The world human dietary protein balance: improving existing protein sources and exploring new ones for future food supply

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Date of publication: 03-03-2009

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Introduction

Still the world is 854 million undernourished people rich (figure 1): 820 million in developing countries, 25 million in transition countries and 9 million in industrialized countries (FAO, 2007b).

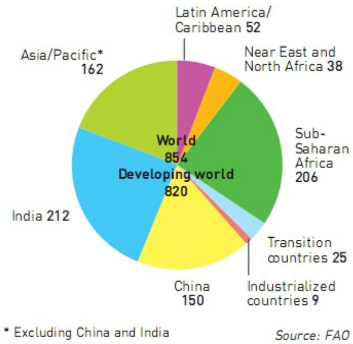

Figure 1: Number of undernourished people (in millions) in different parts of the world (2001-2003) (FAO, 2006c).

In 1996 at the World Food Summit (WFS) 180 nations committed to themselves the attainable intermediate target to half the number of undernourished people in the world by 2015. Compared with the baseline of 1990–92, the number of undernourished people in the developing countries has declined by 3 million, a number that falls within the bounds of statistical error and shows much geographical differences (FAO, 2006c). In terms of percentage, the proportion of undernourished people in developing countries has declined from 20 to 17 percent between 1969-2004, with the largest decrease till 1990. Projections of the Food and Agriculture Organization of the United Nations (FAO) suggest that the Millennium Development Goal (MDG) of reducing half of the proportion of people who suffer from hunger could be reached and has a crucial role to play in attaining many development outcomes embodied in the other MDGs (UN, 2004, page 5). In spite of the international consensus on the right on food [1] and all attempts for reduction of undernourishment, we will not reach the absolute WFS target following the FAO prognoses (figure 2), as 582 million people will still be undernourished in 2015 (FAO, 2006c). There is much geographical difference in the way in which change is achieved. Figure 3 shows that numbers of undernourished people have both increased and decreased in different areas of the world.

1 **Rome Declaration on World Food Security, 1996: "We, the Heads of State and Government ... reaffirm the right of everyone to have access to safe and nutritious food, consistent with the right to adequate food and the fundamental right of everyone to be free from hunger."**

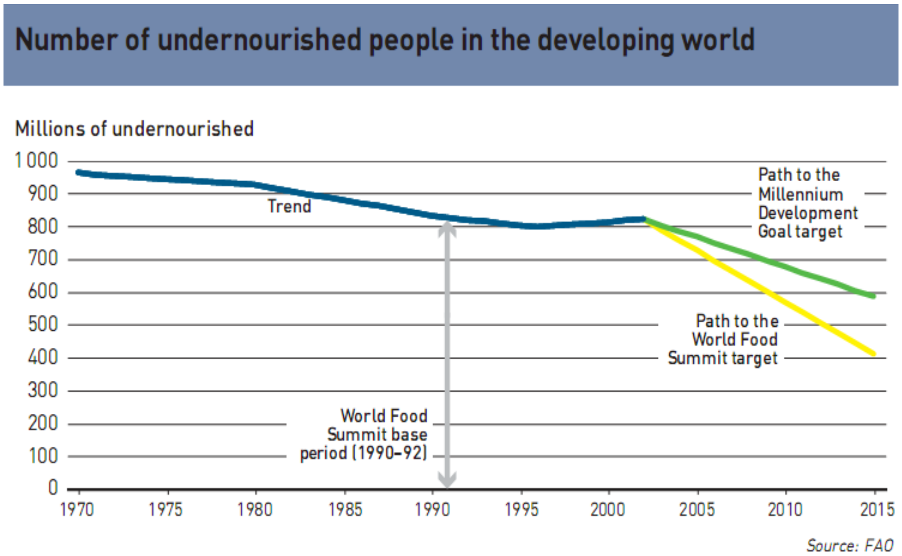

Figure 2: Number of undernourished people in the developing world and FAO prognoses compared with the UN World Food Summit and Millennium Development Goal targets (FAO, 2006c).

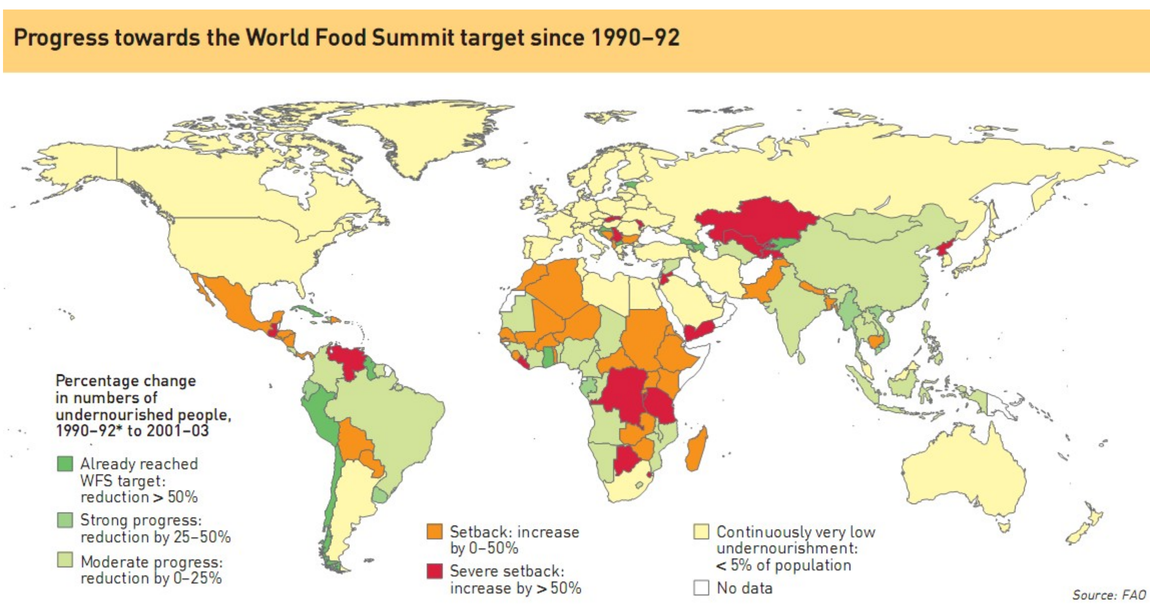

Figure 3: Geographical differences in the percentage of change in number of undernourished people (FAO, 2006c).

According to the FAO and the World Health Organization (WHO), adequate nourishment is defined by an energy intake lower than 2,200 kcal per person per day. This is a quantitative way of looking at human food requirements and is part of the whole range of malnutrition: an imbalance between requirements and intake of energy, macro- and micro nutrients. An adequate, healthy diet must satisfy human needs both for energy and essential nutrients. Dietary energy needs and recommendations cannot be considered in isolation of other nutrients in the diet, as the lack of one will influence the others (FAO, 2004). Worldwide 30 percent of the population suffers from malnutrition, which causes 55 percent of the 12 million child deaths each year. Most common forms are protein-energy and micro-nutrient malnutrition (Clugston & Smith, 2002). One of the major forms of malnutrition prioritized by the WHO (2000a, nutrition) includes protein-energy malnutrition (PEM). PEM is a multiple nutritional deficiency problem in many developing countries and is at least partly caused by a deficiency in protein in combination with a deficiency in energy and micro-nutrient. These deficiencies are mainly due to unbalanced diets or no food at all. If chronic, it has many short-term and long-term physical and mental effects, including growth retardation, lowered resistance to infection and increased mortality rates in young children (Kocabas et al., 2003; Collins & Sadler, 2002; Badaloo et al., 2002; Fechner et al., 2001; Lipton, 2001; Manar et al., 2001; Reid et al., 2000).

