Technical University of Denmark

PardNor - PARameters for ingestion Dose models for NORdic areas

Status report for the NKS-B activity 2008

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PardNor - PARameters for ingestion Dose models for NORdic areas. Status report for the NKS-B activity 2008

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Abstract

The ECOSYS foodchain model is built into the European standard decision support systems ARGOS and RODOS, which are integrated in the preparedness for radiological events in the Nordic countries. However, a review has revealed that a number of parameters in ECOSYS do not reflect the current state-of-the-art knowledge, and do not adequately represent Nordic conditions. Improved and country/region specific data is required for ECOSYS to give trustworthy results. It is the aim of the PardNor activity to collect new data, and thus enable reliable use of ECOSYS for scenarios involving contamination of Nordic food production areas. In the reported work period of the PardNor activity, analyses have been performed for each Nordic country to determine the sensitivity of the ingestion dose end-point in ECOSYS to variation in 9 selected, potentially important parameters (human dietary components and animal fodder components). This parametric sensitivity was found to vary considerably between the different Nordic countries, reflecting considerable differences in diet and domestic production, and highlighting the importance of last year's work to identify appropriate location-specific parameters. A simple empirical Danish soil temperature based methodology for calculation of more reliable location-specific values of leaf area index (LAI) was tested for Swedish conditions and applied to estimate the seasonal LAI variation in other countries. The leaf area index reaches its maximum value much earlier in the southern parts of the Nordic region than in the northern. This means that the conditions for deposition and interception to vegetation would over a certain time span be very different in different Nordic areas. Also the influence on ECOSYS dose estimates of resuspension enrichment factors, leaching rates, fixation rates and desorption rates was investigated in the reported activity period, identifying new data sets where needed.

Key words

Foodchain modelling, ingestion dose, ECOSYS, consumption habits, radioactive contamination

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PardNor

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1. Introduction

In compliance with the agreement, this year's work on the PardNor activity had three main objectives, all directed towards improving the Nordic knowledge platform required to make reliable estimates, using the ECOSYS model, of ingestion doses in the event of a contaminating incident. As the ECOSYS model is implemented in both of the European decision support systems, ARGOS and RODOS, which are used by the Nordic authorities, the work constitutes an important step towards an improved and harmonised Nordic preparedness. The three main tasks this year were: (i) investigations of ingestion dose sensitivity to Nordic diets, food import and animal feeding regimes, (ii) application of an improved and site-specific methodology for description of plant leaf area indices (LAI's), and (iii) investigations of the importance on dose estimates of introducing improved estimates of soil leaching rate, fixation rate, desorption rate and resuspension enrichment factor.

In addition the activity is currently producing a journal paper for publication in Radiation Protection Dosimetry, on results obtained so far in the PardNor activity. The working title of this paper is: 'Effect of Nordic diets on ingestion doses estimated with the ECOSYS model'.

2. Estimation of ingestion dose sensitivity to Nordic diets, food import and animal feeding regimes

The ECOSYS model does not in the excel-version made available to the PardNor activity, nor in the versions implemented in the ARGOS and RODOS decision support systems, contain features enabling analysis of sensitivity or uncertainty of model end-points towards parametric variation. However, having investigated in PardNor the differences in a number of input parameter values among the different Nordic countries, defining country-specific 'best estimate' datasets, it is of interest to assess whether the estimated variation in a single country's parameter values might have an impact on end-point estimates that could be comparable in magnitude to the variation between the country-specific values. At the same time, it is interesting to examine whether values believed to be representative of one Nordic country or region fall within the uncertainty bounds of values taken to be representative of a neighbouring area of an other Nordic country. If decision-making in nearby areas differs greatly, it will require particularly careful explanation and communication with the public to maintain trust in the authorities' ability to handle the situation appropriately. An investigation of end-point sensitivity against parametric variation would show which input parameters are most important to define with high resolution for each country. To this end, the partners representing the different Nordic countries in the activity have all been asked to apply the country specific input data they deduced in the previous activity period for dietary and fodder components in ECOSYS model run series, varying each of a number of input parameters deemed to be potentially particularly important by 10 %. The scenario chosen involves dry deposition of ^{137}Cs on the 1st of July, to include the mechanism of direct deposition to standing crops, and the end-point to be investigated was taken to be the 1st year ingestion dose. At the same time, an investigation is made, where data is judged to be sufficient, of the uncertainty/variability that each of these input parameters contributes to the total uncertainty/variability of the end-point prediction. Again, since no inherent feature was available for systematically varying input parameters, as in Monte Carlo analyses, it was agreed to carry out calculations of the influence on the 1st year dose end-point of individually varying values of input parameters between 'best estimates' and estimates of upper and lower bound values. It would be reasonable to assume that the variation of these parameter values can in reality be adequately represented by normal distributions. It is often difficult to determine from limited available data, what is the maximum or minimum perceivable value under the given circumstances. Therefore, an alternative that seems somewhat easier to judge has been applied in the investigations: the variation caused by parametric variation within two standard deviations. The parameters to be varied were:

- Human intake of leafy vegetables
- Human intake of milk
- Human intake of beef
- Human intake of lamb
- Human intake of wheat
- Lactating cow's intake of fodder
- Beef cattle's intake of fodder
- Lamb's intake of fodder

2.1. Ingestion dose sensitivity in Denmark

Table 1 shows the 'best estimate' values of these parameters, as identified for Danish conditions.

Table 1. 'Best estimate' values of input parameters (dietary components and animal fodder composition) for examination of end-point sensitivity and uncertainty. Human dietary components are given for all four age groups covered by the activity (kg/y), and animal feeding rates are in units of kg per day FW.

	Young children	Teenagers	Adults	Seniors
Leafy vegetable	2	15.7	16.4	9.3
Milk	147.5	144.2	80.5	96.5
Beef, cow	0.9	6.6	9.5	12.8
Beef, bull	0.4	2.6	4	5.1
Lamb	0.4	0.5	1.1	0.9
Wheat	18.8	38.7	45.1	38
Fruits	83	40,5	58.4	103.1
		Grass	Maize	Hay
Lactating cow's fodder		20	50	
Beef cattle fodder		50*	or	50*
Lamb fodder		8*	or	1.5*

*Fodder regime varies between grass and hay according to season.

Table 2 shows the influence on the end-point of varying each of these input parameters by 10 %.

Table 2. Results of examination of end-point sensitivity to systematic 10 % changes in a number of input parameters (contamination scenario as described above). Figures are the percentage variation in the end-point caused by the input variation. Values are given for all four age groups covered by the activity.

	Young ch.	Teenagers	Adults	Seniors
Change leafy veg. 10 %	0.03 %	0.3 %	0.3 %	0.1 %
Change milk 10 %	3.9 %	3.6 %	1.7 %	1.8%
Change beef 10 %	0.2 %	0.9 %	1.1 %	1.2 %
Change lamb 10 %	0.02 %	0.1 %	0.1 %	0.04 %
Change wheat 10 %	0.6 %	0.9 %	1.5 %	1.4 %
Change fruits 10 %	1.0 %	0.5 %	0.4 %	1.1 %
Change lactating cow's fodder 10 %	4.3 %	4.3 %	2.4 %	2.8 %
Change beef cattle fodder 10 %	0.2 %	0.4 %	0.5 %	0.5 %
Change lamb fodder 10 %	0.02 %	0.1 %	0.1 %	0.1 %

As can be seen from the data in Table 2, especially variation in milk consumption and in the amount of fodder consumed by lactating cows can significantly influence the 1st year dose for the given scenario. This is particularly true for children, who consume comparatively large quantities of milk. Beef consumption has influence on the doses to the three most senior age-groups, but since much of the beef that is consumed in Denmark actually comes from cows rather than bulls, changing the bulls' fodder rate by 10 % has limited effect on dose. Wheat consumption was for adults and seniors found to have almost as great influence as milk on the end-point.

The consumption of leafy vegetables was in the early phase found to be the main contributor to daily ingestion doses, but accumulated over a whole year, leafy vegetables were not found to be of much significance. In addition to those dietary components that were agreed to be examined, also fruits were here examined, since it was found that these can have some influence on the first year dose, even though it was, in-line with the findings of the previous activity period, assumed that as much as 90 % of the fruit was imported (by default in ECOSYS from uncontaminated areas). Very little lamb meat is consumed in Denmark, and about 80 % of it is imported. Therefore changes in parameters pertaining to lamb meat have little influence on dose in general.

Table 3 shows estimates of two standard deviations from the 'best estimate' values of the various dietary and fodder input data. The values for diets are estimated on the basis of reported uncertainties from surveys, where available, and of data from different years as well as the variation over the age spans represented by each figure (Fagt et al., 2002; Groth & Fagt, 2002; Haraldsottir et al., 2005; Lyhne et al., 2005). For fodder, the standard deviations were evaluated from the variation observed over different years (CALT, 2002; Danmarks Statistik, 2001; Danske Slagterier, 2008; Dansk Landbrugs Grovvareselskab, 2008), and partially on the basis of consulting an experienced farming representative.

Table 3. Estimates of uncertainty on input parameters for diets and fodder regimes, expressed as two standard deviations. Human dietary components are given for all four age groups covered by the activity (kg/y), and animal feeding rates are in units of kg per day FW.

	Young children	Teenagers	Adults	Seniors
Leafy vegetable	3.0	6	6	4
Milk	100	60	60	80
Beef, cow	0.8	6	12	8
Beef, bull	0.4	2.4	4.4	3.2
Lamb	0.4	0.6	1.4	1.0
Wheat	6	12	16	1.4
Fruits	16	10	24	60
		Grass	Maize	Hay
Lactating cow's fodder		20	20	0
Beef cattle fodder		20*	or	20*
Lamb fodder		4*	or	0.6*

*Fodder regime varies between grass and hay according to season.

Table 4 shows how variation by two standard deviations affects the end-point for the given scenario. Again, milk ingestion and lactating cow's fodder are major contributors to the variation, together with beef (for the 3 most senior age groups). As a whole, essentially the same trends are observed as in the sensitivity investigation. Overall, the uncertainties estimated for the end-point are not very large, which may possibly reflect a rather limited background material for evaluating some of the input uncertainties, e.g., for diets originating from only few national surveys. Anyway, it is clear from the work during the previous activity period that the variation between Nordic countries of the values in many of these input parameters is much greater than the uncertainty/variation within the countries, which demonstrates the importance of applying correct site- and case- specific input values in the calculations.

Table 4. Results of examination of end-point response to a variation of a number of input parameters by two standard deviations (contamination scenario as described above). Figures are the percentage variation in the end-point caused by the input variation. Values are given for all four age groups covered by the activity.

	Young ch.	Teenagers	Adults	Seniors
Leafy vegetables	0.8%	1.2%	0.8%	0.6%
Milk	32.6%	14.8%	13.2%	16.2%
Beef	2.0%	8.6%	14.2%	9.4%
Lamb	0.3%	0.4%	0.6%	1.0%
Wheat	1.8%	3.8%	4.2%	3.8%
Fruits	1.6%	1.2%	2.4%	5.8%
Lactating cow's fodder	18.4%	15.6%	10.0%	11.6%
Beef fodder	10.2%	4.2%	5.6%	6.7%
Lamb fodder	0.1%	0.2%	0.2%	0.3%

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2.2. Ingestion dose sensitivity in Sweden

In this investigation of end-point sensitivity against parametric variation the intention has been to use the country specific dietary and fodder data deduced and reported in the previous activity period. However, the fodder data previously reported was found to be less suitable for input to the ECOSYS model and new estimations have been used for cattle. For lamb fodder the Danish data, collected from the 2007 status report, has been used. The Swedish dietary data and the feeding regimes used as 'best estimate' in the simulations are summarised in Table 5. Due to lack of dietary data for wheat the parameters that were varied were:

- Human intake of leafy vegetables
- Human intake of milk
- Human intake of beef
- Human intake of lamb
- Human intake of fruits
- Lactating cow's intake of fodder
- Beef cattle's intake of fodder
- Lamb's intake of fodder

In the Swedish dietary surveys (SLV, 2002; SLV, 2003), consumption of different kinds of meat is reported as one single quantity. To separate beef and lamb, the relative consumption of these meats (Swedish Meats, 2003) has been used to deduce the consumption. It has then been assumed that the same relative consumption is valid for all age groups.

The feeding rate for cattle in Sweden is about 10 kg dry matter per day as a mean value for the year (Gustafsson, 2008). There is some variation concerning the type of fodder and inclusion of mineral fodder, depending e.g. on the lactation, which is difficult to estimate. The figures given in Table 5 could therefore be considered a rough mean value for Swedish conditions.

Import factors used in the model runs were:

- Leafy vegetables: 0.42
- Milk: 0.97
- Beef: 0.68
- Lamb: 0.33
- Fruits: 0.08

Table 5. 'Best estimate' values of input parameters for Swedish conditions. Human dietary components are given for all four age groups covered by the activity (kg/y), and animal feeding rates are in units of kg per day FW.

	Young children	Teenagers	Adults	Seniors
Leafy vegetable	14.2	17.2	33.2	37.2
Milk	143.3	165.1	135.4	127.2
Beef, cow*	0.0	0.0	0.0	0.0
Beef, bull	8.4	12.9	13.5	12.9
Lamb	0.3	0.5	0.5	0.5
Fruits	42.9	30.8	35.6	55.8
		Grass		Hay
Lactating cow's fodder		50**	or	50**
Beef cattle fodder		50**	or	50**
Lamb fodder		8**	or	1.5**

*Total consumption of beef

**Fodder regime varies between grass and hay according to season.

Varying each of the input parameters by 10 % gave the influence on the end-point shown in Table 6.

Table 6. Results of examination of end-point sensitivity to systematic 10 % changes in the input parameters for Swedish conditions. Figures are the percentage variation in the end-point caused by the input variation. Values are given for all four age groups covered by the activity.

	Young ch.	Teenagers	Adults	Seniors
Change leafy veg. 10 %	0.07 %	0.08 %	0.2 %	0.2 %
Change milk 10 %	1.9 %	2.0 %	1.7 %	1.6 %
Change beef 10 %	0.8 %	1.2 %	1.3 %	1.2 %
Change lamb 10 %	0.01 %	0.01 %	0.01 %	0.01 %
Change fruits 10 %	0.2 %	0.1 %	0.1 %	0.2 %
Change lactating cow's fodder 10 %	2.4 %	2.5 %	2.2 %	2.1 %
Change beef cattle fodder 10 %	0.8 %	1.2 %	1.3 %	1.2 %
Change lamb fodder 10 %	0.01 %	0.01 %	0.01 %	0.01 %

The largest impact is found for variations in milk consumption and a change in lactating cow´s fodder, although the actual figures may change if another feeding rate is used. The small amount of consumed lamb meat, together with a rather large import makes the contribution small. The small variation in first year ingestion dose from fruit consumption is probably due to the large amount of imported fruit.

In Table 7 is shown estimates of two standard deviations added to the ‘best estimate’ values. The values for diets are estimated on the basis of reported standard deviations from surveys (SLV, 2002; SLV, 2003). For fodder, no estimations could be made due to lack of data.

Table 7. Estimates of uncertainty on input parameters for diets and fodder regimes, expressed as two standard deviations added to the ‘best estimate’. Human dietary components are given for all four age groups covered by the activity (kg/y).

	Young children	Teenagers	Adults	Seniors
Leafy vegetable	33	36	66	70
Milk	248	254	244	256
Beef, cow	0.0	0.0	0.0	0.0
Beef, bull*	16	21	22	22
Lamb	0.6	0.8	0.8	0.9
Fruits	82	60	87	106

*Total consumption of beef

Table 8 shows how variation by two standard deviations affects the end-point for the given scenario.

Table 8. Results of examination of end-point response to a variation of a number of input parameters by two standard deviations (contamination scenario as described above). Figures are the percentage variation in the end-point caused by the input variation. Values are given for all four age groups covered by the activity.

	Young ch.	Teenagers	Adults	Seniors
Leafy vegetables	1.0 %	0.9 %	1.6 %	1.6 %
Milk	13.8 %	10.9 %	13.7 %	16.3 %
Beef	8.1 %	7.4 %	8.4 %	8.8 %
Lamb	0.1 %	0.08 %	0.08 %	0.1 %
Fruits	1.7 %	1.2 %	2.1 %	2.0 %

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2.3. Ingestion dose sensitivity in Norway

Human diets

- Standard diets used were taken from last year's PardNor work.
- Consumption (kg/year per person) of various foodstuffs in Norway - Gender averages, are shown in Table 9.

Table 9. 'Best estimate' values of input parameters for Nordic conditions. Human dietary components are given for all four age groups covered by the activity (kg/y), and animal feeding rates are in units of kg per day FW.

Product	**Young children** (4 years)	**Teenagers** (13 years)	**Adults** (16-29 years)	**Seniors** (60-79 years)
Spring wheat, flour[a)]	41	67	88	63
Leafy vegetables[b)]	3.8	4.8	8.5	12
Fruit[c)]	25	17	27	43
Milk (incl. yoghurt)	136	131	210	137
beef (cow)[d)]	2.7	4.7	4.9	3.6
beef (bull)[d)]	4.5	7.8	8.1	6.0
Lamb/sheep[d)]	2.2	3.7	3.9	2.9

[a)] Dietary data reported as bread/cereals. Consumption of different flour types calculated using weighing factors based on data from the Norwegian agricultural authority for the period 2001-2006. All wheat and rye are assumed to be flour.

[b)] Data regarding vegetables, generally, were available from dietary surveys. Leafy, root and fruit vegetable weighting factors derived from household consumption surveys 2003-2005. Leafy vegetables include cabbage.

[c)] Consumption of fruit and berries (excluding juice) from dietary surveys. Fruit weighting factors derived from household consumption surveys 2003-2005.

[d)] Total meat consumption available from dietary surveys. Production statistics 2001-2005 used to derive weighting factors for various types of meat. Note that beef (bull) also comprises heifer meat.

For the time being it was only possible to derive statistical information regarding milk intake. Therefore, the 'two standard deviations' approach was limited to that food item. However, as evident from above milk seems to be the most important of the foodstuffs considered for this study.

For the age group 16-79 years 393 kg milk per year represents two standard deviations above average. Data was derived from Norkost 1997 (dietary study).

Import fractions

- Import fractions used were taken from PARNOR 1.
- Mean import fraction for the considered food items are shown in Table 10.

Table 10. Best estimates for Norwegian conditions of import fractions of different dietary components.

Product	Import fraction (%)
Spring wheat, whole grain	33
Leafy vegetables	45
Fruit	94
Milk	0
beef (cow)	5
beef (bull)	5
Lamb	5

Animal feeding regimes

Standard feeding regimes were derived from PARDNOR 1 using the following conversion factors from dry weight to fresh weight:

- Grass silage (=hay): 0.22
- Grass: 0.20
- Barley/oats: 0.85

Results

Changing human diets:

- Increased intake of a specified food item by 10 %.
- Results given as percentage increase in annual dose to age groups:

Table 11. Results of examination of end-point sensitivity to systematic 10 % changes in the food item consumption parameters for Norwegian conditions. Figures are the percentage variation in the end-point caused by the input variation. Values are given for all four age groups covered by the activity.

