Changes in Consumption Patterns: Options and Impacts of a Transition in Protein Foods

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INTRODUCTION

Food sustainability and the protein chain

Food is important to individuals and society, providing nutrients and generating income (Tansey and Worsley, 1995). The relationships between food production, environment and society are complex. In fact, the evolution of agriculture has both shaped and been shaped by world population growth (Evans, 1998). At any rate, a major proportion of global environmental pressure is generated by food-related human activities. Crops are produced, transported, processed and turned into food products in ever larger volumes, with ever-increasing impacts on the environment (Smil, 2001; Tilman et al., 2002). Lindblom (1990) notes that, although sustainability is a socially accepted goal, relative consensus exists concerning its ‘ills’ (such as food production related impacts), but hardly concerning its ‘ideals’. In this respect, some large multinationals (WBCSD, 2004) claim they can protect sustainability better than anyone else. However, their definition of sustainability does not coincide with that of the average consumer or NGO, the difference being in attributes such as ‘natural’ and ‘just’, in particular (Kloppenburg et al., 2000). In order to reduce global environmental change, the production of food, energy and water have been identified as three main targets for stepwise transition, instead of gradual improvement (Vellinga and Herb, 1999). Moreover, these three main activities are not independent of one another, since food production appropriates a major share of freshwater and energy produced. Therefore, when striving for a major step towards sustainable production in the next few decades, it should be realised that agriculture, climate change and land-use change are inextricably intertwined.

Within the realm of food, meat has a unique status since consumers endow it with esoteric qualities (Beardsworth and Keil, 1997). Furthermore, its production is responsible for a disproportionate share of environmental pressure. When

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striving for sustainable food production and consumption systems (Aiking and Vellinga, 2000; Green et al., 1999), therefore, the protein chain is a good place to start for more than one reason. Due to continued growth of the world population and the proportion of meat in the global diet, the pressure of food production and consumption on the environment is rising steadily. A large proportion of this environmental pressure derives from meat production (Bradford, 1999; Delgado et al., 1999), due to the inherently inefficient conversion step from plant protein to animal protein. Already, we are feeding 40-50% of the global grain harvest to livestock (Evans, 1998; Smil, 2000). A significant amount of deforestation, loss of biodiversity, and pollution by harmful inputs - such as pesticides, fertilisers and greenhouse gases - might be avoided if protein-rich crops were destined for direct human consumption, rather than *indirectly*, via cattle feed. In this respect, the multidisciplinary *PROFETAS* programme[1] (Aiking et al., 2000; Vellinga and Herb, 1999), endorsed by the International Human Dimensions Programme on Global Environmental Change (IHDP), aims to explore a (partial) transition from animal to plant protein as a means to decouple the increase in food demand from a concomitant increase in environmental pressure.

Establishing the boundary conditions

In order to develop more sustainable protein production *PROFETAS* did not have to start from scratch, since the results of a strategic programme on Sustainable Technology Development (STD) were available (Weaver et al., 2000). Though the latter had been a desk study exclusively, the STD programme had yielded clear conclusions on development of so-called Novel Protein Foods (NPFs). STD's rather convincing rationale had been that predicting actual products 10-40 years in advance is not feasible. So STD recommends that it is better to now develop the methodologies and the tools to facilitate problem solving in the future, as opposed to hardwired solutions for presently perceived future problems. The main conclusion of STD's NPF programme had been that trying to mimic whole meat chops (such as steaks or cutlets) with plant proteins is simply not feasible. Its main recommendation, therefore, was to develop novel plant protein products, which may serve as protein-containing meal ingredients.

Both the underlying toolbox philosophy and the ingredients focus were adopted, approximately focusing on the year 2020. Therefore, the programme should compare opportunities for the NPF sector with options for the intensive livestock sector. In addition, consumer preferences will be taken to be predominant in product development. Furthermore, environmental, industrial and social issues will be studied from the national and West-European perspectives in a global context, rather than vice versa. Although sustainability is a global issue, European researchers will experience difficulty enough trying to grasp what's on

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[1] Under the *PROFETAS* (Protein Foods, Environment, Technology And Society) programme multidisciplinary researchers have been examining the dietary transition from meat towards NPFs (Novel Protein Foods) based on plant proteins. An interesting result is that combined sustainable production of both plant protein and biofuel is emerging as an important option, which may simultaneously mitigate agricultural resource depletion, agricultural pollution, and climate change.

the minds of European consumers (Verbeke, 1999), and could not possibly dream of modelling the non-European consumer with any degree of accuracy. Nevertheless, a trend setting Western diet change might have an impact world wide.

In summary, in 16 concerted projects *PROFETAS* (2005) studies the hypothesis that a substantial shift from animal to plant protein foods is environmentally more sustainable than present trends, technologically feasible, and socially desirable. The latter aspect includes environmental as well as economic considerations, thus leading to a clear transdisciplinary (environmental, economic, technological, ecological, political and chemical) design and evaluation of alternative protein production options and their impacts.