At the moment, the term malnutrition refers mainly to suboptimal food energy intake. The daily reference intake ranges from 2,600-3,000 kcal, in which the minimum corresponds to 0.7 kg of cereals per day or 250 kg/year. Quantitatively there is enough food to feed the human world population on average. Since 1960, the average food consumption per capita rose from 2,280 to 2,800 kcal/person/day, which is sufficient if compared with the required optimal food energy intake of 2,600–3,000 kcal per day (FAO, 2007b). Following the FAO projections, the increase of average food consumption of 2.3 percent per year now, will fall to 1.5 percent in the next decades, and to 0.9 percent in 2050. This diminished increase of food production will be enough to balance population growth. The population of the 32 most undernourished countries is expected to increase from the current 580 million to 1.39 billion by 2050 and, under the above assumptions, average food consumption could increase from the current 2,000 kcal/person/day to 2,450 kcal in the next 30 years (FAO, 2007b).

The question stands if we can still handle the world food issue if we zoom in to the level of the composition and quality of the human dietary needs and the specific components of agricultural output that are produced. Given their significant role in protein-energy malnutrition, proteins as a macro-nutrient seem to be of great importance in an adequate human diet. At the moment, the protein aspect does not get the full attention that it needs, probably because of a contra reaction after a period of much attention (Jackson, 2001). In this literature survey I will have a look in greater detail at the protein part of the world food balance. Following two main research questions I will try to answer if there is enough human dietary protein available, now and in the future, and how we can increase the availability in biological ways:

1) What does the present and future human dietary protein balance look like? Do we have enough proteins available for the human world population if we give full attention to human body protein and amino acid requirement?

2) Can we increase the availability of human food proteins with already existing biological solutions, without using the new genetic options in the life sciences such as genetic manipulation?

The fact that we live in an ongoing changing world makes it even more interesting and complex to find answers to these questions. Global population is one of the main driving forces in food demand and production. But we will also have to deal with significant impact on food production caused by other challenges like climate change, erosion, desertification, water and nutrient depletion, loss of biodiversity and genetic resources and a necessary transition to sustainable (bio)energy. Agricultural output depends on these factors, at least because of the impact and competition on available natural resources and space in the form of agricultural land. All these factors will not be the main subject of this thesis, but of course will directly or indirectly be addressed. The future will also bring possible opportunities like new scientific and technological developments and human diet changes which will indeed be a main topic here.

Chapter one is about the global dietary protein balance. It starts with an introduction on the concepts of body nitrogen balance, protein quality and essential amino acids, and ends with an overview and calculation of the world human dietary protein balance. Chapter two will continue on this basic information and will address the question how we could t the protein needs in the future. After an introduction on the types of proteins and routes of protein production, different methods to enhance the protein balance will be discussed.

Chapter 1 The global dietary protein balance: protein availability for human consumption

1.1 Individual protein and amino acid demands

1.1.1 Human dietary protein requirements

Like all other organism, human can maintain health throughout the life-cycle by consuming an adequate amount and quality of food. One of the three macro nutrients are proteins, following the WHO (2007) proteins are essential element of a healthy diet because of their role in for example body growth, production of nitrogenous compounds and DNA and metabolic protein synthesis and maintenance. The amount of protein that has to be consumed to achieve the desired structure and function is identified as the requirement and must always be measured and seen from the perspective of a whole diet including the intake of calories, protein, amino acids and nitrogen in a total diet. The demand is inherently variable between individuals and in the same individual at different stages in life.

1.1.2 Dietary influences on protein demand

Food consumption is determined by the level of energy expenditure and the greatest variability reflects differences in levels of activity. Following the WHO (2007), a more active person expends greater amounts of energy, consumes greater amounts of food and hence has a higher absolute level of protein demand. At constant levels of energy expenditure, increased energy intake improves nitrogen balance independently of the nature of the excess energy, which could be carbohydrate or fat. The demand for amino acids and nitrogen increases to a much lesser extent than energy demands. This means that at lower levels of food consumption, a diet that might have been adequate for protein at high levels of activity may no longer be adequate at lower levels of activity due to a lower absolute intake of energy. Conversely, a higher energy intake usually also leads to a better protein intake.

Besides the major role of macro-nutrients, the micro-nutrient quality of our food consumption can also play a significant role in changing the individual protein demand. The pathways of amino acid metabolism and interchange are critically dependent upon an adequate micro-nutrient status, and hence upon the amount and quality of food consumed (Jackson, 1999). Looking at the dietary influences on demand from a broader perspective, the WHO (2007) conclude that the variability of protein demand is significant throughout the life cycle and varies by effective factors such as programmed metabolic capacity, age, sex, diet, body composition, physiological state, pathological or environmental stressors, and lifestyle.

1.1.3 Achieving nitrogen balance

According to the WHO (2007), in order to match the demand for protein synthesis and other metabolic pathways, adequate amounts of amino acids of a suitable pattern must be provided in the diet. This intake could either be in a preformed state or as appropriate precursors that can be used to generate a suitable mix of amino acids following endogenous transformations.

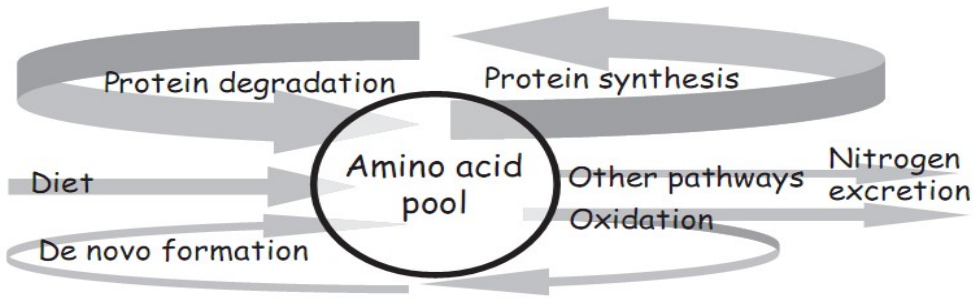

Figure 1.1: General model for amino acid metabolism and interchange (WHO, 2007).

Figure 1.1 shows a general model of the flows of a nitrogen balance of an individual, which has been reviewed by the WHO (2007). This human nitrogen balance turnover is described in the amount of amino acids per time-unit ("Amino Acid Pool"). The amino acid pool consist of a new input of amino acids derived from dietary ingestion via a person's "diet" and an output via "other pathways" in the form of "nitrogen excretion". Most amino acids stay in the pool because of internal recycling of proteins (upper loop) and reuse of amino acids out of oxidation pathways (lower loop) (WHO, 2007). To a substantial degree, the amino acids deriving from protein degradation will match the amount and pattern going to protein synthesis, apart from a fraction of amino acids which have undergone post-translational modifications such as methylations.

1.1.4 Protein utilization, quality, bio-availability and biological value

In most circumstances, ***protein utilization*** in human nutrition appears to be inefficient, independently of the dietary protein source. Following the WHO (2007) this seems evident from the fact that the adult requirement value for good-quality protein determined in nitrogen balance studies appears to be about twice the value of the obligatory nitrogen loss, implying a net protein utilization of only about 50%.

The WHO (2007) defines the ***protein quality*** as the capacity of food protein sources and diets to satisfy the metabolic demand for amino acids and nitrogen. The overall quality of dietary protein should predict the overall efficiency of protein utilization. Protein quality in other words is ***protein bio-availability***, the generic term for the proportion of any nutrient that can be absorbed from the diet and utilized. Following the WHO there are a number of difficulties relating to protein quality evaluation that have not been fully resolved. The most important conceptual difficulty is that of establishing the values for the quality of individual proteins and dietary protein mixtures, which enables their utilization in human nutrition to be accurately predicted in absolute terms. The WHO (page 93) concludes that in practice, protein quality evaluation has aimed to predict relative utilization of different protein sources rather than absolute values. By doing this, in general animal proteins seem to have a better quality, although in relative terms plant proteins can be good enough.

In the nitrogen balance model, as described earlier, there is a fresh input of nitrogen through the ingested diet. The effectiveness with which nitrogen balance can be achieved for a given amount of absorbed dietary nitrogen is defined by the WHO (2007) in terms of ***biological value***: nitrogen utilized/digestible nitrogen intake. This value can never exceed 1, since for any quantity of absorbed nitrogen the best that can be achieved is that the amino acid pattern is an exact match of requirements. The biological value of a protein is most often defined and discussed in terms of indispensable amino acid patterns relative to demand, because these amino acids are most restrictive and thus are the perspective that is most worth working with. However, following the WHO it must be clear that biological value in fact depends on the relative amounts of both dispensable amino acids (DAA) and indispensable amino acids (IAA), versus other nitrogen-containing compounds.

