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Environmental impacts of using new manure tools

Juha Grönroos, Katrin Kuka, Ann Kristin Eriksson, Natalia Kozlova, Friederike Lehn, Suvi Lehtoranta, Lauris Leitans, Ulrika Listh, Katri Rankinen, Vytautas Ribikauskas, Tapio Salo, Piotr Skowron, Igor Subbotin, Avo Toomsoo, Damian Wach

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Abstract

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The project carried out farm and regional studies to assess the environmental impacts of the new manure data produced by the project. Not only for the environment, but also for the use of non-renewable resources and the farm economy, it is important that fertiliser nutrients are utilised as effectively as possible in agriculture. No matter how good the manure information is, it is of no use if there are no suitable application sites for manure, or if the fertilisation recommendations do not emphasize the importance of crop and farming condition specific fertilisation recommendations.

A good knowledge base is a prerequisite for good decisions. This project showed that better manure information may be of great importance to the environmental impacts of manure utilisation. The project also showed that obtaining better manure information can be challenging, especially for dry manure because of its heterogeneity which makes it difficult to take representative manure samples. On the other hand, estimating the properties of manure using mass balance calculations is also difficult, since gaseous losses are very case- and circumstance-specific.

It is also possible to use different methods in parallel. One option at the farm level would be to use national manure data (table values) at the same time with the farm's own manure analysis results. Using the average of these two sources as the basis for fertilisation could reduce the risk of incorrect application rates of manure nutrients, for example due to failed manure sampling. Here we present the possible environmental impacts e.g. leaching risk, carbon sequestration, N mineralisation if different nutrient values are taken into account when planning and executing fertilisation.

Keywords:

Manure, properties, nutrients, emissions, carbon sequestration, environmental impacts

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1. Introduction

Standards to be used for determining manure quantity and quality are called as manure tools. The environmental impacts of the new manure tools (i.e. the new manure standards) were assessed based on the differences between current (= old) manure data and the data provided by the new manure tools developed in this project (= new manure data). The assessment included:

- how the precision of understanding manure quantity and quality is changed with the new manure tools (comparison of the old and new manure data),
- whether they bring a deeper insight into the ‘real properties’ of manure, and
- whether the use of the new manure tools affect estimated emissions / emission potential, if, at the same time, guidance for (manure) fertilisation remains the same (changes in nutrient balances, and in nutrient leaching and atmospheric emissions potential, including carbon sequestration and nitrogen mineralisation).

The basic assumption was that the manure data provided by the enhanced manure sampling and analysing, or farm and regional level manure calculation tool as new manure tools, describe manure quantity and quality more precisely than the current manure data. If the new manure tools show that the current understanding of manure nutrient content has underestimated e.g. the nitrogen content of manure, too much nitrogen has been applied per hectare. This has resulted in a higher risk for nitrogen leaching. Similarly, if manure nitrogen content has been overestimated, fertilisation has been insufficient, resulting in decreased crop growth and nutrient uptake.

In this activity, the impact of such potential differences was studied with respect to nutrient leaching, carbon sequestration and atmospheric emissions. The pilot farms in every country (selected in WP2) served as examples on how farm-scale nutrient fluxes change when using the new manure tools instead of the current ones.

A nutrient balance-based method developed during this project, and mathematical modelling were used to estimate environmental impacts, due to introducing the new manure data.

2. Materials

The main materials used in the environmental impact assessment consisted of the following data and data sources:

- pilot farm data on cultivation practices collected in WP2: field size, crop type, fertilisation, and yield,
- regional data on use of agricultural land from national statistics,
- old and new manure data: currently used table values and new manure data based on the results of the work packages 2 and 3. Data are shown in the country-specific results in chapter 4,
- national emission data for atmospheric NH_3, NO and N_2O emissions from livestock farming.

See chapter 4 and the outputs of other work packages for more detailed descriptions of the materials used.

3. Methods

3.1. Nutrient balance-based method (NBBM)

An Excel-based calculation tool was developed to estimate the impacts of the new manure data to the nitrogen (N) and phosphorus (P) leaching risk in the pilot farms.

3.1.1. Calculating changes in nutrient balances

The tool shows how the actual fertilisation and nutrient balances would change if new manure data were introduced on the pilot farms. Based on this, it was possible to estimate how the nutrient leaching risk would change.

The basic assumption was that the new manure data give us more accurate information on manure properties than the old data. When fertilisation with manure is planned (and realised) using the new manure data, the use of manure becomes more accurate: the actual fertilisation (e.g. kg N/ha) is the same or close to the planned fertilisation. At least, the gap between these two is smaller than in the case when old (= present) manure data are used.

The tool shows - based on the new manure data - what the actual fertilisation levels (kg/ha) are when fertilisation is planned and realised with the present (= old) manure data, and how the actual fertilisation and nutrient balances would change if the new manure data were introduced.

If the new manure data show that the actual manure nutrient concentration (kg/ton) is higher than was supposed based on the old data, then the actual fertilisation level is higher than was planned, resulting in over fertilisation (actual application rate > planned). In this case, introducing new manure data in fertilisation planning decrease nutrient input per ha (actual = planned), decreasing nutrient surpluses in the field balances and nutrient leaching risk.

If the new manure data show that the actual nutrient content is lower than was supposed based on the old data, the actual fertilisation is lower than was planned, resulting under fertilisation. In this case, introducing new manure data would make the farmer increase the amounts of applied nutrients per ha, resulting in higher yields. If the application rate exceeds the optimal level, the surplus in nutrient balances will increase and thus result in a higher nutrient leaching risk.

The assumption behind this judgement is that increasing and decreasing nutrient inputs will lead to increasing and decreasing nutrient balances, respectively (e.g. Valkama et al., 2013).

If manure nutrient content is presently under estimated, introducing new manure data cause decreasing fertilisation rates and nutrient balances, and vice versa. The model assumes that primarily *mineral fertilisation* is adjusted if fertilisation adjustment is needed due to the changes in manure nutrient composition data. The reason why the model does not automatically change manure application rates but the fertilisation adjustment is done by changing mineral fertilisation rates is that changing manure application rates affect the allocation of the total amount of manure to the farm's total field area. Because it was not known how the reallocation should be done for each pilot farm, the manure application rates were decided to be kept unaffected. However, if it was not possible to change mineral fertilisation, then the only choice was to change manure application rates.

3.1.2. Calculating nutrient balances: effect of the yield

In addition to the fertilisation levels, it is also necessary to estimate the yield as accurately as possible because it affects the nutrient balances in the NBBM. New manure data will change the available N rate for crop, and thus also affect yields.

To estimate yield with a given N fertilisation rate, the first and recommended option is to use appropriate yield response to N fertilisation functions. The shape of these curves may vary between different fields and years. In the default version of the tool, a default function is in use. The user is able to change the function to another, if one is available. If it is not possible to use yield response functions, national or pilot farm specific default yields can be used.

The default (Mitscherlich) function (1) used in the study was:

$$y = c+(a(1-e^{-bx})) \qquad (1)$$

where,

y = yield, kg FM/ha

c = yield without N fertiliser, kg FM/ha (Control)

a = maximum yield increase due to N fertilisation, kg FM/ha

b = constant that governs the rate of the yield response (steepness of the yield response curve)

x = N fertilisation rate

The b-constant can be calculated with equation (2):

$$b = -1*(LN(0.05)/N_{opt}) \quad (2)$$

where,

N_{opt} = optimal N fertilisation kg/ha to reach 95% of the maximum yield.

3.1.3. Estimating changes in N and P leaching risk

For nitrogen, the relative change in pilot farm's average N balance can be used as a rough indicator for the change of N-leaching risk when the farm management otherwise remains the same. This is, however, true only with higher N balance values. With lower N balances, nitrogen leaching risk does not change even if the N balance changes, due to the N turnover from organic matter (e.g. Salo et al. 2013). In the NBBM model, the default limit is 50 kg N/ha, meaning that after this point nitrogen leaching risk starts to grow. The relative change in N leaching risk is the same as is the relative change in N surplus in the field balance. The default limit is based on the study of Salo et al. (2013), but user can change it if other information is available.

For phosphorus, the change in P balance does not affect the risk of losses directly in the same way as for nitrogen, although it gives an indication of the probable direction of change in the P leaching risk if all other factors are kept constant. However, to make more accurate predictions of the development of P leaching risk, there are many other factors that must be considered, like precipitation, topography, soil type, soil structure, properties of the subsoil and how well the drainage system works. The change in soil test P (STP) concentration can be estimated, by using the relationship between the P balance change and that of STP change (within a given time period, e.g. 10 years). In NBBM, a Finnish model (Uusitalo et al. 2016) was included where STP is determined by acid (pH 4.65) ammonium acetate extraction, which is only in use in Finland. In other countries, other methods are used to assess the amount of plant available P in the soil, e.g. P-AL or Olsen P. The model can possibly be fitted for Olsen P data as well, but model calibration with large datasets is needed. It was noted that applying this method for other countries than Finland may require too much resources and therefore using it was optional.

3.2. CANDY carbon balance (CCB) model

The CCB model (CANDY carbon balance) (Franko et al., 2011) is a simplified version of the process-oriented Carbon Nitrogen Dynamics model (CANDY) (Franko et al., 1997) with less demand for input data. It simulates the dynamics of total organic carbon, soil organic matter (SOM) reproduction and nitrogen mineralisation in annual time steps in arable fields and grassland. Site conditions e.g. soil properties, climate data and different management activities e.g. crop rotation, application of organic manure and mineral fertiliser can be considered to estimate their effect on carbon and nitrogen cycles.

In CCB, the soil organic matter (SOM) is, in addition to the fresh organic matter carbon input pool (FOM), divided into three different pools, which are characterised by a specific turnover activity. These are an active soil organic pool (A-SOM), where the fastest mineralisation takes place, and a passive soil organic matter (S-SOM) pool which representing the passive but decomposable part of SOM. Additionally there is a long-term stable organic matter pool (LTS-SOM), which is independent of the crops and fertiliser additions and is not involved in the turnover processes. All pools are influenced by the indicator of turnover activity (BAT - biologic active time) determined from climate e.g. average rainfall and air temperature and soil parameters. The BAT is calculated for every year and describes the impact of environmental conditions on biologic activity on soil organic matter (SOM) turnover (Franko et al., 1995).

In addition to the BAT, the model considers the carbon replication flux (Crep) and the indicator for humus supply (Rep_XI). The Crep desrcribes the reproduction flux from FOM, which is transferred to the SOM pool within one year. In order to determine Crep, information on the management (crop, yield, organic manure including co-product use) is necessary.

Rep_IX is an indicator of the humus supply of a location, which can be calculated using the CCB results BAT and Crep (Rep_IX = Crep / BAT). The indicator provides a statement about the Corg content of a location under steady-state conditions. The higher REP_IX, the higher the Corg content is in the steady-state. To calculate Rep_IX the results of BAT and Crep are needed (Rep_IX = Crep / BAT).

Land use has a strong influence on the current Corg content and the Corg turnover. For example, reduced tillage reduces carbon mineralisation from the organic matter. The model can represent the effect of the management measure on turnover processes.

All simulations were carried out for 30 years under same management, weather and site conditions.

Additionally, the field balance on farm level was estimated using the CCB model. N-Inputs are from 1) Mineral fertilisers, 2) Organic fertiliser, 3) symbiotic and asymbiotic N-fixation, 4) Seeds as well as 5) Atmospheric N deposition. N offtake as N-Output from the field includes main product and - if not left on the field - by-product as well. The N balance is calculated taking into account the N inputs minus the N outputs results N balance.

3.3. Other methods

3.3.1. Method for estimating fertilisation accuracy in regional level

In national/regional level, the impact of new manure data on nutrient leaching risk was estimated using the following method. First, the old and new manure properties data were used to calculate soluble/plant available nitrogen and total phosphorus content of manure build up in the region. Then, the difference between these two datasets for N and P was calculated. Finally, those values were related to the N and P demand of the crops in the region.

If old manure data indicate lower amounts of nutrients in the manure than calculated with new data, old data have underestimated manure nutrient content, resulting in over fertilisation. Introducing new manure data in fertilisation planning will then decrease previously over-optimal fertilisation rates, resulting in reduced nutrient leaching risk. In the opposite case the nutrient leaching risk may increase

3.3.2. Change in estimates of national atmospheric emissions originating from manure

The aim was also to estimate the relative change in national estimates of atmospheric emissions (NH_3, NOx, N_2O) from livestock farming when the old excretion data are replaced with new.

This was done based on the latest emission inventory results reported to UNECE and EU and the excretion values for total nitrogen used in the emission inventories (representing the old manure data), and the new excretion data obtained from this study.

In emission inventory calculations, nitrogen excretion rates are one of the most important parameters. The higher annual N (or TAN[1]) excretion rate per animal place, the higher N emission rate (e.g. ammonia). If all other affecting factors remain the same, the relative change in emission estimates is equal with the relative change in N excretion rate.

This information was used to calculate new emission estimates for each animal category separately. After summing up emissions of all animal categories for old and new emissions values, the relative change between the estimates of total emissions was calculated separately for each emission parameter.

[1] TAN = Total Ammoniacal Nitrogen

4. Country-specific results

The results and country specific data sources and modifications to the methods are presented separately for each BSR country (except Denmark, which was not participating in WP4) in alphabetical order.

4.1. Estonia

4.1.1. Comparison of the old and new manure data

In the farm scale modelling, old values were based on the regulation of Ministry of Agriculture No. 71. 14. 07. 2014 “Estimated values of nutrient content of different types of manure, methodology for calculating the volume of manure storage facilities and coefficients of conversion of livestock into livestock units”, related to the Water Act. These table values were used as old manure data, to be used as reference values. The new values were based on manure samples taken from the pilot farms.

According to manure sampling and analyses, performed in 2017, the dairy farms with slurry showed lower total nitrogen and total phosphorus content than table values. The content of ammonium nitrogen was about twice higher than the old value. (**Table 1**.)

For the beef cattle on deep litter, the content of total and ammonium nitrogen were higher, and content of total phosphorus was lower than table values.

For poultry farms, the analysed values were in general much higher than table values. There was also a big difference between farms.

For the national level, table values from the regulation of Ministry of Agriculture (see above) were used as old values and manure properties calculated with the regional calculation tool in WP3 were used as new values. Old and new data are shown in **Table 2**.

Table 1. Old and new ex storage manure data for total nitrogen (Tot-N), ammonium nitrogen (NH_4-N) and total phosphorus (Tot-P), used as manure parameters in pilot farm scale (kg/ton of manure), and the percentage change between new and old values. Old data are based on the table values (Regulation of the Ministry of agriculture, see text), and new data are based on the manure samples taken by the professional in WP2.

