Developments in the nitrogen surplus and the fossil energy use in Danish agriculture during the 20th century

T. Dalgaard & A. Kyllingsbæk
Danish Institute of Agricultural Sciences, Denmark

Abstract

This paper goes through the development in nitrogen imports, nitrogen exports, nitrogen surplus, and fossil energy use in Danish agriculture during the 20th century. The nitrogen export in the form of animal and vegetable products rose throughout the century. Until around 1950, atmospheric N derived by leguminous crops was the dominant nitrogen import, but then N fertilisers became dominant. Since 1983, the fertiliser import and the nitrogen surplus have dropped, and nitrogen imported in the form of concentrate fodders now equals the amount imported in the form of fertilisers. The fossil energy use generally follows the fertiliser use and, like the nitrogen surplus, has been in a continuous decline since the mid-eighties after an almost exponential growth period from 1945-1970.

On the basis of the nitrogen and energy accounts, the sustainability of the present development and the potential for future sustainable development are discussed. As a tool to structure this discussion, the development is divided into characteristic phases, where the lessons for each phase, regarding sustainable development, are derived and discussed according to the parallel historical developments during the 20th century.

1 Introduction

The aim of this study is to evaluate the development in Danish agriculture during the 20th century in the context of sustainability. This evaluation is made from an agro-ecological viewpoint, where inputs and outputs to agriculture are compared on a 100-year time scale. Especially developments in Nitrogen (N) inputs and -outputs,
and the use of fossil energy (E) use are investigated. The emphasis on N and E is chosen because, on one hand, they are essential resources to attain agricultural production, while on the other hand, excessive use of these two resources can lead to severe environmental problems. The use of N leads to N-losses and eutrophication of the environment, and the use of E leads to emissions of greenhouse gases, which again leads to global, climate changes.

What is special about this study, compared to most previous studies on N- and E, is the 100 years' time horizon. The aim of including such a long period is to be able to evaluate the present resource use towards historical records, and on this basis to discuss the sustainability of the present development and the potential for future sustainable development. As a tool to structure this discussion, the development in the 20th century has been divided into characteristic phases, where the lessons for each phase, regarding sustainable development, are derived and discussed according to the parallel historical developments during the 20th century.

2 Materials and methods

2.1 Agricultural statistics

The study is based on the last 100 years, official agricultural statistics of Denmark. For the period 1900-1960, figures from several publications, gathered in two summarizing volumes regarding plant [1], and animal production [2], are typed into a database. For the period 1961-2000, figures are obtained from annual publications with agricultural statistics [3] and typed into the same database. However, uncertainties are larger for the statistics early in the century.

For each year, national totals of input factors used, crops harvested, and animals produced are registered in the database. Moreover, the number of dairy cows and pigs, and the area with wheat cereals are typed for each county, in order to be able to map spatio-temporal changes in these factors (Figure 1). Note, until 1920 the southern part of Jutland was occupied by Germany, and is therefore not included in the statistical material analysed.

2.2 Nitrogen import, export, and surplus

In accordance with Kyllingsbæk’s methods [4], [5], the national N-surplus is calculated on a yearly basis as the difference between N imports and N exports to and from Danish agriculture.

N imports include N in commercial fertilisers and waste materials spread to the fields, N in imported concentrate fodder stuffs like soy bean cakes, meat and bone meals, fodder urea, fish products etc., and N derived from the atmosphere. The latter includes estimated values for net N deposition and N fixation via legumes and free-living micro-organisms.

N exports include N in 1) animal products, in the form of eggs, milk, meat, live animals or livestock received by offal destruction plants, and 2) vegetable products,
in the form of cereals, seeds for manufacturing and sowing, beets for sugar production, potatoes and other fruits and vegetable products.

2.3 Fossil energy use

In this study, the development in the fossil energy use is accounted according to Schroll’s methods [6], and the standards for calculation of fossil energy use in Danish agriculture, defined by Dalgaard et al. [7]. These standards include both direct and indirect energy uses. Direct energy is the energy in fuels, electricity, coal, etc., which can be directly converted into energy units, while indirect energy is the energy used to produce input factors like fertilisers, machinery, pesticides, etc.

3 Results

3.1 Spatio-temporal changes in the animal and vegetable production

Figure 1 illustrates the spatio-temporal changes in the Danish animal production (indicated with the number of dairy cows and pigs) and the vegetable production (indicated with the wheat area), during the 20th century. The three main results, derived from the time sequence mapped, are: 1) The dairy cows concentrate more and more in the western parts of Denmark – i.e. on the poorest soils. 2) The pig production has increased tremendously all over the country, but especially over the last 25 years. 3) Wheat, and primarily winter wheat, has gone from being a rare crop, only grown on the rich soils in eastern Denmark, to be one of the most common cereals grown all over the country. The developments in dairy cows, pigs, and wheat area all indicate parallel changes in the nitrogen surplus and energy use, as well as reasons for these changes. This will be discussed in the following sections.