In spite of the fact that protein quality and thus protein utilization are very important factors, especially in situations with undernourishment, it is a too complex to discuss them in more detail in this thesis. I will focus on the concept of essential amino acids and especially the differences between plant and animal based dietary proteins, which is an important aspect of the dietary protein balance.

1.1.5 The concept of indispensable amino acids

Work carried out during the 1960s showed that the "efficiency" of utilization of indispensable amino acids (IAA) depends upon the total nitrogen and the form of nitrogen in the diet. As discussed by the WHO (2007), the higher the total nitrogen in the diet, the lower the consumption of IAA to achieve nitrogen balance. This also means that the minimum nitrogen intake for nitrogen balance is determined by the intake of IAA and that at a given level of nitrogen intake with enough indispensable amino acids, the nitrogen balance improves when the protein is partially replaced by dispensable amino acids. Even at sufficiently high levels of nitrogen consumption, relatively poor sources of nitrogen, such as ammonia and urea, can have beneficial effect (Jackson et al., 1996). The WHO conclude that there is an absolute metabolic need for both indispensable and dispensable amino acids, the rate of formation of dispensable amino acids in the body appears to be determined by the total intake of nitrogen, and at lower levels of total nitrogen consumption the formation of adequate amounts of non-essential amino acids.

The WHO (2007) defines the indispensable amino acids as leucine, isoleucine, valine, lysine, threonine, tryptophan, methionine, phenylalanine and histidine. Histidine is considered just now to be an indispensable amino acid because of the detrimental effects on haemoglobin concentrations that have been observed when individuals are fed histidine-free diets (Kriengsinyos et al., 2002). In recent literature it has been suggested that more attention should be given to the IAAs with regulatory functions such as leucine, instead of only these with substrate functions. At the moment, only amino acids with substrate functions are taken into account in current methods for assessing protein quality (Millward et al., 2008; Garlick, 2005; Layman, 2003).

As described by the WHO (2007), ***lysine*** has received most attention given its nutritional importance as the likely limiting amino acid in cereals as a staple crop, especially wheat. Like lycine, ***threonine*** is also a nutritional important amino acid, present at low concentrations in cereal proteins. According to the WHO, after the sulfur amino acids, it is the second rate-limiting amino acid in the maintenance requirement, probably because it accounts for the largest single component of the ileal loss into the large bowel (Fuller et al., 1994; Millward, 1997). ***Tryptophan*** is generally less available in proteins than many other amino acids and is nutritionally important since it is a precursor for some important metabolites. Its content is low in cereals, especially maize, where it may be the nutritionally limiting amino acid in some varieties. The ***aromatic amino acids*** **(AAC)** and ***sulfur amino acids*** **(SAA)** are special indispensable amino acid couples of respectively ***phenylalanine*** and ***tyrosine*** and ***methionine*** and ***cysteine.*** In both cases the former amino acid is nutritionally indispensable while the latter, as a metabolic product of respectively phenylalanine and methionine catabolism, is dependent on sufficient indispensable amino acids to supply the needs for both other dispensable amino acids. The SAA are nutritionally relevant since their concentrations are marginal in legume proteins, although they are abundant in cereal and animal proteins. Their occurrence in proteins is less abundant than other amino acids and they are important metabolically to the extent that their relative requirement for maintenance is probably higher than that for human growth.

1.1.6 Essential amino acids (EAA) in different food sources and plant based diets
According to the WHO (2007), with respect to its efficiency in supporting body protein metabolism, the assessment of protein quality of a diet should include consideration of the capacity of the single food sources to provide substrate needs for protein synthesis and any other biosynthetic pathways. As described above this should include at least sufficient total nitrogen and IAA, also in that way DAA requirements could be met by human body production. The WHO compared the ratios in absolute terms by comparing the IAA content of the major food proteins with the proposed IAA requirement pattern (figure 1.2) and in relative terms the distribution of IAA in food proteins and diets as percentages of requirement pattern (table 1.1).

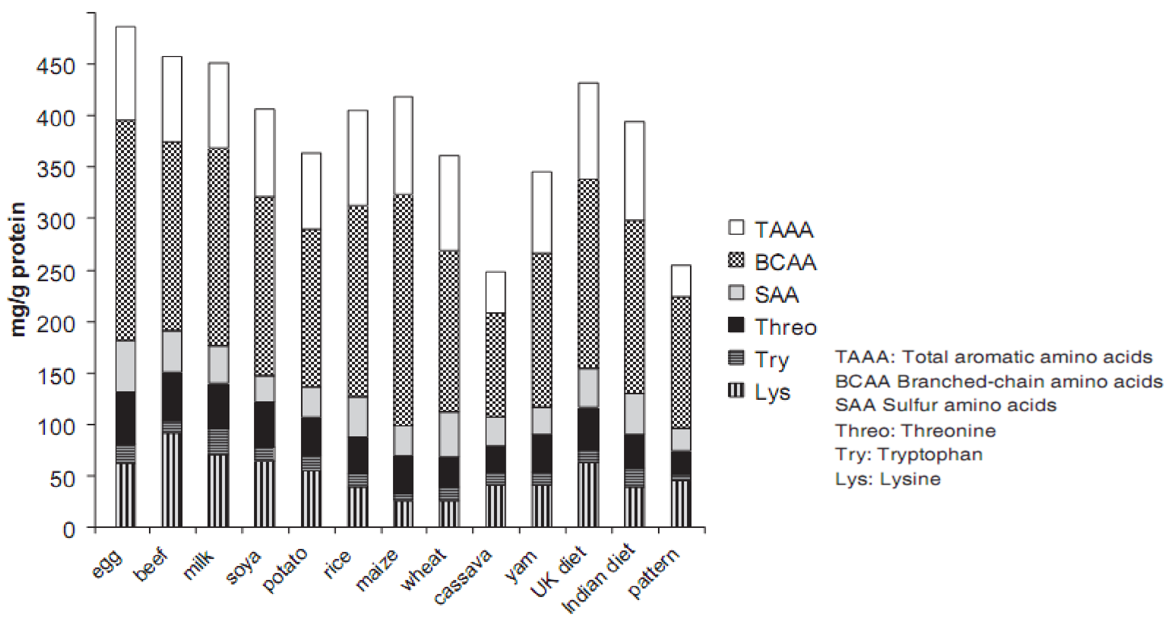

Figure 1.2: Indispensable amino acids in food proteins and diets compared with the requirement pattern, in mg/g protein (WHO, 2007).

As shown in figure 1.2, the WHO (2007) concludes that in the examples of staple crops the total IAA content is overall more than the proposed requirement values. Table 1.1 also shows a balanced amino acid pattern content for the different protein sources from animal products, legume, root and cereal crops. Lysine and the branched-chain amino acids (BCAA) are the two exceptions on this overall positive conclusion. Cassava, one of Africa main staple crops, has an overall lower IAA content than the pattern required. Lysine is most limiting in world's largest human food and animal feed staple crops such as maize (58 % of the required composition) and cereals/wheat (57 %). This is also the case in rice (86 %), which is the main Asian pacific staple crop, and the main African staple crops cassava (92 %) and yam (91 %). Cassava is also limiting in branched-chain amino acids (BCAA) with a 79 % content of leucine, isoleucine and valine. The average UK and Indian diets, following the WHO respectively an average diet for developed and developing countries are also compared with the requirement pattern and only lysine shows to be limiting in the Indian diet.

	Percentage of requirement pattern[a]											
	Egg	Beef	Milk	Soya	Potato	Rice	Maize	Wheat	Cassava	Yam	UK diet[b]	Indian diet[c]
Lys	139	203	158	144	121	**86**	**58**	**57**	**92**	**91**	140	**87**
Tryp	293	213	417	217	240	224	117	217	192	213	211	293
Threo	223	202	191	191	167	153	157	127	115	157	177	143
SAA	225	182	164	114	131	176	132	203	124	125	174	182
BCAA	168	144	151	136	120	146	177	122	**79**	116	143	132
TAAA	301	275	271	281	243	305	314	306	135	265	311	317

TAAA: Total aromatic amino acids
BCAA Branched-chain amino acids
SAA Sulfur amino acids
Threo: Threonine
Try: Tryptophan
Lys: Lysine

Table 1.1: Distribution of amino acids in food proteins and diets, given in percentage of requirement pattern (WHO, 2007).