	Tot-N (kg/t)			NH_4-N (kg/t)			Tot-P (kg/t)		
	Old	New	Diff.	Old	New	Diff.	Old	New	Diff.
Dairy cattle, slurry (Pilot farm 1)	4.74	4.15	-12%	1.23	2.55	+107	1.22	0.64	-47%
Poultry, deep litter (Pilot farm 2)	11.27	32.1	184%	5.75	5.33	-7.3	3.32	7.7	132%
Beef cattle, deep litter (Pilot farm 3)	5.40	5.9	9	0.49	0.85	+73.5	1.08	0.66	-39%
Dairy cattle liquid (Pilot farm 4)	4.74	3.5	-26	1.23	2.25	+82.9	1.22	0.58	-52%
Poultry, solid (Pilot farm 5)	11.27	21.75	93	5.75	14.95	+160	3.32	4.58	38%
Beef cattle, deep litter (Pilot farm 6)	5.40	6.45	+19	0.49	1.55	+216	1.08	0.72	-33%

Table 2. Old and new ex storage manure data used as manure parameters in national scale studies. Old data are based on the table values (Regulation of the Ministry of agriculture) and new data are based on the manure calculation tool developed in WP3.

	Tot-N (kg/t)			NH_4-N (kg/t)			Tot-P (kg/t)		
	Old	New	Diff.	Old	New	Diff.	Old	New	Diff.
Cattle solid manure	4.36	6.63	+52%	0.68	0.82	+20%	1.37	0.7	-49%
Cattle slurry	4.74	3.78	-20%	1.23	1.9	+54%	1.22	0.6	-51%
Cattle urine									
Pig solid manure	4.92	*	-	1.45	*		1.25	*	-
Pig slurry	5.50	*	-	2.74	*		1.27	*	-
Pig urine									
Sheep solid manure	6.71	*	-	0.68	*		1.20	*	-
Goat solid manure	6.84	*	-	0.68	*		1.24	*	-
Horse solid manure	6.56	*	-	0.38	*		1.59	*	-
Laying hen solid manure	11.27	19.5	+73%	5.75	8.0	+39%	3.32	5.5	+66%
Broiler solid manure	9.31	25.2	+171%	5.75	10.37	+80%	3.79	5.67	+50%

* new values were not calculated in this project

4.1.2. Impacts of using the new manure data

4.1.2.1. Results from the pilot farm modelling

NBBM modelling

Data from dairy cattle farm (pilot farm 1) were used in NBBM model (N efficiency factors mode) to calculate the impacts of the new manure data to nutrient balances and nitrogen leaching risk in farm level. Four other pilot farms had only animal production without plant production and could not be used as example farms. In calculations the reference values from the regulation of Ministry of Agriculture were used as old manure data, and the results from manure analysis as new manure data. When introduced new manure data, there was slight increase in nitrogen balance, and moderate increase in phosphorus balance (**Table 3**)

Relative change in nitrogen leaching risk after introducing new manure data was -2%.

Table 3. Relative change in average nutrient balances after introducing new manure data in pilot farm 1.

Total N	Plant available N	Total P	Plant available P
-6%	-7%	-3%	-7%
decrease	decrease	decrease	decrease

CCB modelling

Farm EE1 representing large scale Estonian loose housing dairy farm. In 2017 winter barley and hemp were grown on the farm. The textural class of soil according USDA is identified as a loamy sand; soil organic carbon content of soil amounts 3.02%, the mean air temperature and precipitation is about 6°C respectively 733 mm (**Table 4**). This results in a relatively high BAT of 26.7 d (**Table 6**), which causes to a comparatively fast turnover of organic matter in the soil.

The table values and measured values of manure quality are more or less similar except for the C content, which is below the table values (**Table 5**). This results in a lower Rep_IX (**Table 6**) and to a lower C saldo, CO_2 production as well as N mineralisation (**Figure 1**) by using measured values of manure quality. However, carbon storage in both cases remains at approximately the same level (**Figure 1**).

Table 4. Soil and climate input data for the CCB model.

Corg (%) start value	3.02
Soil texture	Clay 11.7%; Silt 14.3%
Air Temperature (C°)	5.95
Precipitation (mm/yr)	732.95

Table 5. Utilised parameters (DM - Dry matter, N – Nitrogen, C - Carbon, CNR – C/N ratio) of manure from national references (table values) and measurements of laboratories (measured values).

Cattle slurry	**DM [%]**	**N [kg/t FM]**	**C [kg/t FM]**	**CNR**
Table values	8.00	4.75	53.52	11.27
Measured values	7.65	4.15	46.74	11.27

Table 6. Simulated Biologic active time (BAT) and Soil organic matter reproduction index = $C_{reproduction}$/BAT (REP_IX).

	BAT (d/a)	**Rep_IX**
Table values	26.7	43.9
Measured values		39.8

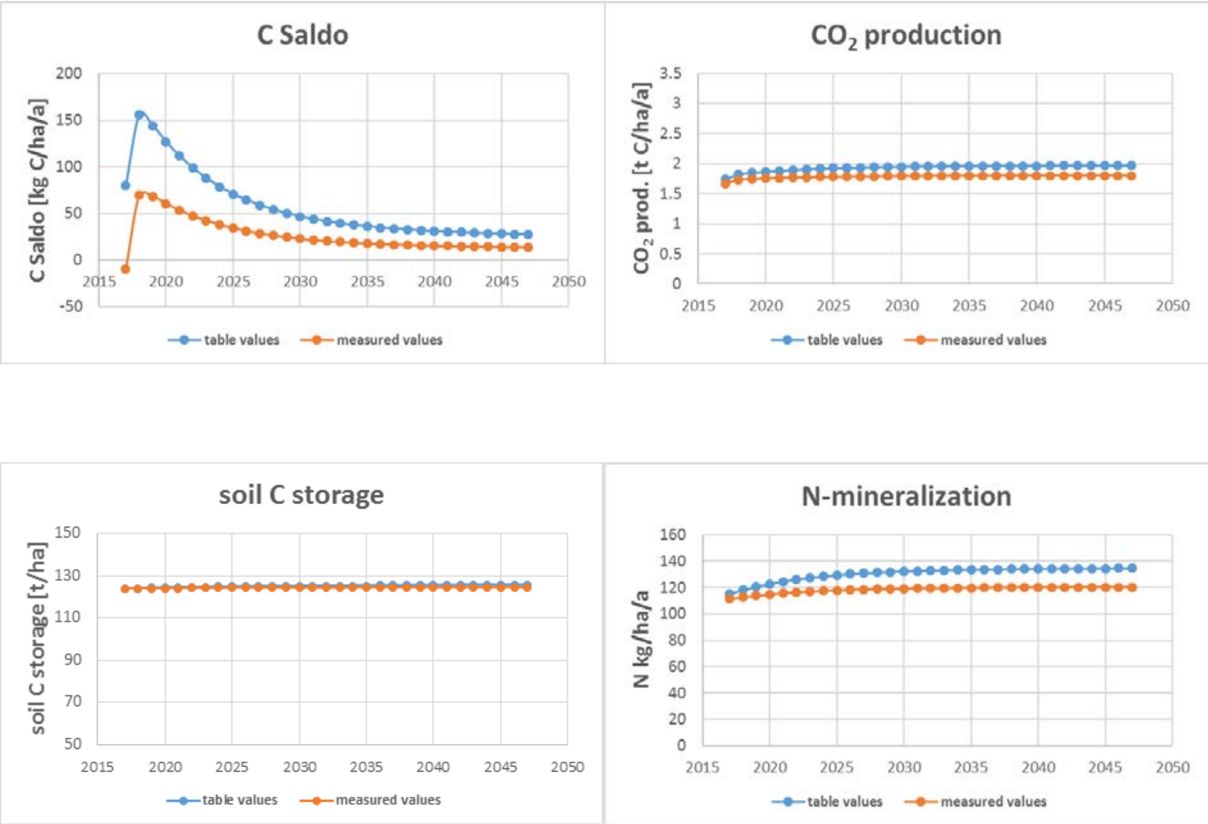

Figure 1. Simulated C saldo, CO_2 production, soil C storage and N-mineralisation of Farm EE1

4.1.2.2. Results from the regional modelling

CCB modelling

EE_Jogeva representing a region of Estonia. In 2017 spring and winter rape, spring and winter barley, spring and winter wheat, oat, winter rye, potato, pea as well as winter triticale were grown in this region. Main textural class of soil according USDA is identified as a sandy loam; soil organic carbon content of soil is presumed to be 2%, the mean air temperature and precipitation is about 6°C respectively 667 mm (**Table 7**). This results in a relatively low BAT of 10.5 d (**Table 9**), which causes to a comparatively slow turnover of organic matter in the soil.

Scenario 1 assumes 100% mineral fertiliser use and Scenario 2 replaces 60% of the nitrogen requirement with organic fertilisers of the quality from **Table 8**. In both cases, more carbon will be sequestered in the soil than is emitted into the atmosphere (***Figure 2***). However, in scenario 2, the C saldo and C storage level is higher, and more carbon and nitrogen are mineralised.

Table 7. Soil and climate input data for the CCB model.

Corg (%) start value	2 (presumed)
Soil texture	Clay 17%; Silt 40%
Air Temperature (C°)	5.9
Precipitation (mm/yr)	667

Table 8. Utilised parameters (DM - Dry matter, N – Nitrogen, C - Carbon, CNR – C/N ratio) of manure from national references (table values).

	DM [%]	N [kg/t FM]	C [kg/t FM]	CNR
Table values	8.08	3.83	43.15	11.26

Table 9. Simulated Biologic active time (BAT) and Soil organic matter reproduction index = $C_{reproduction}$/BAT (REP_IX).

	BAT (d/a)	Rep_IX
Scenario 1	10.5	69.5
Scenario 2		108.0

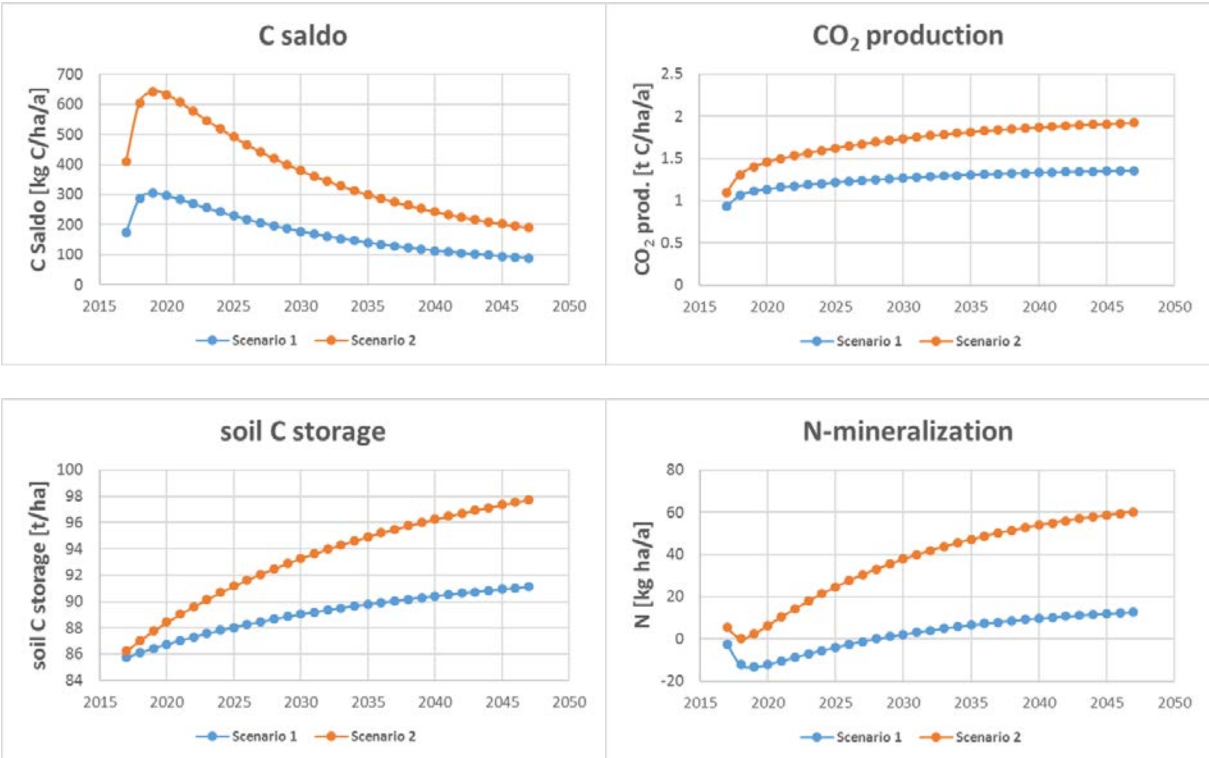

Figure 2. Simulated C saldo, CO_2 production, soil C storage and N-mineralisation of the EE_Jogeva region.

4.2. Finland

4.2.1. Comparison of the old and new manure data

Ex storage manure data for fertilisation planning

In Finland, table values in nitrates decree (1250/2014) are used as ex storage manure data for fertilisation planning. Animal farms can also use their own manure analysis results. Manure must be analysed at least every fifth year (1250/2014). In this project, table values were used as old manure data, to be used as reference values in national and pilot farm level. Because the original values were per cubic meter of manure, they were converted to mass based (per ton) values. When converting, pilot farms were supposed to use their own manure analysis results for manure volume weights (**Table 10**).

In the case of using the table values in national level, the mass-based values were taken from the same large manure analysis database as used when the volume-based table values have been produced (**Table 11**). In regional studies, the results of the Finnish normative manure system (Luostarinen et al. 2017) were used as new manure data because data for all animal categories were not available from the manure calculation tool developed in WP3.

Table 10. Old and new ex storage manure data for total nitrogen (Tot-N), soluble nitrogen (Sol-N) and total phosphorus (Tot-P), used as manure parameters in pilot farm scale (kg/ton of manure), and the percentage change between new and old values. Old data are based on the table values (Nitrates decree; 1250/2014, see text), and new data are based on the manure samples taken by the professional in WP2.

	Tot-N (kg/t)			Sol-N (kg/t)			Tot-P (kg/t)		
	Old	New	Diff.	Old	New	Diff.	Old	New	Diff.
Dairy cattle, slurry (Pilot farm 1)	2.9	3.1	+8%	1.7	2.0	+16%	0.5	0.4	-29%
Dairy cattle, solid manure (dung) (Pilot farm 2)	4.3	4.8	+12%	1.2	1.5	+31%	1.1	0.8	-24%
Dairy cattle, urine (Pilot farm 2)	2.5	0.8	-67%	1.7	0.6	-64%	0.5	0.02	-96%
Beef cattle, slurry (Pilot farm 3)	2.9	3.0	+2%	1.7	1.8	+6%	0.5	0.5	+8%
Suckler cows, deep litter (Pilot farm 4)	4.3	6.7	+57%	1.2	1.2	-1%	1.1	1.2	+16%
Fattening pigs, slurry (Pilot farm 5)	3.4	4.3	+27%	2.2	2.9	+33%	0.8	0.9	+8%
Broilers, deep litter (Pilot farm 6)	21.4	23.1	+8%	6.6	5.5	-17%	8.9	5.4	-39%

** Based on Nitrates decree 1250/2014, where manure properties are expressed as kg/m^3 of manure. The conversion to kg/ton was made using the volume weights obtained from pilot farms' own manure analysis results.

Table 11. Old and new ex storage manure data used as manure parameters in national scale. Old data are based on the table values (Nitrates decree; 1250/2014; see text) and new data are based on the Finnish normative manure system (Luostarinen et al. 2017).