Consequences of a protein transition for European agriculture, climate change and future land-use patterns

As indicated above, changes in consumption patterns are required for environmental reasons (including climate change and resource depletion of agricultural land and freshwater). As a potential mitigation response, it is suggested above that even a partial transition from meat to NPFs would constitute an important step in that direction. Consequently, such a meat to NPFs transition might lead to huge changes in land-use during one generation (20 years). Drawing on selected *PROFETAS* results, it is the purpose of this chapter to underpin these assumptions. First, economic-environmental modelling will substantiate the necessity and impacts of a transition (why and how much?). Second, crop growth modelling will address the spatial component (where can we expect land-use changes in Europe?). Third, alternative crop options will be dealt with (which protein crops are realistic sustainable options?). Taken together, these three projects will provide us with a sneak preview of environmentally desirable changes in consumption patterns and the concomitant changes to be expected in land-use patterns beyond 2015. Through this approach the present chapter will contribute to the book's objective to delineate the major interactions between agriculture, climate change and changes in land-use patterns to be expected in the near future.

ENVIRONMENTAL AND ECONOMIC ASPECTS OF PROTEIN FOODS

Reference chains

Food production and consumption are supported by the natural resource base and the environment, using them both as a source of inputs and for the disposal or recycling of wastes. Food production and consumption systems include the whole chain of human-organised activities from agriculture through food processing and retailing to the food service sector and, of course in consumption by households, including the activity of shopping, cooking and waste disposal. Any economic system in pursuit of sustainability needs to consider this system as a whole with its interconnecting regional, national and international dimensions.

Protein food production and consumption results in environmental impacts in all phases of the production and consumption chain. Two reference production and consumption chains were devised in the *PROFETAS* programme. For the animal protein chain, the pork chain was selected as a common reference meat chain since it makes a major contribution to the production of animal-based protein products (European Commission, 2002). Also pork production is characterised by the absence of secondary products such as milk or eggs. In addition, pigs are among the most efficient animals in converting feedstuffs and agricultural wastes (by-products) into high-quality protein for human consumption. Finally, pork production is causing large environmental impacts both in developing and developed countries (Bolsius and Frouws, 1996). For the plant protein chain, it has been decided in the *PROFETAS* programme to focus on NPFs from green peas as the model raw material (Aiking et al., 2000; Smil, 2002).

Pork production in the European Union (EU) has strong environmental impacts and impacts on human health and animal welfare. First of all, the intensive production system results in a series of environmental problems due to manure surplus, which affects the quality of soil, water and air.

Second, large-scale imports of feed determine that the problems related to the European and in particular the Dutch pork production system are not only local but also global. For example, the increased production of raw materials for animal feed in Thailand, Brazil and Argentina has resulted in large-scale deforestation. Feed production is quite land and water intensive, which imposes a strong pressure on natural resources in the developing world.

Third, concentration of livestock might lead to increases in the incidence of animal diseases (e.g. swine fever or foot-and-mouth-disease) and in the incidence of food-borne human diseases. Intensive animal production systems, especially in areas close to population concentrations, result in increased risks of disease infection to livestock as well as to human beings. Finally, intensive livestock production may also lead to practices with a negative impact on animal welfare.

What can be done about these problems? First, from an environmental point of view, more pork production could be located in areas with arable products. This would reduce feed transport, and fewer problems would arise in terms of air, water and soil pollution. Agriculture is, however, often the economic locomotive of a region and an important source of direct and indirect employment. For example, a reduction by 5 million pigs in the Netherlands would in the short run mean a loss of 28,000 jobs (Bolsius and Frouws, 1996). Simply closing pork production incurs economic costs. So we need to make a trade-off between environmental improvement and its economics impacts.

In the following sections we deal with several environmental and economic aspects of protein production and consumption chains. The objective is to understand the main environmental pressures of the pork chain and the NPFs chain, and to obtain some insights into the effects of a shift from animal protein foods to plant protein foods on the environment and the economy.

Environmental assessment

For the environmental assessment, life cycle analysis (LCA) was carried out for both the pork chain and the NPFs chain. Environmental life cycle assessment is a method for assessing the environmental impacts of a material, product, process or service throughout its entire life cycle. It is an increasingly important tool for supporting choices at both the policy and industry levels (Guinee, 1995; Mattsson, 1999). LCA is intended for comparative use, i.e. the results of LCA studies have a comparative significance rather than providing absolute values on the environmental impact related to the product.

For the LCA we first provide a systematic description of both protein chains, which is useful for developing a consistent framework for a quantitative analysis of the chain. Then we develop a number of environmental pressure indicators for the assessment of environmental impacts. Finally, we compare the indicators for both chains.

The pork chain includes several stages. Along the pork chain, crops are grown for the supply of compound feed. Such crops are processed into feed, which is then fed to pigs. Pigs are slaughtered, and parts of the carcass are processed into meat products and transported to the retailers for distribution. Finally, the consumers will prepare and consume the meat products. Similarly, a production and consumption chain of Novel Protein Foods includes agricultural production of peas, NPFs processing (including protein extraction, texturisation and flavour addition), distribution and consumption. Compared with the pork chain, the NPFs chain has fewer stages.