These outcomes show that, in theory it is physically possible for humans to live on a full plant based diet. Following the WHO (2007), the animal based products like eggs, milk and meat contain significant higher amount of amino acids, but some plant based products could meet the absolute requirements of the for human necessary essential amino acids. This theory seems to be more difficult in reality because the main staple crops for human consumption at the moment are not adequate in providing lysine. Inadequate provision of IAA can be compensated by a more diverse diet and higher caloric and thus protein intake than in the normal situation. Different authors reported a lower efficiency of utilization of individual plant based protein sources compared with animal based protein sources in individual nitrogen or [13C]leucine balance comparisons for wheat gluten, beef, egg, milk, rice and lupin seeds (Millward et al., 2002; Millward et al., 2000; Egana et al., 1992). Following Millward et al. (1989), these differences are less relevant given the fact that they often differ less than the differences between studies with the same protein. The same conclusion is supported by the meta-analysis study of Rand et al. (2003) on the potential important and influential factors on the estimation of nitrogen requirement in healthy adults. They analyzed primary studies of dietary protein intakes derived from animal (n=64), vegetable (n=77) or mixed (n=94) protein sources. These three groups of dietary source of protein indicated no differences for the requirement, which is in contrast with the influences of sex, age and climate shown in the same study. The experimental plant based diets include complementary mixtures of vegetable proteins, such as corn, beans, rice and good-quality soy protein, which is following the WHO an important condition on which the results are based.

1.1.7 Protein and amino acid quality aspects of the protein balance

In their most progressive perspective, the WHO (2007) conclude that mixtures of cereal proteins with relatively modest amounts of legumes or oil seeds are unlikely to be limiting through their amino acid content. Following Mangels et al. (2003), the American Dietetic Association and Dietitians of Canada concluded in their position paper that appropriately planned vegetarian diets are healthful, nutritionally adequate, and provide healthy benefits in the prevention and treatment of certain diseases.

Different other authors concluded that well-planned vegan and other types of vegetarian diets are appropriate for all stages of the life cycle, including stages such as pregnancy, lactation, infancy, childhood, and adolescence (Mangels et al., 2003; Millward, 1999; Sanders, 1999; Young & Pellett, 1994). Furthermore, the same literature suggest that it is getting more and more clear that plant based diets offer a number of nutritional benefits, including lower levels of saturated fat, cholesterol, and animal protein as well as higher levels of carbohydrates, fiber, magnesium, potassium, folate, and antioxidants such as vitamins C and E and phytochemicals. At the same time, different authors discuss the possible drawbacks and make clear that there must always be special attention given to a possible lack in (some) essential amino acids, riboflavin, iron, zinc, calcium and vitamin A, B12 and D. (Murphy & Allen, 2003; Mangels et al., 2003, Neumann et all., 2002). Like in the case of the IAA, it has been argued by Murphy & Allen (2003) that plant based food products contain enough, but relative less of these nutritious compounds compared to animal based food products. There are opposing views that argue for the importance of meat in the provision of key bio-available nutrients in the case of child growth and development. Especially in the case of unnourished children in developing countries, where in some parts >50 % of young children have impaired height growth (Waterlow, 1997), different authors argue that it is necessary and important to be more careful and specific with the provision of dietary proteins (Neumann et al., 2002; Dagnelie et al., 1994). They argue that in these cases animal products with animal based proteins could be an easy source to manage the urgent forms of malnutrition.

My personal conclusion would be that animal proteins are an optional and non-essential component of a healthy diet, as long as the alternative diet is divers and contains legumes, especially soy. This will be an important assumption for the rest of this thesis.

1.1.8 Individual dietary protein requirements

A requirement of 105 mg nitrogen/kg body weight, comparable with 0.66 g/kg body weight per day of protein, is used as the population average requirement for healthy adults. According to the WHO (2007) is clear that there is a high level of variability in the balance responses, with some individuals in positive balance with protein intakes approaching a low level of 50 mg nitrogen/kg per day and others in negative balance at intakes of 150 mg nitrogen/kg per day. The official WHO *safe level* protein recommendation of 0.83 g/kg per day would be expected to meet the requirements of most (97.5%) of the healthy adult population. It must be said that this recommendation is an unisexual generalization. As described by the WHO, in reality there are sex differences in body composition with generally higher fat and lower lean content of women compared with men, which result in a lower requirement per kg in women in line with their lower basal metabolic rate and energy requirements. However, the WHO takes the safe side for women by putting them in the same category as men.

Body weight (kg)	Safe level of protein intake (g/kg per day)[b]
40	33
45	37
50	42
55	46
60	50
65	54
70	58
75	62
80	66

[a] All ages >18 years.
[b] 0.83 g/kg per day of protein with a protein digestibility-corrected amino acid score value of 1.0.

Table 1.2: Safe level of protein intake for adult men and women (WHO, 2007).

As defined by the WHO, the protein requirements are derived as amounts per kg body weight of subjects whose weight is within the acceptable range for height (adults) or age (children). In practice, the requirements per person, within the acceptable ranges of body weights, can be based on the actual weight or normalized to the median weight for height or age. Table 1.2 shows the official WHO safe level of protein intake for adult men and women according to the person's weight ranging from 40 to 80 kilograms. Table 1.3 shows the official WHO safe level of protein intake for infants, children and adolescent boys and girls ranging from 0.5 years to 18. In this case the protein requirements are given in grams per kg body weight per day, but also in grams per day by using the average body weights per age category (WHO, 2007).

Age (years)	Boys			Girls		
	Weight [a] (kg)	Safe level of protein intake [b] (g/kg/day)	Safe level of protein intake (g/day)	Weight [a] (kg)	Safe level of protein intake [b] (g/kg/day)	Safe level of protein intake (g/day)
0.5	7.8	1.31	10.2	7.2	1.31	9.4
1	10.2	1.14	11.6	9.5	1.14	10.8
1.5	11.5	1.03	11.8	10.8	1.03	11.1
2	12.3	0.97	11.9	11.8	0.97	11.4
3	14.6	0.90	13.1	14.1	0.90	12.7
4–6	19.7	0.87	17.1	18.6	0.87	16.2
7–10	28.1	0.92	25.9	28.5	0.92	26.2
11–14	45.0	0.90	40.5	46.1	0.89	41.0
15–18	66.5	0.87	57.9	56.4	0.84	47.4

[a] WHO reference values (*1*).
[b] From Tables 33a and 33b.

Table 1.3: Safe level of protein intake for infants, children and adolescent boys and girls (WHO, 2007).

All above mentioned dietary protein intake recommendations are effected by and must be seen in relation to the person's dietary energy intake. The WHO (2007) concludes that the reference protein:energy ratio increases with age, is higher for females than males, is higher for small than large adults at any age and decreases with physical activity. These kinds of dietary relations can also have major impact on the protein requirements of people in developing countries who are often living on low-energy diets. In the next section, these average individual protein requirements will be used to calculate the worldwide protein demand.