Food item	Children	Teenagers	Adults	Seniors
Milk	5,5	4,1	4,9	4,6
Wheat	2,2	3,0	2,8	2,8
Beef	1,9	2,4	1,8	1,9
Fruits	0,2	0,1	0,2	0,3
Lamb	0,1	0,2	0,2	0,2
Leafy vegetables	0,1	0,1	0,1	0,2

Input of 393 kg/y milk lead to:

- 43% increase in annual dose for adults,
- 84% increase in annual dose for seniors

Changing feeding regimes

- Reduced roughage feeding regimes (i.e. 10 %).
- Results given as percentage increase in annual dose to various age groups**:**

Table 12. Results of examination of end-point sensitivity to systematic 10 % changes in the fodder item consumption parameters for Norwegian conditions. Figures are the percentage variation in the end-point caused by the input variation. Values are given for all four age groups covered by the activity.

	Children	Teenagers	Adults	Seniors
Lactating cow´s fodder	-5,3	-4,3	-4,9	-4,5
Beef cattle fodder	-0,9	-1,2	-0,9	-1,0
Lamb fodder	-0,2	-0,2	-0,2	-0,1

- Minimum roughage feeding regimes.
- Results given as percentage increase in annual dose to various age groups:

Table 13. Results of examination of end-point sensitivity to reduction to the minimal fodder item consumption parameters for Norwegian conditions. Figures are the percentage variation in the end-point caused by the input variation. Values are given for all four age groups covered by the activity.

	Children	Teenagers	Adults	Seniors
Lactating cow´s fodder	-19,9	-16,1	-18,2	-16,7
Beef cattle fodder	-5,5	-7,6	-5,8	-5,9
Lamb fodder	-0,6	-0,8	-0,6	-0,5

2.4. Ingestion dose sensitivity in Finland

Table 14. 'Best estimate' values of input parameters (dietary components and animal fodder composition) for examination of end-point sensitivity and uncertainty. Human dietary components are given for children, men, women and adults (kg/y), and animal feeding rates are in units of kg per day FW.

	Young children	Men	Women	Adults
Leafy vegetables	*8*	12.5	12.5	12.5
Milk	188	124.1	78.8	99.4
Beef, cow	*5*	8.4	5.5	6.8
Beef, bull				
Lamb	*0.4*	0.4	0.4	0.4
Wheat	*25*	29.2	21.5	25
Fruits	*70*	71.7	71.7	71.7
		Grass	Maize	Hay
Lactating cow's fodder		38		2
Beef cattle fodder		20		
Lamb fodder		7.5		0.1

Table 15 shows the influence on the end-point of varying each of these input parameters by 10 %.

Table 15. Results of examination of end-point sensitivity to systematic 10 % changes in a number of input parameters. Figures are the percentage variation in the end-point caused by the input variation.

	Adults, %
Change leafy veg. 10 %	0.24
Change milk 10 %	2.6
Change beef 10 %	1.0
Change lamb 10 %	-
Change wheat 10 %	0.70
Change fruits 10 %	0.08
Change lactating cow's fodder 10 %	2.9
Change beef cattle fodder 10 %	1.0
Change lamb fodder 10 %	-

Table 16. Estimated harvest periods and yields of various crops in Finland.

Crop	Harvest period	Yield (kg/m^2 FW)	Crop	Harvest period	Yield (kg/m^2 FW)
Spring barley	15-30 Aug.	0.35	Fodder beet	1-31 Oct.	4.0
Winter barley	-	-	Maize	-.	-
Spring wheat	15-30 Aug.	0.37	Fruit vegetables	15 Jul-30 Aug.	3.4
Winter wheat	1 Aug.-30 Aug.	0.42	Leafy vegetables	1 Jun-30 Sep.	2.3
Winter rye	15-30 Aug.	0.28	Potatoes	1 Sep-30 Sep.	2.1
Oats	20-30 Aug.	0.29	Fruit	1 Sep-1 Oct.	0.71
Root vegetables	1 Sep-15 Oct.	3.4	Berries	1 Jul-30 Aug	0.24

Barley is the cereal most widely grown in Finland. It is grown all over the country. Most of barley is feed barley (83%), malt barley (17%) is grown mainly in southern Finland. The growing period is 70-85 days. All the barley grown in Finland is spring barley.

The wheat grown in Finland is mainly spring wheat. The proposition of winter wheat is about 22%. Wheat is grown only in southern part of Finland, mainly in south-western Finland, where also winter wheat is grown. The growing period is 340 days for winter wheat, and 86-98 days for spring wheat.

Rye is grown mainly in southern Finland. All the rye grown in Finland is winter rye, which is usually sown during the last week of August. The growing period for rye is 340-350 days.

Oats is grown mostly in southern and central Finland, less in northern parts of the country. Oats is mainly grown for feed. Oats is sown in spring, and the growing period is 95-100 days.

References

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2.5. Ingestion dose sensitivity in the Faroes

There is very little information about dietary consumption, import fraction of consumed food and about the animal feeding regimes in the Faroe Islands. It is, therefore, only possible to do some very preliminary estimates of ingestion dose sensitivity in the Faroe Islands. The estimates are based on data used in previous contributions to the NKS activities EcoDoses and PardNor (Nielsen and Andersson, 2006 and 2007). The study includes only adults.

The default milk consumption is set to 142 kg/year (Vestergaard and Zachariassen, 1987). Most of the Faroese mutton is lamb meat, and the default lamb meat consumption is set to 24.8 kg/year in the model (Vestergaard and Zachariassen, 1987).

The sensitivity analysis is based on a 10% increase in consumption of cow milk and lamb meat, respectively. In addition, a study is made on a 10% increase in the feed intake of lamb.

The deposition scenario in all cases is only dry deposition of ^{137}Cs on 1 July, and the end-point of the study is one year later.

Table 17. Results of examination of end-point response due to 10% increase in selected parameters in the ECOSYS model.

Parameter	Milk consumption	Meat consumption	Lamb feeding
End point increase (%)	8.6	5.0	5.0

The results indicate that a 10% increase in the selected parameters may have a considerable influence on the dose to adults one year after the deposition.

References

Sven P. Nielsen and Kasper G. Andersson (Ed.): PardNor; PARameters for ingestion Dose models for NORdic areas. Final report for the NKS-B activity 2007.

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Trygvi Vestergaard and Petur Zachariassen: Føðslukanning 1981-82 (Nutritional Investigation 1981-82). Annales Societatis Scientiarum Færoensis (Fróðskaparrit) 33, 1987.

2.6. Ingestion dose sensitivity in Iceland

There is information available from dietary studies in Iceland as has been reported in previous PardNor report (Nielsen and Andersson, 2007). Much of the data is however not in a format directly compatible for input to the ECOSYS system. For a preliminary study, some additional assumptions had thus to be made. The main effect of a variation of the assumed food intake by adults (the age category most compatible with the Icelandic data) was seen for milk, where an increase of intake by 10% resulted in a 2.2% variation in the resulting 1 year dose. This is slightly higher than quoted for Denmark and Sweden in this report, but less than the values given for Finland, Norway and the Faroe Islands.

Even though this was only based on a preliminary study, it is clear as for the other Nordic regions, that the assumptions used in ECOSYS should be tailored better for local condition. Knowledge on these assumptions is essential, both for improving the predictions and for understanding their limitations.

Reference

Sven P. Nielsen and Kasper G. Andersson (Ed.): PardNor; PARameters for ingestion Dose models for NORdic areas. Final report for the NKS-B activity 2007.

3. Estimation of seasonal leaf area index (LAI) development in different Nordic regions

The leaf area index is the factor in ECOSYS which determines the state of growth of all vegetation. As demonstrated in the NKS-ECODOSES activity, it has great bearing on the deposition (dry and wet) to crops, and thus also great influence on ingestion dose in general. Since LAI depends strongly on the climate (soil temperature variation), it is essential to identify LAI data that adequately represent the location to be modelled. For instance, the Danish Institute of Agricultural Sciences has, based on large amounts of measurement data, developed a simple empirical model / data set describing the seasonal variation of LAI for a number of different crops (Plauborg & Olesen, 1991; Olesen, 2006). The key variables are here the sowing time, soil temperature and harvest time. Values are given for normal and low fertilisation status. The model can thus be applied for different climates, and should be applicable also for other Nordic conditions, where the variation over the year in soil temperature is known. An example of a temperature sum and LAI data set is given below for spring barley, with normal fertilisation level. TSum represents a summation over days multiplied by the average daily values of temperature (degree days). Based on the time-variation of TSum at a given location, a date can be associated to each (generic) TSum in the table below.

		TSum	LAI-total
Spring barley	Before sowing	0	0
		110	0
		210	0.41
		310	1.16
		410	2.53
		509	5
		750	5
		880	5
		900	5
		1180	5
		1590	2
	After harvest	0	0.3

3.1. LAI data for Denmark

To test the general validity of the Danish data for description of LAI development in Nordic areas, an annual soil temperature variation dataset was obtained from the Swedish University of Agricultural Sciences in Uppsala (SLU, 2008; Kyllmar & Johnsson, 2006). Compared with a Danish data set for the location Herfølge, the Swedish temperatures are over the entire year some 1-5 °C lower (as shown in Fig. 1). The results of applying the soil temperature data from Uppsala in the Danish model for barley can be compared with measured values of LAI for barley in Uppsala, at two different times of the year: the 18th of June and the 13th of July, 1995 (Thorgeirsson & Søgaard, 1999). Fig, 2 shows the development of LAI over a season, modelled on the background of the Danish dataset and the soil temperature data reported for Uppsala, assuming respectively normal and low fertilisation status. As can be seen, the model curves are in good agreement with the measured LAI data for the Uppsala location (denoted by the triangles in Fig.2), indicating that the Danish model dataset may also be applied for other localities with (slightly) different climates. However, it should be noted that in the northernmost areas of the Nordic countries, crop sort varieties are sometimes specially selected to give rapid development, to make the most of the short growing season. The sowing time in Uppsala was, as in the Danish studies, assumed to be the date where the soil temperature reaches about 8 °C (Farsø Markservice, 2006; Kaarde, 2006; Dansk Landbrugsrådgivning, 2008). This occurs about one month later in Uppsala than in Denmark/Herfølge.

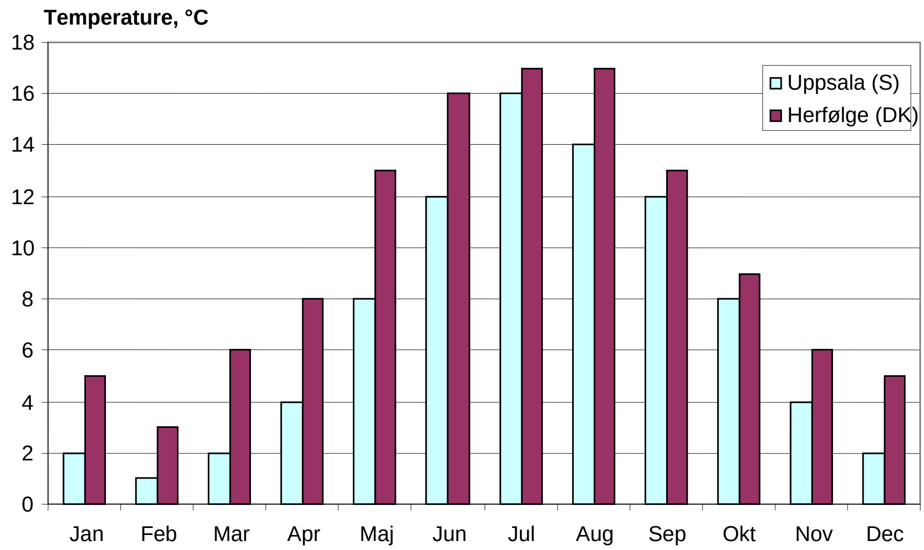

Fig.1. Monthly average soil temperature at 10 cm depth in Uppsala (S) and Herfølge (DK). Data for both locations recorded in 2005.

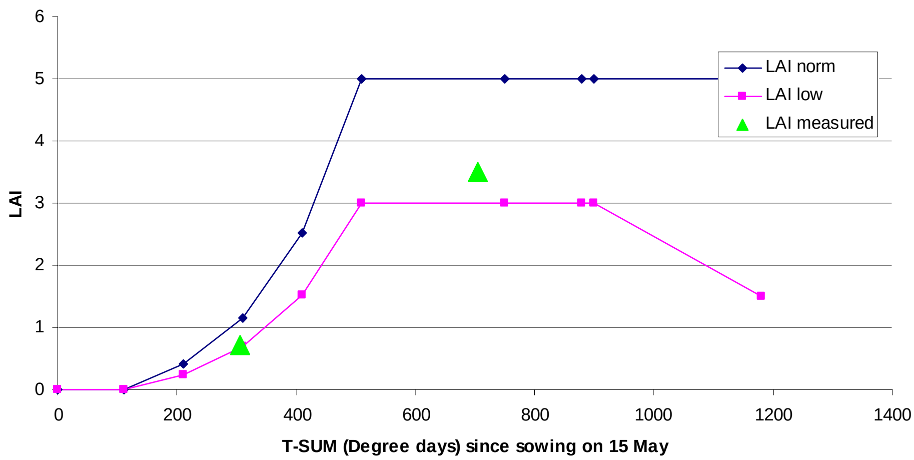

Fig.2. Seasonal variation in LAI for barley at Uppsala (S). Model curves compared with two measured data points.

For Danish localities, soil temperature data measured at 10 cm depth is available from Aarhus University's database (2008). Fig. 3 shows a series of examples of the data that is available from Aarhus University. According to data from the Royal Veterinary and Agricultural University of Denmark (2006), practically the only difference between soil temperature curves for 0 cm and 20 cm depth is a small ripple variation in the uppermost soil layers, which reflects a somewhat greater sensitivity to phenomena at the surface. The three top curves in Fig.3 show the soil temperature variation in 2007 in 3 different localities distributed over the country: one in Jutland, one in Zealand, and one in Bornholm. As can be seen, the differences between soil temperatures in different parts of Denmark are insignificant. The bottom curve shows the temperature variation for the same Bornholm location for 2003. This is to demonstrate that differences in soil temperature between different years are also minor.

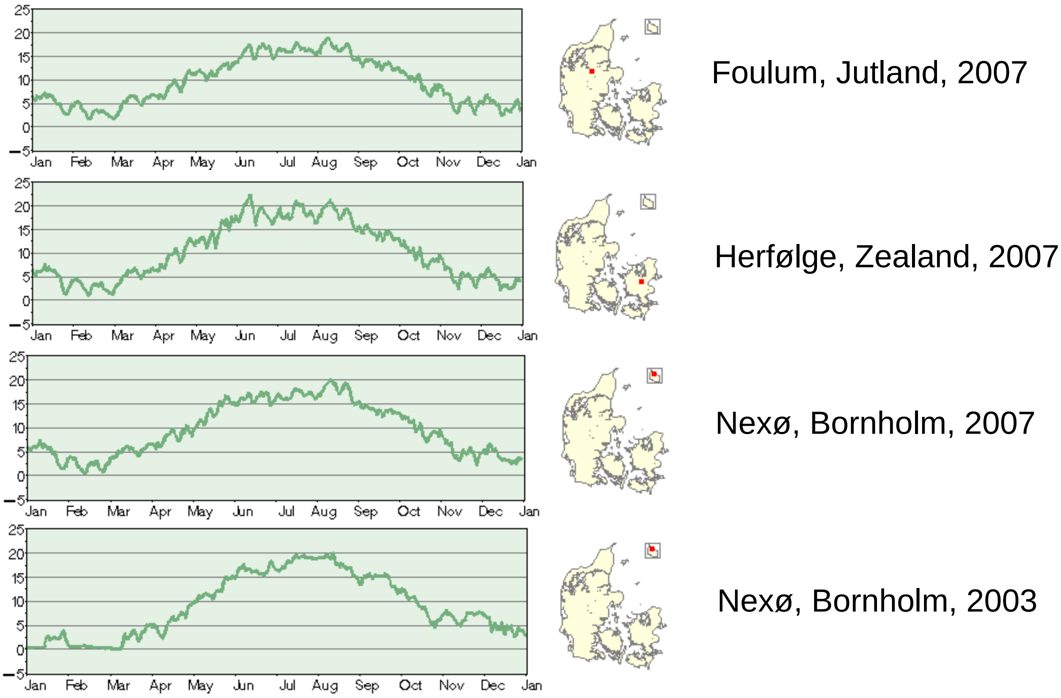

Fig. 3. Soil temperature variation (10 cm depth) at different Danish localities. Data for Nexø shown both for 2003 and 2007.

On this basis, the average temperature dependence shown in Fig. 4 was applied in the calculations of LAI in Denmark, with interpolation.

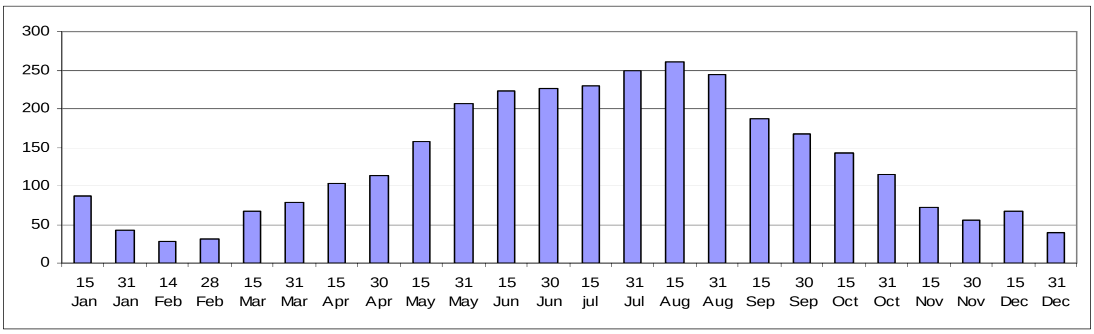

Fig. 4. Applied data for Danish soil temperature variation. Temperature sum shown for each half month.

Tables 18-20 show the results of the implementation of this Danish temperature variation in the LAI model. Table 18 shows the seasonal development of LAI of grain crops, whereas Table 19 shows the corresponding LAI values for vegetables and grass, and Table 20 shows the LAI values for fruit and berries.

Table 18. Estimated seasonal development in Denmark of LAI for barley, wheat, rye and oats, based on the Danish LAI development data and representative values of soil temperatures.

