UPWARD REVISION OF RESTRICTIONS ON NITROGEN APPLICATIONS IN DENMARK

Keywords: Nitrogen regulation, regulation of nitrogen input; Value of protein and optimal Nitrogen Supply, Yield and optimal Nitrogen rates

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SUMMARY

In Denmark regulation of use of manure, fertiliser and land use started in 1985. The current regulation is based on the plan for sustainable agriculture from 1991, where nitrogen quotas and fertiliser accounts were introduced.

In the period from 1999 to 2016 the N-quotas were based on sub optimal N-rates, but a political agreement in 2015 stops the demand for fertiliser quotas below the economical optimum with effect as from 2017. The regulation of use of nitrogen has been very effective, and the use of nitrogen in mineral fertiliser has been reduced by 50 percent. The outlet of nitrogen to the coastal waters has declined with nearly 50 percent from 1990 to 2014, but it is difficult to see an improvement in the ecological status in the sea.

The sub optimal N-quotas has resulted in a higher loss of income for agriculture than expected. The under fertilisation have increased because of the nitrogen demand increase over time due to higher yield potential and lower mineralisation of nitrogen from the soil because of a lower input. Also increasing prices on protein cause higher nitrogen demands. Including value of protein in feed in calculating optimal N-rates for winter wheat the optimal N-rate increases by approx. 30 kg nitrogen per hectare. The total loss of income in agriculture as a consequence of reduced quotas has been calculated of SEGES to 300 million euro per year (140 Euro per ha).

A political agreement in 2015 stopped the demand for fertiliser quotas below the economical optimum, but kept the target for reducing nitrogen outlet nearly unchanged. The higher nitrogen quotas result in an increased outlet of nitrogen and must be replaced by other instruments to reduce the outlet. Collective initiatives like wetlands, constructed wetlands, afforestation are examples of other possibilities, but a significant demands reduction in outlet from catchments to vulnerable fiords and inlets which

probably will result in new restricted nitrogen qoutas, higher demands for mandatory catch crops on the agricultural land.

1 INTRODUCTION

In Denmark as well as in other western European countries there has been focus on the negative impact of loss of nitrogen from agricultural land on the aquatic environment since the 1980s. In the beginning most interest was directed to the protection of drinking water against high nitrate content. But the main problem in Denmark with loss of nitrogen to the aquatic environment is related to eutrophication of the coastal saline waters. In freshwater, phosphorous is normally the limiting nutrient for growth of algae while nitrogen is regarded as the limiting factor in a period of the year in salt water. The problem is largest in relative closed fiords near the coast, where the denitrification of nitrogen and the mixing with water from open sea is limited. More than 75 percent of the agricultural land in Denmark is located in catchments to relatively closed fiords, where leaching of nitrogen from agriculture is claimed to be the reason why the demanded “Good Ecological Status” in the EU-Water Frame Directive is not fulfilled. Actually “Good Ecological Status” in 2014 was fulfilled in only 5 per cent of the coastal waters in Denmark according to an analysis carried out by of the State prior to the second period (2015-2021) of the Water Frame Directive (Naturstyrelsen, 2014).
The mandatory second river basin management plans, according to the EU Water Frame Directory, shows for Denmark that the outlet of nitrogen must be reduced by 23 percent compared to the outlet from 2010 to 2014. This means that the leaching of nitrogen from agriculture must be reduced by approx. 30 percent because nearly all the reduction must derive from agricultural land. Approx. 50 percent of the needed reduction is postponed to the third period in the Water Frame Directive (2021-2027), because implementation in the second period (2015-2021) from a political view will result in too high costs for agriculture especially in vulnerable catchments.

It must be noticed that the goal of a 30 percent reduction in outlet of nitrogen from agricultural land must be obtained compared to the situation 2010-2014, where the nitrogen quotas was about 20 percent lower than the requirements of the crops and there was a mandatory requirement of 10-14 percent cover crops.

The agricultural organisations in Denmark and specialists on SEGES (The Agricultural Advisory Service) do not agree with the targets for reduction of nitrogen outlet in the river basin management plan. The main arguments are, that a lot of other factors than nitrogen influences the ecological status in the coastal waters and that no real improvements in the ecological status have been seen even if the outlet of nitrogen have been reduced by more than 50 percent since 1990.