	Tot-N (kg/t)			Sol-N (kg/t)			Tot-P (kg/t)		
	Old	New	Diff.	Old	New	Diff.	Old	New	Diff.
Cattle solid manure	5.45	3.98	-27%	1.40	0.67	-52%	1.42	0.68	-52%
Cattle slurry	2.90	4.2	+45%	1.68	2.48	+48%	0.48	0.74	+55%
Cattle urine	2.50	4.47	+79%	1.50	4.25	+183%	0.10	0.12	+20%
Pig solid manure	6.98	11.67	+67%	1.85	2.50	+35%	4.26	3.95	-7%
Pig slurry	3.44	3.94	+15%	2.24	2.58	+15%	0.81	0.89	+9%
Pig urine	2.00	3.46	+73%	1.30	3.36	+158%	0.20	0.16	-20%
Sheep solid manure	9.02	n.d.	-	1.67	n.d.	-	2.18	n.d.	-
Goat solid manure	9.02	6.00	-33%	1.67	1.20	-28%	2.18	1.40	-36%
Horse solid manure	4.87	3.40	-30%	0.92	0.48	-48%	1.00	0.76	-24%
Laying hen solid manure	12.83	14.00	+9%	5.29	3.50	-34%	7.73	5.40	-30%
Broiler solid manure	22.22	24.30	+9%	6.60	4.18	-37%	9.06	11.90	+31%
Turkey solid manure	17.15	30.00	+75%	6.10	5.20	-15%	9.60	11.90	+24%

n.d. = no data

Ex animal manure data for atmospheric emission estimates

To be able to estimate changes in national atmospheric nitrogen emission estimates for animal husbandry, also new and old excretion values of total nitrogen, total ammoniacal nitrogen (TAN) and volatile solids (as kg/animal place/year) were compared. Currently in Finland, excretion values used in national emission inventories are calculated by Natural Resources Institute Finland (Luke), and are documented in national emission inventory reports. As new excretion data **for cattle**, values obtained from manure calculation tool developed in WP3 were used. **For pigs,** most recent excretion data based on the updated national calculation method of Luke were used. New excretion data were not available for other animal categories and the old data were used. Both data sets and the percentage change between them per animal category and manure parameter are presented in **Table 12**.

Because in the Finnish calculation system the emissions of NH_3, and NOx are based on the TAN content of manure, the TAN of excreted manure must be known. For mammals, it is assumed that all nitrogen in urine is TAN and all nitrogen in faeces is organically bound (e.g. Haenell et al. 2016). For poultry, uric acid nitrogen (UAN) excreted is considered completely TAN (Haenell et al. 2016). However, as the Finnish normative manure system calculates only total nitrogen excretion for poultry, the proportion of UAN is assumed to be 70% of the total nitrogen, following the default value presented in EMEP/EEA (2016).

Table 12. Old and new excretion data (total nitrogen, total ammoniacal nitrogen (TAN), as kg/animal place/year) and the percentage changes between them, used in atmospheric emission estimation. For other animals than poultry the TAN content of excreted manure equals with the total nitrogen content of urine. For poultry, 70% of total nitrogen is assumed to be TAN, following the default value presented in EMEP/EEA (2016).

	Tot-N (kg/ap/yr)			TAN (kg/ap/yr)		
	Old	New	Diff.	Old	New	Diff.
Dairy cow	133.41	126.7	-5%	79.81	61.7	-23%
Suckler cow	69.98	71.0	+6%	42.92	51.7	+20%
Heifer >1 yr	55.51	52.6	-5%	36.23	36.5	+1%
Bull >1 yr	69.63	43.9	-37%	45.65	30.1	-34%
Calf <1 yr	40.91	34.50	-16%	26.68	22.90	-14%
Sow (with piglets)[a]	31.95	25.07	-22%	24.03	20.33	-15%
Boar (50- kg)	20.81	14.52	-30%	15.34	11.04	-28%
Fattening pig (50- kg)	17.22	16.50	-4%	11.38	12.20	+7%
Weaned pig (<50 kg)	9.13	4.35	-52%	4.93	3.44	-30%
Laying hen breeder	0.60	n.d.	-	0.42	n.d.	-
Cockerel	0.97	n.d.	-	0.68	n.d.	-
Broiler	0.48	n.d.	-	0.33	n.d.	-
Broiler breeder hen	0.99	n.d.	-	0.69	n.d.	-
Pullet	0.39	n.d.	-	0.27	n.d.	-
Turkey	1.66	n.d.	-	1.16	n.d.	-
Other poultry	0.64	n.d.	-	0.45	n.d.	-
Horse	59.53	n.d.	-	39.54	n.d.	-
Pony	44.48	n.d.	-	29.33	n.d.	-
Sheep	9.97	n.d.	-	5.98	n.d.	-
Goat	10.70	n.d.	-	6.42	n.d.	-
Fox	3.00	n.d.	-	1.80	n.d.	-
Mink	1.31	n.d.	-	0.78	n.d.	-
Reindeer	10.70	n.d.	-	6.42	n.d.	-

[a] An average of farrowing, gestating and mating sows + piglets until weaning
n.d. = no data. Old values are used instead in further calculations.

4.2.2. Impacts of using the new manure data

4.2.2.1. Results from the pilot farm modelling

NBBM modelling

Data from six pilot farms were used to calculate the impacts of new manure tools to fertilisation and nutrient balances in the farm level. Based on that, the impacts on nitrogen and phosphorus leaching risk were estimated, based on the methods described in chapter 3. In the Finnish case, the NBBM mode for soluble nitrogen concentrations was used. The yields of cereals and grasses were estimated based yield response to fertilisation functions based on the Finnish studies of Valkama et al. 2013 (cereals) and Salo et al. 2013 (grasses).

Averagely 40% of the total acreage of the pilot farms was used for manure application. For all farms, table values were used as old manure data, and farms' new manure analysis results from this study were used as new manure data (see chapter 4.2.1). When introducing new manure data, the level of change in nutrient balances in farm level depends on the difference between old and new manure data and the share of fields where manure is applied.

If manure nutrient content is presently under estimated, introducing new manure data cause decreasing fertilisation rates and nutrient balances, and vice versa. However, the model assumes that only mineral fertilisation is adjusted if fertilisation adjustment is needed due to the changes in manure nutrient composition data. This means that, as is the case for Finnish fattening pig pilot farm, if manure phosphorus content is under estimated but no mineral P is currently applied on fields receiving manure, the actual P fertilisation level does not change due to introducing new manure data because manure application rates remain unaffected. However, when, at the same time, nitrogen fertilisation is decreased on the fields receiving manure (because old manure data under estimated manure nitrogen content), yields on those fields decrease, causing increase in P balances (see **Table 13**).

The reason on why the model does not automatically change manure application levels but the fertilisation adjustment is done by changing mineral fertilisation rates, is that changing manure application rates affect the allocation of the total amount of manure to the farm's total field area. Because it was not known on how the reallocation should be done for each pilot farm, the manure application rates were decided to be kept unaffected.

Among the Finnish pilot farms, the change in nitrogen and phosphorus leaching risk due to introducing new manure data is rather small or is negative. It must be kept in mind that the risk values describe only the effect of introducing the new manure data. For all Finnish pilot farms, because of the low, usually negative, phosphorus balances when either old or new manure data are used, the trend in STP concentration and thus also the risk for P leaching is decreasing. Introducing new manure data only speeds up or slows down this trend.

Table 13. Summary table for Finnish pilot farm results of NBBM modelling.

Animal type	Manure type	Farm acreage (ha)	% of acreage received manure	Basis of manure application rates		Average nutrient balances with old manure data (present actual; kg/ha)			Average nutrient balances with new manure data (new actual; kg/ha)			Difference between "new" and "present" nutrient balances (%)			Difference in leaching risk (from "present" to "new", %)	
				Old manure data	New manure data	Ntot	Nsol	Ptot	Ntot	Nsol	Ptot	Ntot	Nsol	Ptot	Nsol	P (10 yrs)
Suckler cows	Deep litter	376.1	16%	Table values	Farm's new manure analysis taken by Luke	41.85	17.15	-3.43	41.92	17.22	-3.70	0%	0%	-8%	0.1%	-0.2%
Broilers	Deep litter	157.9	20%	Table values	Farm's new manure analysis taken by Luke	45.68	40.51	-8.81	45.98	40.81	-8.81	1%	1%	0%	0.0%	0.0%
Dairy cattle	Slurry	207.2	73%	Table values	Farm's new manure analysis taken by Luke	86.09	56.42	-6.49	80.55	50.88	-6.32	-6%	-10%	+3%	-3.5%	+0.2%
Dairy cattle	Solid+urine	56.9	32%	Table values	Farm's new manure analysis taken by Luke	-3.56	-19.59	-10.30	-1.75	-17.78	-9.22	51%	9%	+10%	0.0%	+2.0%
Bulls	Slurry	89.6	51%	Table values	Farm's new manure analysis taken by Luke	11.16	1.91	-3.96	10.78	1.54	-4.02	-3%	-19%	-2%	0.0%	-0.1%
Fattening pigs	Slurry	125.4	77%	Table values	Farm's new manure analysis taken by Luke	88.61	61.43	+4.98	75.41	48.23	+5.20	-15%	-21%	+4%	-16.2%	+0.2%
		1013.1														
		Received manure:										**Weighted averages:**				
		403.5 ha	40%									-0.4%	-5.6%	-1.4%	-2.7%	+0.1%

CCB modelling

Farm FI1 represents Finnish dairy production and a slurry-based housing system. All of the area is grassland. The textural class of soil according USDA is identified as a clay loam; soil organic carbon content of soil amounts 5.1%, the mean air temperature and precipitation is about 3°C respectively 644 mm (**Table 14**). This results in a BAT of 5.9 d (**Table 16**), which causes to a comparatively slow turnover of organic matter in the soil.

Table 14. Soil and climate input data for the CCB model.

Corg (%) start value	5.1
Soil texture	Clay 27.5%; Silt 32.27%
Air Temperature (C°)	3.45
Precipitation (mm/yr)	644

The table values and measured values of cattle solid are more or less similar except for the C content, which is below the table values (**Table 15**). This all together results in a lower Rep_IX (**Table 16**) and to a little less C saldo and CO_2 production (***Figure 3***) by using measured values of manure quality. However, carbon storage level as well as N mineralisation in both cases are similar (***Figure 3***).

Table 15. Utilised parameters (DM - Dry matter, N – Nitrogen, C - Carbon, CNR – C/N ratio) of manure from national references (table values) and measurements of laboratories (measured values).

Cattle solid	**DM [%]**	**N [kg/t FM]**	**C [kg/t FM]**	**CNR**
Table values	22.80	3.09	81.17	26.31
Measured values	17.00	3.24	60.52	18.68
Cattle urine	**DM [%]**	**N [kg/t FM]**	**C [kg/t FM]**	**CNR**
Table values	1.80	1.00	4.14	4.14
Measured values	0.40	0.22	0.92	4.11

The table values and measured values of cattle solid are more or less similar except for the C content, which is below the table values (**Table 15**). It is different with the cattle urine. At a same CN ratio, the measured values are more than half smaller. This all together results in a lower Rep_IX (**Table 16**) and to a little less C saldo and CO_2 production (***Figure 3***) by using measured values of manure quality. However, carbon storage level as well as N mineralisation in both cases are similar (***Figure 3***).

Table 16. Simulated Biologic active time (BAT) and Soil organic matter reproduction index = $C_{reproduction}$/BAT (REP_IX).

	BAT (d/a)	Rep_IX
Table values	5.9	310.7
Measured values		295.8

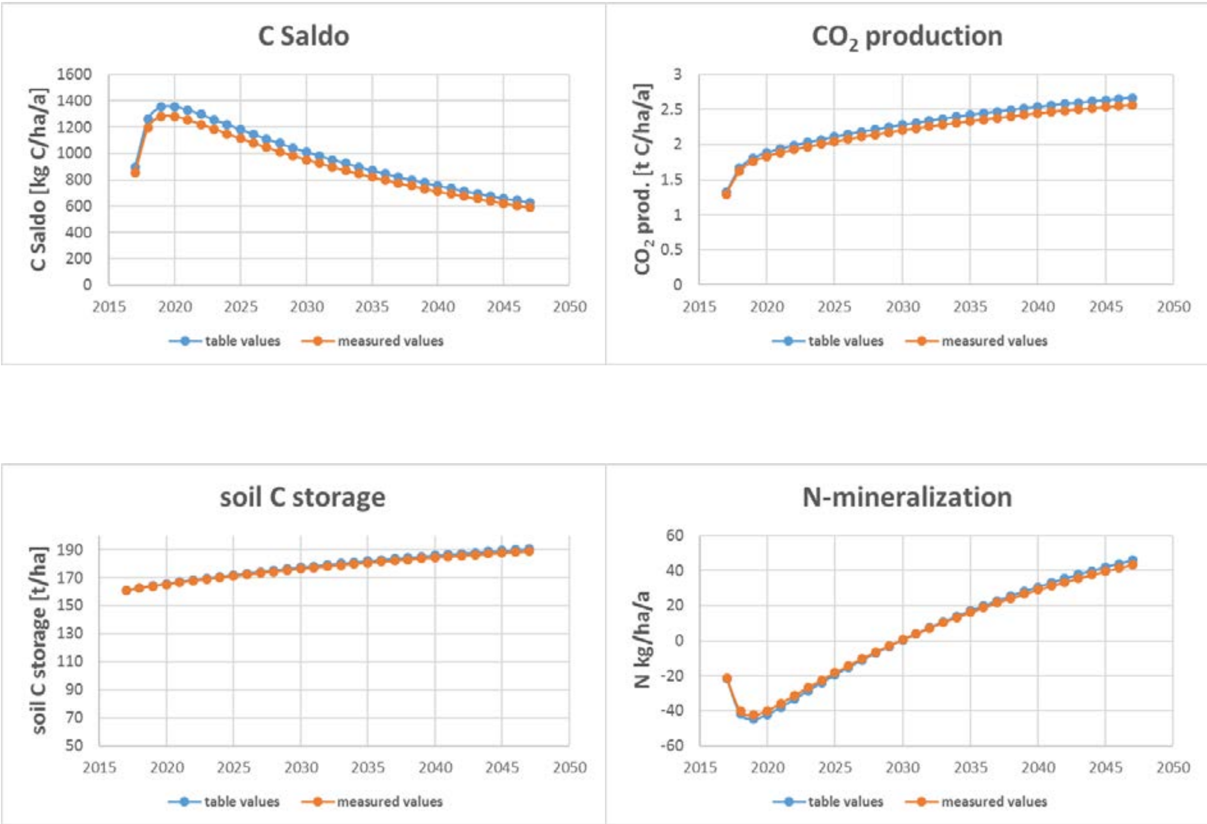

Figure 3. Simulated C saldo, CO_2 production, soil C storage and N-mineralisation of Farm FI1.

Farm FI2 represents also Finnish dairy production. In 2017 winter rye, oat, field bean, winter wheat and green rye were grown on the farm. Two third of the area is grassland. The textural class of soil according USDA is identified as a silty clay; soil organic carbon content of soil is presumed to be 2%, the mean air temperature and precipitation is about 5°C respectively 597 mm (**Table 17**). This results in a BAT of 13.7 d for plowed arable land and 7.8 for grassland (**Table 19**), which causes to a comparatively moderate turnover on arable land and slow turnover on grassland of soil organic matter.