Spring barley			**Winter barley**			**Spring wheat**		
	Normal fertlisation	Low fertilisation		Normal fertlisation	Low fertilisation		Normal fertlisation	Low fertilisation
10-apr	0	0	15-sep	0	0	10-apr	0	0
25-apr	0	0	25-sep	0	0	25-apr	0	0
06-maj	0.41	0.25	16-okt	0.5	0.5	06-maj	0.3	0.2
15-maj	1.16	0.7	01-mar	0.5	0.5	15-maj	0.8	0.5
23-maj	2.53	1.52	31-mar	0.5	0.5	23-maj	1.6	1
31-maj	5	3	15-apr	1.6	1	31-maj	2.9	1.7
23-jun	5	3	28-apr	5	3	07-jun	5	3
15-jul	5		29-maj	5	3	05-jul	5	3
03-aug		1.5	09-jun		3	08-jul		3
08-aug	2		15-jun	5		16-jul	5	
After harvest	0.3	0.2	08-jul		1.5	09-aug		1.5
			10-jul	2		11-aug	2	
			After harvest	0.3	0.2	After harvest	0.3	0.2
Winter wheat			**Winter rye**			**Oats**		
	Normal fertlisation	Low fertilisation		Normal fertlisation	Low fertilisation		Normal fertlisation	Low fertilisation
15-sep	0	0	15-sep	0	0	10-apr	0	0
25-sep	0	0	25-sep	0	0	25-apr	0	0
16-okt	0.5	0.5	16-okt	0.5	0.5	06-maj	0.41	0.25
31-mar	0.5	0.5	01-mar	0.5	0.5	15-maj	1.16	0.7
15-apr	1	0.7	31-mar	0.5	0.5	23-maj	2.53	1.52
29-apr	2.2	1.5	15-apr	1.6	1	31-maj	5	3
09-maj	5		28-apr	5	3	16-jun	5	3
14-maj		3	13-jun	5	3	23-jun	5	3
18-jun		3	18-jul	5	3	24-jun	5	3
18-jul	5		10-aug		1.5	18-jul	5	
10-aug		1.5	12-aug	2		06-aug		1.5
14-aug	2		After harvest	0.3	0.2	09-aug	2	
After harvest	0.3	0.2				After harvest	0.3	0.2

For winter crops it is generally assumed that the sowing takes place around the 15th of September, whereas it is for spring crops assumed that sowing takes place around the 10th of April (it is at about this time that the ground in Denmark facilitates it). Intensively grown grass is modelled on the basis of the values for 'grass for harvest', whereas extensively grown grass is modelled using the values for 'ungrazed pasture', from the LAI base of Olesen (2006). In reality, both fruit vegetables and root vegetables may be many different types of crops, but the modelling has here been done from the available data in the LAI base for respectively carrot and pea. For leafy vegetables, fruit and berries, data were not available from the LAI base, and the data was sought elsewhere. The data applied for these crops was mainly derived from the database of Aarhus University (2008) and Dansk Landbrugsrådgivning (2008), and partially from Danmarks Statistik (1999).

Table 19. Estimated seasonal development in Denmark of LAI for root vegetables (carrots), fodder beets, maize, fruit vegetables (peas), leafy vegetables, potatoes, and intensively and extensively grown grass, based on the Danish LAI development data and representative values of soil temperatures.

Root vegetab. (carrot)

	Normal fertlis.	Low fertilis.
10-apr	0	0
06-maj	0	0
23-maj	0.02	0.02
30-maj	0.1	0.1
07-jun	0.25	0.25
13-jun	0.5	0.5
21-jun	1.2	1.1
05-jul	2	1.7
30-jul	5	3
After harvest	0	0

Fodder beet

	Normal fertlis.	Low fertilis.
10-apr	0	0
05-maj	0	0
13-maj	0.3	0.1
22-maj	0.8	0.5
31-maj	1.6	1
06-jun	2.9	1.7
11-jun	5	3
12-jul	5	3
After harvest	0	0

Maize

	Normal fertlis.	Low fertilis.
10-apr	0	0
05-maj	0	0
07-jun	0.5	0.4
12-jun	0.9	0.6
19-jun	1.8	1.1
29-jun	5	3
16-jul	5	3
15-aug		3
21-aug	5	
29-okt		1.5
01-nov	3	
After harvest	0.2	0.2

Fruit v. (peas)

	Normal fertilis.
10-apr	0
30-apr	0
23-maj	0.2
30-maj	1.1
07-jun	3.9
09-jun	5
24-jun	5
31-jul	2.5
15-sep	0.2
31-dec	0
After harvest	0

Leafy vegetab.*

	Normal fertlis.	Low fertilis.
10-apr	0	0
01-maj	1	0.3
01-jun	5	3
15-sep	4	2
31-okt	2.5	1.5
15-nov	0	0
After harvest	0	0

Potatoes

	Normal fertlis.	Low fertilis.
10-apr	0	0
14-maj	0	0
21-maj	0.6	0.5
30-maj	1	0.7
07-jun	1.5	1
14-jun	2.2	1.4
22-maj	3.3	2.1
28-maj	5	3
18-jul		3
31-jul		0.5
10-aug	5	
28-aug	1	
After harvest	0	0

Grass, intens.

	Normal fertlis.	Low fertilis.
01-jan	1	1
01-mar	1	1
31-mar	1	1
07-apr	1.2	1.1
22-apr	2	1.6
10-maj	3.7	2.4
13-maj	5	4
25-maj	5	4
30-sep	5	4
15-okt	1	1
31-dec	1	1
After harvest	1	1

Grass, extens.

	Normal fertlis.
01-jan	3
01-mar	2
31-mar	2
23-apr	3
05-maj	4
14-maj	5
19-jun	5
30-sep	5
15-okt	1
31-dec	1
After harvest	1

* Leaf vegetables not covered by the LAI model, but estimated from data from Aarhus University,

Table 20. Estimated seasonal LAI development in Denmark of fruits and berries.

Fruit		Berries	
	Normal fertlisation		Normal fertlisation
01-maj	0	01-apr	0
15-maj	0.5	10-apr	1
01-jun	4	01-maj	3
15-jul	5	20-jun	5
01-okt	4	15-aug	5
31-okt	0	15-sep	0

In the above Table 20, particularly important fruits are for Denmark assumed to be apples, pears and plums, whereas the most important berries are strawberries, cherries, blackcurrants, and redcurrants (Dansk Landbrugsrådgivning, 2008).

Also needed for ECOSYS runs is information on the harvest periods and yields of harvested crops. These are taken from Aarhus University (2008), Dansk Landbrugsrådgivning (2008), and Danmarks Statistik (1999 and 2007), and the data are shown in Table 21.

Table 21. Estimated harvest periods and yields of various crops in Denmark.

Crop	Harvest period	Yield (kg/m^2 FW)	Crop	Harvest period	Yield (kg/m^2 FW)
Spring barley	15-30 Aug.	0.50	Fodder beet	1-31 Oct.	6.6
Winter barley	30 Jul-15 Aug.	0.58	Maize	1-30 Sep.	3.9
Spring wheat	15-30 Aug.	0.53	Fruit vegetables	1 Jul-15 Aug.	1.5
Winter wheat	30 Jul-15 Aug.	0.73	Leafy vegetables	1 Jun-31 Oct.	2.0
Winter rye	15-30 Aug.	0.51	Potatoes	15 Sep-15 Oct.	4.1
Oats	20-30 Aug.	0.51	Fruit	15 Sep-15 Oct.	2.5
Root vegetables	1-31 Oct.	5.0	Berries	20 Jun-15 Aug	1.2

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3.2. LAI data for Sweden

Temperature sums are estimated for three sites in Sweden: Kulbäcksliden, Ultuna and Lanna (Figure 5). Kulbäcksliden is situated in the northern region of Sweden and belongs to the production area "Nedre Norrland" (NN); Ultuna belongs to the production area "Svealands slättbygder" (SS); Lanna is situated in the production area "Götalands södra slättbygder" (GSS).

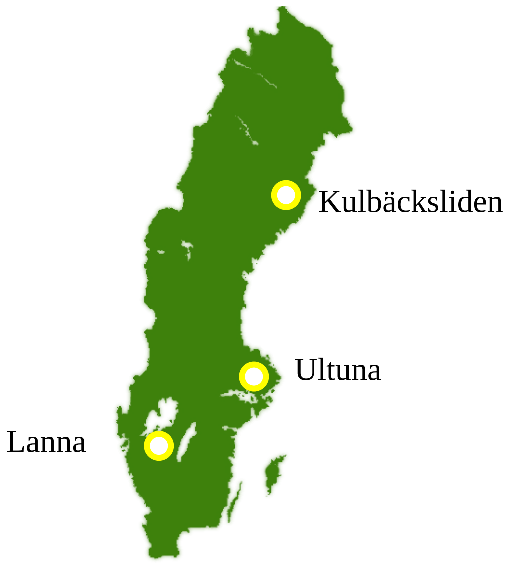

Fig.5. Location of the three sites, which are representing three production areas in Sweden.

Temperature sums for Ultuna and Lanna was calculated for the year 2005, based on monthly measurements of soil temperatures at 20 cm depth (Kyllmar & Johnsson, 2006; Kyllmar & Grill, 2007). Data for calculation of the temperature sum at Kulbäcksliden was taken from Ottosson Löfvenius (2007) by estimating monthly averages from a curve showing daily measurements at 20 cm depth in the year 2006.

Estimating LAI from tables relating temperature sums to LAI for different crops

The cumulative temperature sums were estimated as described above and are shown in Figure 6. The monthly data points were then used to fit the parameters A_1, A_2, x_0 and dx in the expression

$$\frac{A_1 - A_2}{\left(1 + e^{(x-x_0)/dx}\right) + A_2}$$

for each of the three sites. The variable x is the Julian day.

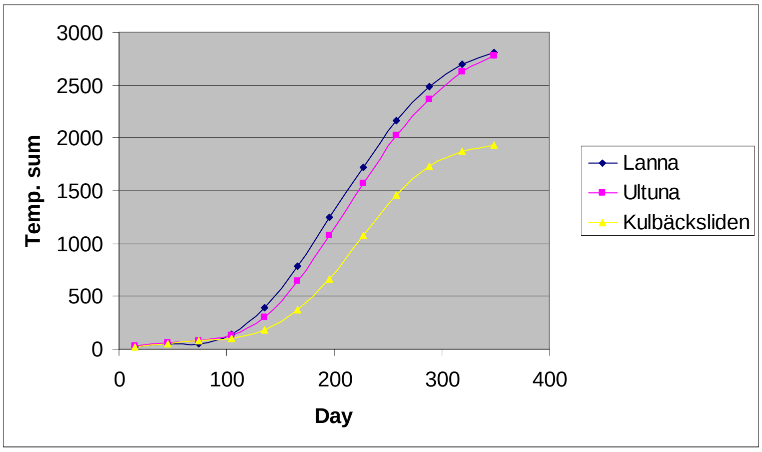

Figure 6. Cumulative temperature sums.

Then, in order to determine at which day a given temperature sum is reached, the inverse of the above expression was used. The expression above should not be interpreted as a physical model of the cumulative temperature sum but is used only to facilitate interpolation.

Dates for seeding and harvest

Data was taken from two sources: “Livsmedelsproduktion vid nedfall av radioaktiva ämnen” from the Swedish Board of Agriculture (SJV) and Berglund *et al.*, (2002). For some crops it was not possible to find any data on seeding and harvest and these table entries are marked “No data”. The date entered at “After harvest” is the day after the harvest day given in the references. That is, if the mean harvest date is 18 sept the date 19 sept is given in the table. For some crops the specified temperature sum is reached after the day of harvest. Especially in the production area NN the number of different crops is restricted and a crop not produced is marked by “NA” in the tables.

Table 22. Estimated seasonal development for the production area GSS in Sweden of LAI for some crops, based on the Danish LAI development data and representative values of soil temperatures.

		Normal fertilisation level			Low fertilisation level		
		Date	TSum	LAI-total	Date	TSum	LAI-total
Spring barley	From sowing	14-apr	0	0	14-apr	0	0
			110	0		110	0
		15-maj	210	0,41	15-maj	210	0,25
		25-maj	310	1,16	25-maj	310	0,7
		3-jun	410	2,53	3-jun	410	1,52
		11-jun	509	5	19-jun	609	3
			750	5		720	3
			880	5		830	3
			900	5		850	3
			1180	5	13-aug	1500	1,5
		18-aug	1590	2			
	After harvest	19-aug	0	0,3	19-aug	0	0,2
Winter wheat	From sowing	20-sep	0	0	20-sep	0	0
			110	0		110	0
		7-nov	400	0,5	7-nov	400	0,5
	From 1st of March	1-mar	0	0,5	1-mar	0	0,5
			142	0,5		142	0,5
		30-apr	242	1	30-apr	242	0,7
		13-maj	342	2,2	13-maj	342	1,5
		24-maj	445	5	29-maj	505	3
			800	5		800	3
			1449	5		1000	3
		25-aug	1848	2	22-aug	1800	1,5
	After harvest	28-aug	0	0,3	28-aug	0	0,2
Grass for harvest	From 1st of January	1-jan	0	1	1-jan	0	1
	From 1st of March	1-mar	0	1	1-mar	0	1
			142	1		142	1
		23-apr	200	1,2	23-apr	200	1,1
		7-maj	300	2	7-maj	300	1,6
		19-maj	400	3,7	19-maj	400	2,4
		23-maj	442	5	29-maj	500	4
			650	5		700	4
	After harvest	11-jun	0	0,5	11-jun	0	0,5
			40	0,5		40	0,5
		18-jun	100	0,8	18-jun	100	0,7
		25-jun	200	1,7	25-jun	200	1,2
		1-jul	300	3,7	1-jul	300	2,1
		4-jul	340	5	7-jul	400	4
			650	5		700	4
Clover grass	From 1st of January	1-jan	0	1			
for harvest	From 1st of March	1-mar	0	1			
			142	1			
		23-apr	200	1,2			
		7-maj	300	2			
		19-maj	400	3,7			
		23-maj	442	5			
			650	5			
	After harvest	11-jun	0	0,5			
			40	0,5			
		18-jun	100	0,8			
		25-jun	200	1,7			
		1-jul	300	3,7			
		4-jul	340	5			
			650	5			

Grass for continuous grazing	From 1st of January	1-jan	0	1				
	From 1st of March	1-mar	0	1				
			142	1				
		23-apr	200	1,2				
		7-maj	300	2				
		15-maj	365	3				
Ryegrass sown the year before	From 1st of January		0	1				
	From 1st of March		0	1				
			142	1				
			200	1,2				
No data			300	2				
			400	3,7				
			442	5				
			820	5				
			1100	5				
			1400	5				
			1800	4				
	After harvest		0	0,5				
Peas	From sowing	16-apr	0	0				
			150	0				
		3-jun	400	0,2				
		11-jun	500	1,1				
		19-jun	600	3,9				
		20-jun	621	5				
			870	5				
		9-aug	1431	2,5				
	After harvest	16-aug	0	0,2				
Spring rape	From sowing	16-apr	0	0	16-apr	0	0	
			140	0		140	0	
		19-maj	240	0,4	19-maj	240	0,2	
		29-maj	340	1,2	29-maj	340	0,6	
		6-jun	440	2,6	6-jun	440	1,3	
		14-jun	533	5	17-jun	570	3	
			850	5		850	3	
			1495	5		1200	3	
		27-aug	1725	2	23-aug	1650	1,5	
	After harvest	5-sep	0	0,1	5-sep	0	0,1	
Winter rape	From sowing	19-aug	0	0	19-aug	0	0	
			140	0		140	0	
		4-sep	240	0,4	4-sep	240	0,2	
		11-sep	340	1,2	11-sep	340	0,6	
		25-sep	500	3	25-sep	500	2	
		30-okt	800	4	30-okt	800	2,5	
	From 1st of March	1-mar	0	2	1-mar	0	1,5	
			142	2		142	1,5	
		30-apr	242	2,8	30-apr	242	1,8	
		11-maj	332	5	14-maj	352	3	
		10-jun	650	5	10-jun	650	3	
			1179	5		950	3	
		25-aug	1848	2	13-aug	1650	1,5	
	After harvest	13-aug	0	0,1	13-aug	0	0,1	
Carrot	From sowing		0	0		0	0	
			300	0		300	0	
No data			400	0,02		400	0,02	
			500	0,1		500	0,1	
			600	0,25		600	0,25	
			700	0,5		700	0,5	
			800	1,2		800	1,1	

			1000	2		1000	1,7
			1400	5		1400	3
	After harvest		0	0		0	0
Winter rye	From sowing	18-sep	0	0	18-sep	0	0
			110	0		110	0
		3-nov	400	0,5	3-nov	400	0,5
	From 1st of March		0	0,5		0	0,5
			142	0,5		142	0,5
		30-apr	242	1,6	30-apr	242	1
		11-maj	332	5	14-maj	352	3
			900	5		900	3
			1443	5		1000	3
		24-aug	1828	2	22-aug	1800	1,5
	After harvest	13-aug	0	0,3	13-aug	0	0,2
Triticale	From sowing	18-sep	0	0	18-sep	0	0
			110	0		110	0
		3-nov	400	0,5	3-nov	400	0,5
	From 1st of March		0	0,5		0	0,5
			142	0,5		142	0,5
		30-apr	242	1,2	30-apr	242	0,9
		13-maj	342	3,2	14-maj	352	1,7
		18-maj	392	5	20-maj	410	3
			900	5		900	3
			1443	5		1000	3
		24-aug	1828	2	22-aug	1800	1,5
	After harvest	20-aug	0	0,3	20-aug	0	0,2
Winter barley	From sowing	17-sep	0	0	17-sep	0	0
			110	0		110	0
		31-okt	400	0,5	31-okt	400	0,5
	From 1st of March		0	0,5		0	0,5
			142	0,5		142	0,5
		30-apr	242	1,6	30-apr	242	1
		11-maj	332	5	14-maj	352	3
			700	5		700	3
			953	5		850	3
		25-jul	1333	2	23-jul	1300	1,5
	After harvest	26-jul	0	0,3	26-jul	0	0,2
Spring wheat	From sowing	14-apr	0	0	14-apr	0	0
			110	0		110	0
		15-maj	210	0,3	15-maj	210	0,2
		25-maj	310	0,8	25-maj	310	0,5
		3-jun	410	1,6	3-jun	410	1
		11-jun	510	2,9	11-jun	510	1,7
		19-jun	610	5	19-jun	610	3
			1000	5		1000	3
			1200	5		1050	3
		22-aug	1650	2	19-aug	1600	1,5
	After harvest	5-sep	0	0,3	5-sep	0	0,2
Lupin	From sowing		0	0			
			150	0			
No data			300	0,2			
			400	1			
			500	2,5			
			600	5			
			870	5			
			1400	5			
			1850	2			
	After harvest		0	0,2			

Fodder beats (Sugar beet)	From sowing	28-apr	0	0	28-apr	0	0
			200	0		200	0
		30-maj	280	0,3	30-maj	280	0,1
		9-jun	400	0,8	9-jun	400	0,5
		17-jun	500	1,6	17-jun	500	1
		24-jun	600	2,9	24-jun	600	1,7
		30-jun	700	5	30-jun	700	3
			1100	5		1000	3
	After harvest	12-okt	0	0	12-okt	0	0
Maize	From sowing		0	0		0	0
			200	0		200	0
No data			620	0,5		620	0,4
			700	0,9		700	0,6
			800	1,8		800	1,1
			940	5		940	3
			1200	5		1200	3
			1808	5		1700	3
			2572	3		2500	1,5
	After harvest		0	0,2		0	0,2
Ungrazed pasture	From 1st of January	1-jan	0	3			
		10-apr	200	2			
	From 1st of March		0	2			
			150	2			
		7-maj	300	3			
		19-maj	400	4			
		29-maj	500	5			
		5-jul	1000	5			
Potatoes, for eating	From seeding	3-maj	0	0	3-maj	0	0
			300	0		300	0
		12-jun	400	0,6	12-jun	400	0,5
		19-jun	500	1	19-jun	500	0,7
		26-jun	600	1,5	26-jun	600	1
		3-jul	700	2,2	3-jul	700	1,4
		9-jul	800	3,3	9-jul	800	2,1
		15-jul	900	5	15-jul	900	3
			1600	5		1250	3
		17-sep	1900	1	17-aug	1450	0,5
	After harvest	21-sep	0	0	21-sep	0	0
Potatoes, industrial	From seeding	3-maj	0	0			
			300	0			
		12-jun	400	0,6			
		19-jun	500	1			
		26-jun	600	1,5			
		3-jul	700	2,2			
		9-jul	800	3,3			
		15-jul	900	5			
			1650	5			
		30-sep	2050	1			
	After harvest	3-okt	0	0			
Oats	From sowing	21-apr	0	0	21-apr	0	0
			110	0		110	0
		19-maj	210	0,41	19-maj	210	0,25
		29-maj	310	1,16	29-maj	310	0,7
		6-jun	410	2,53	6-jun	410	1,52
		14-jun	509	5	21-jun	609	3
			750	5		720	3
			880	5		830	3
			900	5		900	3
			1250	5	18-aug	1550	1,5
		21-aug	1600	2			

	After harvest	30-aug	0	0,3	30-aug	0	0,2

Table 23. Estimated seasonal development for the production area SS in Sweden of LAI for some crops, based on the Danish LAI development data and representative values of soil temperatures.