1.1 Overview of nitrogen regulation in Denmark 1985-2021

Table 1 provides an overview of the regulation in Denmark from 1985 to 2021 primarily implemented to reduce the outlet of nitrogen from agricultural land.

Table 1. Overview of the Danish regulation as to reduction of leaching of nitrogen (modified from Blicher-Mathiesen et. al. 2015)

Year	Action plan	Elements in the plan	Target
1985	**N**itrogen-**P**hosphorous-**O**rganic matter (NPO)	Ban of direct outlet of manure to drain and streams. Ban of manure spreading on frozen soils, minimum spreading area of manure per animal unit	

1987	Water Environment Plan I	Demand for storage capacity for animal manure, ban of spreading autumn and winter on bare soils, requirement for a minimum coverage of soil with crops autumn and winter, mandatory fertiliser plans	50 pct. reduction of nitrogen leaching from agriculture relative to leaching in the 1980s
1991 and 1996	Plan for sustainable agriculture	Maximum Nitrogen quotas (optimal rates), minimum requirements for utilisation of nitrogen in animal manure, mandatory fertiliser accounts	50 pct. reduction of nitrogen leaching from agriculture relative to leaching in the 1980s
1998	Water Environment Plan II	10 per cent reduction of nitrogen quotas from optimal levels, mandatory minimum area with catch crops, wetlands, afforestation.	50 pct. reduction of nitrogen leaching from agriculture relative to leaching in the 1980s
2004	Water Environment Plan III	Increasing demand for mandatory catch crops, volunteer buffer strips	13 pct. reduction in nitrogen leaching relative to the leaching in 2003
2009	Green Growth	Ban soil tillage autumn before spring sown crops, 50,000 ha mandatory buffer strips, 140,000 hectare extra	Reduction of outlet of nitrogen with 30 pct. relative to the outlet 2004-

		cover crops in catch-ments to vulnerable fjords	2008
2016	Food and agri-cultural Plan	Increasing quotas of nitrogen to the optimal level with effect as from 2017. Stop for mandatory buff-er strips and cancella-tion of the 140,000 hec-tare extra cover crops. Wetlands, constructed wetlands, afforestation, 100,000 hectare extra volunteer catch crops in 2017 and 2018. Targeted regulation of catchment to vulnerable fjords 2018-2021 (in-struments unknown)	Reduction of the outlet of nitrogen by 13 percent until 2021 related to the outlet 2010-2014 and fur-ther 9 percent in the period 2021-2027

Until 2016 reduction in nitrogen input has played a major role in the regulation. Maximum nitrogen quotas and minimum requirements for utilisation of nitrogen in animal manure were introduced from harvest 1994. The quotas were based on recommendation for nitrogen levels from the advisory service (optimal N-rates). Especially the minimum requirements for utilisation of nitrogen in animal manure reduced the use of mineral fertiliser. To control that the farmers do not use a lot of nitrogen, they must submit a fertiliser account to the Ministry each year.

If the farmer uses to much nitrogen he will have a fine at 1.35-2.70 Euro per kg nitrogen in surplus (Knudsen, 2003).

Basically, this system for input control of nitrogen still works. But since 1994 the regulation on nitrogen quotas has changed several times, the minimum requirements for utilisation of nitrogen in animal manure have been increased, possibilities to make individual correction have been reduced and control has been intensified.

The system has been very efficient in controlling and reducing the total use of nitrogen (Figure 1). From the beginning of the 1990[s] before the regulation, the total use of nitrogen was nearly 800,000 ton while it is only about 500,000 ton today. The major source is a reduction in use of mineral fertiliser from 400,000 ton nitrogen to 200,000 ton nitrogen. In the period from 2003 to 2015 the use of nitrogen in mineral fertiliser has been constant.