Feed is the main input for pork production and peas are the main input for NPF production. Both use land, water, energy, fertilisers and pesticides. Energy, fertiliser and pesticide production leads to emissions of gases (e.g. CO_2, SO_2 and NO_x), minerals (e.g. N and P), and toxic substances (e.g. Cu, Zn). In addition, manure is also a main output, which leads in turn to emissions of minerals (e.g. N, P), and gaseous substances (e.g. NH_3, CH_4 and N_2O).

Considering the diversity of the emissions and their environmental impacts, we define emission indicators based on environmental themes. The emissions contributing to the same environmental impact can be aggregated into one indicator. The emissions of CH_4, CO_2 and N_2O lead to global warming and thus can be converted into CO_2 equivalents. Similarly, the emissions of NH_3, NO_x and SO_2 can be aggregated into an acidification indicator by using NH_3 equivalents. Nitrogen (N) and phosphate (P) emissions to soil and water systems cause eutrophication and can be included in the eutrophication indicator by using N equivalents. Emissions from pesticides and fertilisers have effects of ecotoxicity and human toxicity. Finally, we include the direct pesticide use and fertiliser use as environmental indicators. Therefore, for the protein chains, we define five emission indicators: (i) CO_2 equivalents for global warming, (ii) NH_3 equivalents for acidification, (iii) N equivalents for eutrophication, (iv) pesticide use and (v) fertiliser use.

In addition to the environmental indicators, we define resource use indicators, because agriculture requires land and water as inputs. The consideration of land use is relevant, because there is a competition for available cropland (De Haan et al., 1997; Bradford, 1999). It is true that land use has other functions such as providing landscape, amenity and biodiversity. However, land use for crops also reduces the opportunity of land being used for other purposes. ‘Saving land for nature’ is advocated and the best quality farmland is already used for agriculture. This means that future land expansion would occur on marginal land that is vulnerable to degradation (Tilman et al., 2002). Therefore, land use can be viewed as an important resource indicator. Water use also is an example of natural resource use. Therefore, we include two resource use indicators: land use and water use.

We use 1,000 kg of protein consumption for both chains as a functional unit in the comparative LCA study. Table 10.1 shows the results of the study.

Table 10.1 Emission and resource use indicators per functional unit (1,000 kg consumable protein in both cases)

	Pork	NPFs	Ratio (pork/NPF)
Acidification (NH_3 equivalent, kg)	675	11	61
Global warming (CO_2 equivalent, kg)	77,883	12,236	6.4
Eutrophication (N equivalent, kg)	2,491	417	6.0
Pesticide use (active ingredient, kg)	18	11	1.6
Fertiliser use ($N+P_2O_5$, kg)	485	144	3.4
Water use (m^3)	36,152	10,912	3.3
Land use (hectares)	5.5	1.95	2.8

Source: Zhu and Van Ierland (2004).

The resulting LCAs show that the pork chain contributes to acidification 61 times more than the NPFs chain, to global warming 6.4 times more, and to eutrophication 6 times more. The pork chain also uses 1.6 times more pesticides, 3.4 times more fertilisers, 3.3 times more water and 2.8 times more land than the NPFs chain. According to these environmental indicators, the NPFs chain is clearly more environmentally friendly than the pork chain. So replacing animal protein by plant protein shows promise for reducing environmental pressures, in particular acidification.

However, some caution is needed for generalisation of the results to animal protein foods. For example, in the literature a much higher water use was reported for animal production than crop production, because pig feed (such as mixed corn-soybean feed) requires 10-16 times more water than grains and pulses in addition to the pigs’ direct water consumption (Smil, 2000). Dutch pig feed used in our study consists of grains and pulses and food industry by-products. We consider water use for feed production and direct water consumption of pigs, but for simplification we did not include water use for processing. It should be realised that the difference in water use could be considerably larger if all water use categories would be included.

Economic modelling

Introducing more environmentally friendly foods such as NPFs to replace animal products seems promising for environmental improvement according to LCA. A limitation of LCA, however, is that it cannot show how the rest of world will react if consumers in the EU partly replace pork by NPFs. As long as pork is highly demanded in the whole world and feed is imported from the rest of the world, the pork issue remains an international issue. If eastern Asian countries have an increasing demand for meat (Keyzer et al., 2003), what would be the implications for meat producers in the EU? To answer such questions, we need a more extensive economic analysis, to understand how international trade and resource allocation will change if more NPFs consumption will take place in the EU.

The international dimension of EU animal protein production means that substantial changes in the pig production sector in the EU have a direct impact on agricultural producers and traders elsewhere in the world. For this study we have chosen to use an Applied General Equilibrium (AGE) model, because AGE models are suitable for studying world-wide issues (Shoven and Whalley, 1992; Ginsburgh and Keyzer, 1997). In order to include the environmental aspects in the economic model, we refer to the relationship between economic activities and the environmental system (Figure 10.1).