		Normal fertilisation level			Low fertilisation level		
		Date	TSum	LAI-total	Date	TSum	LAI-total
Spring barley	From sowing	7-maj	0	0	7-maj	0	0
			110	0		110	0
		2-jun	210	0,41	2-jun	210	0,25
		12-jun	310	1,16	12-jun	310	0,7
		20-jun	410	2,53	20-jun	410	1,52
		28-jun	509	5	5-jul	609	3
			750	5		720	3
			880	5		830	3
			900	5		850	3
			1180	5	29-aug	1500	1,5
		4-sep	1590	2			
	After harvest	5-sep	0	0,3	5-sep	0	0,2
Winter wheat	From sowing	15-sep	0	0	15-sep	0	0
			110	0		110	0
		20-okt	400	0,5	20-okt	400	0,5
	From 1st of March	1-mar	0	0,5	1-mar	0	0,5
			142	0,5		142	0,5
		8-maj	242	1	8-maj	242	0,7
		22-maj	342	2,2	22-maj	342	1,5
		3-jun	445	5	8-jun	505	3
			800	5		800	3
			1449	5		1000	3
		5-sep	1848	2	2-sep	1800	1,5
	After harvest	30-aug	0	0,3	30-aug	0	0,2
Grass for harvest	From 1st of January	1-jan	0	1	1-jan	0	1
	From 1st of March	1-mar	0	1	1-mar	0	1
			142	1		142	1
		2-maj	200	1,2	2-maj	200	1,1
		17-maj	300	2	17-maj	300	1,6
		29-maj	400	3,7	29-maj	400	2,4
		2-jun	442	5	8-jun	500	4
			650	5		700	4
	After harvest	25-jun	0	0,5	25-jun	0	0,5
			40	0,5		40	0,5
		1-jul	100	0,8	1-jul	100	0,7
		8-jul	200	1,7	8-jul	200	1,2
		15-jul	300	3,7	15-jul	300	2,1
		17-jul	340	5	21-jul	400	4
			650	5		700	4
Clover grass for harvest	From 1st of January	1-jan	0	1			
	From 1st of March	1-mar	0	1			
			142	1			
		2-maj	200	1,2			
		17-maj	300	2			
		29-maj	400	3,7			
		2-jun	442	5			
			650	5			
	After harvest	25-jun	0	0,5			

			40	0,5			
		1-jul	100	0,8			
		8-jul	200	1,7			
		15-jul	300	3,7			
		17-jul	340	5			
			650	5			
Grass for continuous grazing	From 1st of January	1-jan	0	1			
	From 1st of March	1-mar	0	1			
			142	1			
		2-maj	200	1,2			
		17-maj	300	2			
		25-maj	365	3			
Ryegrass sown the year before	From 1st of January		0	1			
	From 1st of March		0	1			
			142	1			
			200	1,2			
No data			300	2			
			400	3,7			
			442	5			
			820	5			
			1100	5			
			1400	5			
			1800	4			
	After harvest		0	0,5			
Peas	From sowing	4-maj	0	0			
			150	0			
		18-jun	400	0,2			
		26-jun	500	1,1			
		3-jul	600	3,9			
		5-jul	621	5			
			870	5			
		24-aug	1431	2,5			
	After harvest	3-sep	0	0,2			
Spring rape	From sowing	4-maj	0	0	4-maj	0	0
			140	0		140	0
		4-jun	240	0,4	4-jun	240	0,2
		13-jun	340	1,2	13-jun	340	0,6
		21-jun	440	2,6	21-jun	440	1,3
		28-jun	533	5	1-jul	570	3
			850	5		850	3
			1495	5		1200	3
		12-sep	1725	2	6-sep	1650	1,5
	After harvest	23-sep	0	0,1	23-sep	0	0,1
Winter rape	From sowing	11-aug	0	0	11-aug	0	0
			140	0		140	0
		25-aug	240	0,4	25-aug	240	0,2
		1-sep	340	1,2	1-sep	340	0,6
		11-sep	500	3	11-sep	500	2
		5-okt	800	4	5-okt	800	2,5
	From 1st of March	1-mar	0	2	1-mar	0	1,5
			142	2		142	1,5
		8-maj	242	2,8	8-maj	242	1,8
		21-maj	332	5	23-maj	352	3
		21-jun	650	5	21-jun	650	3
			1179	5		950	3
		5-sep	1848	2	24-aug	1650	1,5
	After harvest	15-aug	0	0,1	15-aug	0	0,1
Carrot	From sowing		0	0		0	0

			300	0		300	0
No data			400	0,02		400	0,02
			500	0,1		500	0,1
			600	0,25		600	0,25
			700	0,5		700	0,5
			800	1,2		800	1,1
			1000	2		1000	1,7
			1400	5		1400	3
	After harvest		0	0		0	0
Winter rye	From sowing	5-sep	0	0	5-sep	0	0
			110	0		110	0
		5-okt	400	0,5	5-okt	400	0,5
	From 1st of March		0	0,5		0	0,5
			142	0,5		142	0,5
		8-maj	242	1,6	8-maj	242	1
		21-maj	332	5	23-maj	352	3
			900	5		900	3
			1443	5		1000	3
		4-sep	1828	2	2-sep	1800	1,5
	After harvest	15-aug	0	0,3	15-aug	0	0,2
Triticale	From sowing	5-sep	0	0	5-sep	0	0
			110	0		110	0
		5-okt	400	0,5	5-okt	400	0,5
	From 1st of March		0	0,5		0	0,5
			142	0,5		142	0,5
		8-maj	242	1,2	8-maj	242	0,9
		22-maj	342	3,2	23-maj	352	1,7
		28-maj	392	5	30-maj	410	3
			900	5		900	3
			1443	5		1000	3
		4-sep	1828	2	2-sep	1800	1,5
	After harvest	22-aug	0	0,3	22-aug	0	0,2
Winter barley	From sowing	12-sep	0	0	12-sep	0	0
			110	0		110	0
		15-okt	400	0,5	15-okt	400	0,5
	From 1st of March		0	0,5		0	0,5
			142	0,5		142	0,5
		8-maj	242	1,6	8-maj	242	1
		21-maj	332	5	23-maj	352	3
			700	5		700	3
			953	5		850	3
		5-aug	1333	2	3-aug	1300	1,5
	After harvest	29-jul	0	0,3	29-jul	0	0,2
Spring wheat	From sowing	7-maj	0	0	7-maj	0	0
			110	0		110	0
		2-jun	210	0,3	2-jun	210	0,2
		12-jun	310	0,8	12-jun	310	0,5
		20-jun	410	1,6	20-jun	410	1
		28-jun	510	2,9	28-jun	510	1,7
		5-jul	610	5	5-jul	610	3
			1000	5		1000	3
			1200	5		1050	3
		8-sep	1650	2	4-sep	1600	1,5
	After harvest	13-sep	0	0,3	13-sep	0	0,2
Lupin	From sowing		0	0			
			150	0			
No data			300	0,2			
			400	1			
			500	2,5			
			600	5			

			870	5			
			1400	5			
			1850	2			
	After harvest		0	0,2			
Fodder beats (Sugar beet)	From sowing	NA	0	0	NA	0	0
			200	0		200	0
			280	0,3		280	0,1
			400	0,8		400	0,5
			500	1,6		500	1
			600	2,9		600	1,7
			700	5		700	3
			1100	5		1000	3
	After harvest		0	0		0	0
Maize	From sowing		0	0		0	0
			200	0		200	0
No data			620	0,5		620	0,4
			700	0,9		700	0,6
			800	1,8		800	1,1
			940	5		940	3
			1200	5		1200	3
			1808	5		1700	3
			2572	3		2500	1,5
	After harvest		0	0,2		0	0,2
Ungrazed pasture	From 1st of January	1-jan	0	3			
		21-apr	200	2			
	From 1st of March		0	2			
			150	2			
		17-maj	300	3			
		29-maj	400	4			
		8-jun	500	5			
		16-jul	1000	5			
Potatoes, for eating	From seeding	20-maj	0	0	20-maj	0	0
			300	0		300	0
		27-jun	400	0,6	27-jun	400	0,5
		4-jul	500	1	4-jul	500	0,7
		11-jul	600	1,5	11-jul	600	1
		17-jul	700	2,2	17-jul	700	1,4
		23-jul	800	3,3	23-jul	800	2,1
		29-jul	900	5	29-jul	900	3
			1600	5		1250	3
		4-okt	1900	1	1-sep	1450	0,5
	After harvest	18-sep	0	0	18-sep	0	0
Potatoes, industrial	From seeding	20-maj	0	0			
			300	0			
		27-jun	400	0,6			
		4-jul	500	1			
		11-jul	600	1,5			
		17-jul	700	2,2			
		23-jul	800	3,3			
		29-jul	900	5			
			1650	5			
		18-okt	2050	1			
	After harvest	30-sep	0	0			
Oats	From sowing	8-maj	0	0	8-maj	0	0
			110	0		110	0
		3-jun	210	0,41	3-jun	210	0,25
		12-jun	310	1,16	12-jun	310	0,7
		21-jun	410	2,53	21-jun	410	1,52

		28-jun	509	5	6-jul	609	3
			750	5		720	3
			880	5		830	3
			900	5		900	3
			1250	5	2-sep	1550	1,5
		5-sep	1600	2			
	After harvest	5-sep	0	0,3	5-sep	0	0,2

Table 24. Estimated seasonal development for the production area NN in Sweden of LAI for some crops, based on the Danish LAI development data and representative values of soil temperatures.

		Normal fertilisation level			Low fertilisation level		
		Date	TSum	LAI-total	Date	TSum	LAI-total
Spring barley	From sowing	24-maj	0	0	24-maj	0	0
			110	0		110	0
		24-jun	210	0,41	24-jun	210	0,25
		4-jul	310	1,16	4-jul	310	0,7
		13-jul	410	2,53	13-jul	410	1,52
		21-jul	509	5	29-jul	609	3
			750	5		720	3
			880	5		830	3
			900	5		850	3
			1180	5	15-okt	1500	1,5
		1-nov	1590	2			
	After harvest	18-sep	0	0,3	18-sep	0	0,2
Winter wheat	From sowing	NA	0	0	NA	0	0
			110	0		110	0
			400	0,5		400	0,5
	From 1st of March		0	0,5		0	0,5
			142	0,5		142	0,5
			242	1		242	0,7
			342	2,2		342	1,5
			445	5		505	3
			800	5		800	3
			1449	5		1000	3
			1848	2		1800	1,5
	After harvest		0	0,3		0	0,2
Grass for harvest	From 1st of January	1-jan	0	1	1-jan	0	1
	From 1st of March	1-mar	0	1	1-mar	0	1
			142	1		142	1
		29-maj	200	1,2	29-maj	200	1,1
		13-jun	300	2	13-jun	300	1,6
		25-jun	400	3,7	25-jun	400	2,4
		29-jun	442	5	5-jul	500	4
			650	5		700	4
	After harvest	5-jul	0	0,5	5-jul	0	0,5
			40	0,5		40	0,5
		13-jul	100	0,8	13-jul	100	0,7
		21-jul	200	1,7	21-jul	200	1,2
		29-jul	300	3,7	29-jul	300	2,1
		1-aug	340	5	5-aug	400	4
			650	5		700	4
Clover grass for harvest	From 1st of January	1-jan	0	1			
	From 1st of March	1-mar	0	1			
			142	1			

		29-maj	200	1,2			
		13-jun	300	2			
		25-jun	400	3,7			
		29-jun	442	5			
			650	5			
	After harvest	5-jul	0	0,5			
			40	0,5			
		13-jul	100	0,8			
		21-jul	200	1,7			
		29-jul	300	3,7			
		1-aug	340	5			
			650	5			
Grass for continuous grazing	From 1st of January	1-jan	0	1			
	From 1st of March	1-mar	0	1			
			142	1			
		29-maj	200	1,2			
		13-jun	300	2			
		21-jun	365	3			
Ryegrass sown the year before	From 1st of January		0	1			
	From 1st of March		0	1			
			142	1			
			200	1,2			
No data			300	2			
			400	3,7			
			442	5			
			820	5			
			1100	5			
			1400	5			
			1800	4			
	After harvest		0	0,5			
Peas	From sowing	23-maj	0	0			
			150	0			
		12-jul	400	0,2			
		20-jul	500	1,1			
		28-jul	600	3,9			
		29-jul	621	5			
			870	5			
		5-okt	1431	2,5			
	After harvest	19-sep	0	0,2			
Spring rape	From sowing	23-maj	0	0	23-maj	0	0
			140	0		140	0
		26-jun	240	0,4	26-jun	240	0,2
		6-jul	340	1,2	6-jul	340	0,6
		15-jul	440	2,6	15-jul	440	1,3
		22-jul	533	5	25-jul	570	3
			850	5		850	3
			1495	5		1200	3
		18-dec	1725	2	15-nov	1650	1,5
	After harvest	9-okt	0	0,1	9-okt	0	0,1
Winter rape	From sowing	NA	0	0	NA	0	0
			140	0		140	0
			240	0,4		240	0,2
			340	1,2		340	0,6
			500	3		500	2
			800	4		800	2,5
	From 1st of March		0	2		0	1,5
			142	2		142	1,5
			242	2,8		242	1,8
			332	5		352	3
			650	5		650	3

			1179	5		950	3
			1848	2		1650	1,5
	After harvest		0	0,1		0	0,1
Carrot	From sowing		0	0		0	0
			300	0		300	0
No data			400	0,02		400	0,02
			500	0,1		500	0,1
			600	0,25		600	0,25
			700	0,5		700	0,5
			800	1,2		800	1,1
			1000	2		1000	1,7
			1400	5		1400	3
	After harvest		0	0		0	0
Winter rye	From sowing	NA	0	0	NA	0	0
			110	0		110	0
			400	0,5		400	0,5
	From 1st of March		0	0,5		0	0,5
			142	0,5		142	0,5
			242	1,6		242	1
			332	5		352	3
			900	5		900	3
			1443	5		1000	3
			1828	2		1800	1,5
	After harvest		0	0,3		0	0,2
Triticale	From sowing	NA	0	0	NA	0	0
			110	0		110	0
			400	0,5		400	0,5
	From 1st of March		0	0,5		0	0,5
			142	0,5		142	0,5
			242	1,2		242	0,9
			342	3,2		352	1,7
			392	5		410	3
			900	5		900	3
			1443	5		1000	3
			1828	2		1800	1,5
	After harvest		0	0,3		0	0,2
Winter barley	From sowing	NA	0	0	NA	0	0
			110	0		110	0
			400	0,5		400	0,5
	From 1st of March		0	0,5		0	0,5
			142	0,5		142	0,5
			242	1,6		242	1
			332	5		352	3
			700	5		700	3
			953	5		850	3
			1333	2		1300	1,5
	After harvest		0	0,3		0	0,2
Spring wheat	From sowing	NA	0	0	NA	0	0
			110	0		110	0
			210	0,3		210	0,2
			310	0,8		310	0,5
			410	1,6		410	1
			510	2,9		510	1,7
			610	5		610	3
			1000	5		1000	3
			1200	5		1050	3
			1650	2		1600	1,5
	After harvest		0	0,3		0	0,2

Lupin	From sowing		0	0			
			150	0			
No data			300	0,2			
			400	1			
			500	2,5			
			600	5			
			870	5			
			1400	5			
			1850	2			
	After harvest		0	0,2			
Fodder beats	From sowing	NA	0	0	NA	0	0
(Sugar beet)			200	0		200	0
			280	0,3		280	0,1
			400	0,8		400	0,5
			500	1,6		500	1
			600	2,9		600	1,7
			700	5		700	3
			1100	5		1000	3
	After harvest		0	0		0	0
Maize	From sowing		0	0		0	0
			200	0		200	0
No data			620	0,5		620	0,4
			700	0,9		700	0,6
			800	1,8		800	1,1
			940	5		940	3
			1200	5		1200	3
			1808	5		1700	3
			2572	3		2500	1,5
	After harvest		0	0,2		0	0,2
Ungrazed	From 1st of January	1-jan	0	3			
pasture		25-maj	200	2			
	From 1st of March		0	2			
			150	2			
		13-jun	300	3			
		25-jun	400	4			
		5-jul	500	5			
		13-aug	1000	5			
Potatoes,	From seeding	26-maj	0	0	26-maj	0	0
for eating			300	0		300	0
		13-jul	400	0,6	13-jul	400	0,5
		21-jul	500	1	21-jul	500	0,7
		29-jul	600	1,5	29-jul	600	1
		5-aug	700	2,2	5-aug	700	1,4
		12-aug	800	3,3	12-aug	800	2,1
		20-aug	900	5	20-aug	900	3
			1600	5		1250	3
		-	1900	1	10-okt	1450	0,5
	After harvest	16-sep	0	0	16-sep	0	0
Potatoes,	From seeding	26-maj	0	0			
industrial			300	0			
		13-jul	400	0,6			
		21-jul	500	1			
		29-jul	600	1,5			
		5-aug	700	2,2			
		12-aug	800	3,3			
		20-aug	900	5			
			1650	5			
		-	2050	1			
	After harvest	28-sep	0	0			

Oats	From sowing	22-maj	0	0	22-maj	0	0
			110	0		110	0
		22-jun	210	0,41	22-jun	210	0,25
		3-jul	310	1,16	3-jul	310	0,7
		12-jul	410	2,53	12-jul	410	1,52
		20-jul	509	5	28-jul	609	3
			750	5		720	3
			880	5		830	3
			900	5		900	3
			1250	5	22-okt	1550	1,5
		1-nov	1600	2			
	After harvest	18-sep	0	0,3	18-sep	0	0,2

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3.3. LAI data for Norway

For Norway the soil temperature that is a driving factor for the leaf area index varies greatly because Norway is a long country with varying altitude and both inland and coastal areas. With respect to LAI we have chosen to divide the country into three growing zones based on when the average daily air temperatures normally exceeds 5°C. Above 5°C most plants have ability to grow. The areas including the southern coast and the most southern inland areas have temperatures above 5°C before May 1st, while areas along the northern coast and in the southern inland have temperatures above 5°C between May 1st and June 1st, and the areas with the highest altitude or at the coast of the north east have temperatures above 5°C after June 1st (Table 25, Fig 7).