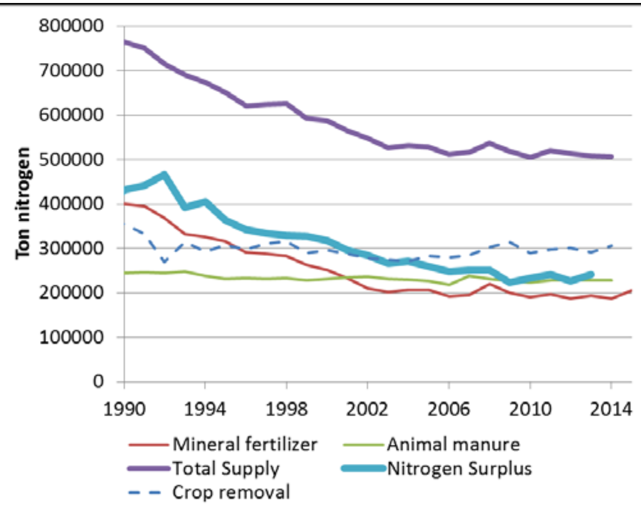
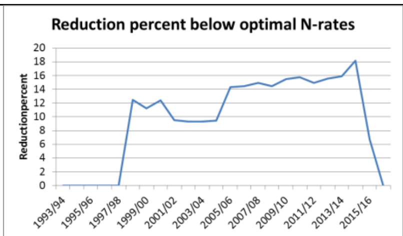


Figure 1. Key numbers for use of nitrogen in Danish agriculture 1990-2015

2 CONSEQUENCES FOR YIELD AND PROTEIN LEVEL OF REDUCED SUPPLY OF NITROGEN

The background for introduction of a 10 percent reduction in nitrogen quotas in 1999 below the recommendations based on economical optimal rates was a perception that the influence on yield and quality of the crops was limited. This was mainly based on an evaluation of one year nitrogen trials and that the value of protein was low.

In the period 1999-2015 the under fertilisation increased from 10 to 20 percent because the total quota for the whole country was fixed at a total level 10 percent lower than the total quota for 1998 (figure 2). The increase in under fertilisation is due to an increase in the optimal rates over time caused by increasing yield potential, higher prices on protein and a declined mineralisation of nitrogen from soil because of lower total supply of nitrogen with fertiliser. Another reason for the increasing under fertilisation was the end of the EU set-aside scheme, which meant the cropping area increased and the total nitrogen quota was spread over a bigger area.



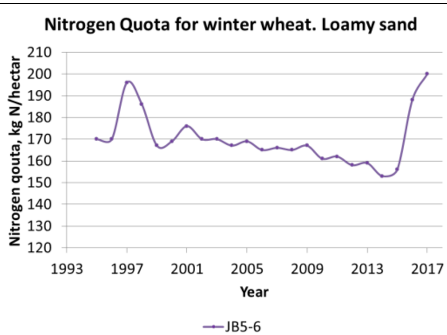


Figure 2. Reduction of nitrogen qoutas below the optimal N-	**Figure 3.** Nitrogen quota for winter wheat on loamy sand (yield 8 ton per

rates from 1994-2017 (Data from NaturErhvervstyrelsen).	ha). (Data from NaturErhvervstyrelsen).

In figure 3 the actual N-quota for winter wheat with previous crop cereals on loamy sand is shown for each year since 1994. The quota decreases from 180 kg nitrogen per hectare to 152 kg per hectare in 2015. In 2016 and 2017 the quota has increased due to the political decision to phase out the under fertilisation.

2.1 Impact on yield of reduced nitrogen supply.

The consequences for yield of the reduced supply of nitrogen cannot be evaluated exactly. SEGES has estimated the loss of yield from a number of traditional one year trials with increasing amount of nitrogen and has estimated the effect of a long term effect of reduced nitrogen from special trials designed to show this effect.

The calculation of the short term effect was based on 102 trials in winter wheat 2008-2012. The optimal N-rate in the trials was without correction for value of protein calculated to 184 kg nitrogen per ha with a yield at 9.4 ton per hectare. The N-quota for these trials was in 2012 144 kg nitrogen per ha. From the yield curves for each individual trial the yield loss was in average 0.47 ton per hectare (Knudsen, 2013).

