pattern approach
After indicating that the product is consumed by the household, the sections below become active and can be altered. The proportion of produce consumed in a certain season and/or by specific household members can be indicated as well as the content of relevant nutrients.

Effects of processing and preparation on product nutrient content can be taken into account in the development of the dietary guidelines.

In the process of multi-objective optimization, the balance between the amount of produce available and the requirements could be included as an objective (aiming to match the food available with the requirements) or constraint (allowing the generation of scenarios in which availability matches the requirements only).

3 Conclusion & Discussion

Based on a literature review a conceptual framework was developed describing concepts and relations relevant to the incorporation of household dietary and nutritional needs in quantitative farming systems analysis. Subsequently, relevant dimensions and three distinct options for incorporation where identified (a dietary diversity proxy, a nutrient balance approach and a food pattern approach), and implementation methodology for each option for the whole farm model FarmDESIGN was described.

As the time available for this research was limited, the literature review covered only a part of available literature on the subject. This may have cause the conceptual framework to lack coverage and depth in some parts. By focusing mainly on review articles, the available time was used to get the picture as complete as possible. Although the lack of depth in the description of some components may be evident, it did not form a limitation for the deduction of incorporation options using a systems approach.

Important to realize is the fact that although the scope of this research was interdisciplinary and therefore relatively broad, it was still limited in respect to the complexity of reality. Not all factors influencing the four dimensions of food and nutrition security (availability, access, utilization and stability (Burchi, Fanzo, & Frison, 2011)) are taken into account, nor are the impacts of changing farming system configuration on factors other than household diet and nutrition (e.g. environmental impact). Factors influencing adoption of proposed farming system configuration other than dietary and nutritional needs have not been investigated in this research but can play an important role (e.g. gender related issues and the need for education).

Earlier attempts to incorporate household dietary and nutritional needs in quantitative farming systems analysis were able to theoretically improve nutrient balance of households under study (T. Amede & Delve, 2008; Amede et al., 2004; McIntyre et al., 2001). However, food habits were taken into account by setting a minimum constraint for production of current staple crops only, while in reality food habits are more complex. In addition, all options proposed by Amede et al. (2004, 2008) yield a reduction in crop diversity and therefore a possible decrease of dietary diversity (depending on what the extra income generated would be used for).

The systems approach used in this research has helped identify shortcomings in the above mentioned approaches to incorporate household dietary and nutritional needs in quantitative farming systems analysis. In addition, alternative options were identified including their strengths and weaknesses. While McIntyre et al. (2001) and Amede et al. (2004 and 2008) have in their own way tested the nutrient balance approach, the food pattern approach and the incorporation of a dietary diversity proxy remain to be tested.

The developed methodologies for incorporation of household dietary and nutritional needs in FarmDESIGN are now transferred to the supervisors of this research for fine-tuning and implementation. The resulting module could be a step towards increasing farm productivity tailored to the household needs. It will be tested within the Nutrition-Sensitive-Landscape approach in the Humidtropics project.

Hopefully, this document is useful in the path to better understanding between agriculture and nutrition specialists. It could provide them with a starting point for discussion and further integration between the two fields.

Recommendations for future research include the investigation of possible benefits of collaboration between nutrition and agronomic specialists in the development of food-based dietary guidelines, as until now, food-based dietary guidelines are founded on a sufficient nutrient intake only and do not consider environmental or production issues. Furthermore, the benefits and implications of including a food biodiversity indicator in addition to a dietary diversity indicator to evaluate the biodiversity present in the food supply could be investigated. This would not require major changes to the analysis methodology, as it basically exists of the same method complemented with information at variety level.

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