Table 25. The three selected growing zones, normal date when the air temperature exceeds 5°C and the areas included in each growing zone.

	Avegare air temperature above 5°C	Areas in the growing zone
Growing zone 1	Before May 1 st	Southern coast and the most southern inland
Growing zone 2	Between May 1st and June 1 st	Northern coast and the southern inland with medium altitude
Growing zone 3	After June 1st	Inland at the highest altitude or at the north-east coast

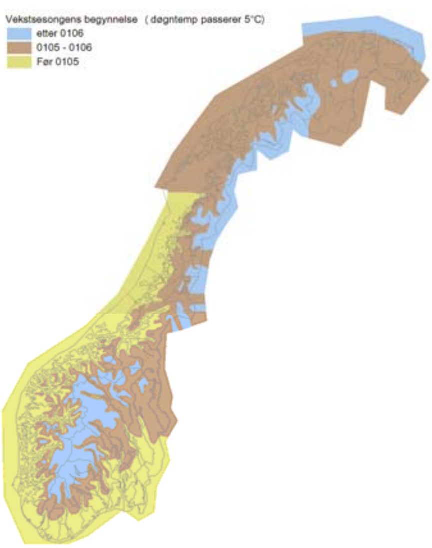

Fig 7. Areal distribution of the three selected growing zones in Norway.

Soil temperature

Soil temperature has been estimated by the Norwegian Institute for Agricultural and Environmental Research (Bioforsk) at a number of locations important for agricultural production. We have used the soil temperature at 10 cm to estimate LAI for Norway. The soil temperature is registered at 10 cm depth on an hourly basis. In the present work we have used monthly averages of the 10 cm soil temperature. Within each growing zone data from between 3 and 5 measurement locations were used and an average of the monthly 10 cm soil temperature from those locations were used to estimate an average 10 cm soil temperature for each of the three growing zones (Fig 8).

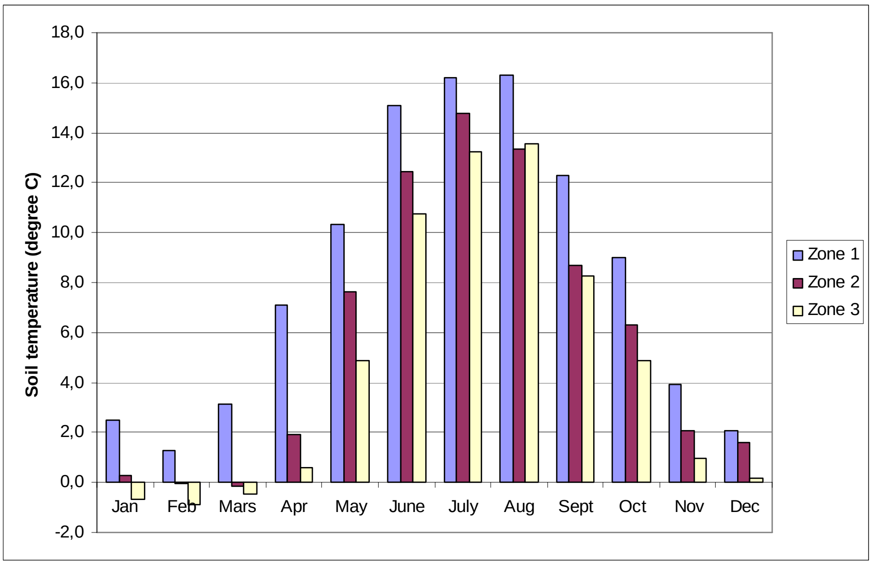

Fig. 8. Average soil temperature at 10 cm in the growing zones 1-3.

The average soil temperature in the zone with the earliest start of the growing season (Growing zone 1) was above 5°C from April to November with a maximum of 15-17°C from June to August (Fig 7). In growing zone 2 the soil temperature was above 5°C from May to November with a maximum of 12-15°C from June to August. In growing zone 3 the soil temperature was above 5°C from June to September with a maximum of 13°C in July and August (Fig 8). Among the three growing zones the soil temperature varies most during April and May. This indicates that contamination during this period could have large impacts on the food production in growing zone 1 and much less impact in growing zones 2 and 3, given the same amount of contamination in all areas.

The monthly average soil temperature in growing zone 1 was compared to the average soil temperature for Denmark (Fig 9). The soil temperature followed the same pattern, even though the monthly soil temperature was between 1 and 3 degrees lower in growing zone 1 in Norway compared to Denmark.

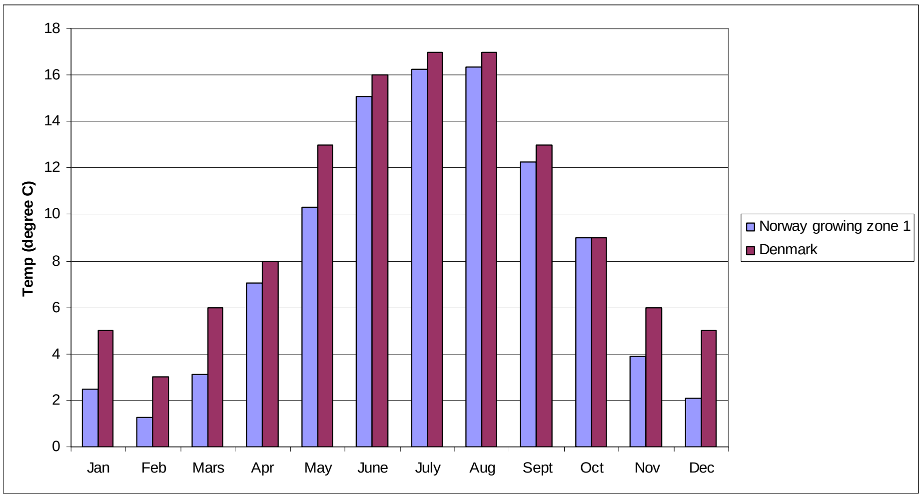

Fig. 9. Average soil temperature at 10 cm depth in Denmark and in growing zone 1 in Norway.

Leaf area index

Based on the description of the soil temperature we should develop three sets of LAI, one for each growing zone. However, because the soil temperature in growing zone 1 in Norway is similar to soil temperature in Denmark we will use the LAI developed for Denmark for areas included in growing zone 1 in Norway, for the appropriate products. For growing zone 2, seasonal development of LAI has been calculated (Tables 26 and 27). For growing zone 3 seasonal development of LAI has been calculated only for grass (Table 27), because that is the most important plant for food production in areas included in growing zone 3.

Table 26. Estimated seasonal development of LAI for barley, wheat and oat in Norway, based on soil temperatures.

Spring barley		**Spring wheat**		**Oat**	
	Normal fertilisation		Normal fertilisation		Normal fertilisation
15-Apr	0	15 Apr	0	15 Apr	0
01-May	0.41	20 Apr	0.3	20 Apr	0.41
15-May	1.16	10 May	0.8	10 May	1.61
01-June	2.53	20 May	1.6	20 May	2.53
15 June	5	25 May	2.9	25 May	5
15 Aug	2	1 June	5	1 June	5
After harvest	0.3	15 Aug	2	15 Aug	2
		After harvest	0.3	After harvest	0.3

Table 27. Estimated seasonal development of LAI for grass in growing zone 2 and 3 in Norway, based on soil temperatures.

Grass zone 2		**Grass zone 3**	
	Normal fertilisation		Normal fertilisation
15. Apr	1	15 May	1
20. Apr	1.2	20 May	1.2
5. May	2	5. June	2
10. May	3.7	10 June	3.7
15. May	5	15 June	5
10 June	1	10 July	1
15 June	1.2	15 July	1.2
1 July	2	1 Aug	2
10 July	3.7	10 Aug	3.7
20 July	5	20 Aug	5
1 August	1	1 Sept	1

Yield

Average data for harvest period and yield (Statistics Norway, 2008) of the agricultural products from Norway are given below (Table 28).

Table 28. Estimated harvest periods and yields of various crops in Norway.

Crop	Harvest period	Yield (kg/m^2 FW)	Crop	Harvest period	Yield (kg/m^2 FW)
Spring barley	15 Aug-15 Sept.	0.39	Fodder beet	1-31 Oct.	
Winter barley			Maize	not grown	na
Spring wheat	15 Aug-15 Sept	0.45	Fruit vegetables	1 Jul-15 Aug.	
Winter wheat			Leafy vegetables	1 Jun-31 Oct.	
Winter rye			Potatoes	15 Sep-15 Oct.	
Oats	1-15 Sept.	0.39	Fruit	15 Sep-15 Oct.	
Root vegetables	1-31 Oct.		Berries	20 Jun-15 Aug	
Gras	1.June-1. Oct	20			

na = not appropriate

References

Norwegian Institute for Agricultural and Environmental Research (Bioforsk). Agricultural meteorological data for Noray. http://lmt.bioforsk.no/lmt/index.php?weatherstation=5&loginterval=1&tid=1225710585

Statistics Norway, 2008. Average yield of wheat, barley and oat, 1995 to 2007. http://www.ssb.no/emner/10/04/10/korn/fig-2007-12-05-02.gif

3.4. LAI data for Finland

Figure 10 shows how the annual temperature sum and precipitation sum varies over different regions of Finland, showing a need for different LAI development data for different parts of the country.

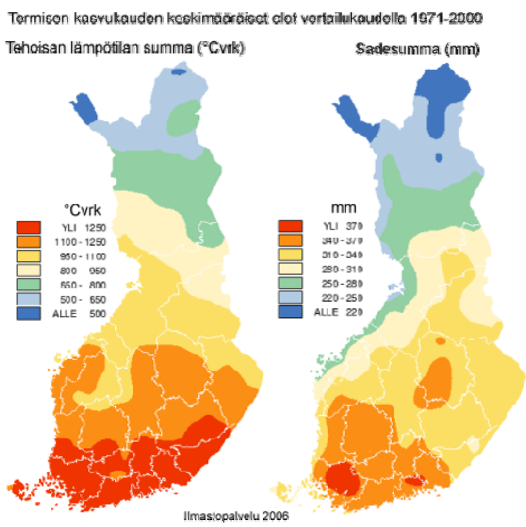

Fig. 10. Average annual temperature and precipitation sums in Finland during the period 1971-2000. The effective temperature values considered were over +5 ^{o}C (FMI).

Figure 11 shows colour codes for beginning and termination of the thermal growing season in the different parts of Finland.

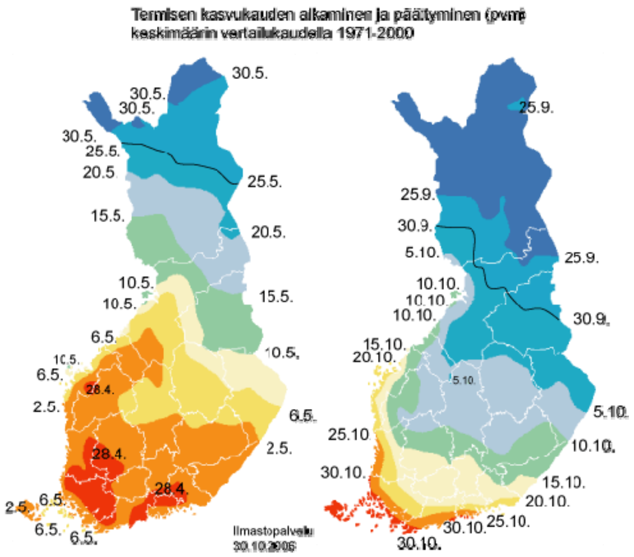

Fig. 11. Beginning and termination of the thermal growing season. During the thermal growing season temperature is defined to be over +5 ^{o}C (FMI).

Figure 12 shows the annual temperature variation in southern (e.g. in Turku) and northern (e.g. in Sodankylä) Finland.

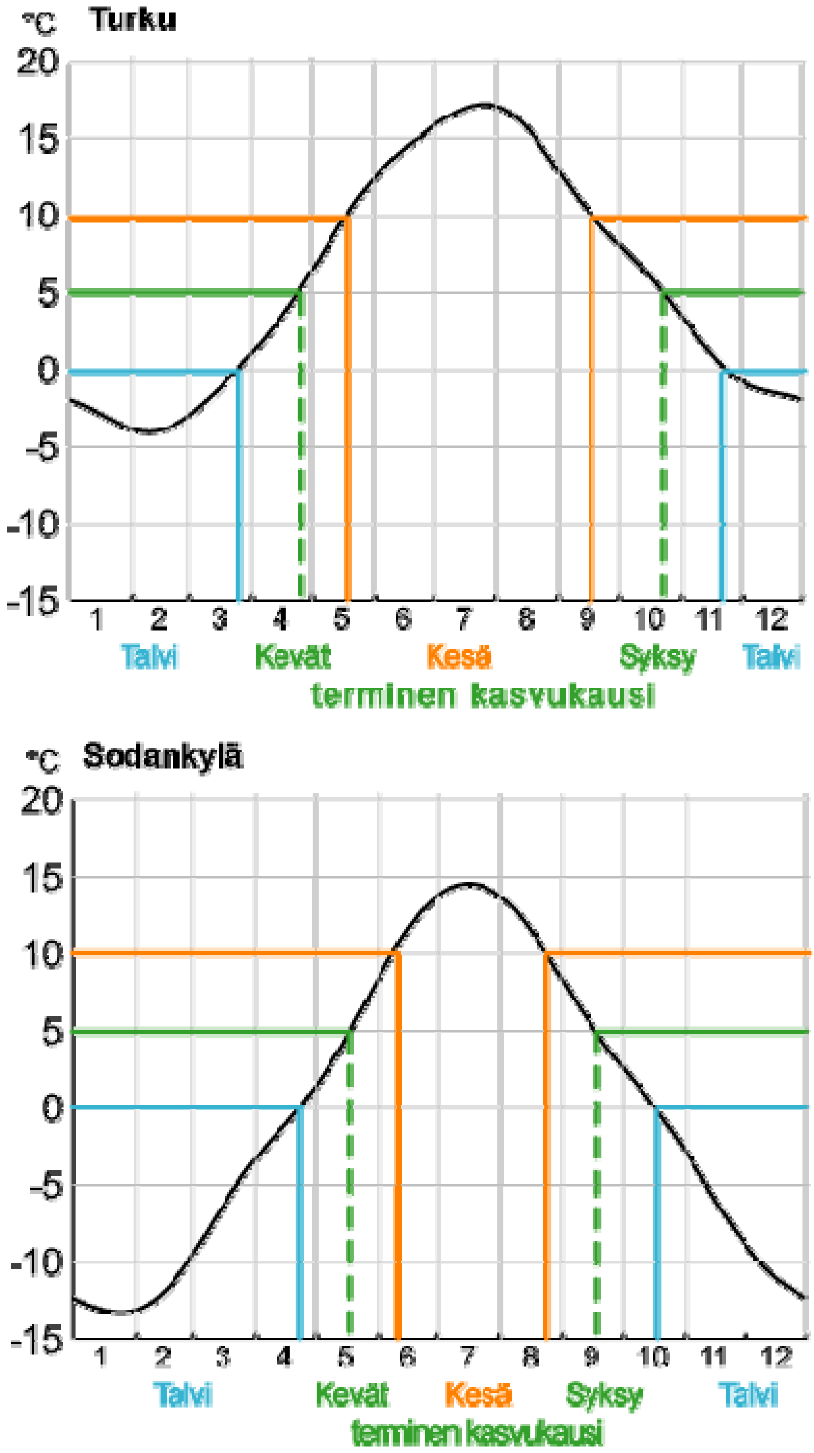

Fig. 12. Annual temperature variation in southern (e.g. in Turku) and northern (e.g. in Sodankylä) Finland. During the thermal growing season temperature is defined to be over +5 °C (FMI).

Fig. 13 shows the temperature sum variation over the year in southern Finland, whereas Fig. 14 shows the corresponding variation in northern Finland.

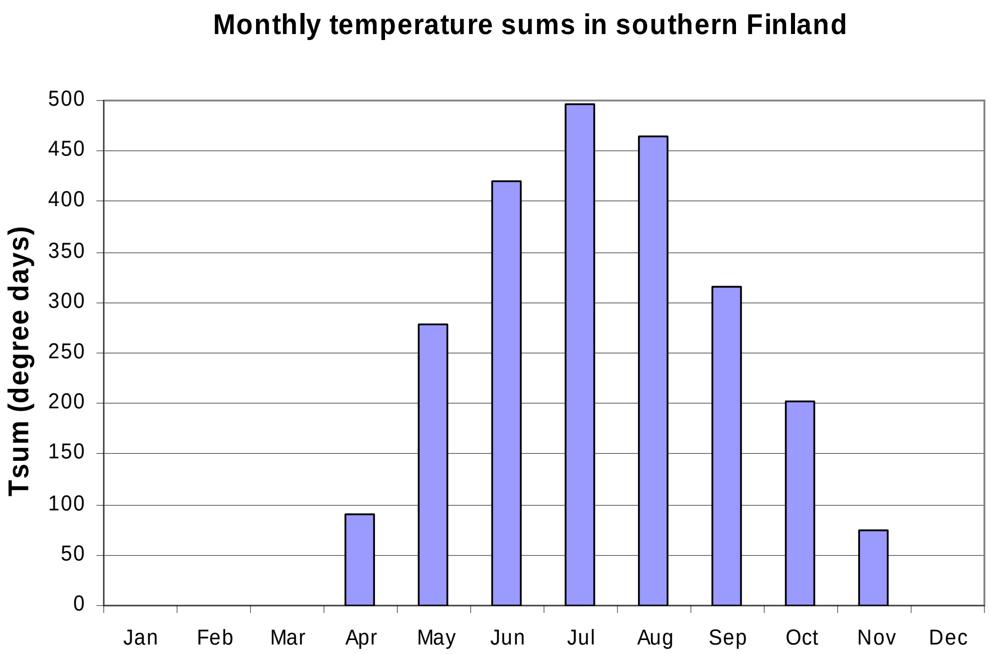

Fig. 13. Data for soil temperature variation in southern Finland. Temperature sum shown for each month.