In the same investigation an additional loss of yield due to the long term reduction of nitrogen supply was estimated to 0.15-0.3 deciton per hectare. This estimate was based on trial results from trials with different levels of nitrogen for a period of more than 30 years divided up in small plots in the last years to compare the short term and the long term effect (Petersen et. al. 2012). Se figure 4.

Knudsen (2013) also included the yield reduction caused by reduced nitrogen supply in a comparison between yield of cereals in Germany and in Denmark in different periods. In Germany there has been none restrictions in use of nitrogen until now. This comparison shows (Table 2), that the difference between Denmark and Germany has increased during the years.

Tabel 2. Yield of cereals in Denmark and Germany. Deciton per hectare (FAOstat)

	1999-2010	1994-98	1980-94
Denmark	603	604	495
Germany	667	621	502
Difference	-64	-17	-06

Based on the trials showing the short term effect, the trials showing the long term effect and the comparison between development of yields in Germany and Denmark Knudsen (2013) concluded, that the loss of yield due to the reduced nitrogen quotas was 0,6 deciton per hectare. This estimation was upgraded to 0.73 deciton per hectare in 2014 because the under fertilisation has increased slightly (Knudsen, 2015).

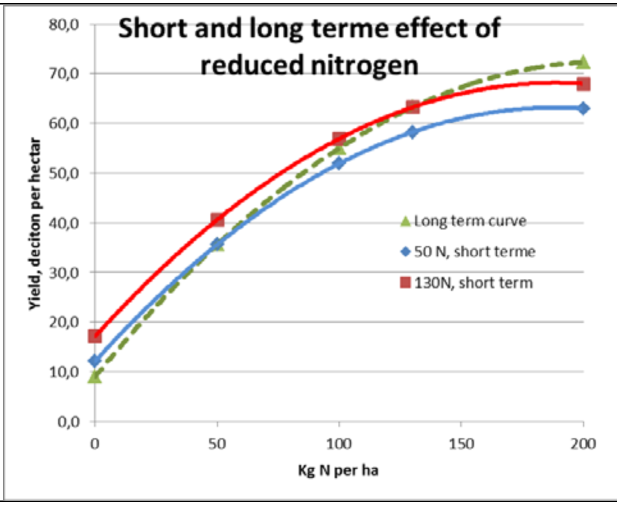


Figure 4. Effect on reduced nitrogen supply on yield of spring barley. Data from Petersen et. al, 2012

The University of Aarhus and the University of Copenhagen estimated in 2014 that the loss of yield in cereals due to the reduction of the nitrogen quota was between 0.3 and 0.5 deciton per ha (Kristensen et. al. 2013).

2.2 Impact of reduced nitrogen supply on protein content in cereals

The content of protein in cereals for feed production in Denmark has been monitored by SEGES, Knowledge Centre for Pig Production since the 1980's. Each year a number of grain samples geographical distributed in Denmark are analysed for protein content to give the pig producers a general information of the level of protein in the actual harvest.

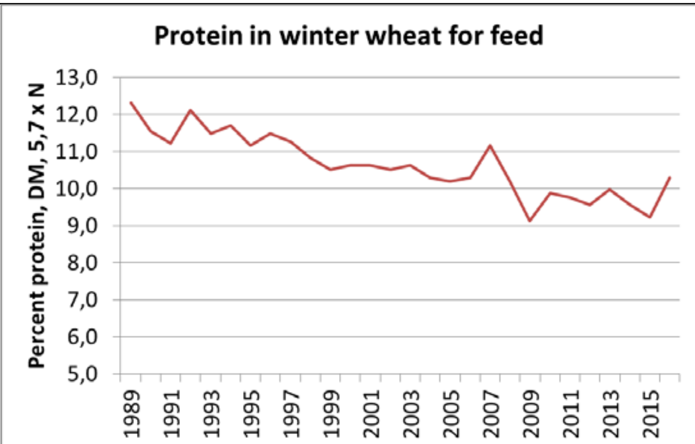


Figure 5, Protein content in winter wheat for feed 1989-2016 in Denmark

The protein content has decreased approx. 2.0 percent units from medio 1990's to the 2010's. This decrease has resulted in a significant economic loss especially for pig producers, also due to the fact that the value of protein has increased as a result of an increasing price difference between winter wheat and soya at the world market since 2008. For cereals for feed the 2 percent units loss of protein has resulted in a loss of money close to 70 Euro per ha (7.5 ton, 0.5 Euro per percent protein per deciton).