For an economic system consisting of production and consumption, we use the environmental resources as input, and we also emit some substances to the environment. In the environmental system, resource stocks and emission inflows from economic activities change the quality of the environment following the distribution and conversion in biophysical processes. The environmental quality supplies feedback to the economic system by influencing the amenity values of the environment and through impacts on economic productivity, resulting in interactions between the economic system and the environmental system (Costanza et al., 2000).

Our AGE model is a four-region global model. The model includes consumers' life style change, different production systems, and emissions from agricultural sectors. For the model simulations we consider a change in behaviour of consumers, because health and safety concerns have become pivotal in purchasing food products. For a large number of consumers, these concerns become manifest in the selection of products, as seen in increased purchases of diet and low-fat foods. In the final years of the millennium, more people in the developed countries have begun to change their attitudes towards animals, and an increasing number of consumers share the view that the meat industry does not care enough for animal welfare and is responsible for severe environmental damage. This tends to increase the demand for meat products that are produced in an animal-friendly way, or for meat substitutes (Miele, 2001; MAF, 1997; Jin and Koo, 2003). These concerns reflect that the consumers' attitudes towards food

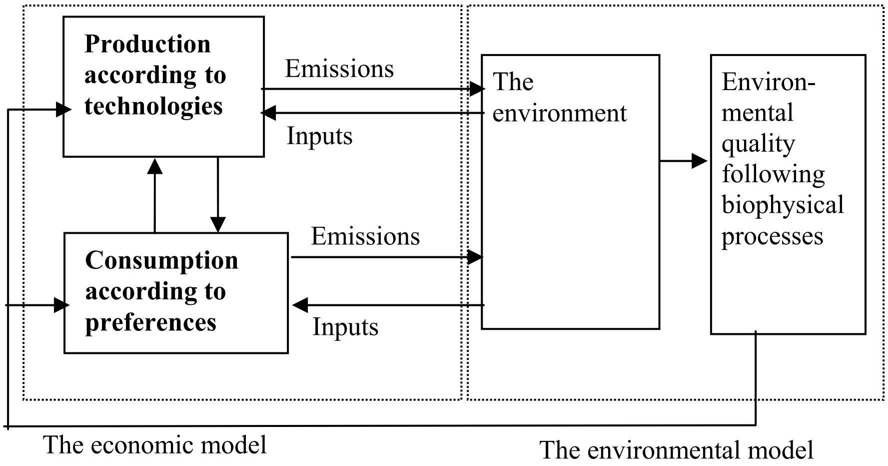

Figure 10.1 Links between the economic model and the environmental model

consumption, or in general, their lifestyles are changing. To analyse the potential impacts of these changes in consumer behaviour, we applied the model to simulate different levels of replacements of meat by NPFs in the protein consumption of 'rich' consumers.

In our applied model, we focus on the environmental emissions from the agricultural sector. Agricultural activities including manure storage, soil fertilisation and animal husbandry are important sources of ammonia (NH_3), methane (CH_4) and nitrous oxide (N_2O) emissions. The CO_2 emissions from agricultural processes are not covered in this study as agriculture itself is considered both a source and a sink. For example, in the Netherlands the CO_2 emission from agriculture is only 4% of total national CO_2 emissions in 1998 and largely related to glasshouse horticulture (CBS, 1999). For the same reason, SO_2 and NO_x emissions are not considered because NO_x emissions from agriculture are only 2% of the total emission of NO_x and SO_2 from agriculture was negligible in the Netherlands in 1998 (CBS, 1999). It was therefore decided to focus on three gases: NH_3, CH_4 and N_2O.

The model simulation shows that substitution of NPFs for meat as a preference change will decrease meat demand. This substitution will also change the relative prices of meat and NPFs and thus consumer food expenditures. As an overall effect, the meat demand in the EU, other high-income, middle-income and low-income regions will decrease. The extent of the change is greater in the EU and other high-income regions than in the other two regions, because there is higher meat consumption largely due to the increased incidence of 'rich' consumers.

Results show that the higher the replacement of all meat (including pork, beef and poultry) by NPFs, the lower the NH_3 emission. For the emissions of N_2O and CH_4, the same trend holds. See Figure 10.2 for the development of emissions under different replacement levels of meat by NPFs by the rich consumers. The reason is obvious, because the emissions are lower for the production of peas (the primary crop from which NPFs are assumed to be made) than for meat production. However, the emission reduction through life style change is very limited if only a small fraction of meat consumption is replaced by NPFs. This result can be explained by the restriction that only 'rich' people will currently switch to NPFs. Since the meat consumption of 'intermediate' consumers is increasing, the total meat production and consumption does not decrease so much. As a result, the production of meat still takes place in intensive livestock production systems.