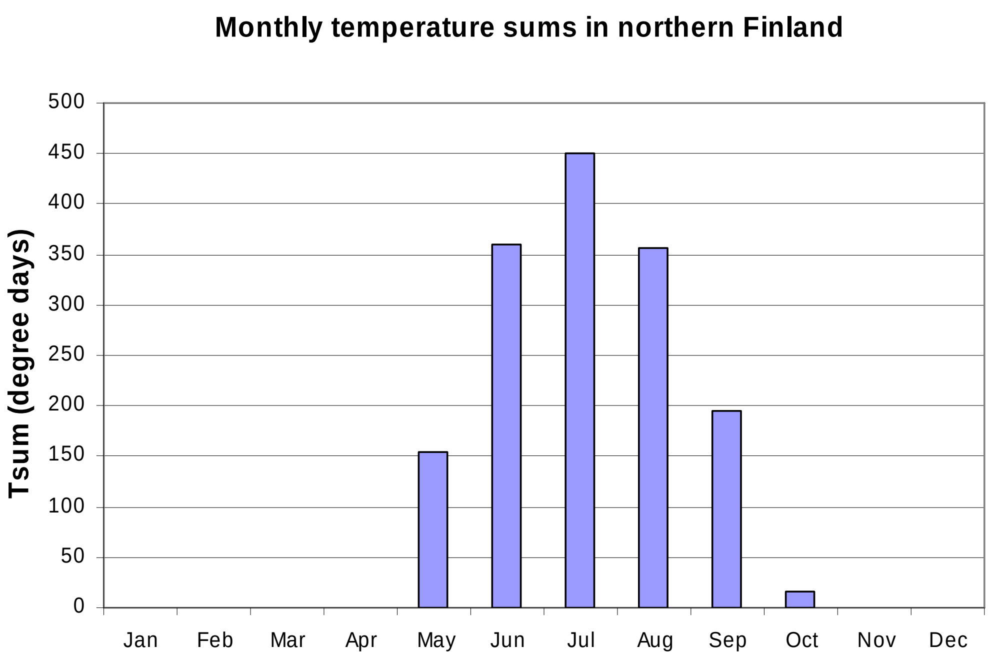

Fig. 14. Data for soil temperature variation in northern Finland. Temperature sum shown for each month.

On the background of the data in Figures 13, LAI variation for a variety of important crops has been described for southern Finland (Tables 29, 30 and 31).

Table 29. Estimated seasonal development in southern Finland of LAI for barley, wheat, rye and oats, based on the LAI development model/data (Plauborg & Olesen, 1991; Olesen, 2006) and representative values of soil temperatures.

Spring barley			**Winter barley**			**Spring wheat**		
	Normal fertilisation	Low fertilisation		Normal fertilisation	Low fertilisation		Normal fertilisation	Low fertilisation
Apr	0	0	Sep	0	0	Apr	0	0
May	2.3	1.4	Oct	0.5	0.5	May	1.4	0.9
Jun	5	3	Mar	0.5	0.5	Jun	5	3
Jul	5	3	Apr	0.5	0.5	Jul	5	3
Aug	2	1.5	May	5	3	Aug	2	1.5
After harvest	0.3	0.2	Jun	5	3	After harvest	0.3	0.2
			Jul	2.1	1.6			
			Aug	2	1.5			
			After harvest	0.3	0.2			

Winter wheat			**Winter rye**			**Oats**		
	Normal fertilisation	Low fertilisation		Normal fertilisation	Low fertilisation		Normal fertilisation	Low fertilisation
Sep	0	0	Sep	0	0	Apr	0	0
Oct	0.5	0.5	Oct	0.5	0.5	May	2.3	1.4
Mar	0.5	0.5	Mar	0.5	0.5	Jun	5	3
Apr	0.5	0.5	Apr	0.5	0.5	Jul	5	2.5
May	2.4	1.6	May	5	3	Aug	2	1.5
Jun	5	3	Jun	5	3	After harvest	0.3	0.2
Jul	5	3	Jul	5	3			
Aug	2.1	1.6	Aug	2.1	1.6			
After harvest	0.3	0.2	After harvest	0.3	0.2			

Table 30. Estimated seasonal development in Finland of LAI for root vegetables (carrots), fodder beets, fruit vegetables (peas), leafy vegetables, potatoes, and grass, based on the LAI development model/data (Plauborg & Olesen, 1991; Olesen, 2006) and representative values of soil temperatures.

Root vegetables (carrot)			**Fodder beet**			**Fruit vegetables (peas)**	
	Normal fertilisation	Low fertilisation		Normal fertilisation	Low fertilisation		Normal fertilisation
Apr	0	0	Apr	0	0	Apr	0
May	0.02	0.02	May	0.8	0.5	May	0.2
Jun	1.2	1.1	Jun	5	3	Jun	5
Jul	4.6	2.8	Jul	5	3	Jul	2.8
Aug	5	3	Aug	5	3	Aug	2.5
After harvest	0	0	After harvest	0	0	After harvest	0

Leafy vegetables*			**Potatoes**			**Grass**		
	Normal fertilisation	Low fertilisation		Normal fertilisation	Low fertilisation		Normal fertilisation	Low fertilisation
Apr	0	0	Apr	0	0	Apr	0	0
May	3	2	May	0.6	0.5	May	3.7	2.4
Jun	5	3	Jun	3.3	2.1	Jun	5	4
Jul	5	3	Jul	5	3	Jul	5	4
Aug	3.5	2.4	Aug	4.7	2.8	Aug	5	4
Sep	3	2	After harvest	0	0	Sep	5	4
Oct	2	1.3				Oct	1	1
After harvest	0	0				After harvest	1	1

* Estimated LAI values

Table 31. Estimated seasonal LAI development in Finland of fruits and berries

Fruits		Berries	
Normal fertilisation		Normal fertilisation	
May	0	May	0
Jun	3.5	Jun	4.4
Jul	5	Jul	5
Aug	5	Aug	5
Sep	4	Sep	5
Oct	0	Oct	3.5
		Nov	0

Examples of measured seasonal variation of LAI for grass and barley in different soil types are shown in Figures 15 and 16. For barley, LAI increased evenly reaching the maximum value in clay and peat soils in the middle of July, in fine sand soil the maximum was seen in June. The values of LAI for grass in different soils were similar, only in peat soil the LAI after the cutting increased in shorter time than in clay and fine sand soils.

The overall measured seasonal development of LAI values is in reasonable agreement with the above results of the model/data calculations. The measured LAI peaks at a value of about 6.5, whereas the model suggests a value of 5. However, measured data will always be associated with some uncertainty. A multiple grass harvest over the year is clearly reflected in the data in Figure 15.

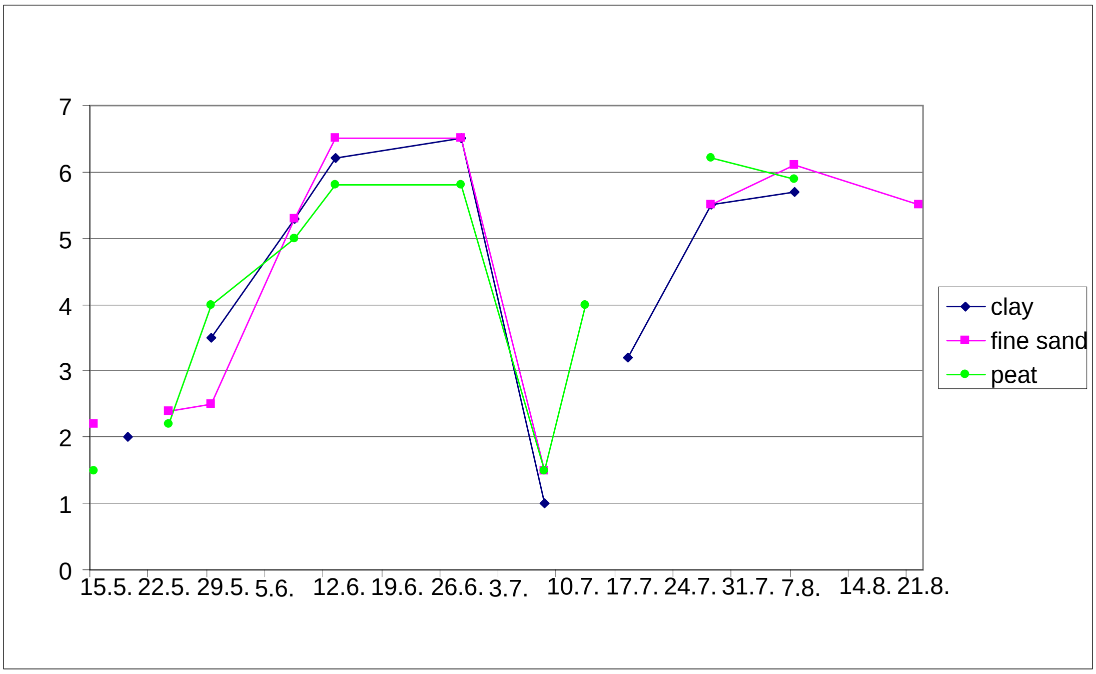

Fig. 15. Seasonal variation in LAI for grass, measured data points.

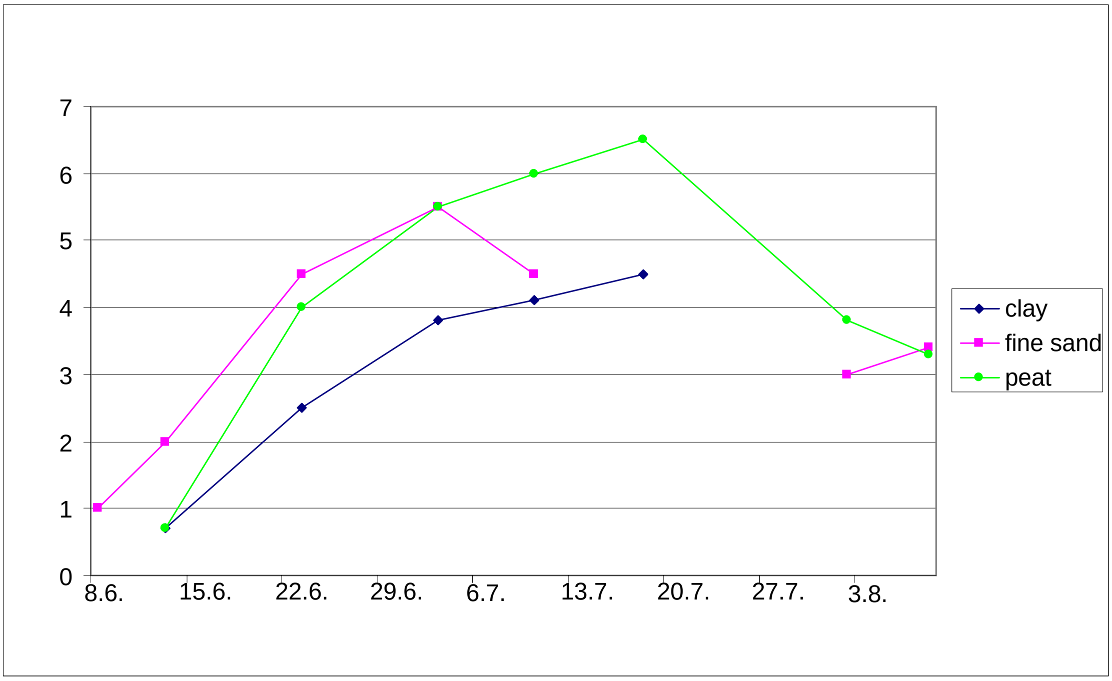

Fig. 16. Seasonal variation in LAI for barley, measured data points.

References

Plauborg, F. & Olesen, J.E. (1991). Development and validation of the model MARKVAND for irrigation scheduling in agriculture (in Danish), Tidsskrift for Planteavls Specialserie, Beretning nr. 2113.

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FMI (Finnish Meteorological Institute).

3.5. LAI data for the Faroes

No data was available for the Faroes to describe LAI according to any detailed seasonal sequence, nor could maximum LAI values for the Faroes be deduced. Anyway, as noted in last year's PardNor activity progress report, extremely few types of crops are grown to any significant extent in the Faroes. About 10 % domestically produced potatoes, and grass for fodder for lambs and a small number of cattle are the only influences on the diet.

3.6. LAI data for Iceland

The method of estimating the LAI development as a function of time is similar as has been used for the other Nordic countries in this report. The tables by Olesen(2006) give the relationship between LAI and the temperature sum days (TSum) at 10 cm soil depths for various crops. Knowing at what date the TSum in soils reaches a given value in the table makes it possible to associate the date with the corresponding LAI value in the table and thus to evaluate the LAI development over time.

Soil temperature

Soil temperature data suitable for LAI analysis is not available yet in published reports from Iceland. The Agricultural University of Iceland is conducting a study at a study site Geitasandur in the main agricultural region of Iceland (the southern lowland), where soil temperatures have been measured automatically every 10 minutes and a 30 minutes average then stored in a data logger. Raw data from the data loggers was kindly provided for use in the LAI study (Orradóttir, 2008).

The temperature time series for the 3 experimental sites are shown in Figures 17-19. The original temperature data (the 30 minutes averages) are shown in yellow, calculated daily averages are shown in red and a smoothed curve (using spline smoothing) is shown in black.

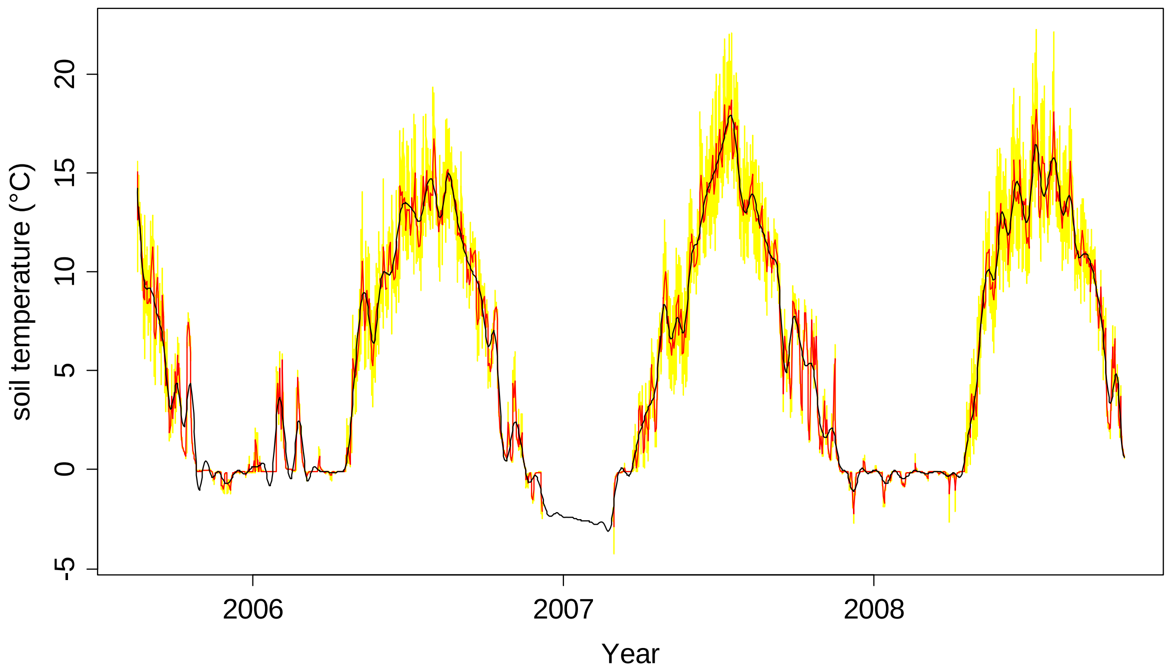

Figure 17. Soil temperature at 10 cm depth at site A2. Sandy soil with limited vegetation. Vegetation cover ca. 55%, where of grasses only 15%.

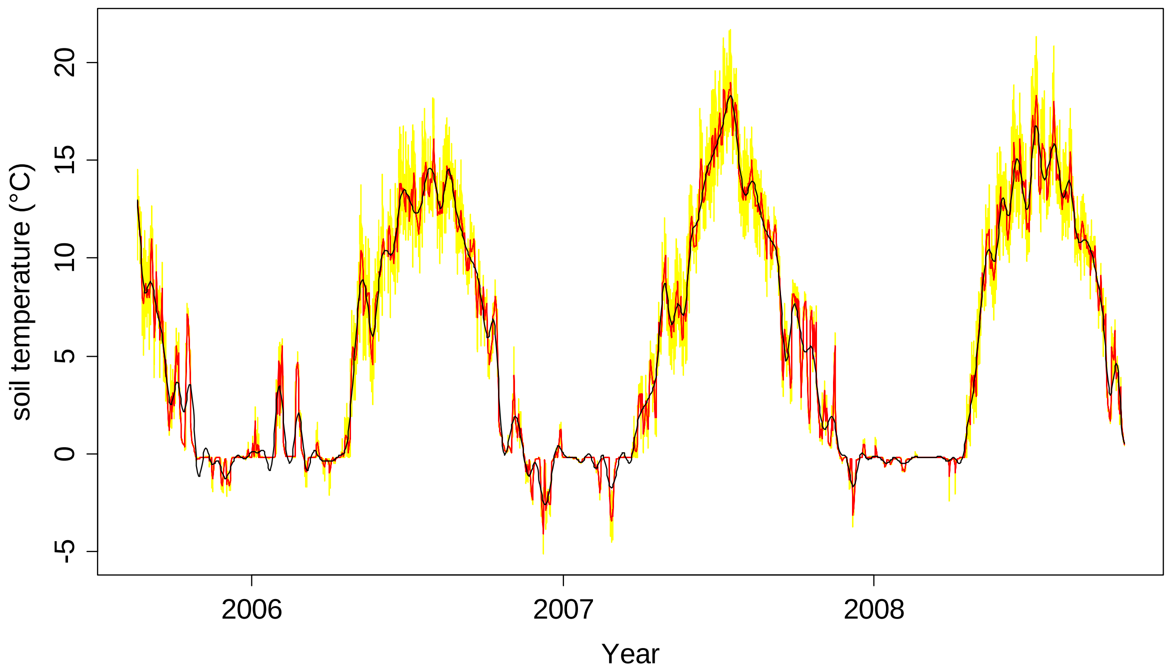

Figure 18. Soil temperature at 10 cm depth at site H8. Sandy soil, grassland with patches of birch. Vegetation cover ca. 70%, where of grasses ca. 8 – 10%.

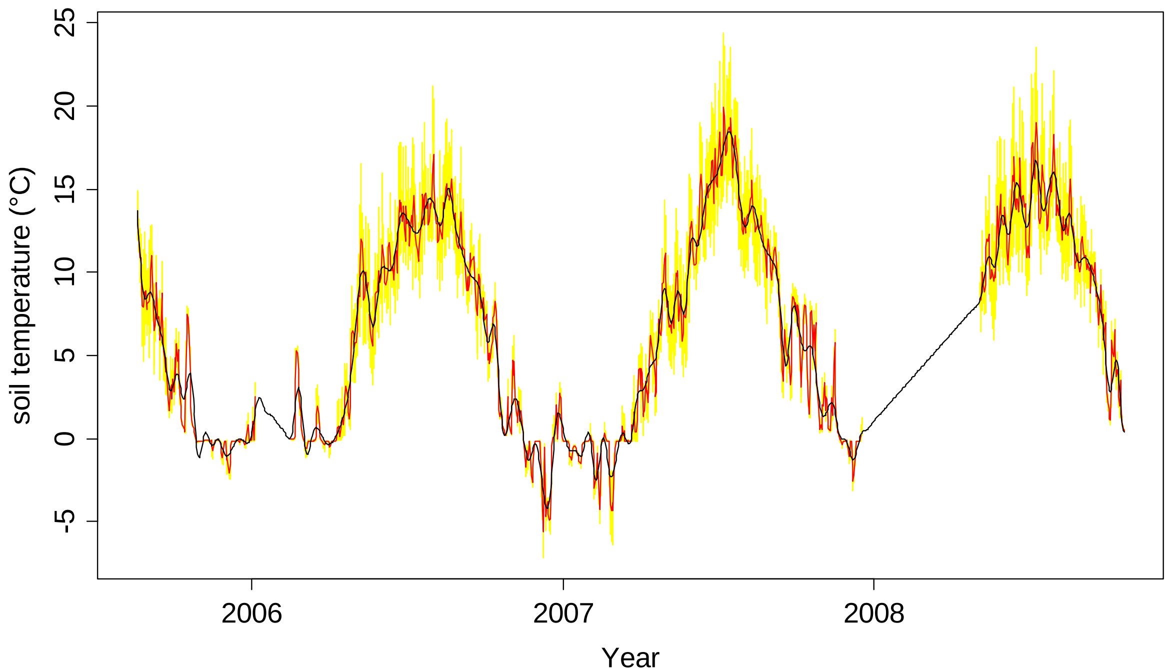

Figure 19. Soil temperature at 10 cm depth at site A3. Sandy soil with limited vegetation. Vegetation cover ca. 5%, where of grasses only 2-4%. There is unfortunately a gap in the 2008 data for the first part of the year. Temperature-sum graphs can however be constructed for vegetation planted in late spring or early summer.