For winter wheat for bread there has been an extra nitrogen quota on approx. 70 kg nitrogen per ha to be able to obtain a sufficient quality of the wheat. This extra quota was restricted to about 40.000 hectares. For winter wheat to export the low protein percent have resulted in lower prices. For spring barley for malting normally the problem has been that the protein content was too high. But especially in the last years (2011-2015) with high yields in spring barley the protein level in many cases has been to low (below 9 percent protein) and rejected as malting barley, which results in a significant loss of money for the farmer. In 2016 with higher N-quotas and a low yield the problem has been a too high level of protein.

2.3 Loss of income in agriculture due to reduced nitrogen quotas

Knudsen et. al. (2015) summarised the estimated total loss for Danish agriculture to a loss in income of 300 million Euro per year or about 120 Euro per hectare due to loss of yield and quality. Jacobsen et. al. (2016) estimates a total loss of 175-250 million Euro, Kristensen et. al. (2013) estimates a loss of 70-130 million Euro and Troelsen et. al. 2016 estimated a loss of 450 million Euro (180 Euro per hectare).

The assessment of the total loss due to reduced nitrogen quotas varies quite much between different institutes. Some of the differences are to be found in different methods, but for a number of years, SEGES has claimed, that the universities underestimates the losses and that reduced nitrogen quotas was a more expensive instrument to reduce leaching than the estimation from the universities, on which the Ministry bases their decision. The underestimation is primarily due to an underestimation of the value of protein and the effect on yield of a long term reduction in nitrogen supply.

3 ENVIRONMENTAL IMPROVEMENT DUE TO REDUCED NITROGEN INPUT

The policy to reduce nitrogen input in Danish agriculture aims to improve the environmental status of the near coastal waters also to a certain degree to reduce leaching of nitrogen to ground water to avoid pollution of drinking water.

It has been possible to reduce the outlet of nitrogen to the coastal water. The outlet has been monitored by measuring nitrogen concentrations and water flow in the streams and from this the outlet has been calculated. This monitoring only covers about 50 percent of the Danish land - the rest has been calculated by modelling based on the measured part.

The outlet of nitrogen has been reduced approx. 50 percent from 1990 to 2014. The reduction is both due to a reduction in outlet from agricultural land and from point sources like water treatment plants. Most of the reduction has happened in outlet from agricultural land.

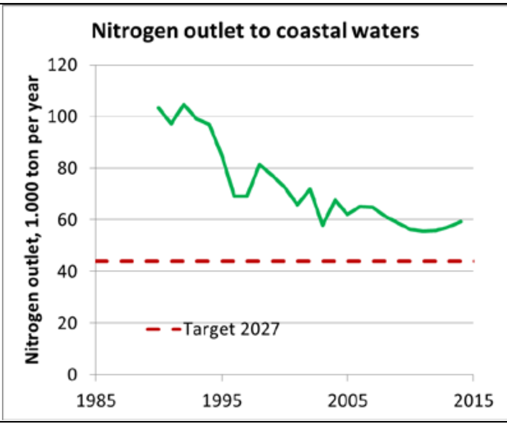


Figure 6. Measured nitrogen outlet from Denmark to the coastal waters (normalised for climatic variation). The target for 2027 is set by the ministry to fulfil the Water Frame Directive. Data from Aarhus University.

The reduction in outlet was most significant from 1990 to 2000. In this period the utilisation of nitrogen in animal manure was improved by bringing more than 90 percent of liquid manure out in spring and in autumn only to grass and oilseed rape with high nitrogen uptake in autumn. Since 2000 there has only been a minor decrease in outlet of nitrogen. Since 1990 the outlet of nitrogen has nearly been reduced by 50 percent.