1.2 Worldwide human dietary protein demand

In calculating a simple world dietary protein demand we face at least three major problems. Firstly, the distinction between the protein requirements for adults and non adults require knowledge about the world population age structure. Secondly, the requirements for infants, children and adolescents depend on age and require therefore detailed information on the age structure within this group of non-adults. The third and last problem is a very difficult one, namely the problem that the adult protein requirements are given in grams per human body weight, which require knowledge about the world population weight structure or the average human body weight. The United Nation Population Division (UNPD) publishes data on the world population age structures that can be used for the first two problems, but there is a lower resolution because of the use of larger age groups which are not totally compatible with the protein requirement groups used by the WHO (2007). The protein requirements of the WHO groups non-adults in small groups in a range from 0.5 to 18 year. This is in conflict with the groups in the UNPD population age database and is used in several reports of United Nations on ageing and age structures (UNDESA, 2005; UNDESA, 2007). These groups are grouped according to working and non working individuals, namely in the groups 0-14 years, 15-59 years, +60 years and in reports about ageing also +80 years. The 15-18 year protein recommendation group is not used as an individual age group in the database of the UNPD, which raise serious problems in giving special attention to it in the calculations of the worldwide protein demand. Although the fact that the safe level of protein intake of 0.87 gram/kg/day for this non adult group is slightly higher than the 0.83 gram for adults, the average body mass will be lower for adolescents which will have a balancing effect on these different requirements. For simplicity, this line of thoughts will be followed. The UNPD age groups will be used and consequently the 15-18 year group will not be seen as an individual non adult recommendation group, but will be given the same requirements and weight as adults. In the online population age databases of the UNPD, there is the possibility to increase the resolution in age groups a little bit by splitting up the youngest group in a 0-4 years and 5-14 years group. Although the upper age limit of this first group falls within the 4-6 year protein recommendation group, it is theoretically possible, to use this new group for the calculations of the protein demand for the age ranging from 0.5-3 years with corresponding protein requirement recommendations. In doing this we should be aware of an underestimation of the real protein demand because of the higher safe level protein requirement for the 4-6 year group (13.1 gram per day) compared to the value for a 3 year old child (17.1 gram/day), caused by a higher average reference weight.

There are solutions to the third problem, but they are far from satisfactory. There is no worldwide population weight structure available at the moment. In the past, the FAO (1981, body) and WHO together published a report which described body weights and heights per country. This report covers only a low number of countries for which data was available at that moment and the results are far from up to date at this moment. Besides these practical defects, we should question the theoretical usability of such data. The measured average human body weight is not the same per se as the average body weight that people should have, seen from a health or medical perspective. The fact that we face a 'global obesity epidemic' (WHO, 2000b, Obesity) in the developed countries, but also in some developing countries at the moment, makes this all even more problematic. Since the FAO report from 1981, both the WHO and FAO put much energy in the science of anthropometry and the development of indicators for the measurement of both weight and height of humans. At the moment the body mass index (BMI) is the most accepted one and is used by both the UN institutions and nutritionists around the world. This method is based on the ratio between weight and height (BMI = weight/length^2) and can be used to calculate the average normal weight for a adult person with a certain height. In the case we have knowledge about the average human body height, we could use the upper and under limit of this BMI as the average upper and lower limit of weight. Unfortunately, at the moment, for this height indicator there also seems to be no official data or average value available. Height is in a certain way dependent on a person’s food and nutrients consumption pattern and shows variability between individuals and populations around the world (Barbar et al., 2004), as is also the case with BMI scores.

The literature seems to give no other possibility to get a value for an average human body weight, neither for an average human body height. Given these difficulties it will not be possible for me to calculate a precise and worldwide dietary protein demand in this literature survey. Consequently, this means that it is not possible to calculate a balance between supply and demand. In my opinion this outcome is unsatisfactory because it is essential to increase our knowledge about the world food balance in more detail, especially in the light of future limits in agriculture that we will face.

1.3 Worldwide human dietary protein supplies

The agricultural production and food consumption together form our worldwide food balance, which is dynamic and uncertain because of the global scale and regional differences. Following the State of Food and Agriculture report of 2007, the worldwide per capita protein supply increased from 67 gram in 1979–1981 to 75 gram in 2001–2003, with an intermediate amount of 72 gram in 1989–1991.The FAO does not give any more attention to dietary protein production at the moment, other than mentioning the per capita protein supply in their FAOSTAT database for the world as a whole, regions and individual UN member states. Unless other references are given, the FAOSTAT database will be the basis of all of my figures, numbers and calculations, with a maximum data range from 1961 to 2003.

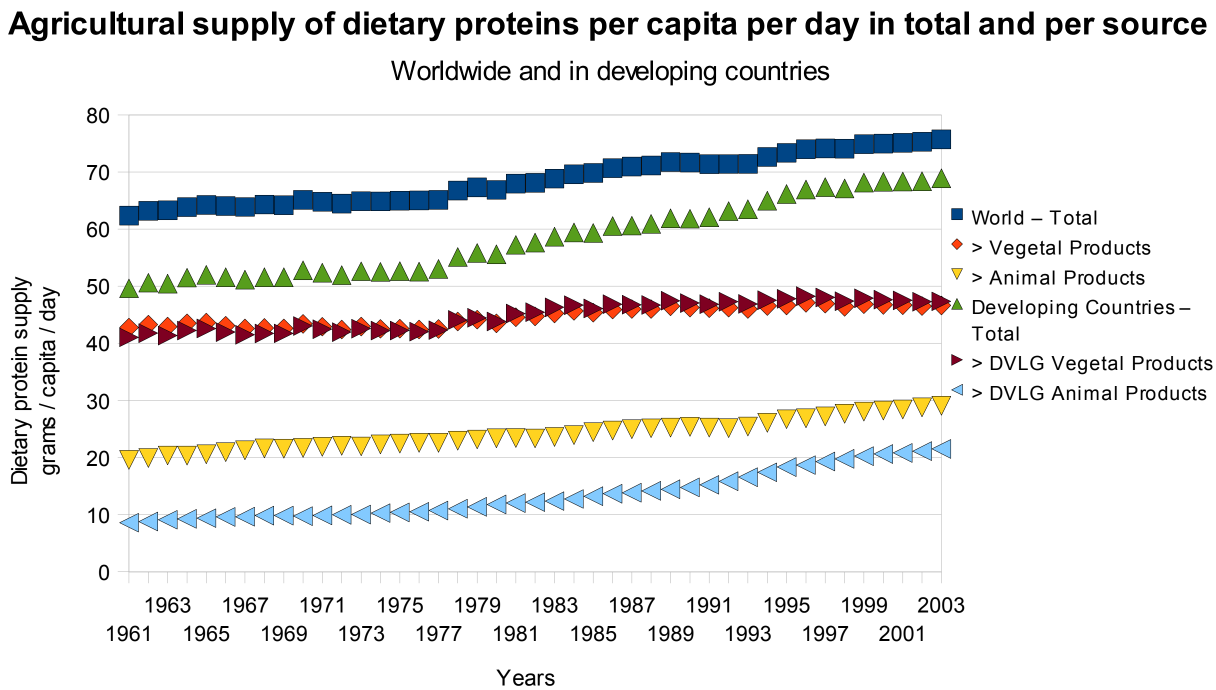

Figure 1.3: The amount and type of dietary proteins supply per capita per day for the whole world and developing countries (DVLG) alone. Personal calculations from the FAOSTAT database Food Balance Sheets.

The total time range of the FAOSTAT database shows an increase in per capita protein supply of 13.36 grams in 40 years, from 62.36 gram in 1961 to 75.72 gram in 2003,of which 3.88 gram and 9.49 gram is coming from respectively plant and animal based products (figure 1.3). This higher increase in animal based proteins caused a decreasing animal:plant based protein ratio from 1:2.18 in 1981 tot 1:1.6 in 2003. The same figure also shows the slightly different dynamics of protein supply per capita for the developing countries and therefore gives more insight in the worldwide spatial variation. Since 1977, the per capita protein supply in developing countries shows a higher increase compared to the world as a whole. In the last 40 years the developing countries show an increase in per capita protein supply of 19.24 grams, from 49.64 gram in 1961 to 68.88 gram in 2003, of which 6.3 gram and 12.94 gram of this increase is coming from respectively plant and animal based products (figure 1.3). Although the dynamics of the amount of plant based proteins are almost the same as for the whole world, in steady state at the moment, the amount of animal based protein supply in developing countries increased overwhelmingly with a animal:plant ratio changing from 1:4.78 in 1961 to 1:2.2 presently. The same dynamics are also visible in table 1.4, showing the calculated growth rates of per capita dietary protein supply in percentages of change for the period of 1961-2000. This rapid growth of animal based protein supply for both the whole world and developing countries should receive extra interest as will be discussed in chapter 2, as well as the high growth of total protein supply in developing countries.