Table 17. Soil and climate input data for the CCB model.

Corg (%) start value	2.0 (presumed)
Soil texture	Clay 45%; Silt 27.5%
Air Temperature (C°)	5.25
Precipitation (mm/yr)	596.5

The measured values of manure quality are more or less similar except for the N content and CN Ratio, which is different from table values (**Table 18**). This results in a comparable Rep_IX (**Table 19**) and to equal results of C saldo, CO_2 production and and soil C storage (***Figure 4*** & ***Figure 5***) by using measured or table values of manure quality. Due to higher assumed application rate N mineralisation in arable land is increased by using measured values (***Figure 4***).

Table 18. Utilised parameters (DM - Dry matter, N – Nitrogen, C - Carbon, CNR – C/N ratio) of manure from national references (table values) and measurements of laboratories (measured values).

Cattle deep litter	**DM [%]**	**N [kg/t FM]**	**C [kg/t FM]**	**CNR**
Table values	22.80	4.39	83.22	18.94
Measured values	22.50	5.55	82.13	14.78

Table 19. Simulated Biologic active time (BAT) and Soil organic matter reproduction index = $C_{reproduction}$/BAT (REP_IX).

	BAT (d/a) (arable land)	**Rep_IX (arable land)**	**BAT (d/a) (grassland)**	**Rep_IX (grassland)**
Table values	13.8	74.4	7.9	206.7
Measured values		73.8		206.5

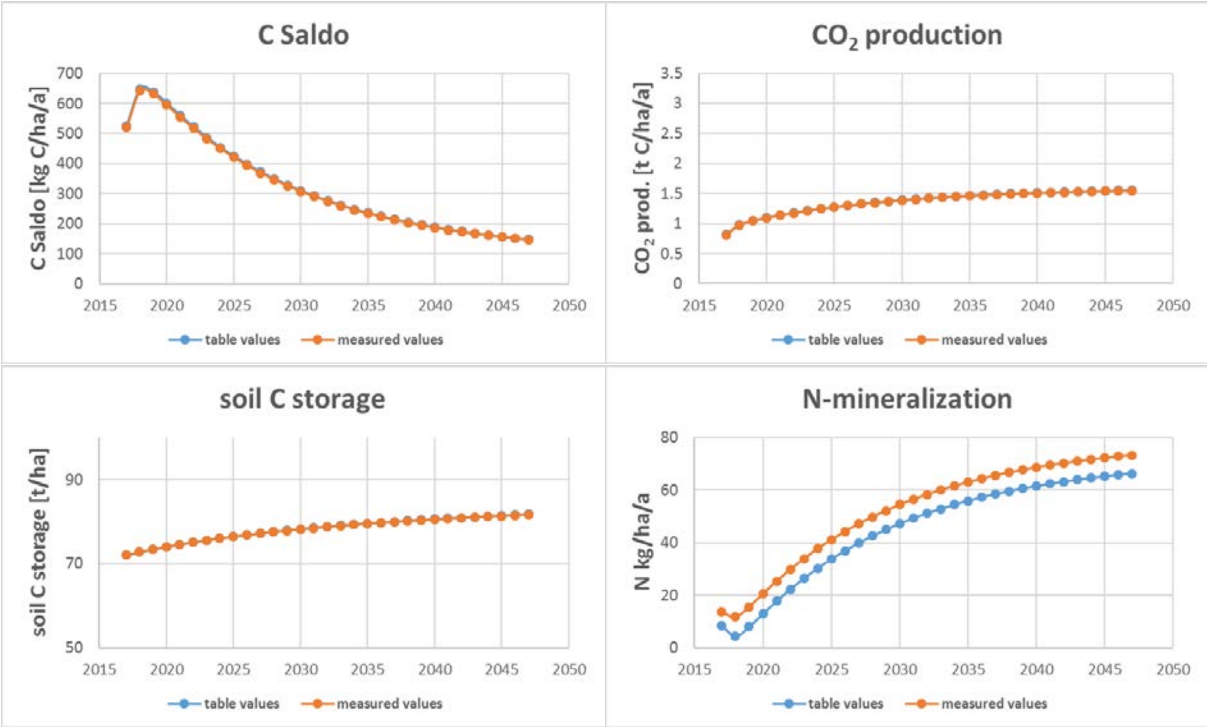

Figure 4. Simulated C saldo, CO_2 production, soil C storage and N-mineralisation of Farm FI2 arable land.

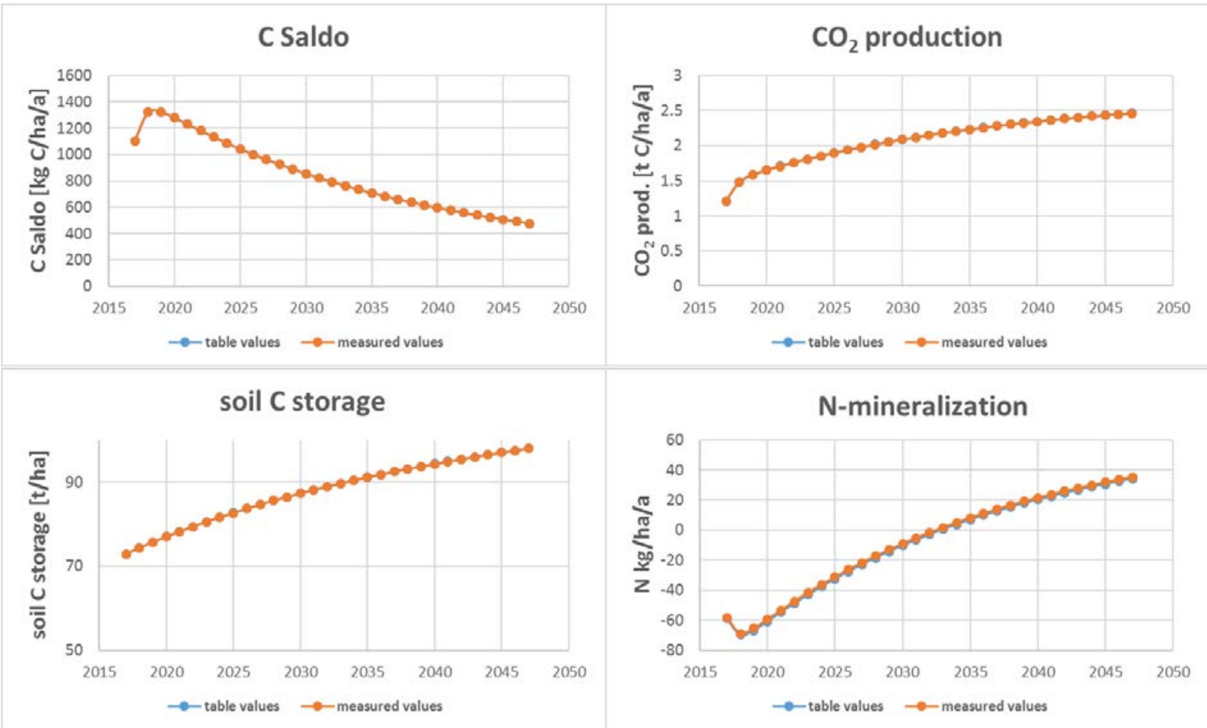

Figure 5. Simulated C saldo, CO_2 production, soil C storage and N-mineralisation of Farm FI2 grassland.

Farm FI3 is focused on beef cattle with mixed bull and heifer production. In 2017 winter/spring wheat, sugar beet, winter barley, oat and winter triticale were grown on the farm. Half of the area is grassland. The textural class of soil according USDA is identified as a silty clay; soil organic carbon content of soil amounts 3%, the mean air temperature and precipitation is about 5°C respectively 597 mm (**Table 20**). This results in a BAT of 13.7 d for plowed arable land and 7.8 for grassland (**Table 22**), which causes to a comparatively moderate turnover on arable land and slow turnover on grassland of soil organic matter.

The table values and measured values of manure quality are similar (**Table 21**). This results also in a comparable Rep_IX (**Table 22**) and to similar C saldo, CO_2 production and soil C storage (***Figure 6*** & ***Figure 7***) by using measured values or table values of manure quality. However, only N mineralisation is increased by using measured values (***Figure 6*** & ***Figure 7***).

Table 20. Soil and climate input data for the CCB model.

Corg (%) start value	3
Soil texture	Clay 45%; Silt 27.5%
Air Temperature (C°)	5.25
Precipitation (mm/yr)	596.5

Table 21. Utilised parameters (DM - Dry matter, N – Nitrogen, C - Carbon, CNR – C/N ratio) of manure from national references (table values) and measurements of laboratories (measured values).

Cattle slurry	**DM [%]**	**N [kg/t FM]**	**C [kg/t FM]**	**CNR**
Table values	5.50	1.20	19.86	16.55
Measured values	5.20	1.16	18.77	16.14

Table 22. Simulated Biologic active time (BAT) and Soil organic matter reproduction index = $C_{reproduction}$/BAT (REP_IX).

	BAT (d/a) (arable land)	**Rep_IX (arable land)**	**BAT (d/a) (grassland)**	**REP_IX (grassland)**
Table values	13.7	51.0	7.9	244.8
Measured values		50.0		242.0

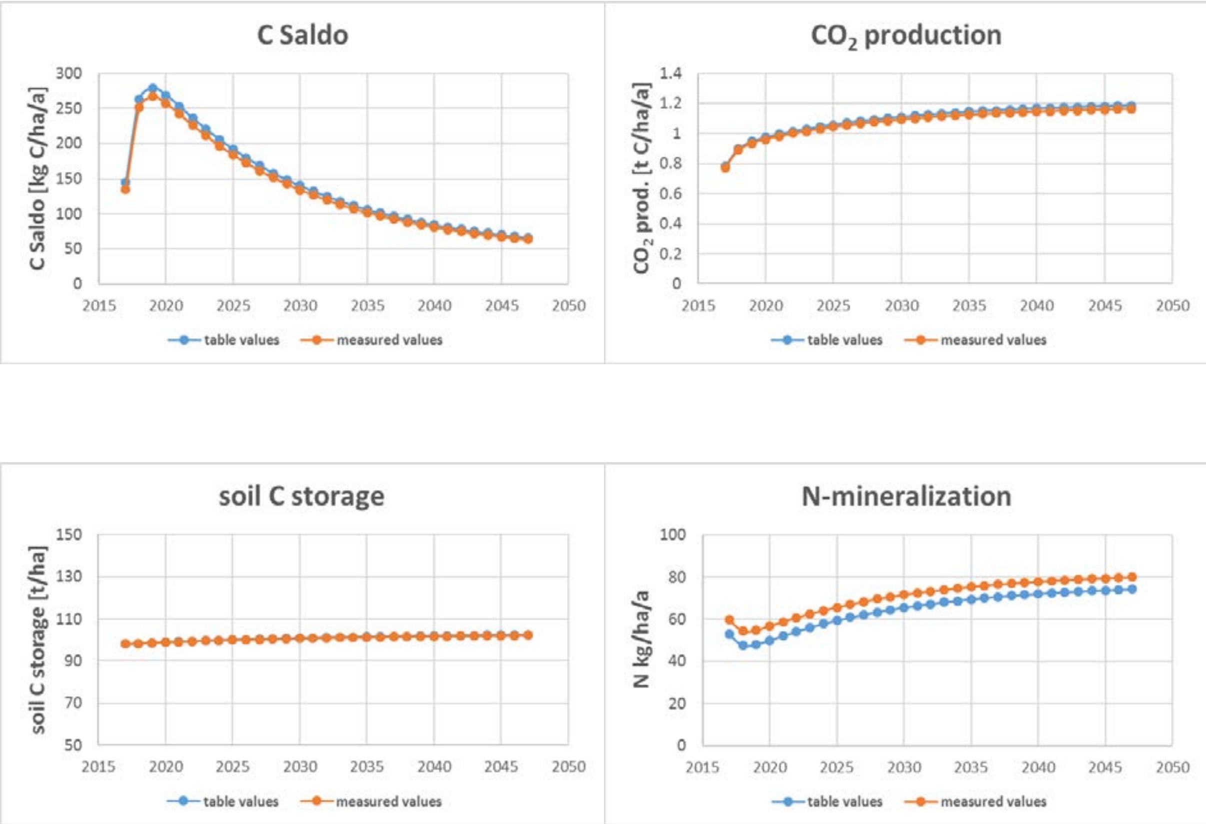

Figure 6. Simulated C saldo, CO_2 production, soil C storage and N-mineralisation of Farm FI3 arable land.

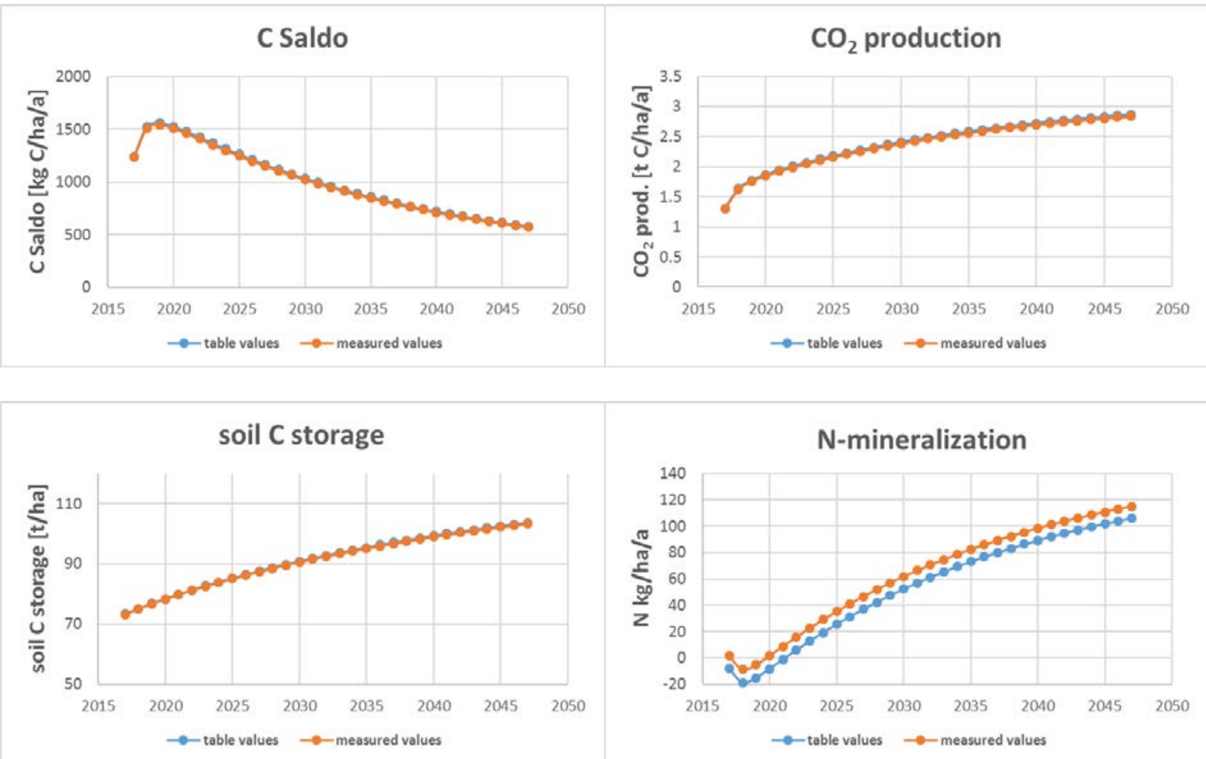

Figure 7. Simulated C saldo, CO_2 production, soil C storage and N-mineralisation of Farm FI3 grassland.