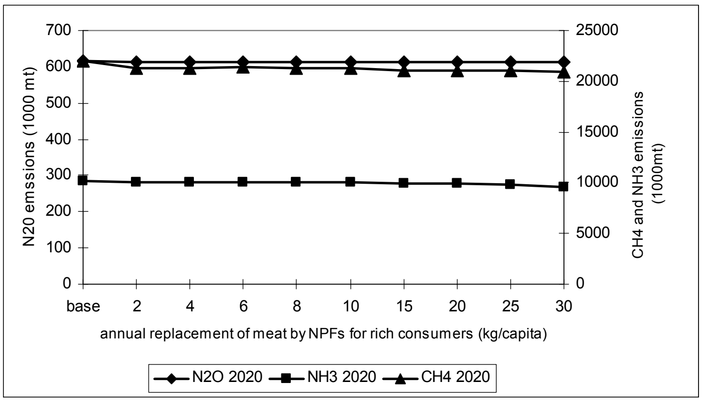

Figure 10.2 Development of emissions under different replacement levels of meat by NPFs by the 'rich' consumers

LOCATION OF PLANT PROTEIN PRODUCTION SYSTEMS

Crop growth modelling

Pea (*Pisum sativum* L.) production was chosen as the model crop for the plant protein chain, primarily because of its protein content, its ability to grow in Western Europe, the absence of unwanted substances in pea and the availability of scientific expertise on its characteristics (Linnemann and Dijkstra, 2002). It was the objective of the project to design a tool for understanding how genotypes of peas respond to different environments, so that an optimal pea production system can be defined, with respect to quantity and quality of product and to resource use efficiency. Subsequently, potential pea producing areas are identified.

The complexity of primary production systems and the need to fulfil multiple objectives call for a systems approach to better understand the chain of production processes. The method to achieve this goal is based on ecophysiological modelling. To this end, the model has to be robust, being capable of predicting crop growth responses to genotypic characteristics and environmental variation. Based on potentially useful elements from existing models, such an innovative model was developed. In addition, the main processes specific to leguminous crops (such as symbiotic nitrogen fixation) and to the *PROFETAS* programme (such as seed protein production) were identified. Once the model has been evaluated and proved robust, it can be a powerful tool for designing a sustainable primary production system at the field level.

Three major developments of modelling physiological components are to determine:

- the growth function;
- generic relationships between leaf area index and canopy nitrogen; and
- a new equation for electron transport in leaf photosynthesis.

Further, modelling the individual processes has been elaborated for nitrogen fixation, root senescence in analogy to leaf senescence, the formation and remobilisation of stem and root carbon reserve pools, and seed protein predicted from the amount of nitrogen partitioned to seeds. New methods reported in the recent literature for simple mechanistic modelling of canopy photosynthesis and crop respiration have also been incorporated. Integration of these individual model components resulted in the new, innovative generic crop growth model GECROS (Genotype-by-Environment CROp Simulator) (Figure 10.3).

The model is generic, applicable to any crop at any production level free of pests, and requires only minimum parameter inputs, which can be readily obtained in general. In addition to yielding characteristics that most existing crop models predict, crop quality aspects such as seed protein are also predicted by GECROS. Interestingly, the model predicts that within the range of seed protein percentage reported in the literature it is impossible to increase total seed protein production per ha by using pea cultivars of high protein concentration, because such cultivars would have lower seed biomass yields. The underlying reason is that for accumulation in high-protein seeds nitrogen needs to be withdrawn from the leaves. Such withdrawal causes faster leaf senescence and a shortened crop photosynthetic duration.

Application to land-use aspects

In order to assess the potential for pea production in Europe, the model was applied to a range of European conditions for pea crops, based on parameters for the standard cultivar ‘Solara’, which has been used in other *PROFETAS* projects. Since nitrogen is usually not a limiting factor for peas, the model was run with three water supply scenarios: supply as crop demand versus 200 mm and 100 mm initial soil available water. These three water supply scenarios represent pea cultivation with ample water supply (i.e. irrigation), pea cultivation on loamy clay soil without irrigation, and pea cultivation on sandy soil without irrigation, respectively. Simulations used climate data (1991-2000) from the Environment