The soil temperatures in Figures 17 – 19 show lower values than e.g. for southern Sweden and Denmark (as shown in Figures 1, 3 and 4), but comparable to growing zones 2 and 3 in Norway (as seen in Figure 8).

The main crop of relevance for Iceland would be grass and to some degree potatoes.

Grass

A TSum graph was constructed using the smoothed average temperature for each of the 3 study sites for the 3 years (9 combinations in all). The summing was started when the smoothed soil temperature at 10 cm had reached 5°C and stopped when it reached 0°C. Since the resulting data set from A3 was incomplete for 2008 there where only 8 combinations that could be used. The results can be seen in Figure 20.

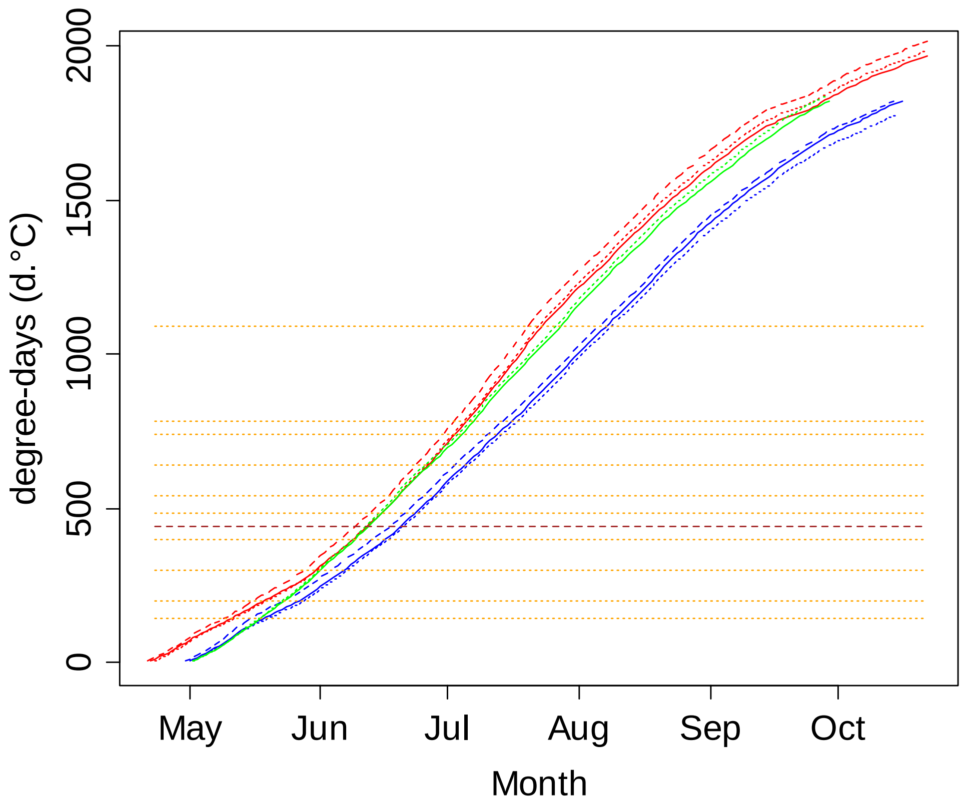

Figure 20. The sum of daily temperature averages (Tsum) for the 3 study sites, A2 (solid line), A3 (dashed line) and H8 (dotted line) for the 3 years 2006 (blue), 2007 (red) and 2008 (green). The summing was started when the smoothed averaged soil temperature at 10 cm reached 5 °C. The reference value of Tsum associated with harvesting the grass, 442 °C days, is shown as a horizontal brown dashed line. The reference Tsum values of 142, 200, 300, 400, 482, 542, 642, 742, 782 and 1092 are shown as horizontal orange coloured dotted lines.

The reference values for TSum shown in Figure 20 are those given in LAI base of Olesen(2006) table for *Grass for harvest, normal fertilisation level*.

The corresponding date for each curve can easily be obtained by interpolation and the range of these dates can be used as an estimate of the time period when a given LAI-total value is likely to be reached, based upon these 3 study sites and data from the years 2006-2008. These time period are shown in Table 32 for each of the given LAI reference levels.

Time of harvest

The time of harvest in Iceland is often in the second half of June, but it depends of course upon the climatic conditions in the previous months and the choice of the time of harvest is based upon the development of the grass. It is therefore probably more realistic to assume that harvesting takes place when a certain LAI value has been reached rather than at a fixed calendar date. According to the table for normal fertilisation level, the LAI reaches its maximum of 5 when TSum reaches 442. This value is shown by a dashed brown horizontal line in Figure 4. The corresponding time period is 9 – 20 June, which is similar as the time period for harvesting. In this evaluation it is therefore assumed that the harvesting takes place when the LAI value has reached 5 (when the TSum reaches 442) for normal fertilisation levels and when the LAI value reaches 4 (TSum reaches 500) for low fertilisation levels. The TSum values after harvest in Table 32 are those given by Olesen plus the TSum value at time of harvest.

Table 32 Estimated seasonal development of LAI for grass for harvest, based on LAI development data from Denmark and soil temperature data at 10 cm depth. The time period given is based on the range of estimates of dates from 3 sites in southern Iceland during 2006, 2007 and 2008.

		Normal fertilisation level			
		TSum	Time period		LAI-total
Grass for harvest	From 1st of January	0			1
	From 1st of March	0	22-Apr	02-May	1
		142	08-May	19-May	1
		200	16-May	28-May	1.2
		300	28-May	07-Jun	2
		400	05-Jun	16-Jun	3.7
		442	09-Jun	20-Jun	5
	After harvest	442	09-Jun	20-Jun	0.5
		482	12-Jun	23-Jun	0.5
		542	16-Jun	28-Jun	0.8
		642	23-Jun	05-Jul	1.7
		742	29-Jun	13-Jul	3.7
		782	02-Jul	17-Jul	5
		1092	19-Jul	08-Aug	5

			Low fertilisation level		
		TSum	Time period		LAI-total
Grass for harvest	From 1st of January	0			1
	From 1st of March	0	22-Apr	02-May	1
		142	08-May	19-May	1
		200	16-May	28-May	1.1
		300	28-May	07-Jun	1.6
		400	05-Jun	16-Jun	2.4
		500	13-Jun	25-Jun	4
	After harvest	500	13-Jun	25-Jun	0.5
		540	16-Jun	28-Jun	0.5
		600	20-Jun	02-Jul	0.7
		700	27-Jun	10-Jul	1.2
		800	03-Jul	18-Jul	2.1
		900	09-Jul	25-Jul	4
		1200	26-Jul	16-Aug	4

The estimated seasonal development of LAI for grass in growing zone 3 in Norway is similar as seen here. The dates in Table 27 are within the time period given here in Table 32 for normal fertilisation levels.

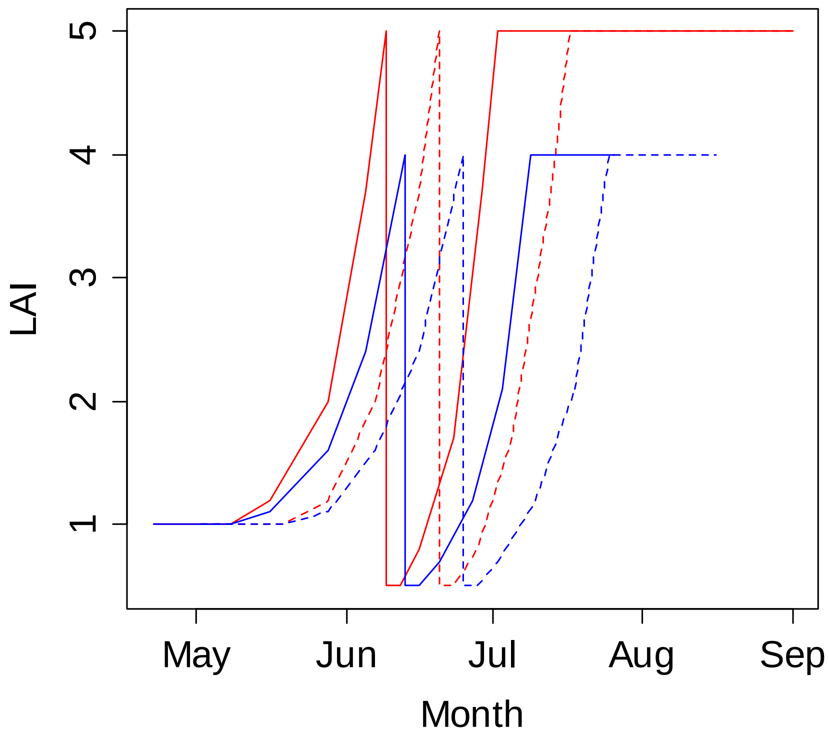

Figure 21. LAI values for grass as a function of time for normal fertilisation (red) and low fertilisation (blue), assuming harvesting when the maximum LAI reference levels have been reached. Each LAI value corresponds to a time period as shown in Figure 4. The beginning of each time period is shown with a solid line, the end with a dashed line.

Potatoes

For potatoes it was assumed that the planting takes place at the beginning of June. The TSum was thus set as 0 at the beginning of June. The resulting TSum graph is shown in Figure 22. The TSum reference levels (given in Table 33) are shown as horizontal orange coloured dotted lines as in Figure 20.

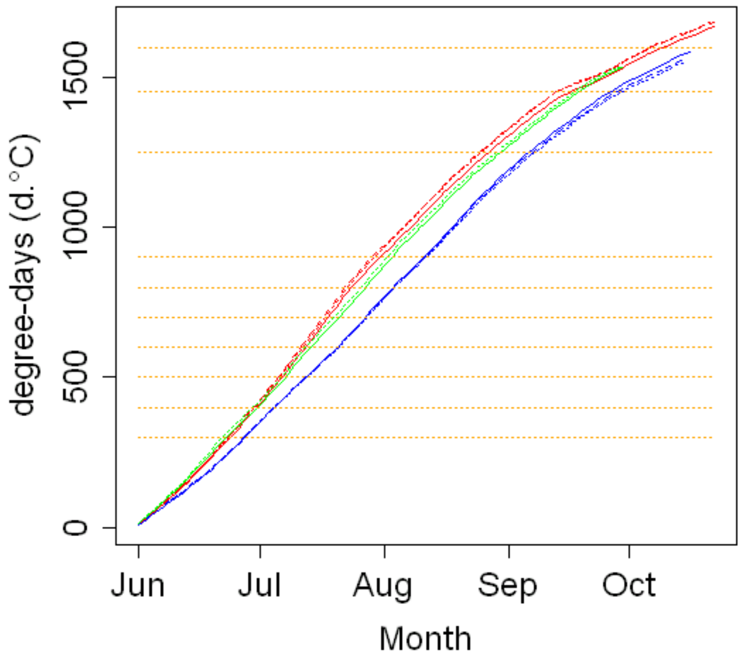

Figure 22. The sum of daily temperature averages (Tsum) for the 3 study sites, A2 (solid line), A3 (dashed line) and H8 (dotted line) for the 3 years 2006 (blue), 2007 (red) and 2008 (green). The summing was started with TSum as 0 at the beginning of June.

Table 33. Estimated seasonal development of LAI for potatoes, based on LAI development data from Denmark and soil temperature data at 10 cm depth. The time period given is based on the range of estimates of dates from 3 sites in southern Iceland during 2006, 2007 and 2008.

	Normal fertilisation level			
	TSum	Time period		LAI-total
From seeding	0	01-Jun	01-Jun	0
	300	22-Jun	27-Jun	0
	400	29-Jun	04-Jul	0.6
	500	05-Jul	12-Jul	1
	600	11-Jul	20-Jul	1.5
	700	16-Jul	27-Jul	2.2
	800	22-Jul	03-Aug	3.3
	900	28-Jul	11-Aug	5
	1600	06-Oct	15-Oct	5
	1900	15-Oct	22-Oct	1

	Low fertilisation level		
TSum	Time period		LAI-total
0	01-Jun	01-Jun	0
300	22-Jun	27-Jun	0
400	29-Jun	04-Jul	0.5
500	05-Jul	12-Jul	0.7
600	11-Jul	20-Jul	1
700	16-Jul	27-Jul	1.4
800	22-Jul	03-Aug	2.1
900	28-Jul	11-Aug	3
1250	24-Aug	07-Sep	3
1450	12-Sep	28-Sep	0.5
0			0

A graph of the LAI development over summer was constructed in a similar manner as for grass and it can be seen in Figure 23.

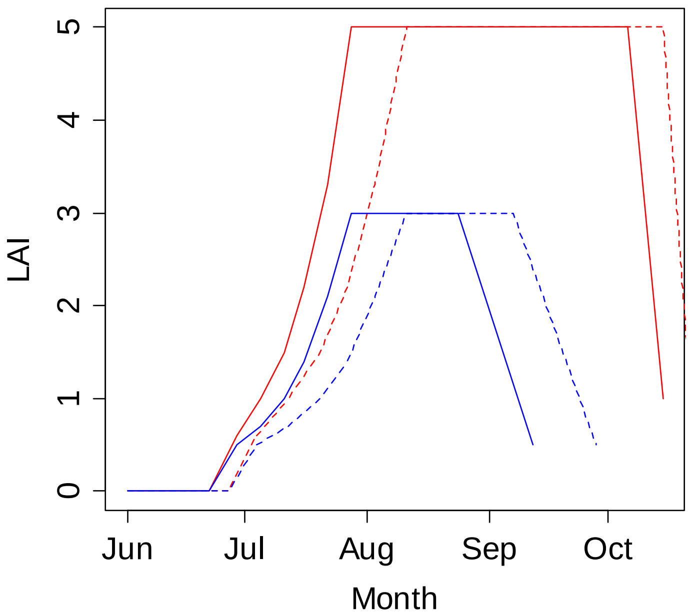

Figure 23. LAI values for potatoes as a function of time for normal (red) and low (blue) fertilisation. Each LAI value corresponds to a time period as shown in Figure 22. The beginning of each period is shown with a solid line, the end with a dashed line.

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4. Influences of resuspension enrichment factors, leaching rates, fixation rates and desorption rates

4.1 Resuspension enrichment factor

The resuspension enrichment factor (REF) is according to the supplementary text in the excel version of the ECOSYS system used to quantify the enhancement of the activity concentration of the resuspended soil relative to the mean activity concentration in soil. The activity concentration in soil is determined over a soil volume corresponding to 25 cm depth (for arable soil), and the activity concentration in the topsoil that can be resuspended is thus often higher. In reality, this depends on the contaminant and its physicochemical form, as well as the soil characteristics (e.g., content of clay), as natural migration will over time deplete the contaminant concentrations in the topsoil layer, but this is not taken into account in ECOSYS. Also anthropogenic mixing of soil layers will over longer periods of time reduce the concentrations at the surface. The default value of the REF in ECOSYS is 1.0 for all contaminants, although it is stated in the supplementary text that it is in general greater than 1 for cationic radionuclides. Compared to the concentration of ^{137}Cs in the top 5 cm soil layer in Zapolie (only 14 km south of Chernobyl NPP), Garger et al. (1998) measured resuspension enrichment factors, which they found to be dependent on the size of the resuspended particles. For small particles (<2 µm) the REF was 3.8 +/-2.2, but for particles in the 7-16 µm range, the REF was found to be 28.8 +/- 15.7. In comparison, NCRP (1999) recommends an average value (based on Chernobyl ^{137}Cs assessments) of 4.4, with lower and upper limits of respectively 2.8 and 8.4, but no parametric dependence is addressed. At Nevada Test Site and the Bikini Atoll values of respectively 3.6 and 3.9 have been recorded for ^{239}Pu particles (<10 µm) (Shinn, 1992). It should be noted that the physicochemical form of radiocaesium at Zapolie may well be different (a high proportion of large fuel fragment particles at this location would also explain the higher average REF for large particles) from that assessed by NCRP, and this may possibly explain the difference.

In ECOSYS, the REF is multiplied by a parameter quantifying the relationship between the contaminant concentration on the plant after deposition of resuspended particles and the contaminant concentration in the resuspendable soil (unit: g soil per g plant d.m.). This product is in ECOSYS used as a ‘transfer factor’ for the process, and the product of this and the average soil contaminant concentration is used to describe a deposition that is assumed to be taken up by the plant. However, in reality, only a small proportion of this would be taken up by the plant, particularly if the contaminants are strongly bound in the soil particles, which would after some time in general be the case for radiocaesium in mineral soils. ECOSYS assumes by default that the contamination attached to a plant (Bq per g plant d.m.) per unit contamination in soil averaged over a depth of 25 cm (Bq per g soil) - regardless of soil type and plant species - is 0.001 (g soil per g plant d.m). In a paper describing the model (Pröhl & Müller, 1996), this parameter is however estimated to 0.002 (a log-triangular distribution with a range of 0.0002 - 0.02). That estimate is among other things based on an assumption of a deposition velocity of 0.01 m s^{-1}, which is claimed to be appropriate for the expected particle size distribution ‘for resuspended material, with a maximum ranging from 1 to 10 µm’. It should be noted that the deposition velocity to, e.g., grass, generally increases by most of two orders of magnitude as the particle size increases from 1 to 10 μm (e.g., McMahon & Denison, 1979), stressing the importance of properly addressing particle size issues in general, as planned in a later stage of the PardNor activity (an improvement of deposition velocity values is a much needed key to better estimates of all crop contamination pathways). Hinton et al. (1996) measured the relationships of respectively 2 g soil /kg plant d.m. and 34 g soil /kg plant d.m. for resuspended soil on cabbage at two locations in the Ukraine that were contaminated by the Chernobyl accident. The location with the lowest value was most sandy, which affected soil adhesion to the plant.

Table 34 shows an example of ECOSYS estimates of the effect of changing REF from 1 to 5 (which would seem a more appropriate value). The scenario involves a dry deposition of ^{137}Cs on the 1st of January. The values given in the table are the percentages by which ingestion dose components (integrated over respectively 6 months and 50 years) from consumption of different dietary constituents increase due to the REF change (assuming a 'standard' Danish diet, import fractions and fodder regimes; all other parameters are ECOSYS defaults). As can be seen, the total dose is relatively unaffected, but for instance fruit consumption is significantly affected. Naturally, if the contamination had occurred during a season with standing crops, the influence of REF would have been less. However, for the various reasons outlined above, the REF part of ECOSYS should not be used uncritically and without changes to parameters and formulae. It should be noted that Hinton et al. (1996) found that 'although foliar absorption of ^{137}Cs from suspended soil is measurable, it is inconsequential relative to other plant contamination pathways, and does not need to be considered as a critical pathway in routine radionuclide transport models'.