3.2 Temporal changes in nitrogen import, export, and surplus

Table 1 shows the calculated N imports, N exports, and the resulting N surpluses in 25-year intervals for Danish agriculture during the 20th century. The general picture is, like in figure 1, an increased animal and vegetable production, and thereby increased exports of N in the form of animal and vegetable products, throughout the century. The interesting question is, though, how this increased production was driven by the import of N in the form of fertilisers, fodders, and N from the atmosphere.

Generally, atmospheric N, derived mainly by leguminous crops, was the major N source in the first half of the century. Then the import of N fertilisers boomed and became the dominant N source. In the same period, the N surplus was more than doubled, whereas in the last 25 years, the use of N fertiliser and the N surplus have dropped, while the N fodder import has increased and may probably be the most important N source in the next 25 years to come.
Figure 1: Examples of structural developments in the animal and vegetable production in Denmark during the 20th century [1], [2], [3].
Table 1: N imports, exports, and surpluses in Danish agriculture 1900-2000 (10^6 kg N).

<table>
<thead>
<tr>
<th>Year</th>
<th>1900</th>
<th>1925</th>
<th>1950</th>
<th>1975</th>
<th>2000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Import:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fertilisers</td>
<td>1</td>
<td>23</td>
<td>60</td>
<td>300</td>
<td>229</td>
</tr>
<tr>
<td>Concentrate fodders</td>
<td>33</td>
<td>78</td>
<td>64</td>
<td>124</td>
<td>218</td>
</tr>
<tr>
<td>From atmosphere</td>
<td>63</td>
<td>100</td>
<td>98</td>
<td>53</td>
<td>62</td>
</tr>
<tr>
<td>Total import</td>
<td>97</td>
<td>201</td>
<td>221</td>
<td>477</td>
<td>509</td>
</tr>
<tr>
<td>Export:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Animal products</td>
<td>25</td>
<td>32</td>
<td>57</td>
<td>71</td>
<td>111</td>
</tr>
<tr>
<td>Vegetable products</td>
<td>8</td>
<td>3</td>
<td>10</td>
<td>57</td>
<td>75</td>
</tr>
<tr>
<td>Total export</td>
<td>34</td>
<td>35</td>
<td>67</td>
<td>129</td>
<td>186</td>
</tr>
<tr>
<td>N-surplus:</td>
<td>63</td>
<td>166</td>
<td>154</td>
<td>349</td>
<td>323</td>
</tr>
</tbody>
</table>

Figure 2: The development in N imports to Danish agriculture. The 2000 situation is set to index = 100 for each type.
In order to set the present N balance into the historic perspective, and to divide the developments in the 20th century into characteristic periods, the 100 years' development in the N import and N export factors accounted was plotted into two graphs (Figure 2, Figure 3). In these graphs, the year 2000 situation (Table 1) was set to index = 100 for each factor. Thereby the graphs show the relative importance of each import and export factor, compared to the present situation, and this information was then used in the following division into characteristic development phases.

![Graph showing the development in N exports from Danish agriculture. The 2000 situation is set to index = 100 for each type.](image)

**Figure 3**: The development in N exports from Danish agriculture. The 2000 situation is set to index = 100 for each type.

### 3.3 Temporal changes in fossil energy use

Figure 4 shows the accounted fossil energy use in Danish agriculture 1935-1995. Characteristic is the high energy value in N fertilisers, and the recent decrease in the fossil energy use, caused by the drop in fertiliser use.
Figure 4: The fossil energy use in Danish Agriculture 1935-1995.

4 Discussion and conclusions

In a sustainable development context, the recent developments in N surplus (Table 1) and fossil energy use (Figure 4) compared to the agricultural production of vegetable and animal products (Table 1) are extremely interesting. Apparently, the production in the last 25 years has risen while the environmental impacts, indicated by the N surplus and the energy use, have decreased. This development has primarily been achieved via a better implementation of agronomic and technological knowledge in the agricultural production system. For example, the milk production per dairy cow was raised via more optimal fodder plans and new breeding technologies, and therefore even though the number of dairy cows has dropped (Figure 1), the milk production was sustained [3]. Another example is the introduction of new wheat cultivars and a more effective crop management including new pesticides and better fertilisation techniques. Among other things, this was the background for the increased area of high-yielding winter wheat crops all over the country (Figure 1) and the increased vegetable production in the period from 1975-2000 (Table 1, Figure 3). However, in the period from 1925-1950, a similar, decreased N surplus and an increased agricultural production was experienced (Table 1), while the energy use was relatively constant (Figure 4). However, as will be discussed in the following, the reasons behind this development
were quite different from the above mentioned, and the experiences from this period, and other characteristic phases of the 20th century, might teach us useful lessons to design the future development in a more sustainable manner.