Despite this significant reduction, it is difficult to show an improvement in the environmental status in the near coastal waters. Data for chlorophyll content in the inlets show a significant decrease, and the secchi depth seems also to have increased but the variation between the years is high. (Jensen et. al., 2015). Despite these improvements “Good Ecological Status” only in 2014 was fulfilled in only 5 percent of the coastal waters in Denmark according to an analysis of the State prior to the second period (2015-2021) of the Water Frame Directive (The Danish Nature Agency, 2014).

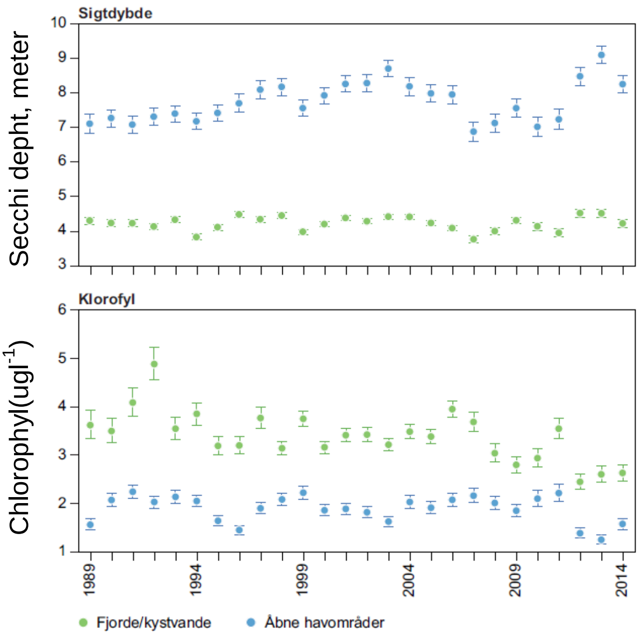


Figure 7. Secchi depth and chlorophyl. Green signature: Inlets and fiords. Blue signature: open sea

4 INCREASING NITROGEN DEMAND

The nitrogen demand or the economical optimal nitrogen has increased over the years. There are three major reasons for that. The yield potential increases over time, the mineralisation from soils decreases according to a decrease in nitrogen supply and the value of protein has increased.

4.1 Increasing demands for nitrogen over time

In figure 7 the yield response in winter wheat (previous crop cereals) trials since 1971 shows that the response for nitrogen has increased significantly. The data are from the Danish trials with increasing amounts of nitrogen. Each year from 5 to 29 trials have been carried out. Part of the reason for the variation between years is to be found in a low number of trials.

The yield in the treatment without nitrogen showed no significant change in the period. In 1971 the response for 100 kg nitrogen per hectare was only 18 deciton per hectare and the additional response from 100 to 200 kg N was only 4 deciton. In 2016 the response for 100 kg nitrogen per hectare was 40 deciton per hectare and the additional yield from 100 to 200 kg nitrogen was 15 deciton per hectare.

The optimal N-rate increases with the crop response. But figure 8 shows that this increase was more pronounced in the period 1971-1990 and smaller in the period from 1991-2016. The reason might be that the yield increase from 1971-1990 was higher than from 1990-2016.

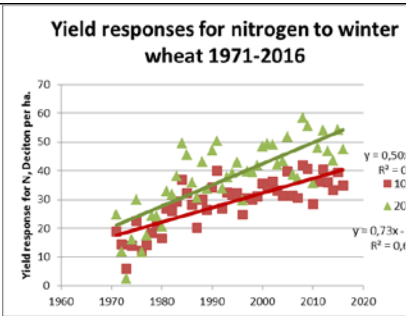


Figure 8. Yield response to nitrogen for winter wheat 1971-2016.

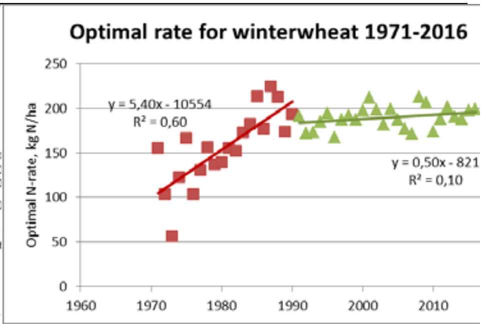


Figure 9. Optimal nitrogen rates for winter wheat from 1971-2016.