4.2.2.2. Results from the regional modelling

Fertilisation accuracy method

As described in chapter 3.3.1, this method reveals roughly the rate of over or under fertilisation which is caused by using the old manure data instead of the new. In the Finnish case, the total country was used as a case region.

The Finnish normative manure system (Luostarinen et al. 2017) was used to calculate the masses of manure nitrogen and phosphorus for the whole country. This data were used as new manure data. Old manure data based on the manure table values. The ratio between new and old manure nutrient concentrations (kg/t of manure) was then used to estimate the total nutrient content of manure based on old manure data (see chapter 4.2.1).

Nutrient demand of the crops was calculated based on the requirements of the environmental compensation payments in rural development programme 2014-2020, and Finnish calculation tool for regional nutrient recycling (used by policymakers and authorities; Luke & SYKE 2019) was used to perform the calculation.

As can be seen from **Table 23**, using the old manure data results under fertilisation of phosphorus, because the new data show that actual manure phosphorus content is lower than is expected based on the old data. Introducing new manure data in fertilisation planning would cause increasing actual application rates of phosphorus, resulting increasing phosphorus leaching risk.

For soluble (plant available) nitrogen, the over fertilisation is relatively small. Introducing new manure data in fertilisation planning would slightly decrease nitrogen fertilisation rates.

Table 23. The accuracy of soluble nitrogen (Nsol) and phosphorus (P) fertilisation currently in Finland, based on the assumption that new manure data (Finnish normative manure system) represents more precise estimate on manure nutrient content than the old data (table values).

Nutrient demand of the crops, (tons)		From manure ex storage (based on old manure data)		Actual amounts of manure nutrients ex storage, based on new manure data		Current over/under fertilisation (tons)		Current over/under fertilisation, % of the nutrient demand	
N	P	Nsol	P	Nsol	P	Nsol	P	Nsol	P
343 900	27 700	33 953	18 136	38 730	15 768	4 777	-2 368	+1.4%	-8.5%

Changes in estimates of national atmospheric emissions originating from manure

Old and new excretion data used in this task are shown in chapter 4.2.1. Emission data of 2017 were obtained from emission inventory reports (Finnish Environment Institute 2019) and if more detailed data were needed, directly from the national emission calculation system (Grönroos et al. 2017). New excretion data were available only for cattle and pigs.

The results show that emission estimates of all three nitrogen compounds decrease if new manure data are introduced (**Table 24**). This I due to decreased nitrogen excretion values of all other animals except suckler cows (total-N and NH_4-N) and fattening pigs (NH_4-N).

Changes in emission estimates for emission inventories and emission reduction commitments (the National Emission Ceilings Directive (NECD) and the Gothenburg Protocol), are only relevant if the new excretion (ex animal) data affect the relative difference in emissions between base year (2005) and the year under review. In this study, it was not possible to estimate the possible changes in the emissions of the base year. However, it is likely that the relative change in the base year emissions estimate would be the same as presented here for 2017. In that case, the new manure data, or rather the new excretion calculation systems, would not affect the achievement of the emission reduction commitments.

Table 24. Summary of emission estimates (2017) for ammonia (NH_3), direct nitrous oxide (N_2O) and nitrogen oxides (NOx) originating from manure, based on currently used (old) manure data and new manure data obtained from this study.

	NH_3	**N_2O**	**NOx**
Original 2017 emission values (tons)	27 763	2 276	3 787
Emissions calculated with new manure data (tons)	24 464	2 079	3 349
Difference (tons)	-3 298	-196	-439
Difference (%)	-12%	-9%	-12%

CCB modelling

FI_Varsinais-Suomi representing a region of Finland. In 2017 winter rape, cereal grain mix, oat, winter barley, winter rye, spring and winter wheat, pea, potato, field bean, sugar beet as well as grass for silage were grown in this region. Main textural class of soil according USDA is identified as a silty clay; soil organic carbon content of soil is presumed to be 2%, the mean air temperature and precipitation is about 5°C respectively 656 mm (**Table 25**). This results in a relatively low BAT of 9 d (**Table 27**), which causes to a comparatively slow turnover of organic matter in the soil.

Scenario 1 assumes 100% mineral fertiliser use and Scenario 2 replaces 60% of the nitrogen requirement with organic fertilisers of the quality from **Table 26**. Scenario 1 shows a constant carbon level and in the scenario 2 the carbon content increases over time (***Figure 8***). However, in scenario 2, also the C saldo and C storage level is higher and more carbon and nitrogen are mineralised.

Table 25. Soil and climate input data for the CCB model.

Corg (%) start value	2 (presumed)
Soil texture	Clay 45%; Silt 30%
Air Temperature (C°)	5.28
Precipitation (mm/yr)	655.7

Table 26. Utilised parameters (DM - Dry matter, N – Nitrogen, C - Carbon, CNR – C/N ratio) of manure from national references (table values).

	DM [%]	N [kg/t FM]	C [kg/t FM]	CNR
Table values	5.6	3.35	22.46	6.7

Table 27. Simulated Biologic active time (BAT) and Soil organic matter reproduction index = $C_{reproduction}$/BAT (REP_IX).

	BAT (d/a)	Rep_IX
Scenario 1	9	42.2
Scenario 2		120.1

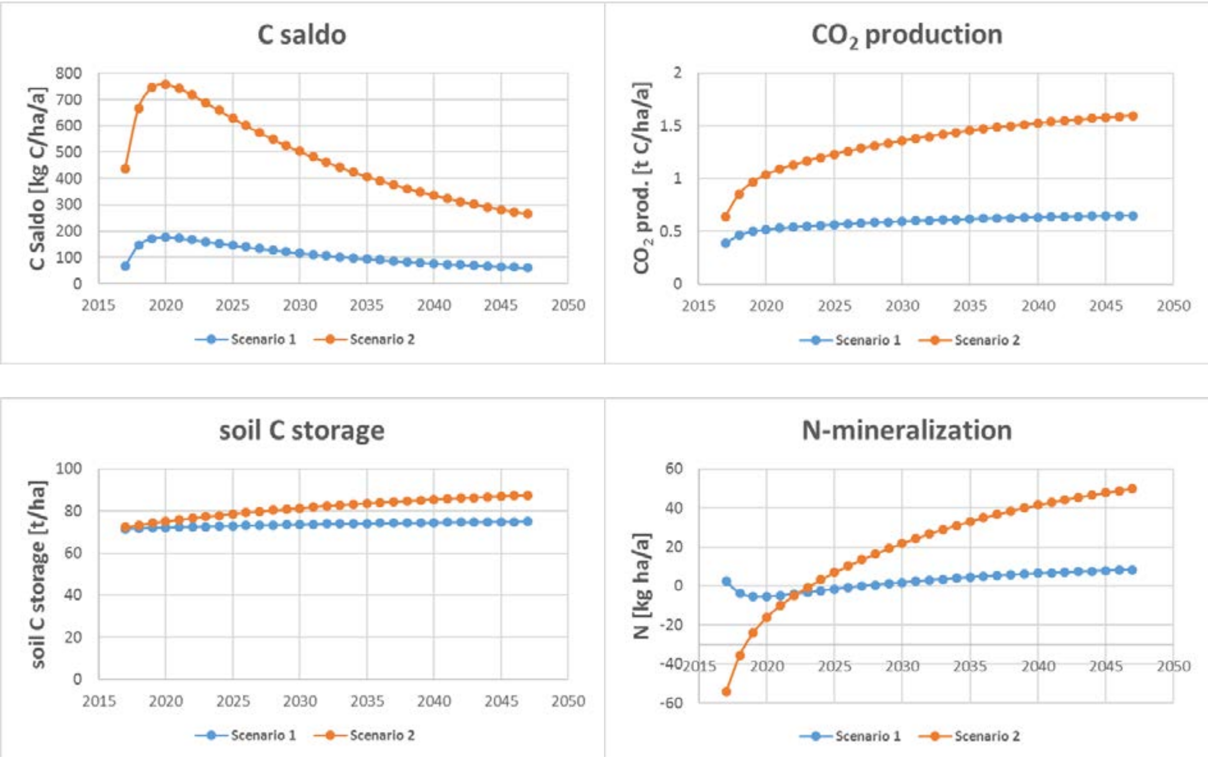

Figure 8. Simulated C saldo, CO_2 production, soil C storage and N-mineralisation of the FI_Varsinais-Suomi region.

4.3. Germany

4.3.1. Comparison of the old and new manure data

Ex storage manure data for fertilisation planning

In Germany, the Fertiliser Ordinance regulates that fertilisers are only allowed to be applied on fields if the content of total nitrogen, plant available nitrogen or ammonium nitrogen and the content of total phosphorus is

(1) known due to the product label of fertiliser,
(2) determined based on data published by the responsible authority according to federal state law, or
(3) determined based on scientifically proven measurement methods by the farmer or other professional samplers before application.

Hence, the farmers can decide whether to use manure sampling analysis results or “table (standard) values” published by the responsible authorities (e.g. Chambers of Agriculture in the federal states).

For the German pilot farms, responsible authorities according to federal state law are the Chambers of Agriculture in Lower Saxony (pilot farm 1) and Schleswig-Holstein (pilot farms 3 and 4). The authorities publish table values for manure properties (dry matter content, nitrogen content, ammonium nitrogen content and phosphorus content). In this project, these table values were used as old manure data for pilot farms 3 and 4. However, pilot farm 1 has specific characteristics and thus, a slightly different approach had to be used. In pilot farm 1, slurry of pigs and cattle is stored together. As the Chamber of Agriculture in Lower Saxony does not publish manure data regarding mix slurry, we had to refer to the Chamber of Agriculture in North Rhine-Westphalia, which is one of the neighbouring federal states with comparable agricultural structures. Respective published manure properties of mix slurry were used as old manure data. Furthermore, pilot farm 1 produces corn silage for a nearby biogas plant and gets related digestates back for field application. For this, published table values from the Chamber of Agriculture in Lower Saxony could be used.

As new manure values, laboratory analysis results of samples taken on the pilot farms 3 and 4 during this project in WP2 were used. However, it must be mentioned that for pilot farm 3, manure samples were taken at Ex housing and not at Ex storage level leading to some uncertainties with regard to nitrogen content of manure. Again, pilot farm 1 needed a different approach. The manure samples taken during this project in WP2 did not include samples from produced mix slurry or received digestates. Fortunately, the farmer provided us laboratory analysis results of mix slurry from his last own sampling. Respective data were used as new manure data. Furthermore, we used table values of the Chamber of Agriculture in Schleswig-Holstein as new manure data for the applied digestates.

Table 28 shows the old and new ex storage manure data used as manure parameters at pilot farm level. Data are given for all pilot farms according to sources explained above.

Table 28. German old and new ex storage manure data for total nitrogen (Tot-N), ammonium nitrogen (NH_4-N) and total phosphorus (Tot-P), used as manure parameters in pilot farm scale (kg/ton of manure), and the percentage change between new and old values.

	Tot-N (kg/t)			NH_4-N (kg/t)			Tot-P (kg/t)		
	Old	New	Diff.	Old	New	Diff.	Old	New	Diff.
Mix slurry (Pilot farm 1)	3.70	1.07	-71%	2.60	0.63	-76%	0.74	0.22	-70%
Biogas digestate (Pilot farm 1)	5.00	5.10	+2.0%	2.25	2.90	+29%	1.09	0.92	-16%
Cattle, slurry (Pilot farm 3)	3.50	3.30	-5.7%	2.00	1.49	-26%	0.65	0.62	-4.6%
Fattening pigs, slurry (Pilot farm 4)	3.60	5.65	+57%	2.80	4.05	+45%	0.74	1.46	+97%

Notes: Sources of manure data are explained in the text.

4.3.2. Impacts of using the new manure data

4.3.2.1. Results from the pilot farm modelling

NBBM modelling

Data from three pilot farms were used to calculate the impacts of new manure tools to fertilisation and nutrient balances at the farm level (see **Table 29**). Based on that, the impacts on nitrogen and phosphorus leaching risk were estimated, based on the methods described in chapter 3. In the German case, the NBBM mode for N efficiency factors was used. For the yields of cultivated crops, farm-specific values were used. For pilot farms 1 and 3, yields for grassland production were derived from information on use (mowing or pasture) and intensity (e.g. number of cuts). Averagely 81% of the total acreage of the pilot farms was used for manure application. For the pilot farms, different sources for old and new manure data were used (see chapter 4.3.1). When introducing new manure data, the level of change in nutrient balances at farm level depends on the difference between old and new manure data and the share of fields where manure is applied.

If manure nutrient content is presently under estimated, introducing new manure data cause decreasing fertilisation rates and nutrient balances, and vice versa. However, the model assumes that only mineral fertilisation is adjusted if fertilisation adjustment is needed due to the changes in manure nutrient composition data. This means that, as is the case for German fattening pig pilot farm, if manure phosphorus content is underestimated but no mineral P is currently applied on fields receiving manure, the actual P fertilisation level does not change due to introducing new manure data because manure application rates remain unaffected. As farm-specific yields are used for this farm, which remain constant when introducing new manure data, the P balance will also remain constant if, at the same time, nitrogen fertilisation is changed on the fields receiving manure (because old manure data under- or overestimated manure nitrogen content). This is different to case mentioned for the Finnish fattening pig pilot farm (chapter 4.2.2), where changes of nitrogen fertilisation also affect the P balance because there, yield response to N fertilisation functions were used and thus, related yields on those fields changed, causing changes in P balances.

Among the German pilot farms, the change in risk of nitrogen leaching due to introducing new manure data varies between -10% and +4%. It was not possible to indicate the change in risk of phosphorus leaching because the change in STP concentration, which is needed for this calculation (cf. chapter 3.1.3), could not be estimated for the German pilot farms. It must be kept in mind that the risk values describe only the effect of introducing the new manure data.

Table 29. Summary table for German pilot farm results of NBBM modelling.

Animal type	Manure type	Farm acreage (ha)	% of acreage received manure	Basis of manure application rates		Average nutrient balances with old manure data (present actual; kg/ha)			Average nutrient balances with new manure data (new actual; kg/ha)			Difference between "new" and "present" nutrient balances (%)			Difference in leaching risk (from "present" to "new", %)	
				Old manure data	**New manure data**	**Ntot**	**NH_4-N**	**Ptot**	**Ntot**	**NH_4-N**	**Ptot**	**Ntot**	**NH_4-N**	**Ptot**	**NH_4-N**	**P (10 yrs)**
Cattle + Pigs + Digestates	Mix slurry + Digestates	454.1	76%	Table values	Farm's manure analysis taken by farmer / table values	0.9	-32.3	-24.8	-17.4	-32.3	-33.4	-2.1%	0%	+35%	4%	n.a.
Dairy cows and bulls	Cattle slurry	200	85%	Table values	Farm's new manure analysis taken by JKI/farmer	47.9	-14.6	-30.8	44.4	-14.6	-31.6	-7.3%	0%	+2.6%	1%	n.a.
Fattening pigs	Slurry	73.3	100%	Table values	Farm's new manure analysis taken by Farmer/JKI	54.6	27.1	-14.0	70.3	27.1	-0.2	+29%	0%	-99%	-10%	n.a.
		727.4														
		Received manure:										**Weighted averages:**				
		588.4 ha	81%									-1.3%	0%	+12.6%	+1.8%	n.a.