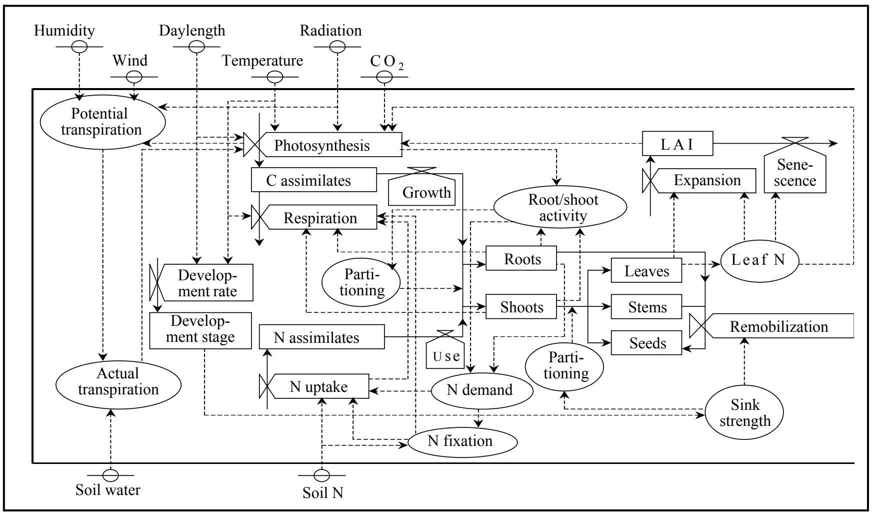

Figure 10.3 The relational diagram of the GECROS crop growth model

and Sustainability Institute of the European Commission for 66 pre-selected locations in Europe. Using GIS, the 10-year average seed yields were mapped for all three water supply scenarios (Figure 10.4).

Not surprisingly, predicted crop productivity depends strongly on water supply for all sites. Annual variability in predicted crop productivity was greater under water-limited conditions than under non-limiting conditions. Areas with potentially high predicted productivity, such as Scotland, Denmark, North Germany, and part of France are, indeed, regions in Europe where peas are currently grown. The Netherlands seems to be well suited for growing peas. The higher productivity in North Western Europe and South Scandinavia compared to Southern Europe was basically due to a longer crop growing period as a result of a cooler environment. However, caution should be taken, since the simulations were done without considering geographic information on soil quality and landscape. Furthermore, the simulation concerned only 66 sites, and in some areas (such as Scandinavia) mapping was merely the result of extrapolating just a few points. Therefore, improved simulations should incorporate local specific soil and landscape information and more locations.

In actual practice, pea performance appears to be sensitive to excess water or drought during flowering and harvesting. Peas easily lodge in heavy rains, presenting a major risk for harvesting (lodged crops remain wet for longer, are susceptible to fungal attack, whereas combine harvesters have difficulty reaping plants that are lying flat on the soil surface). Improved straw stiffness has been a major focus in pea breeding. The effect of drought and lodging severity in reducing canopy photosynthesis and seed set can be well assessed by GECROS.

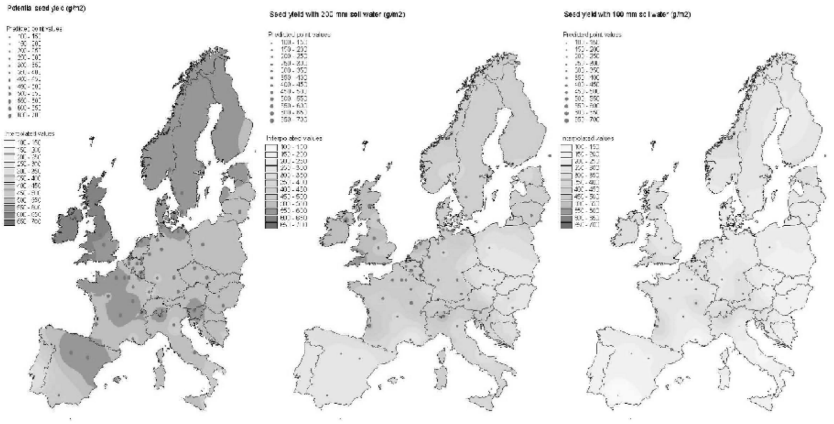

Figure 10.4 Map of pea seed yields under three water supply scenarios (decreasing from left to right, see the text) from interpolation of point model simulation for 66 sites

However, it has been beyond the reach of the current project to rigorously quantify the effect of excess water and lodging incidences per se, because of a lack of data. Soil-borne fungal diseases are a second practical problem of pea. Root rot diseases, in particular 'near wilt', caused by the fungus *Fusarium oxysporum* needs to be mentioned. Since no cure exists, prevention is the only measure that can be taken. The best prevention is to grow a crop of peas on a field only once every six years. In summary, the validated model could be a powerful tool in:

- predicting responses of global environmental change on crop production and cropping systems;
- defining crop ideotypes adapted to a target environment;
- optimising management strategies for specific crop genotype and environment; and
- designing sustainable cropping systems.

If the model is linked to a GIS environment, it can be used for studies on land use, greenhouse gas emissions and water (precipitation) requirements, while providing valuable suggestions for geographic location and fine-tuning in order to optimise sustainable production of crops.

PROTEIN CROP OPTIONS AND CLIMATE CHANGE

A conservative estimate shows that direct human consumption of plant protein, rather than indirect (via meat), has the potential to reduce the claim on natural resources such as land and fossil fuels 4-6 fold (Smil, 2000; Pimentel and Pimentel, 2003). It should be realised, however, that the meat chain has been optimised for thousands of years, resulting in efficient use of almost the whole animal (meat as well as skin, hairs, bones, gut, etc.). When replacing meat with NPFs, by analogy, all parts of the protein crop should be put to use, in order to remain competitive with respect to sustainability. Consequently, it is of the utmost importance to consider what options exist for the non-protein fraction of the raw material. Any crop that is used to produce protein-rich food products will also produce residues that cannot be used for the NPFs, for seed protein content is just 20-40%. These residues may arise in various different forms and may have different compositions depending on the crop used, the part of the production process where they arise, and the actual production techniques used. This means that both the environmental impact and the economic value of the non-protein fraction can vary greatly.