In Denmark the total nitrogen quota had the same total limit from 1999 to 2015. If the nitrogen demands increase with 05-1.0 kg nitrogen per year the optimal rate in that period was increasing 8-16 kg nitrogen per hectare. This means a total limit of the quota results in increasing under fertilisation over time. The increase in the demands for nitrogen also means that it is difficult to base recommendation for N-rates on old trials.

4.2 Including protein in calculating optimal N-rates for cereals

70 percent of the Danish production of cereals is used for feed in Denmark especially for pigs. The reduction in nitrogen input has resulted in a decrease in protein in cereals of approx. 2 percent units (figure 5). Cereal never has a sufficient protein content or protein quality to feed pigs alone but must be supplemented with high protein feeds like typically soya beans. Before it was possible to add synthetic amino acids to the feed if the value of extra protein in cereals was low, because the content of some essential amino acids like lysine and methionine did not increase proportionally with total protein. However, today it is possible to

add synthetic e.g. lysine and methionine to the feed (see table 3). It means that the protein in the feed ration can be balanced, and that the total amount of protein per produced pig can be kept at the same level by reducing the use of soya, if the protein content in cereals is increased by adding more nitrogen to the crop.

Table 3. Relative change in content of amino acids in barley and winter wheat and prices for synthetic amino acids. From Per Tybirk, SEGES, Knowledge Center for Pig Production

Amino acids	Change in percent with a 10 percent increase of total protein		Price for amino acid, Euro per 100 Feeding Unit, pig
	Barley	Winter wheat	
Lysine, g digestilbe pr. kg	8	5	0,13
Methionine, g digestilbe pr. kg	9	8	0,11
Treonine, g digestilbe pr. kg	9	7	0,09
Tryptofane, g digestilbe pr. kg	8	8	0,13
Valine, g digestilbe pr. kg	11	10	0,43
Leucine, g digestilbe pr. kg	12	10	Not available
Isoleucine, g digestilbe pr. kg	12	11	Not available
Histidine, g digestilbe pr. kg	11	10	Not available

The price of protein can be estimated directly from the price of cereals and the price of soya. Since 2008 the price of soya toast has been high and the price difference to winter wheat has been high, which results in a high price for protein. The price for protein is calculated from a feed optimisation for pigs developed by SEGES.

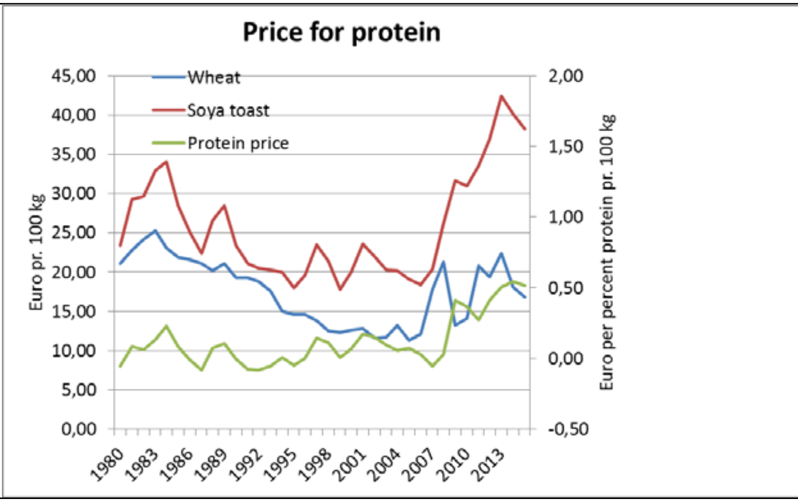


Figure 9. Calculated price of protein in cereals 1980-2015. Different Danish price databases

The average price for protein from 2011-2015 has been 0.47 Euro per percent of protein per deciton of cereal.

The value of protein is included in calculation of the optimal N-rate. The principle is shown in table 4 for 22 trials in winter wheat. The optimal N-rate here is calculated with a 2. degree polynomial directly on the average of the trials. Normally in SEGES it is done for each single trial. The content of protein has increased from 100 to 250 kg nitrogen per hectare. The increase is about 0.2 percent units per 10 kg of additional nitrogen. The protein corrected price increases from the basic price of 134.8 Euro at 9.0 percent protein up to 146.5 Euro per ton with the highest protein content of 11.5 percent.