	Growth rates in percentage of change				
	1961-1970	**1971-1980**	**1981-1990**	**1991-2000**	**1961-2003**
World – Total	4,41	1,59	5,41	5,03	21,42
> Vegetal Products	1,54	2,36	3,84	1,26	9,07
> Animal Products	10,72	4,88	8,42	11,93	48,44
Developing Countries – Total	6,33	2,03	7,98	10,02	38,76
> DVLG Vegetal Products	4,82	2,43	4,05	1,71	15,35
> DVLG Animal Products	13,5	12,12	22,78	35,61	150,64

Table 1.4: Growth rates in percentage of change of the per capita dietary protein supply worldwide and in developing countries (DVLG) for 10 year periods between 1961-2003. Personal calculations from the FAOSTAT database Food Balance Sheets.

The distinction between the developed and developing countries is a basic and important one, but there are more possibilities to describe the spatial variability of protein availability and supply. Figure 1.4 shows the dietary protein supply per capita and its source for all continents and different regions in the world. North America has the highest supply of total (117 gram) and animal based (72 gram) dietary protein per capita, followed by Europe (101gram and 56 gram respectively) and Oceania (99g and 62g), the latter with a slightly relative higher supply of animal based proteins. South America appears to be the most comparable with the average worldwide total protein supply (77g compared to 76g), although it has a significant higher supply of animal based proteins (38g versus 29g). On the other hand Asia can be seen as a perfect comparable example of the average total (70g versus 69g) and animal based (23g versus 22g) protein supply in developing countries. Both the lowest total (61g) and animal based (13g) protein supply per capita can be found on the African continent. This is also the continent with the highest variation between regions.

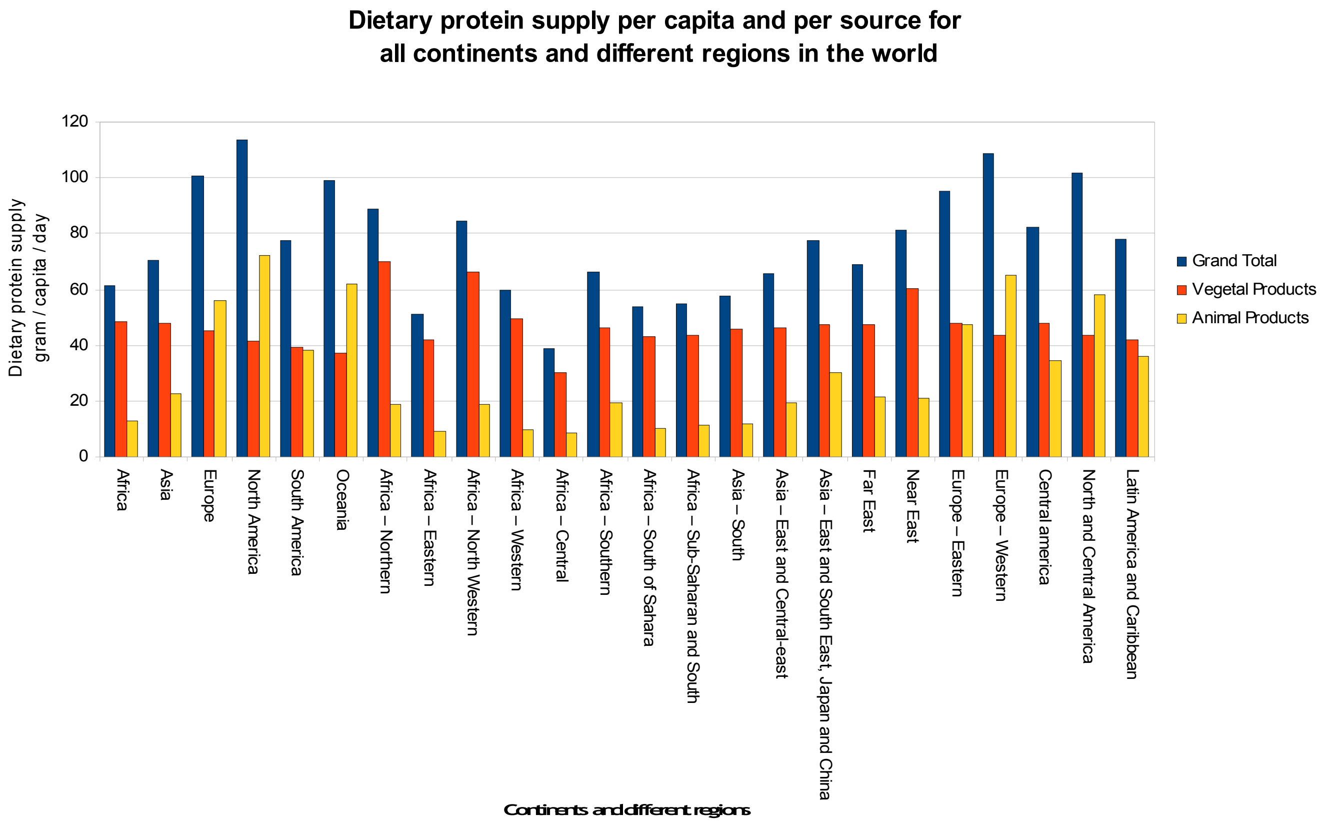

Figure 1.4: Dietary protein supply per capita and per source for all continents and different regions in the world. Personal calculations from the FAOSTAT database Food Balance Sheets.

In general, besides geographical factors, the FAO uses also socio-economical factors like the development stage, income and food availability to select or group countries. Examples of this kind of grouping are low-income food-deficit countries, industrialized countries and OECD countries (which are member of the Organization for Economic Co-operation and Development). Figure 1.5 shows the dietary protein supply per capita for the different groups of countries, the EU and some countries that are frequently used as example by the FAO. Logically, the industrialized, OECD and developing countries show comparable amounts of protein supply, as is the case with the European Union. Table 1.5 gives a ranking overview by listing all the above mentioned groups sorted by their amount of protein supply. In this ranking, the Least Developed Countries (53 grams) show to have the lowest supply, followed by the Low-income Countries (57 gram), developing countries in Africa (60 gram) and Land-locked Developing Countries (61 gram). The United States of America (115 gram), developed countries of North America (114 gram) and the European Union +15 (109 gram) appear to be the groups of countries with highest dietary protein supply in the world.