To study the non-protein fraction, information is needed on the constituents of any crop that could potentially be used for its protein. Of the main commercial food crops the main constituents other than protein are carbohydrates (starch and - to a lesser extent - sugars) and oil or fat. If we widen the scope to more unusual sources of plant protein there may be a need to include a cellulose/lignin fraction. In Europe, crop options might include lupin, pea, quinoa, triticale, lucerne, grasses, rapeseed/canola and potato (Linnemann and Dijkstra, 2002). Outside Europe, at least soy should be added.

For each constituent of the non-protein fraction there are different options. Firstly, for commercial food crops (such as pea or soy) the options are likely to be food, feed, industrial raw materials and energy production, whereas for the crops that are high in cellulose/lignin (such as grass) the options will be feed (cellulose only), industrial raw materials and energy production (Table 10.2). For all of these options estimations must be made with regard to their economic value, in order to be able to judge how realistic any given option is. Furthermore, economic value is also important when it comes to attributing environmental impacts to the different fractions of a given crop.

Table 10.2 Possible uses of the non-protein fractions

	Food	Feed	Raw materials	Energy
Carbohydrates	+	+	?/+	?/+
Oil/fat	+	+	+	+
Cellulose/lignin	-	+/-	?/+	+

A possible tool for assessing uses that are available for the non-protein fractions would be a kind of scorecard. An example for such a scorecard is given in Table 10.3 for an imaginary crop X, with 25% protein, 25% carbohydrates, 25% oil/fat and 25% cellulose/lignin. Please note that, although the scorecard is given here as a 2-dimensional table, a multidimensional, spreadsheet-based card is envisaged, allowing for easy calculation of economic values and environmental impacts.

Table 10.3 Non-protein scorecard for imaginary crop X

		Food	Feed	Stock	Energy
Carbo-hydrates	Main use 1:	syrup	pig feed	syngas	biocrude
	replaces:	corn syrup	maize	mineral oil	mineral oil
Oil/fat	Main use 1:	cooking oil	chicken feed	cleaning agent	biodiesel
	replaces:	sunflower oil	maize oil	palm oil	mineral oil
	Main use 2:	-	-	plasticiser	-
	replaces:	-	-	mineral oil	-
Cellulose/ lignin	Main use 1:	unsuitable	unsuitable	unsuitable	co-firing
	replaces:	-	-	-	coal

In every use/replace combination various aspects can be addressed. Technical aspects must be considered, possibly leading to the verdict unsuitable, if there are very high technical barriers. Likewise economic aspects need to be taken into account, since unrealistically high costs could also rule out options. From the environmental perspective, the same scheme would serve to find the best combination of environmental benefits. Each prospective use can be given an estimated environmental impact, which can then be compared to the environmental impact of the substance it replaces. The information required to use the scorecards is:

- Information on the composition of a specific crop, such as peas.
- Information on the economic attributes of the crop's production chain.
- Information on possible uses for non-protein agricultural products in general, to serve as a backbone for more crop-specific investigations.
- Information on the environmental impacts of the crop production chain.
- Information on the environmental impacts of the replaced product chain using the same methodology as the crop chain.

The contribution of this analysis to sustainability is evident. For without useful application for the non-protein fraction a protein transition is simply not feasible for environmental reasons, because the potential 4-6 fold gain mentioned above would be largely offset by the added waste (up to 80% of the crop). The future results of the project are therefore likely to primarily influence crop selection. As a preliminary result, generally, oil crops seem preferable over starchy crops with regard to biofuel production.

Combined production of plant protein and biomass was the basis for this particular analysis. Since the EU is striving for self-sufficiency in both areas they will be interested. The protein transition and the biomass transition going hand-in-hand towards more sustainable production of protein and energy, respectively, is a clear example of a 'win-win' situation and it illustrates that transitions rarely go alone. If, indeed, the non-protein fraction of a protein crop is utilised for sustainable energy production, no additional, dedicated crop will be required. The converse is also true: it would be a waste to burn the high-quality protein in a dedicated energy crop. Combining sustainable production of protein and energy in one crop seems ideal to combat agricultural resource depletion and pollution, as well as climate change.