CCB modelling

Farm DE1 is a research station to investigate species- and behaviour-appropriate husbandry of farm animals. The farm has several animal categories (cows, pigs, sheep's, and hens) and production branches. In 2017 field grass, winter wheat, brewing barley and maize were grown on the farm. One third of the area is grassland. The textural class of soil according USDA is identified as a loamy sand; soil organic carbon content of soil amounts 1.8%, the mean air temperature and precipitation is about 7°C respectively 690 mm (

Table 30). This results in a BAT of 16.2 d (**Table 32**), which causes to a comparatively moderate turnover of organic matter in the soil.

The table values and measured values of manure quality are very different (**Table 31**). At a same CN ratio, the measured values are more than half smaller. This results in a lower Rep_IX (**Table 32**) and therefore to a lower C saldo and carbon storage level as well as to a less CO_2 production and N mineralisation (***Figure 9***) by using measured values of manure quality. Similar results were estimated for the grassland site of the farm (***Figure 10***). All quantified parameters e.g. soil C storage,CO_2 production, N mineralisation are lower by using measured values of manure quantity in comparison to results estimated with table values due to a higher Rep_IX (***Figure 11***).

Table 30. Soil and climate input data for the CCB model.

Corg (%) start value	1.8%
Soil texture	Clay 10%; Silt 30%
Air Temperature (C°)	7
Precipitation (mm/yr)	690

Table 31. Utilised parameters (DM - Dry matter, N – Nitrogen, C - Carbon, CNR – C/N ratio) of manure from national references (table values) and measurements of laboratories (measured values).

Slurry Mix	**DM [%]**	**N [kg/t FM]**	**C [kg/t FM]**	**CNR**
Table values	4.00	3.70	23.12	6.25
Measured values	1.62	1.07	6.69	6.25

Table 32. Simulated Biologic active time (BAT) and Soil organic matter reproduction index = $C_{reproduction}$/BAT (REP_IX).

	BAT (d/a)	**Rep_IX (arable land)**	**BAT (d/a)**	**Rep_IX (grassland)**
Table values	16.2	51.7	15.1	120.9
Measured values		39.6		107.1

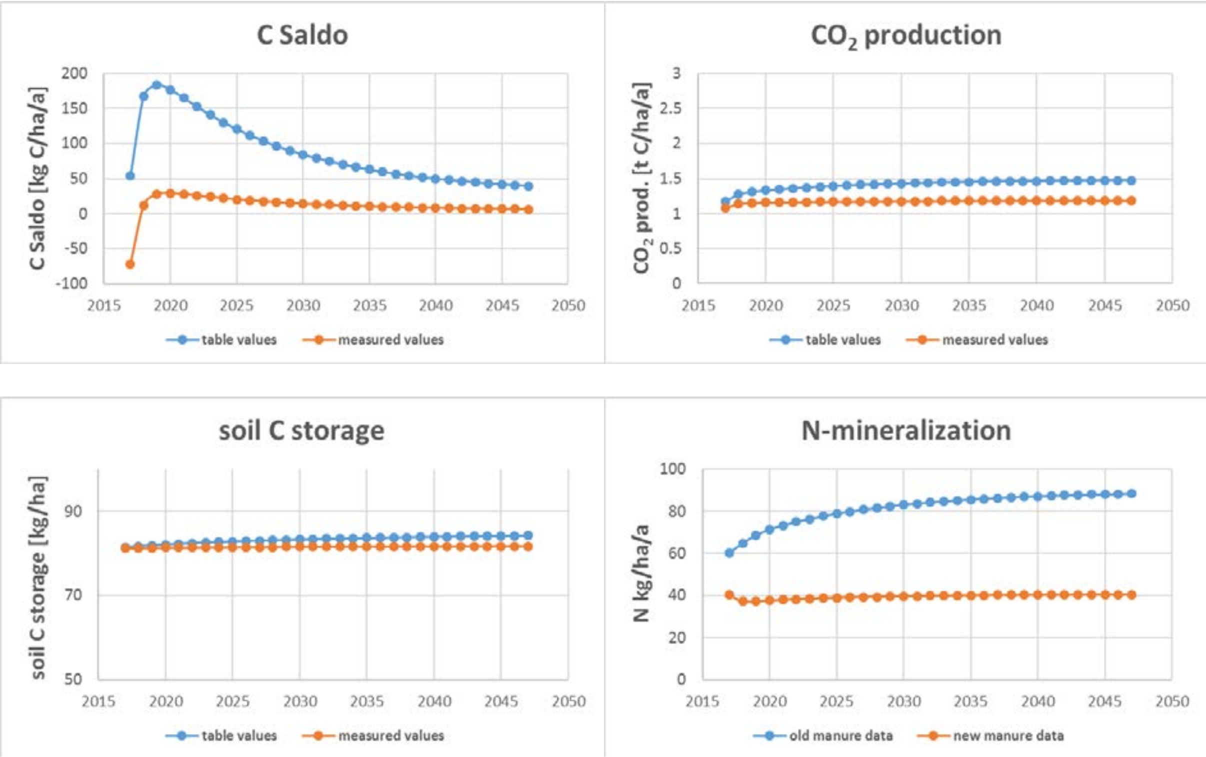

Figure 9. Simulated C saldo, CO_2 production, soil C storage and N-mineralisation of Farm DE1 arable land.

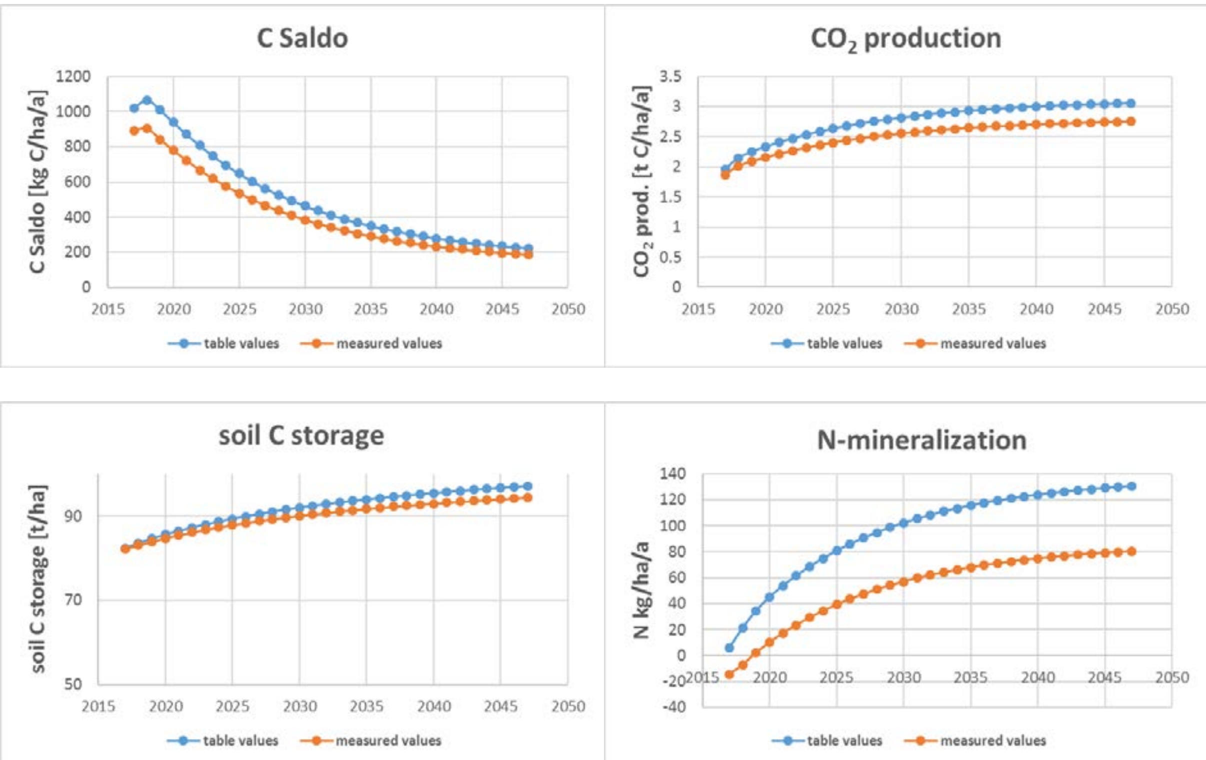

Figure 10. Simulated C saldo, CO_2 production, soil C storage and N-mineralisation of Farm DE1 grassland.

Farm DE3 represents German dairy as well as beef production. In 2017 winter wheat, winter rape and maize were grown on the farm. Half of the area is grassland. The textural class of soil according USDA is identified as a clay loam; soil organic carbon content of soil is presumed to be 2%; the mean air temperature and precipitation is about 8°C respectively 850 mm (**Table 33**). This results in a BAT of 15.9 d for plowed arable land and 9.2 d for grassland (**Table 35**), which causes to a comparatively moderate turnover of organic matter in the soil.

The table values and measured values of manure quality are more or less similar (**Table 34**). This results in a similar Rep_IX (**Table 35**) and leads also to comparable C saldo, CO_2 production, soil C storage level as well as N mineralisation (***Figure 11***) by using table values or measured values of manure quality. Similar results were achieved in grassland, even though at a higher C respectively N level (***Figure 12***).

Table 33. Soil and climate input data for the CCB model.

Corg (%) start value	2.0 (presumed)
Soil texture	Clay 35%; Silt 30%
Air Temperature (C°)	8.2
Precipitation (mm/yr)	850

Table 34. Utilised parameters (DM - Dry matter, N – Nitrogen, C - Carbon, CNR – C/N ratio) of manure from national references (table values) and measurements of laboratories (measured values).

Cattle slurry	**DM [%]**	**N [kg/t FM]**	**C [kg/t FM]**	**CNR**
Table values	7.00	3.50	30.80	8.80
Measured values	6.46	3.33	29.33	8.80

Table 35. Simulated Biologic active time (BAT) and Soil organic matter reproduction index = $C_{reproduction}$/BAT (REP_IX).

	BAT (d/a)	**Rep_IX (arable land)**	**BAT (d/a)**	**Rep_IX (grassland)**
Table values	15.9	101.8	9.2	239.0
Measured values		99.3		235.5

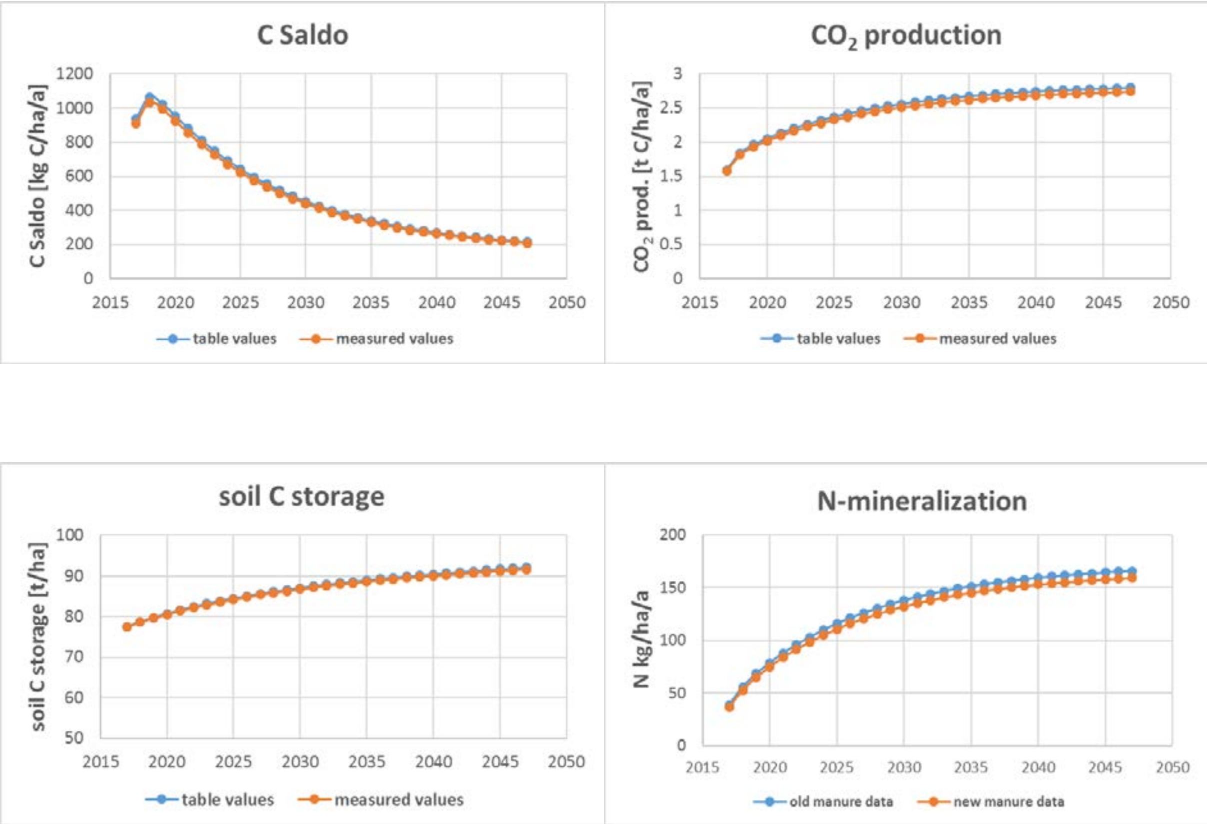

Figure 11. Simulated C saldo, CO_2 production, soil C storage and N-mineralisation of Farm DE3 arable land.