4.1 Development phases in 20th-century Danish agriculture

4.1.1 Co-operative movements and animal farming (1900-1950)

With the starting point in the second half of the 19th century, Danish agriculture turned into animal production, processed in co-operative dairies and slaughterhouses. This development, away from the former grain export, was pushed by the competition from inexpensive grains, transported to Europe from the prairie, with new-built railroads and shipping routes, and until the middle of the 20th century the vegetable exports from Danish agriculture were insignificant (Table 1, Figure 3).

Awareness of the livestock oriented farming is still a key to understand developments in the N surplus and the energy use in Danish agriculture, and was, for example, the reason for the dramatic changes in the N surplus during The First World War (1913-1918). Here fodder imports literally stopped, due to high prices, and especially the pig production dropped by more than 25%.

After The First World War, the increase in the animal production could continue. Until 1938, where the agricultural area peaks, the production increase was mainly driven by land reclamation, and especially for the cattle production by extensive use of high yielding, N fixing fodder crops like clover grass (Trifolium spp.) and alfalfa (Medicago sativa) (Figure 2). Then The Second World War started, with consequences similar to those during The First World War, and with following, significantly reduced N-surpluses. After that a whole new era for Danish Agriculture started:

4.1.2 The green revolution – production, production and more production! (1951-1983)

In the first 25 years after The Second World War, Denmark, like the rest of The Western World, encountered economic growth, and the mechanisation and intensification of agriculture made an important contribution hereto. In the period from 1945-1965, the workhorses were replaced by tractors, and the energy use for fuel increased (Figure 4). The fodder spared for the horses was then used to further increase the number of livestock for sale. In parallel, fertiliser and pesticide use was intensified, and with this so-called green revolution the increase in the animal, and especially the vegetable production, was enforced (Figure 3). Only the years following the oil crisis in 1972-1975 resulted in a temporary break in the growth in fertiliser and fuel use, with following reduced N surpluses and energy use in the mid-seventies. However, the general trend with Denmark as a new member of the EC market for agricultural products, was still higher production through higher use of input factors, and this development characterised the period until 1983 where the total N fertiliser use and the N surplus topped.
4.1.3 Limits to growth (1984-1993)
In 1984, deoxygenation of the seas around Denmark raised a public opinion towards nitrogen pollution, and the Danish parliament passed the first action plan for the aquatic environment. With this and the following action plans, maximum N norms for fertilisation of crops were introduced, and farmers were encouraged to handle manures in order to improve the N use efficiency. The success of this legislation is undisputed, and, as discussed above, implementation of better fertilisation techniques has achieved a continuation of the increase in animal production at lower N fertiliser inputs and with lower N surpluses. However, as figure 3 indicates, the vegetable exports topped around the year of 1990, and the challenge in the present post green revolution period is now to find what to produce within the defined limits of pollution. Obviously, a continued increase in the animal, and especially in the pig production, has had priority over the last 10 years.

4.1.4 Agriculture and the globalisation (1994-?)
With the so-called McSharry reform in 1994, The European Union converted subsidies per product produced to area-oriented payment schemes. This reform was demanded by the World Trade Organisation, and should provide better conditions for free trade. As a result the grain prices decreased and the vegetable exports dropped (Figure 3). The lower grain prices favoured the pig production, and the trend with increased animal production continued.

In the years to come the globalisation of markets and environmental problems will continue to influence Danish agriculture, the N-surplus, and the fossil energy use. One major challenge will be to combine agricultural production with environmental protection. The development in the last decades of the 20th century shows promising possibilities. An interesting background for this development is that actually it is not by one mainstream development of the Danish farms that the increased production under lower N surplus and energy use has been achieved. What actually happens in these years is a diversification into highly specialised, but very different farming types. Most of the production takes place at industrial, but highly effective farm plants, specialised in one or few product types, but also different types of organic farming have experienced a remarkable success. Moreover, in numbers part-time farms are now the most widespread farming type, delivering services demanded, like life in the rural districts, land care, etc. The most important thing, though, is that all farming types adapt the latest information in order to optimise the resource use under the specific conditions of that farming type, and thereby contributes to a further sustainable development.

Acknowledgements

We thank The Danish Research Councils for funding the research project, Agrar 2000 (http://www1.natmus.dk/agrar2000/) from which this paper is publication No 6.
References