DISCUSSION AND CONCLUSIONS

To make food production more sustainable, a stepwise improvement is required, a so-called transition (Green et al., 1999; Weaver et al., 2000). In the past many food transitions have taken place (Grigg, 1995), but they always evolved passively, as products of a multitude of chance factors. In particular a transition from animal to plant protein would be highly beneficial to the environment, due to the inherently inefficient conversion step from plant protein to animal protein (Aiking and Vellinga, 2000; Delgado et al., 1999; Smil, 2000). It is currently thought in The Netherlands that active transition management should be sought by the government (Kemp and Loorbach, 2003). However, many actors are involved, all of which will perceive their own barriers and opportunities. Aiking (2003) identified at least four barriers to such a transition towards decoupling protein production from concomitant environmental impacts:

- social forces opposing change are strong, because meat has a high status (Beardsworth and Keil, 1997);
- economic forces opposing change are strong, because established interests in the meat chain are powerful;
- technological know-how on novel (plant) protein foods is lacking; and
- for centuries the meat chain has been optimised for exhaustive use of all by-products, potentially offsetting a large part of the theoretical environmental gain.

Consequently, important actors include consumers, retailers, food processors, farmers, NGOs and policymakers. Interestingly, opportunities and obstacles for a transition turn out to be strongly different depending on the level (from local to global). In Asia, for example, incentives, crops and consumer taste are different. Therefore, regional approaches to a protein transition are called for (Aiking, 2003).

The present chapter demonstrates that, from an environmental point of view, there is no doubt that Novel Protein Foods are environmentally more friendly than meat. But the real environmental benefits of NPFs depend on their acceptance by the consumers. Even in developed countries, only a minority of the consumers is prepared to avoid meat and if they do, health issues are a much stronger underlying motivation than environmental issues (Beardsworth and Bryman, 2004). In contrast, in developing countries the proportion of meat in the diet is rising rapidly (Bruinsma, 2002). Our economic analysis indicates that if only the ‘rich’ consumers switch to consume more NPFs to replace part of all meat, the meat production and the concomitant emissions will hardly be reduced because of increasing demand of meat of ‘low income’ and ‘middle income’ consumers in developing countries. So NPFs only offer a partial solution for reducing environmental emissions (by less than 1%, unless all meat were replaced with NPFs entirely and all over the world).

Therefore, in a consumer-driven economy, stimulating consumers’ environmental concern and changing consumers’ behaviour are essential to achieve a transition from animal protein foods to plant protein foods. Another option for reducing the environmental emissions from agriculture may be found in environmental policies such as tradable emission permits for greenhouse gases and local emission bounds for local pollutants. Although it may be difficult to implement these policies in practice, they may turn out to be more effective and achieve a higher level of emission reduction than the simulated change in consumer preferences.

LCA shows that a transition from animal to plant protein might result in a threefold lower requirement of agricultural land and freshwater. World-wide, there is potential for an additional reduction in water use by at least another factor of 10. The geographic location of these and other environmental benefits will, however, depend very much on the actual selection of crops to be used as raw materials. Crop growth modelling was applied to pea growth under 3 different soil water availability scenarios. The results suggested that in the EU with low resource input high pea crop yields could be anticipated in Scandinavia (in addition to current production in France and the UK). The same model can be used for other protein crops, thus revealing optimal geographic locations for sustainable protein production.

Finally, a study on protein crop options argued that, in Europe, potential raw materials might include lupin, pea, quinoa, triticale, lucerne, grasses, rapeseed/-canola and potato, and that outside Europe at least soy should be added. However, the feasibility to be a suitable source for NPFs was shown to be an insufficient condition. Since just 20-40% of the seeds is protein, extra waste from the non-protein fraction (up to 80% of the crop) would largely offset the potential 4-6 fold environmental gain from replacing indirect (meat) with direct plant protein consumption. Therefore, useful application of the non-protein fraction is indispensable to a protein transition, and should influence crop selection. As a general result, oil crops seem preferable over starchy crops with regard to biofuel production. In this respect, it was evident that combining sustainable production of protein and energy in one crop would simultaneously mitigate agricultural resource depletion, agricultural pollution, as well as climate change.

In summary, first the necessity and impacts of a protein transition was substantiated by economic-environmental modelling. Second, the expected concomitant geographic location of land-use changes in Europe was addressed by crop growth modelling. Third, alternative crop options were dealt with and led to the conclusion that combining sustainable production of protein and energy could effectively be combined and would benefit both agricultural resource depletion and pollution, and climate change. Taken together, these three projects provide us with a preview of environmentally desirable changes in consumption patterns and the concomitant changes to be expected in land-use patterns beyond 2015. Thus, the present chapter contributes to the book’s objective to delineate the major interactions between agriculture, climate change and changes in land-use patterns to be expected in the near future. In conclusion, this chapter argues that:

- changes in consumption patterns are required for environmental reasons (including climate change and shortages of agricultural land and freshwater);
- even a partial transition from meat to NPFs would constitute an important step in that direction;
- such a transition will lead to huge changes in land-use during one generation (20 years);
- the location of these land-use changes depends on the crop choice; and the crop choice depends on the demands for both NPFs and biofuel, and is also related to available technology.

Since climate, crop choice, environmental impacts and land use are so clearly and inextricably intertwined, the consequences of a transition will be far-reaching in every respect.

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