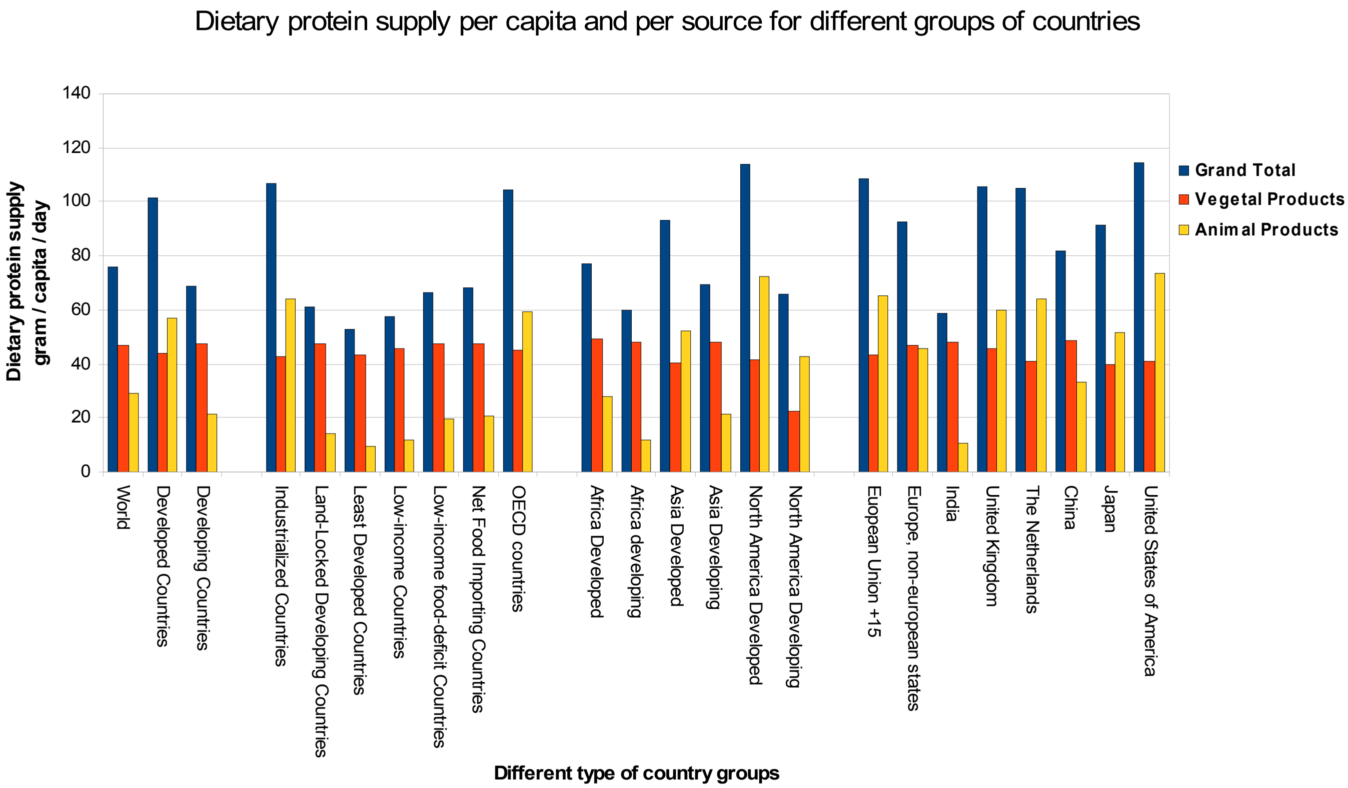

Figure 1.5: Dietary protein supply per capita and per source for different grouped and individual countries. Personal calculations from the FAOSTAT database Food Balance Sheets.

India and the United Kingdom are mentioned by the WHO (2007) as examples of average diets for respectively the developing and developed countries in the light of providing amino acids. On the side of the protein quantity, at least India (59 gram) has a significant lower amount of protein supply per capita than the average supply of the developing countries together (69 gram). Figure 1.5 and table 1.5 also show that the United Kingdom and the Netherlands have comparable protein supplies with the average for the OECD countries. The total dietary protein supply of China (82 gram), which is a developing country that is getting special international attention because of rapid development and growing demand on food, is a little bit higher than the average total supply in the developed countries of Africa (77 grams) and the world average (76 grams). The FAO State of Food and Agriculture (2007) report gives a complete list of the per capita dietary protein supply for all official countries in the world for the periodes 1979-1981, 1989-1991 and 2001-2003. In appendix 1 these numbers can be found, including the energy supply for each country in 2001-2003 for comparison. The countries are ranked from low to high supply and divided in 4 sections according to their differences with the world average of 76 gram protein per capita per day. The first section (red) consist of the 21 countries that have the lowest protein supply ranging from 25 gram (the Democratic Republic of the Congo) up to 50 grams per capita, ending with 49 grams for Rwanda and the Dominican Republic. The second section (orange) is the biggest with 66 countries that have a lower than world average protein supply ranging form 51 gram (the Solomon Islands, Guinea and Cambodia) up to 75 grams per capita (Malaysia and Serbia and Montenegro). The third section (yellow-green) contain 55 countries that have above average protein supply ranging from the world average of 76 gram (Saudi Arabia, Guyana, Belize and Cape

Verde) up to 99 gram (French Polynesia and Poland). The fourth and last section (green) contains the 27 countries with the highest protein of the world ranging from 100 gram (Germany) up to 124 gram (Italia, Iceland and Israel). It must be clear that there is an enormous gap between on the one hand these three countries with a 50% higher supply than the world average and on the other hand the two lowest total per capita protein supplies of the Democratic Republic of the Congo (25 gram) and Liberia (32 gram). Furthermore it should be no surprise that section 1 consist mainly out of developing countries from the African continent and that section 4 contains most of the countries of the European and North American continent. The dietary protein and energy supply are showing broadly the same picture, in the sense that the energy and protein supply per country in the 2001-2003 period are significant correlated (Pearson, $r = 0.911$, $p = 0.000$, 2-tailed). This is probably at the same time an explanation why UN organizations such as the FAO are pinpointing their efforts on increasing the individual caloric consumption, rather than looking at protein supply.

	Grand Total	Vegetal Products	Animal Products
Least Developed Countries	52,99	43,33	9,66
Low-income Countries	57,46	45,71	11,75
India	58,75	47,93	10,83
Africa developing	60,18	48,18	12
Land-Locked Developing Countries	61,16	47,2	13,96
North America Developing	65,72	22,72	43
Low-income food-deficit Countries	66,53	47,18	19,35
Net Food Importing Countries	68,27	47,27	21
Developing Countries	68,88	47,35	21,53
Asia Developing	69,46	48,04	21,43
World	75,72	46,64	29,08
Africa Developed	77,36	49,46	27,9
China	81,8	48,82	32,98
Japan	91,49	39,88	51,61
Europe, non-european states	92,59	46,85	45,74
Asia Developed	92,98	40,54	52,44
Developed Countries	101,2	43,96	57,24
OECD countries	104,43	45,13	59,3
The Netherlands	104,97	40,64	64,33
United Kingdom	105,52	45,49	60,02
Industrialized Countries	106,62	42,46	64,16
Euopean Union +15	108,85	43,57	65,28
North America Developed	113,71	41,42	72,29
United States of America	114,67	40,99	73,68

Table 1.5: Dietary protein supply in grams per capita and per source for different grouped and individual countries, ranked from low to high supply. Personal calculations from the FAOSTAT database Food Balance Sheets.

1.4 Conclusions: interpretation of the per capita dietary protein supply

Although it is very difficult to calculate the world protein demand, this is one of the two necessary steps that should be made to complete the world protein balance. The above mentioned relative comparisons between the world average, countries, regions and the developing and developed world give an idea, but do not provide any absolute answer to what we theoretically need as world population. Besides uncertainties, we will also face gaps in knowledge, given the fact that the answers require information on the world and regional population structure in age, sex and weight. In the same time we should give more attention to factors like development stage, diet choices and dietary caloric requirements, which depend on individuals and groups and have variation in time and space.

The interpretation of the per capita supply of proteins receives almost no attention in scientific literature. Only Smil (2002a, nitrogen) has written a full article on this subject. By using the FAOSTAT database and standard nutritional values of foods, he calculated that during the mid-1990s the worldwide edible agricultural production contained about 25 Mt nitrogen (N), of which 16 Mt N has derived from harvested crops, 7 Mt from meat and diary products and almost 2 Mt from marine and freshwater catches and aquaculture. This grand total N supply is sufficient for a per capita dietary protein supply of 75 gram/day, with 25 gram protein per day coming from animal sources. Smil conclude that this total amount is an adequate supply by any definition, but does not give an explanation or references on which these recommendations and requirements are based. He recognizes and discusses the differences in the per capita protein supply between the developed and developing countries, which are respectively sufficient for almost 100 gram/day and less than 70 gram/day. Following Smil, the supply for developing countries can also be seen as being adequate, but only under the assumption that there is a perfectly equitable distribution of food and protein content. The lowest protein supply can be found in countries of sub-Saharan Africa, with 50 protein gram per day in total and 5-10 gram/day coming from animal sources, an area were at the same time 60-70 % of the people are undernourished compared to the 14 % undernourishment of the total world population.

Smil gives limited references, figures and data. This shortcoming can be explained because most of the time he is writing popular scientific literature, but at the same time he is also facing the problems described above, like insufficient information on the average human body weight. We can try to approximate or calculate this average value. In the WHO (2007) report and almost all therein referred surveys, 50 kilogram and 70 kg are the most used reference weights for an average human body in both calculations and figures. At the same time, the adult requirement recommendations are given for different weights ranging between 40-80 kg, which gives an average of 60 kg (see table 1.2). Based on the BMI classification and the assumption of an average human body height of 180 cm, we can calculate that the normal range of BMI values between 18.50-24.99 is comparable with body weights ranging between 60-81 kg. Consequently, by using the safe protein intake level of 0.83 gram/kg body weight, this range is comparable with a per capita protein demand for adults ranging between 49.75 gram and 67.2 gram per day. The reference weight of 60 kg is thus comparable with a demand of 50 gram per day for adults.