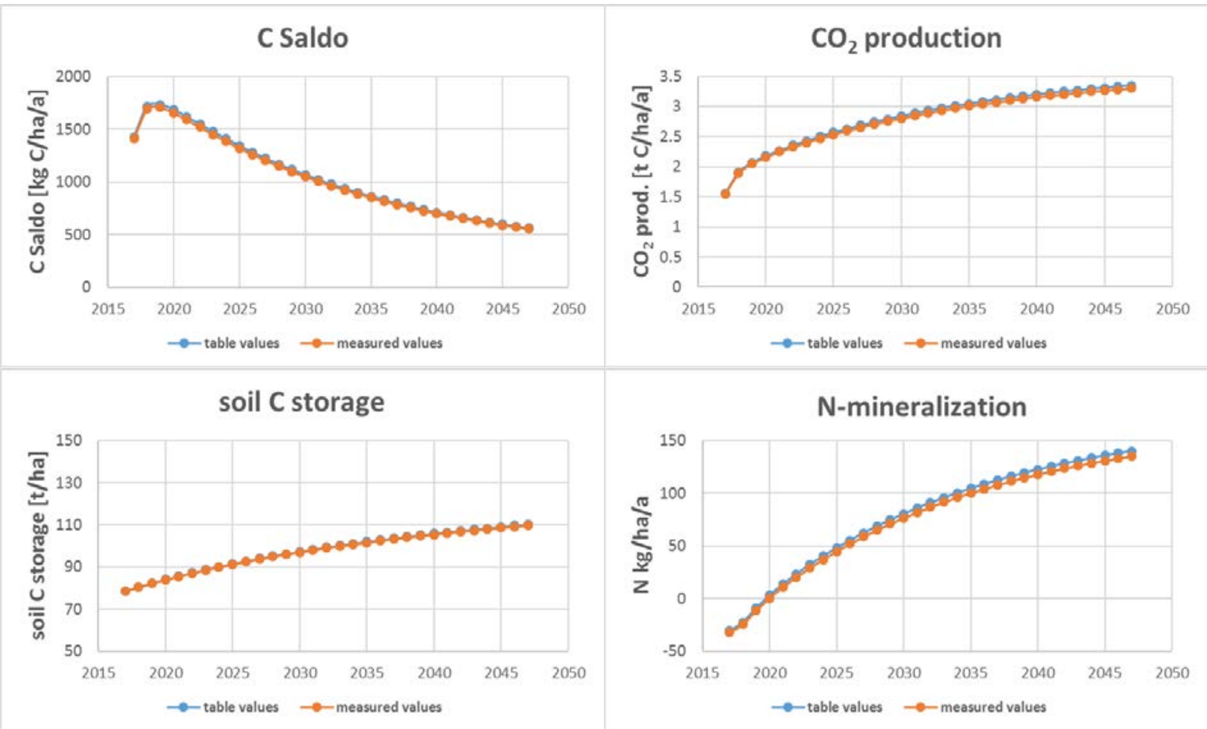

Figure 12. Simulated C saldo, CO_2 production, soil C storage and N-mineralisation of Farm DE3 grassland.

Farm DE4 produces fattening pigs. In 2017 winter rape, winter barley, winter wheat and oat were grown on the farm. The textural class of soil according USDA is identified as a silty clay; soil organic carbon content of soil is presumed to be 2%, the mean air temperature and precipitation is about 7°C respectively 690 mm (**Table 36**). This results in a BAT of 14 d (**Table 38**), which causes to a comparatively moderate turnover of organic matter in the soil.

The table values and measured values of manure quality are very different (**Table 37**). At a same CN ratio, the measured values are higher than table values. This results in a higher Rep_IX (**Table 38**) and therefore to a higher C saldo and carbon storage level as well as to a stronger CO_2 production and N mineralisation (**Figure 13**) by using measured values of manure quality.

Table 36. Soil and climate input data for the CCB model.

Corg (%) start value	2% (presumed)
Soil texture	Clay 45%; Silt 30%
Air Temperature (C°)	7
Precipitation (mm/yr)	690

Table 37. Utilised parameters (DM - Dry matter, N – Nitrogen, C - Carbon, CNR – C/N ratio) of manure from national references (table values) and measurements of laboratories (measured values).

Pig slurry	DM [%]	N [kg/t FM]	C [kg/t FM]	CNR
Table values	3.00	3.60	18.29	5.08
Measured values	6.10	5.61	28.49	5.08

Table 38. Simulated Biologic active time (BAT) and Soil organic matter reproduction index = $C_{reproduction}$/BAT (REP_IX).

	BAT (d/a)	Rep_IX
Table values	14	123.8
Measured values		133.9

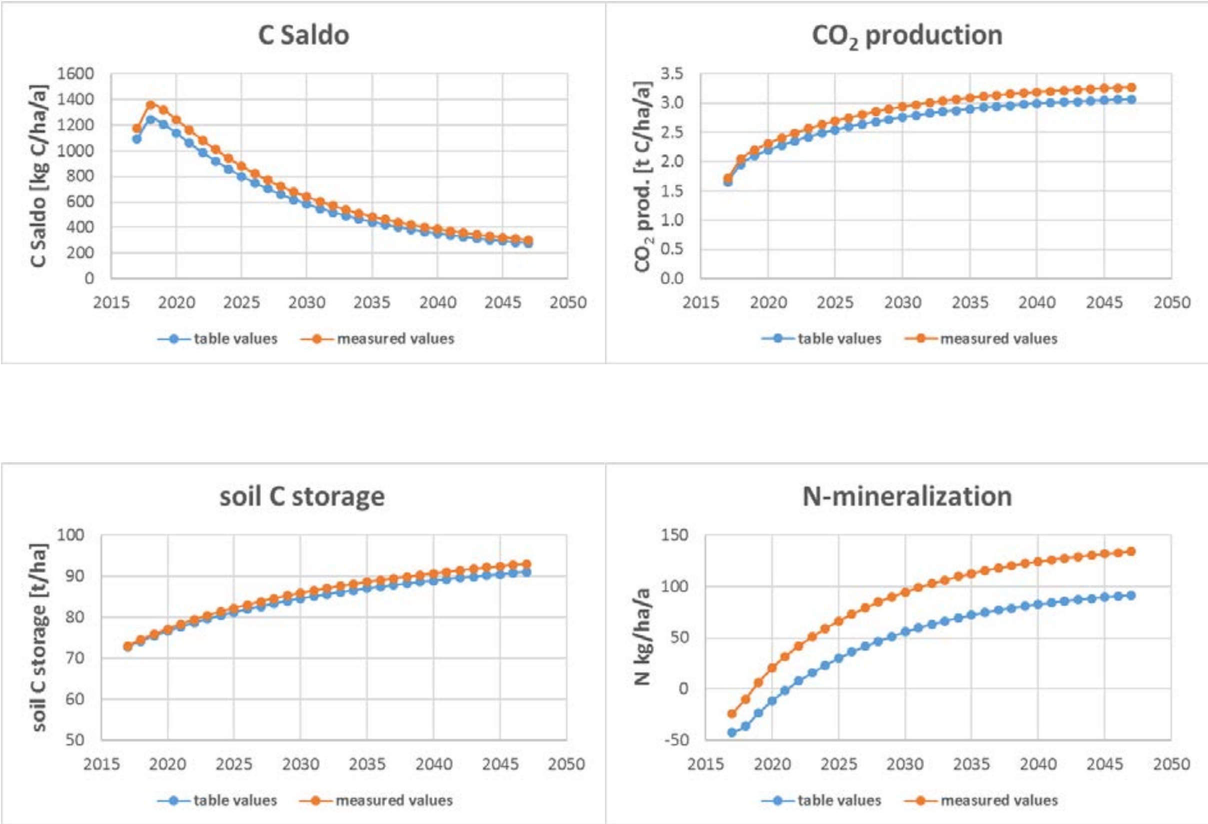

Figure 13. Simulated C saldo, CO_2 production, soil C storage and N-mineralisation of Farm DE4.

4.3.2.2. Results from the regional modelling

CCB modelling

DE_Ostholstein representing a region of Germany. In 2017 spring and winter wheat, lupine, winter rye, winter triticale, spring and winter barley, oat, maize, cereal grain mix, clover-grass, field bean, pea, sugar beet, potato as well as field grass were grown in this region. Main textural class of soil according USDA is identified as a loamy sand; soil organic carbon content of soil is presumed to be 2%, the mean air temperature and precipitation is about 10°C respectively 804 mm (**Table 39**). This results in a relatively high BAT of 26.1 d (**Table 41**), which causes to a comparatively fast turnover of organic matter in the soil.

Scenario 1 assumes 100% mineral fertiliser use and Scenario 2 replaces 60% of the nitrogen requirement with organic fertilisers of the quality from **Table 40**. Scenario 1 shows a slightly negative trend of carbon storage and in the scenario 2 the carbon content increases over time (**Figure *14***). However, in scenario 2, also the C saldo and C storage level is higher and more carbon and nitrogen are mineralised.

Table 39. Soil and climate input data for the CCB model.

Corg (%) start value	2 (presumed)
Soil texture	Clay 10%; Silt 30%
Air Temperature (C°)	9.54
Precipitation (mm/yr)	804.02

Table 40. Utilised parameters (DM - Dry matter, N – Nitrogen, C - Carbon, CNR – C/N ratio) of manure from national references (table values).

	DM [%]	N [kg/t FM]	C [kg/t FM]	CNR
Table values	7.79	3.41	34.12	10

Table 41. Simulated Biologic active time (BAT) and Soil organic matter reproduction index = $C_{reproduction}$/BAT (REP_IX).

	BAT (d/a)	Rep_IX
Scenario 1	26.1	40
Scenario 2		72.3

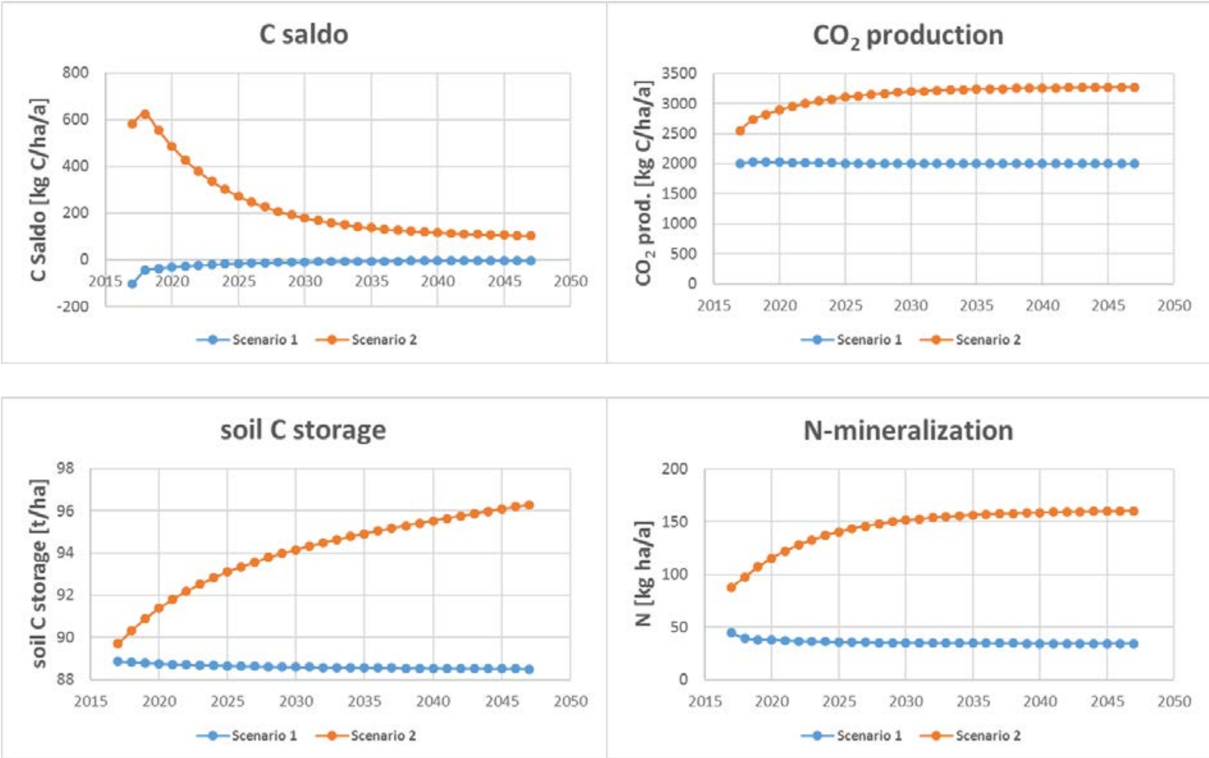

Figure 14. Simulated C saldo, CO_2 production, soil C storage and N-mineralisation of the DE_Ostholstein region.

4.4. Latvia

4.4.1. Comparison of the old and new manure data

Ex storage manure data for fertilisation planning

In Latvia, for fertilisation planning, which is obligatory only for the farmers within the nitrate vulnerable zone, only table values from 23 December 2014 Cabinet Regulation No. 834 or analysis results issued by a laboratory accredited in the field of fertilisers can be used. If laboratory results are used samples must be taken before emptying storage and are valid only for the following spreading. For rest of farmers and growers, plenty of professional guides and information sources are available.

In this project for the farm scale calculations only the table values were used as old manure data. Some of the farms did have previous laboratory results, but they were not used to keep old data comparable. Two different new data sets were used – the first is the results of the samples taken and analysed in WP2 (**Table 42**)., the second is the calculations done with calculation tool developed in WP3 (**Table 43**). An aspect to consider when analyses are used as new data is that other input data for the various models are from year 2017, but the sampling and analyses were carried out in 2018.

At the national level, as the old data FAOSTAT Livestock manure database was used, the data was only available for nitrogen. As the new data calculation tool developed in WP3 with tier 1 calculation method was used (**Table 44**). For tier 1 calculations table values from national data and number of animals from national statistics were used.

Table 42. Old and new ex storage manure data used as manure parameters in pilot farm scale and the difference between the new and old data. The new data are based on analyses carried out in WP2.

Farm, animal and manure type	Dry matter (%)			Total N (kg/t)			Total P (kg/t)			Total K (kg/t)		
	Old	New	Diff.	Old	New	Diff.	Old	New	Diff.	Old	New	Diff.
LV1, dairy cows (milk yield 10.4t) slurry	13	14.2	11%	4.5	3.5	-22%	0.9	1.2	32%	3.0	4.4	48%
LV2, dairy cows (milk yield 11.9t) solid manure	20	21.1	6%	5.5	5.2	-5%	1.0	1.3	30%	3.6	6.6	83%
LV3, dairy cows (milk yield 12.5t) slurry	12	8.7	-28%	4.4	2.7	-39%	1.0	0.7	-30%	2.8	2.8	0%
LV4, fattening pigs slurry	8	3.1	-61%	3.9	0.9	-77%	1.3	0.8	-38%	1.6	1.7	6%
LV5, dairy cows (milk yield 5t) solid manure	21	14.5	-31%	5.4	2.7	-50%	1.1	0.5	-55%	4.5	4.3	-4%

Table 43. Old and new ex storage manure data used as manure parameters in pilot farm scale and the difference between the new and old data. The new data are based on the calculation tool (WP3).

Farm, animal and manure type	Dry matter (%)			Total N (kg/t)			Total P (kg/t)			Total K (kg/t)		
	Old	New	Diff.	Old	New	Diff.	Old	New	Diff.	Old	New	Diff.
LV1, dairy cows (milk yield 10.4t) slurry	13	13	4%	4.5	5.2	16%	0.9	0.7	-19%	3.0	3.9	30%
LV2, dairy cows (milk yield 11.9t) solid manure	20	19	-4%	5.5	5.3	-3%	1.0	0.8	-18%	3.6	4.5	25%
LV3, dairy cows (milk yield 12.5t) slurry	12	13	9%	4.4	3.3	-26%	1.0	0.5	-46%	2.8	1.7	-37%
LV4, fattening pigs slurry	8	4	-54%	3.9	1.8	-53%	1.3	0.4	-68%	1.6	0.7	-59%
LV5, dairy cows (milk yield 5t) solid manure	21	12	-40%	5.4	2.9	-46%	1.1	2.8	155%	4.5	5.0	11%

Table 44. Old and new ex storage manure data used as manure parameters in national scale and the difference between the new and old data.