Table 34. Percentage increase in dose contributions to adults from consumption of various food items (also from total diet), as estimated with ECOSYS by increasing REF from 1 to 5. Scenario: dry deposition of ^{137}Cs on 1st of January (standard Danish diet).

	6 months	50 years
Fruit	15 %	15 %
Milk	0.08 %	1.7 %
Leafy vegetables	0.01 %	0.3 %
Winter wheat flour	0 %	14.5 %
Total	*0.03 %*	*1.7 %*

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4.2. Leaching rates

The leaching rates in soil are according to the supplementary text given in the excel version of ECOSYS used to describe the decrease of activity in the root zone due to migration into deeper soil layers. In ECOSYS, radioactivity leaks out of the zone of interest, when it goes deeper than 25 cm in arable soil and deeper than 10 cm in pasture soil. In general, the leaching half-life is in ECOSYS by default set to 50 or 100 years for all radionuclides for arable soil. However, for pastures, it is set to 40 or 50 years for Cs, I, Ru, Zr, Nb, Ce and Pu, whereas it is set to 20 years for Sr, Te, Zn, Mo, Mn and Ba. The references behind these values in ECOSYS are in general based on pre-Chernobyl work. Obviously migration rates of different radionuclides in soils will vary greatly, depending strongly on soil types. For instance, in Chernobyl-contaminated areas, undisturbed pasture soil profiles with respectively 35 % and 7.5 % of the ^{137}Cs deeper than 10 cm have been recorded after 10 years (Roed et al., 1998). The soil with the high leaching rate was very sandy, whereas the other was a mineral soil. Both soils were found in the Bryansk region, some 200 km north of the Chernobyl NPP, so differences in contaminant characteristics can be ruled out. This implies that at least over the first 10 years after the contamination takes place, leaching half-lives out of the top 10 cm layer in these two soils were respectively 6.5 years and 90 years. Table 35 shows an example of the effect on ingestion dose components of changing the leaching half-life for radiocaesium (for pastures and arable land) to 6.5 years. In this example, dry deposition of ^{137}Cs occurs on the 1st of January, and diets, import fractions and feeding regimes reflect Danish conditions (as defined in the PardNor activity), whereas the rest of the parameters are ECOSYS defaults.

Table 35. Percentage change in ingestion dose contributions to adults integrated over resp. 2 and 50 years, by setting the ^{137}Cs leaching half-life to 6.5 years (scenario described above).

	Winter wheat flour	Fruits	Cow's milk	Beef (cow)	Total
2 years	7.6 %	7.7 %	0.3 %	0.2 %	0.2 %
50 years	46.9 %	46.7 %	5.1 %	4.9 %	6.0 %

As can be seen, leaching rate can have some impact on dose contributions over long periods of time, although caesium is a very immobile element in soil. However, the very sandy soil in the Bryansk region should be regarded as an extreme case, and is hardly representative of Nordic conditions. If instead we look at ^{90}Sr, it has been reported in a fallout study that 40 years after deposition, some 94 % of the contamination had migrated deeper than 10 cm in a silty-sandy clay soil (Fernandez et al., 2006). This corresponds to a leaching half-life of ca. 10 years, compared with the 20 years default in ECOSYS. Table 36 shows an example of the effect on ingestion dose components of changing the strontium leaching half-life to 10 years (for all soils). With the exception of changing the contaminant radionuclide to ^{90}Sr, the example scenario is the same as used above for caesium.

Table 36. Percentage change in ingestion dose contributions to adults integrated over resp. 2 and 50 years, by setting the ^{90}Sr leaching half-life to 10 y. (scenario described above).

	Winter wheat flour	Fruits	Cow's milk	Beef (cow)	Total
2 years	4.4 %	5.6 %	2.5 %	2.2 %	1.8 %
50 years	42.0 %	42.0 %	26.1 %	26.8 %	27.6 %

Also the figures in Table 36 indicate that it may be of some importance to apply case-specific values of leaching rates, reflecting the given soil parameters. It should of course be noted that the approach of defining the root uptake zone by a depth of 10 or 25 cm is very simplified, as the depth over which a crop will search for nutrition, and thus take up radionuclides, depends considerably on crop type/species and fertilisation status in the upper soil layers.

It should be stressed that anthropogenic influences can rapidly move contaminants out of the top 10 or 25 cm soil layer. As an example, consider ploughing. Fig. 24 shows an example of the vertical radiocaesium distribution in natural and ploughed pastures in the same area in Russia (from Salbu et al., 1994). Clearly, by ploughing, most of the contamination would immediately be moved out of the 10 cm topsoil 'zone of interest' of ECOSYS for pastures, and the rest of the contamination would be moved closer to the bottom of the 'zone of interest', and thus subsequently leach out faster.

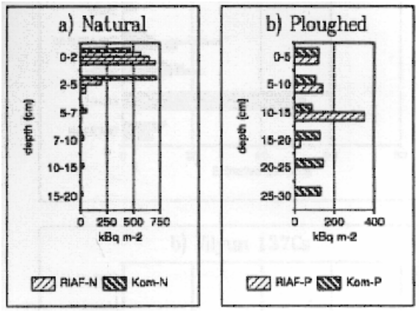

Fig. 24. Example of vertical profiles in soil of ^{137}Cs from Chernobyl in Novozybkov, Bryansk region, Russia, in 1993.

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4.3. Fixation rates

In ECOSYS, fixation rates govern the loss of bioavailability of the contaminants due to strong attachment of radionuclides particularly to clay minerals. Fixation half-lives are generally (with the exception of caesium and strontium) set to very high values (mostly 1000 years), to reflect the low tendency of fixation in soil of most radionuclides considered in ECOSYS. This is reasonable, and dose estimates over 50 years (the longest period over which accumulated ingestion dose can be estimated in the excel version of ECOSYS) would not be affected by refining these parameter estimates. Specifically for caesium, the selective fixation in clay minerals gives a much shorter fixation half-life. Here, the ECOSYS default value is 8.7 years. Like other ECOSYS parameters, this is based on old assessments, not taking into account the many assessments made after the Chernobyl accident, in which the physicochemical forms of the contaminants are representative of those that can be expected in connection with a future large nuclear power plant accident.

Applying a modified version of the sequential extraction technique described by Tessier et al. (1979), it was suggested by Oughton et al. (1990) that the ‘strongly fixed’ fraction of a contaminant in soil could be defined as the part of the contamination that can not be extracted with the most inert solutions, but requires addition of strong acid to go into solution. Such modified Tessier extractions have also been applied by other workers, and it has become a standard technique for sequential extractions to assess the mobility in soil and sediments of contaminants like ^{137}Cs and ^{90}Sr. If it is assumed that the mobile (easily extractable) fraction decreases exponentially over time, sequential extractions carried out by various workers at different times after the contamination from the Chernobyl accident took place (Salbu et al., 1994; Andersson & Roed, 1994; Oughton et al., 1992; Oughton et al., 1990; Salbu et al., 1998; Andersson et al., 2002; Riise et al., 1990; Bunzl et al., 1998, Bunzl et al., 1997; Shand et al., 1994) on soil samples from Nordic, Ukrainian, Russian and other European areas with different characteristics, suggest that radiocaesium fixation half-lives would typically range between about 1.3 and 2.7 years for most soils with significant mineral phases, and some 4-5 years for very sandy or organic soils.

If the fixation half-life for caesium is changed from 8.7 years to 2 years, for the same example scenario as applied above for identification of the influence of leaching rate (^{137}Cs dry deposition on the 1st of January), ECOSYS would estimate the influence on ingestion dose components as shown in Table 37.

Table 37. Percentage change in ingestion dose contributions to adults integrated over resp. 2 and 50 years, by setting the ^{137}Cs fixation half-life to 2 years (scenario described above).

	Winter wheat flour	Fruits	Cow's milk	Beef (cow)	Total
2 years	18.5 %	23.7 %	0.5 %	0.5 %	0.5 %
50 years	67.6 %	69.9 %	7.7 %	8.0 %	9.5 %

The figures in Table 37 show that particularly some of the long term dose contribution estimates could be far off if a fixation half-life value of 8.7 years is used for a mineral soil.

It is also worth noting that this change in fixation half-life changes the estimate of the total ingestion dose received over the period from 10 to 20 years after the deposition by a factor of about 200. Such a difference in estimates could be important in connection with decision support to lift long-term restrictions and return an area to more normal living conditions.

The data for sequential extractions of strontium is sparser, but investigations by Oughton et al. (1990), Oughton et al. (1992) and Salbu et al. (1994) suggest a fixation half-life of respectively 20 years, 11 years and 23 years for soils with mineral content. This is in good agreement with the default fixation half-life of 20 years applied in the ECOSYS model.

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4.4. Desorption rates

In the supplementary text in the datasheet of the excel version of ECOSYS, it is stated that ‘the half-life of desorption represents the remobilisation of fixed radionuclides‘. It may be confusing that the ECOSYS default value for all radionuclides is 0. However, the model is programmed so that entering ‘0’ gives a desorption *rate* of 0, and not a desorption *half-life* of 0. If the value entered in the appropriate table of the model parameter file is greater than 0, that value is used as the desorption *half-life*.

Since fixation of all other contaminants than radiocaesium takes place over extremely long time periods, desorption of these will be of very little importance, considering the time-integration periods over which it would be meaningful to make dose estimates. The process of immobilisation of caesium cations in selective ‘high energy sites’ in clay minerals leads to an extremely strong fixation that is virtually irreversible, even over decades (Cremers et al., 1988; Tamura & Jacobs, 1960). Therefore, the use of the desorption rate parameter will generally be of very little importance. If experimental data are used to describe the fixation process, the ‘fixation rates’ thus deduced would in reality accommodate both fixation and desorption in one ‘effective’ half-life for mobilisation and immobilisation. The desorption rate is not included in the formula of Müller & Pröhl (1993) describing the concentration of bioavailable contaminants in the soil. Here only fixation rates and leaching rates are included.

It could however be relevant to include a desorption or remobilisation rate in cases where the deposited contaminants are initially in the form of large low-solubility particles, which remain on the soil surface until they gradually dissolve. As they dissolve, the released contaminants become bioavailable until they are fixed in soil constituents. It has been suggested that the dissolution process of low-solubility particles in soil can be described by a simple first-order kinetics equation (Kashparov et al., 2004; Petryaev et al., 1991; Konoplev et al., 1992). On the background of measurements, the dissolution half-life was estimated to be of the order of 14 years at pH 7. However, as demonstrated by the model results of Kashparov et al. (2004), which are verified by measurements made by other workers (e.g., Krouglov et al., 1998; Petryaev et al., 1991), the dissolution half-life is considerably shorter at low pH. For instance, it is only about one year at pH 4. The Chernobyl accident demonstrated that the physical fragmentation of fuel from a nuclear power plant in connection with an explosion can lead to generation of large contaminant particles with low solubility. Due to gravity, such particles will deposit over comparatively short distance, and thus affect a rather limited area. Large contaminant particles with low solubility would also be expected in connection with some conceivable malicious dispersion scenarios. Here even smaller areas would be likely to be affected, as the effective release height of contaminants from a ‘dirty bomb’ would be comparatively little (Andersson et al., 2008).

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5. Summary and conclusions

This year's work on the PardNor activity was targeted on the following investigations:

- Assessment of sensitivity of ingestion doses to Nordic diet, food item import fractions, and animal feeding regimes.
- Calculations of improved leaf area index parameters for different crops, on the basis of a soil-temperature-based methodology, which has been validated for Danish conditions.
- Assessment of the importance of case-specific values of leaching rates, fixation rates, desorption rates, and resuspension enrichment factor, for estimates of ingestion dose.

Assessments were made for each Nordic country of the sensitivity of ingestion dose to variation in 9 selected, potentially important input values (human and animal consumption rates). Where data was available, calculations were made for the four age groups investigated in the previous activity period. Table 38 shows a comparison of the results for the different countries for the 'adult' age group. As can be seen, the parametric variation by 10 % of each of the various input parameters had very different effect, depending on the country. For instance, the sensitivity to milk consumption was almost 3 times as great in Norway compared with Denmark and Sweden, and more than 5 times greater in the Faroe Islands than in Denmark and Sweden. The sensitivity to wheat consumption is 4 times greater in Norway than in Finland. On the more extreme, the sensitivity to lambs meat consumption was 25-500 times greater in the Faroe Islands than in Denmark, Sweden, Norway and Finland. These differences reflect the fact that in some of the countries (particularly the Faroes), only few different food items are produced locally, and so each of these will carry an enhanced importance. Also, as demonstrated in the previous activity period, Nordic diets can be very different. The results of these calculations clearly show that it is important to take into account the correct location-specific parameters in calculations of ingestion dose. Also, as mentioned in last year's activity report, it is important to apply recent data, which reflect the current situation.

Sufficiently detailed reported data to facilitate investigations of the end-point response to input variations by two standard deviations was only found to be available for Sweden and Denmark. Although the Danish and Swedish dietary data are in general some of the most similar, some of them are not within one standard deviation of each other. However, they are generally within two standard deviations (95 % confidence) of each other, and can thus not be proven significantly different. However, considering the comprehensive dietary studies conducted in most of the Nordic countries, which constitute the data sources, it would certainly be considered very unlikely that for instance the difference by almost a factor of a hundred between the consumption of domestic spring wheat, as observed between Denmark and Norway, would not be highly significant.

Table 38. Results of examination of end-point sensitivity to systematic 10 % changes in a number of input parameters (contamination scenario as described above). Figures are the percentage variation in the end-point caused by the input variation. Values are here shown for the 'adult' age group.

	DK	S	N	FI	FA	IS
Change leafy veg. 10 %	0.3 %	0.2 %	0.1 %	0.2 %		
Change milk 10 %	1.7 %	1.7 %	4.9 %	2.6 %	8.6 %	2.2 %
Change beef 10 %	1.1 %	1.3 %	1.8 %	1.0 %		
Change lamb 10 %	0.1 %	0.01 %	0.2 %	-	5.0 %	
Change wheat 10 %	1.5 %		2.8 %	0.7 %		
Change fruits 10 %	0.4 %	0.1 %	0.2 %	0.08 %		
Change lactating cow's fodder 10 %	2.4 %	2.2 %	4.9 %	2.9 %		
Change beef cattle fodder 10 %	0.5 %	1.3 %	0.9 %	1.0 %		
Change lamb fodder 10 %	0.1 %	0.01 %	0.2 %	-	5.0 %	

The applicability of a simple Danish empirical model by Plauborg and Olesen for calculation of leaf area index as a function of soil temperature was tested for use for Swedish conditions (Uppsala soil temperatures) by comparison with reported measurements of leaf area index and corresponding soil temperature sums. The model was then applied with soil temperature data for other Nordic countries, to provide a more realistic estimate of the variation of the local leaf area index over the year. As discussed above, it may be that special, faster growing crop variants are applied in some Northern areas of the Nordic countries, which might make the Danish-based model inadequate for such localities, but the positive outcome of the test for Uppsala (and a comparison with Finnish measurement data) indicated that the data that could be obtained with the model would constitute an improvement and certainly be more appropriate than the Southern German default leaf area index data sets. The importance of soil temperature is demonstrated by the data showing that for instance spring wheat is fully matured (max. leaf area index) about one month later in Northern Sweden than in Denmark. If a contaminating incident occurred around the tenth of June, the spring wheat would thus be fully developed in Denmark (leaf area index of 5), but in an early stage of development (leaf area index of about 0.5) in Northern Sweden. This would greatly affect deposition and interception of airborne contaminants.

Resuspension enrichment factors are used in ECOSYS to describe the enhancement of contaminant concentrations in the upper soil layers that can be resuspended. However, a flaw in the model is that it is assumed that the contaminants deposited on the plant surface are taken up by the plant. In reality, little of this would be transferred to plant tissue. It should also be noted that different types/sizes of soil particles adhere very differently to surfaces, wherefore resuspension enrichment factors should be soil type specific. Calculations with the ECOSYS model show little influence of the resuspension enrichment factor on total ingestion doses, whereas contributions to dose from certain food items may be enhanced. The overall conclusion is however that ECOSYS is likely to greatly overestimate the importance of the resuspension enrichment factor.

Leaching rates describing the migration out of the root uptake zone in ECOSYS are largely based on pre-Chernobyl work and need revision. Examples show that using the ECOSYS default leaching rates can lead to significant errors in dose estimates. In general soil type should be taken into account in the evaluation of leaching rates. Also anthropogeneous mixing (e.g., by ploughing) is important to take into account, as some types of ploughs will place practically all the contamination deeper than the standard ECOSYS crop root uptake zone of 10 or 25 cm of topsoil.

Fixation rates govern the gradual loss of contaminant bioavailability from soil over time. The standard ECOSYS fixation half-life for radiocaesium of 8.7 years is based on pre-Chernobyl work, and needs revision. Based on data from sequential extractions determining the binding of contaminants in the soil, revised values of 1.3-2.7 years for mineral soils and 4-5 years for very sandy or organic soils are suggested. Using the ECOSYS default value can lead to considerable errors in estimates of ingestion doses received after some years. The ECOSYS default value for strontium seems to be in reasonable agreement with the post-Chernobyl data.

Desorption rates, governing the detachment of previously fixed radionuclides, were found to be of very little importance, unless contaminants are initially present in the soil as large particles with low solubility, as observed for some of the radiostrontium released by the Chernobyl accident.

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Abstract

The ECOSYS foodchain model is built into the European standard decision support systems ARGOS and RODOS, which are integrated in the preparedness for radiological events in the Nordic countries. However, a review has revealed that a number of parameters in ECOSYS do not reflect the current state-of-the-art knowledge, and do not adequately represent Nordic conditions. Improved and country/region specific data is required for ECOSYS to give trustworthy results. It is the aim of the PardNor activity to collect new data, and thus enable reliable use of ECOSYS for scenarios involving contamination of Nordic food production areas. In the reported work period of the PardNor activity, analyses have been performed for each Nordic country to determine the sensitivity of the ingestion dose end-point in ECOSYS to variation in 9 selected, potentially important parameters (human dietary components and animal fodder components). This parametric sensitivity was found to vary considerably between the different Nordic countries, reflecting considerable differences in diet and domestic production, and highlighting the importance of last year's work to identify appropriate location-specific parameters. A simple empirical Danish soil temperature based methodology for calculation of more reliable location-specific values of leaf area index (LAI) was tested for Swedish conditions and applied to estimate the seasonal LAI variation in other countries. The leaf area index reaches its maximum value much earlier in the southern parts of the Nordic region than in the northern. This means that the conditions for deposition and interception to vegetation would over a certain time span be very different in different Nordic areas. Also the influence on ECOSYS dose estimates of resuspension enrichment factors, leaching rates, fixation rates and desorption rates was investigated in the reported activity period, identifying new data sets where needed.

Key words: Foodchain modelling, ingestion dose, ECOSYS, consumption habits, radioactive contamination

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