If we compare the protein demand values with the per capita supply values, overall we can see a positive picture. The per protein supply worldwide (76 gram) as well as in the developing countries (67 gram) appears to be higher then the calculated average protein demand range. Visa versa, from another perspective, these protein supplies can provide adequate amounts of proteins to individuals with body weights of respectively 92 kg and 81 kg, which is probably above the global average. All continents provide a higher protein supply, except Africa with a provision of 61 gram protein per day, which is a little bit lower than the upper limit. The range of protein demand is almost comparable with that of countries in section 2 shown in appendix 1. Values in section 1 are under the lower limit of the safe protein intake per capita range, which means that 21 countries show a lower provision of dietary protein than adequate for their population.

My overall conclusion at the moment is that worldwide there is a surplus of dietary protein available for the total human population, but the availability is unequally allocated. Protein shortages are a regional problem, but must be seen in a worldwide context including how we produce and consume dietary proteins. Developed countries have protein availability higher than demand and a significant number of developing countries have urgent shortages. Regional factors such as agro-ecological quality, differences in availability of natural resources, political (in)stability and power imbalance seems to be important, although specific research on this is lacking. Spatial variation within regions and countries makes it difficult to make general conclusions and must be seen as more important than average numbers. This is especially the case for developing countries which are a broad group of countries with significant differences.

The African continent should get international attention and where necessary action, given the fact that this continent consist of 18 of the 21 individual countries which face real gaps between supply and demand of dietary proteins. According to the World Population Prospects 2005 of the United Nations, Africa is the world's second-largest and second most-populous continent. It covers 6% of the Earth's total surface area and 20.4% of the total land area. With about 922 million people in 61 territories, it accounts for about 14.2% of the World's human population. On the African continent as a whole, the per capita protein availability should raise with 6.2 gram, which is at least an increase of 10 percent of the present production. These 18 problematic African countries show no significant correlation between the per capita per day availability of food calories and protein *(Pearson, $r = 0.361$, $p = 0.141$, 2-tailed).*

1.5 Discussion: the quality aspects of the protein balance and increasing animal protein consumption

The quantitative aspects of the quality of proteins, such as digestibility, bio-availability and amino acid content and pattern, we are not taking into account in the global dietary protein balance calculations of Smil or myself. At the moment, there is not much relevant data and literature available on this topic to extent the balance to qualitative aspects. Although it can be said that the information is incomplete, the data and discussion of the WHO (2007) report in section 1.1 suggest that the amino acid pattern of the main crops are almost adequate with the exception of the provision of the most limiting amino acid lysine. As described in this chapter, all geographical types of diets contain a significant amount of animal based proteins, ranging from 21% in Africa to 62% in North America. These proteins from animal origin contain significant higher relative amounts of lysine which have a balancing effect on possible lysine shortcomings in the case of eating lysine incomplete crops. Among the major food crops, lysine is only proportional sufficient provided by legumes (like soy) and potato, which are non-staple crops. Therefore, in a lysine restricting agricultural protein production or diet consumption, the most simple and interesting solution would be to increase the production and consumption of pulses, especially soy. This is in major contrast with current situation. The overall per capita dietary protein supply based on the production of pulses decreases since 1960, although at the same time there was a small but fluctuating increase for the soybean based protein supply.

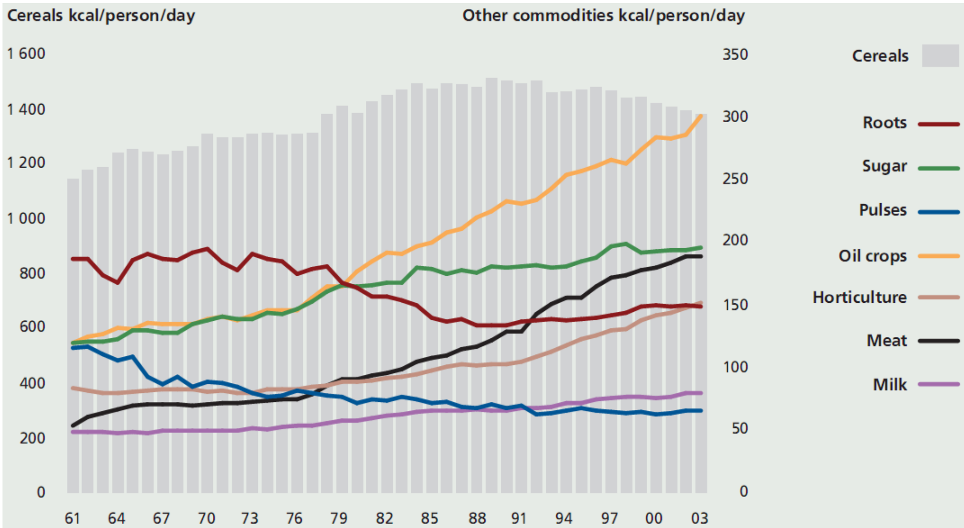

Figure 1.6: Food energy consumption of different food commodities in developing countries between 1961-2003 (FAO, 2007)

According to the FAO (2007a), at the moment we face worldwide shifts in dietary preferences which cause significant changes in the demand and supply of specific agricultural commodities. In the last 150 years the developed countries have shown an enrichment and diversification of their diets mainly due to increases in income and agricultural development. The developing countries are currently engaged in a catching-up process (figure 1.6) at least for these countries that undergo the same economic development. This "nutriton transition" (Popkins, 2001), driven by rising incomes, changes in social levels and lower relative prices for food, is characterized by an accelerated shift from undernourishment to richer and more varied diets. The rapid diet changes, possible within one generation, contain more and more pre-processed food, food with added sugar and fat and food products from animal origin. In the last 40 years the composition of agricultural production has changed (figure 1.7), with a significant higher increase of the production of cereals, oil crops, sugar, vegetables, eggs and meat in comparison with pulses, roots and tubers which has declined relative to the total population growth (FAO, 2007b). This dietary shift towards the consumption of animal based instead of plant based products has a direct and equally effect on dietary protein demands and thus production. In the next part of this thesis, the necessity of a dietary protein transition will be described and discussed, which consist of many problems, solutions and steps following the FAO. The solutions are not only technological or biological, but must be seen in the context of social-economical dynamics given the fact that the increasing consumption of animal proteins is strongly correlated with rising income and increasing level of development.

		1961–76	1977–91	1992–2005	1961–2005
		Annual percentage change			
CEREALS	WORLD	3.5	1.8	1.3	2.2
	Developing countries	3.9	2.8	1.5	2.8
OIL CROPS	WORLD	2.9	4.8	4.2	4.0
	Developing countries	3.1	5.0	4.9	4.4
SUGAR	WORLD	3.4	2.3	0.8	2.2
	Developing countries	3.1	3.5	1.2	2.6
PULSES	WORLD	0.8	1.5	0.9	1.1
	Developing countries	0.5	1.0	1.4	1.0
ROOTS AND TUBERS	WORLD	1.3	0.5	1.5	1.1
	Developing countries	3.0	1.6	2.2	2.3
VEGETABLES	WORLD	1.8	3.2	4.7	3.2
	Developing countries	1.9	4.4	6.1	4.1
EGGS	WORLD	3.0	3.4	3.6	3.4
	Developing countries	4.6	7.0	6.0	5.9
MEAT	WORLD	3.5	3.0	2.6	3.0
	Developing countries	4.3	5.3	4.8	4.8
MILK	WORLD	1.6	1.4	1.2	1.4
	Developing countries	2.7	3.3	3.8	3.2

Figure 1.7: Global annual growth rates for outputs of different main agricultural commodities in periods between 1961-2005 (FAO, 2007).