The optimal N-rate is 37 kg nitrogen higher by including the value of protein in the calculation. As an average of many trials the optimal rates normally increase by 30 kg nitrogen at a protein price of 4.7 Euro per percent protein per ton cereal.

Table 4. Example of including value of protein in calculating optimal N-rate in winter wheat. 22 trials in 2016 in winter wheat with the previous crop cereals. Data from Pedersen et. al. 2016.

Winter wheat (previous crop cereal)	Per-cent protein in dry matter	Yield and yield re-sponse, ton per ha	Protein correct-ed price on cere-al, Euro per ton	Net in-come without protein correc-tion, Euro per hec-tare	Net in-come with protein correc-tion, Euro per hec-tare
No. of trials	*22*	*22*	*22*	*22*	*22*
Basic fertilisati-on	8,7	3,4	133,5	464	459
50 N	8,3	1,9	131,2	716	641
100 N	8,8	3,5	133,7	878	816
150 N	9,7	4,3	138,3	938	909
200 N	10,7	4,7	143,0	936	947
250 N	11,5	4,9	146,5	898	940
LSD		*0,4*			
Optimal N-rate ,kg N/ha[1]:				180	217

[1)] Cereal price, basic at 9.0 percent protein: 134,77 Euro pr. ton, protein perice 4,7 Euro per percent per ton, nitrogen price 1.11 Euro per kg N.

Including the protein price in the calculation of optimal N-rates has a significant influence on the optimal N-rates.

5 FROM SUBOPTIMAL TO OPTIMAL NITROGEN QUOTA IN 2016-2017

In December 2015 the newly formed liberal government in Denmark decided to end the Danish under fertilisation with nitrogen. In a political agreement the nitrogen quotas in 2016 were increased by about 17 percent and in 2017 by approx. 25 percent related to 2015 to end up with optimal N-rates in 2017. The background for the decision was primarily to help the agriculture in a very serious economic crisis caused by low prices on milk and meat. Another reason was that it has become clear that the existing reduced nitrogen quotas were a serious problem for the quality and the yields of the crops. (Ministry of Environment and Food of Denmark, 2015),

The political agreement introduced a new plan for reducing the outlet of nitrogen to the near coastal waters. The already existing target to reduce the outlet to 44.000 ton nitrogen from the current outlet at 56.000 ton per year was nearly unchanged. But a 6.200 ton reduction was postponed to the third period (2021-2027) in the Water Frame Directive.

Table 5. Review of the water plans for 2015-21 for Denmark to full fill the Water Frame Directive

	Ton nitrogen outlet to the coastal waters
Average outlet of nitrogen 2010-2014	56.760
Target for outlet in 2021	44.700
Total demand for reducing the outlet	13.460
Effect of allready decided legislation and	-5.600

general trend in agriculture (baseline)	
Effect of the political agreement in 2015	5.200
Demand for reducing the outlet after the political decission 2015	13.100
Postponing of the reduction to third period (2021-2027)	-6.200
Total target for reduction in 2021	6.900
- Collective initiatives (wetlands, constructed wetlands..)	-3.400
- Regulation in vulnerable areas.	-3.500

Until 2021 there is a total demand for initiatives to reduce outlet of nitrogen by 6.900 ton. About half of this is planned to be obtained by establishing wetlands, constructed wetlands and afforestation.

Since1998 wetlands have been used as an instrument to reduce leaching. Constructed wetlands are a new instrument. Constructed wetlands are used in drained area, and the water surface in a constructed wetland must be 1 percent of the catchment which drains to the constructed wetland. A reduction of 20-30 percent of the nitrogen input to the constructed wetland is expected.

Besides the effect of collective initiatives a reduction on 3.500 ton must obtained in catchments to vulnerable fiords and inlets. Maps published from the Ministry show that about 75 percent of the agricultural land is located in such areas. Still there are no published plans on how to obtain this reduction. It might be a combination of reductions in quotas, more catch crops, set-aside and other well-known instruments.

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