	Total N (kg/t)		
	Old	New	Diff.
Dairy cattle	4.5	5.8	29%
Non-dairy cattle	2.0	5.6	181%
Pigs	4.2	5.9	41%
Laying hens	22.4	29.9	34%
Sheep	5.4	6.3	16%
Goats	5.4	7.5	39%
Horse	4.7	3.6	-24%

4.4.2. Impacts of using the new manure data

4.4.2.1. Results from the pilot farm modelling

NBBM modelling

Survey data was collected from 22 pilot farms. Of all the available farms, 5 farms with best data set and different animal or manure types were chosen. The total acreage of chosen farms was 1922.6 ha of which on average 42% received manure. For the NBBM modelling N efficiency mode was used. For all crops yield response functions were used.

According to NBBM modelling the implementation of the new manure data can have varying effects for each of the farms. If manure analysis results were used as new manure data, then one farm has large increase in both total and plant available nitrogen balances, one farm has large increase only in plant available nitrogen balances (**Table 45**). The big difference for the plant available nitrogen balances is because balances themselves are close to zero. Remaining farms have negligible differences. On average, introducing new manure data results in small increase in total nitrogen balance and small decrease in total phosphorus balance. The largest difference is for plant available nitrogen balance but only in one case there is increase in nitrogen leaching risk with the default limit of 50 kg N/ha. In the case new data are based on the calculation tool (**Table 46**), then situation with large results is similar but there is a noticeable change for the total nitrogen and phosphorus balances – they have opposite signs. That means introducing new manure data results in decrease in total nitrogen balance and increase in total phosphorus balance.

Table 45. Summary of Latvian NBBM modelling, old data – table values, new data – analyses.

Animal type	Manure type	Farm acreage (ha)	% of acreage received manure	Average nutrient balances with old manure data (present actual; kg/ha)			Average nutrient balances with new manure data (new actual; kg/ha)			Difference between "new" and "present" nutrient balances (%)			Difference in leaching risk (from "present" to "new", %)
				Ntot	**Nplant**	**Ptot**	**Ntot**	**Nplant**	**Ptot**	**Ntot**	**Nplant**	**Ptot**	**Nplant**
Dairy cattle	Slurry	1014.7	23	34,2	10,7	63,6	37,0	13,5	62,9	8	26	-1	2
Dairy cattle	Solid manure	163.0	28	62,3	31,1	57,2	61,4	30,2	56,0	-1	-3	-2	0
Dairy cattle	Slurry	393.6	69	44,0	-1,6	52,0	48,2	2,6	52,5	10	260	1	0
Fattening pigs	Slurry	316.4	70	-22,3	-31,8	53,7	-23,2	-32,2	52,3	-4	-1	-3	0
Dairy cattle	Solid manure	34.9	100	77,0	-6,1	16,2	101,8	18,6	16,2	32	404	0	0
		Received manure:								**Weighted averages:**			
		1922.6	42							6,1	73	-1.0	1.1

Table 46. Summary of Latvian NBBM modelling, old data – table values, new data – calculation tool.

Animal type	Manure type	Farm acreage (ha)	% of acreage received manure	Average nutrient balances with old manure data (present actual; kg/ha)			Average nutrient balances with new manure data (new actual; kg/ha)			Difference between "new" and "present" nutrient balances (%)			Difference in leaching risk (from "present" to "new", %)
				Ntot	**Nplant**	**Ptot**	**Ntot**	**Nplant**	**Ptot**	**Ntot**	**Nplant**	**Ptot**	**Nplant**
Dairy cattle	Slurry	1014.7	23	48.4	13.4	59.4	48.5	13.5	60.2	0	0	1	2
Dairy cattle	Solid manure	163.0	28	63.4	31.3	53.4	62.3	30.2	53.5	-4	-4	0	0
Dairy cattle	Slurry	393.6	69	55.3	0.2	48.3	57.7	2.6	49.8	4	1188	3	0
Fattening pigs	Slurry	316.4	70	-10.8	-30.1	44.2	-13.8	-32.2	50.7	-28	-7	15	0
Dairy cattle	Solid manure	34.9	100	5	-4.3	108.2	107.98	18.6	108.2	27	533	0	0
		Received manure:								**Weighted averages:**			
		1922.6	42							-3.6	251	3.6	1.1

CCB modelling

Farm LV2 is an average sized dairy cow farm. In 2017 winter wheat and maize were grown on the farm. The textural class of soil according USDA is identified as a sandy loam; soil organic carbon content of soil amounts 2.93%, the mean air temperature and precipitation is about 7°C respectively 671 mm (**Table 47**). This results in a BAT of 18.0 d (**Table 49**), which causes to a comparatively moderate turnover of organic matter in the soil.

The table values and measured values of manure quality are similar (**Table 48**). This results in a comparable Rep_IX (**Table 49**) and to similar C saldo, CO_2 production and soil C storage (***Figure 15***) by using measured values or table values of manure quality. Only the nitrogen mineralisation is slightly higher by using table values due to higher N content of manure (***Figure 15***).

Table 47. Soil and climate input data for the CCB model.

Corg (%) start value	2.93
Soil texture	Clay 19.9%; Silt 22.07%
Air Temperature (C°)	7.1
Precipitation (mm/yr)	671

Table 48. Utilised parameters (DM - Dry matter, N – Nitrogen, C - Carbon, CNR – C/N ratio) of manure from national references (table values) and measurements of laboratories (measured values).

Cattle solid	DM [%]	N [kg/t FM]	C [kg/t FM]	CNR
Table values	19.60	5.50	86.24	15.69
Measured values	21.10	5.20	89.46	17.21

Table 49. Simulated Biologic active time (BAT) and Soil organic matter reproduction index = $C_{reproduction}$/BAT (REP_IX).

	BAT (d/a)	Rep_IX
Table values	18.0	104.9
Measured values		106.9

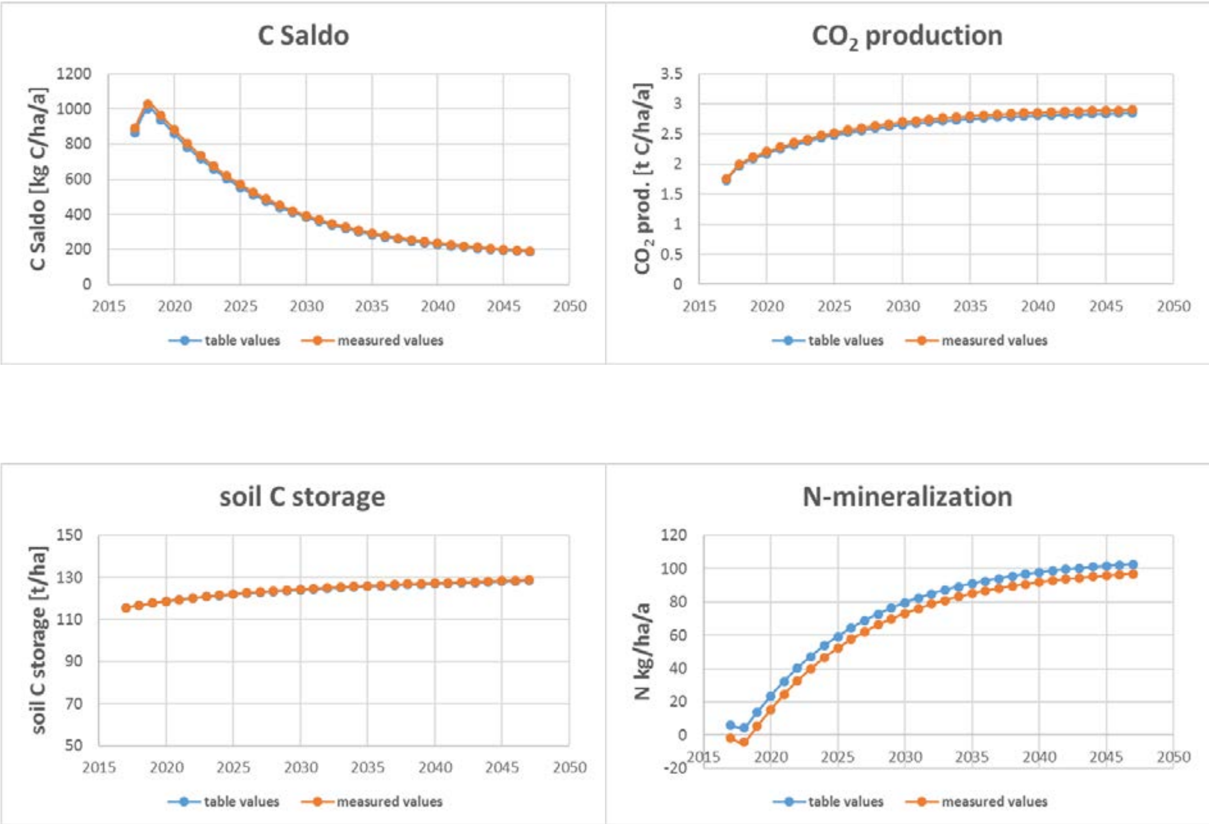

Figure 15. Simulated C saldo, CO_2 production, soil C storage and N-mineralisation of Farm LV2.

Farm LV4 is a large pig farm. In 2017 winter wheat maize were grown on the farm. The textural class of soil according USDA is identified as a clay loam; soil organic carbon content of soil amounts 2.43%, the mean air temperature and precipitation is about 7°C respectively 671 mm (**Table 50**). This results in a BAT of 15.1 d (**Table 52**), which causes to a comparatively moderate turnover of organic matter in the soil.

The table values and measured values of manure quality are very different (**Table 51**). Most of measured values are more than half smaller. This results in a lower Rep_IX (**Table 52**) and therefore to a lower C saldo and carbon storage level as well as to a less CO_2 production and N mineralisation by using measured values of manure quality (***Figure 16***).

Table 50. Soil and climate input data for the CCB model.

Corg (%) start value	2.43
Soil texture	Clay 31.91%; Silt 22.45%
Air Temperature (C°)	7.1
Precipitation (mm/yr)	671

Table 51. Utilised parameters (DM - Dry matter, N – Nitrogen, C - Carbon, CNR – C/N ratio) of manure from national references (table values) and measurements of laboratories (measured values).

Pig slurry	DM [%]	N [kg/t FM]	C [kg/t FM]	CNR
Table values	8.10	3.90	36.29	9.31
Measured values	3.10	0.90	12.21	13.56

Table 52. Simulated Biologic active time (BAT) and Soil organic matter reproduction index = $C_{reproduction}$/BAT (REP_IX).

	BAT (d/a)	Rep_IX
Table values	15.1	168.5
Measured values		139.3

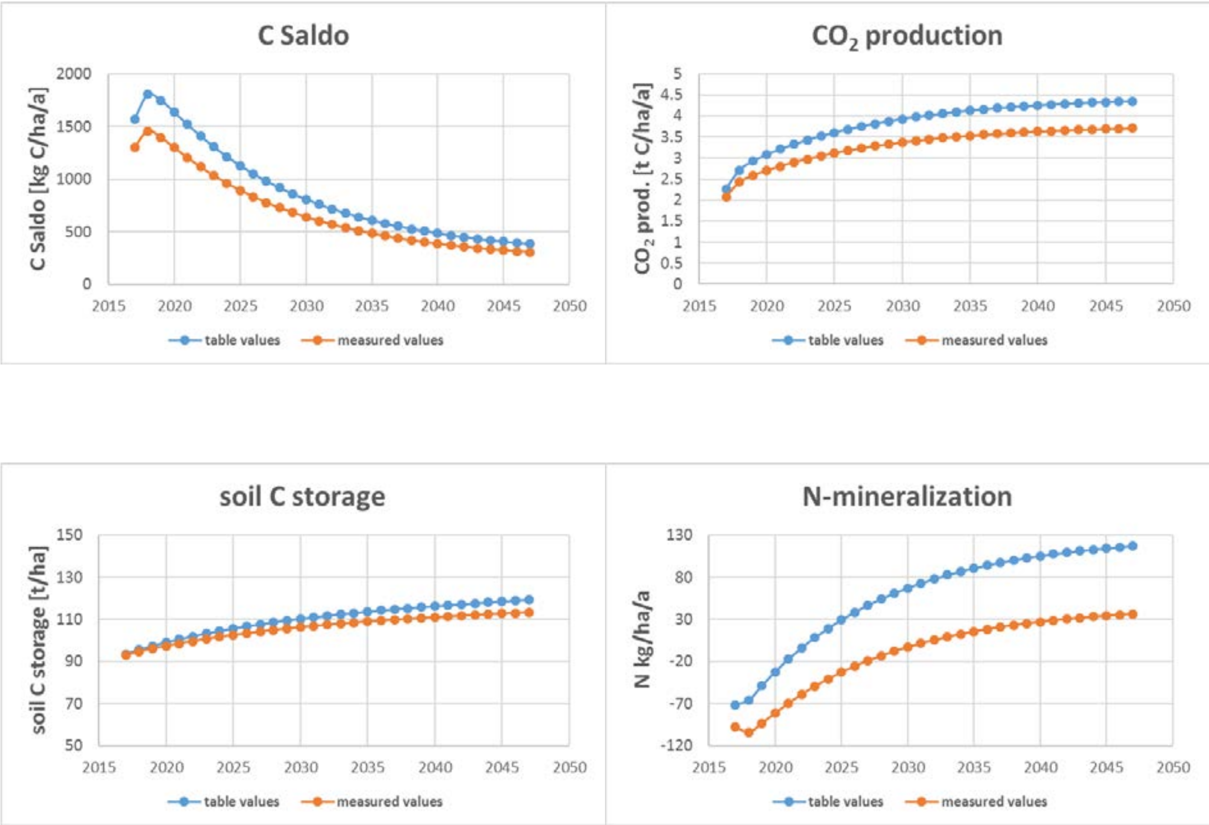

Figure 16. Simulated C saldo, CO_2 production, soil C storage and N-mineralisation of Farm LV4.

Farm LV6 is a dairy cow farm. In 2017 winter wheat, spring wheat and maize were grown on the farm. More than half of the area is grassland. The textural class of soil according USDA is identified as a loamy sand; soil organic carbon content of soil amounts 2.43%, the mean air temperature and precipitation is about 7°C respectively 774 mm (**Table 53**). This results in a BAT of 29.9 d for plowed arable land and 19.5 for grassland (**Table 55**), which causes to a comparatively fast turnover in arable land and moderate turnover in grassland of soil organic matter.

Table 53. Soil and climate input data for the CCB model.

Corg (%) start value	2.43
Soil texture	Clay 10.42%; Silt 17.59%
Air Temperature (C°)	7.3
Precipitation (mm/yr)	774

Table 54. Utilised parameters (DM - Dry matter, N – Nitrogen, C - Carbon, CNR – C/N ratio) of manure from national references (table values) and measurements of laboratories (measured values).

Cattle slurry	DM [%]	N [kg/t FM]	C [kg/t FM]	CNR
Table values	11.90	4.50	53.19	11.82
Measured values	9.10	2.00	42.41	21.20

Table 55. Simulated Biologic active time (BAT) and Soil organic matter reproduction index = $C_{reproduction}$/BAT (REP_IX).

	BAT (d/a) (arable land)	Rep_IX (arable land)	BAT (d/a) (grassland)	Rep_IX (grassland)
Table values	29.9	68.6	19.5	128.6
Measured values		58.6		118.4

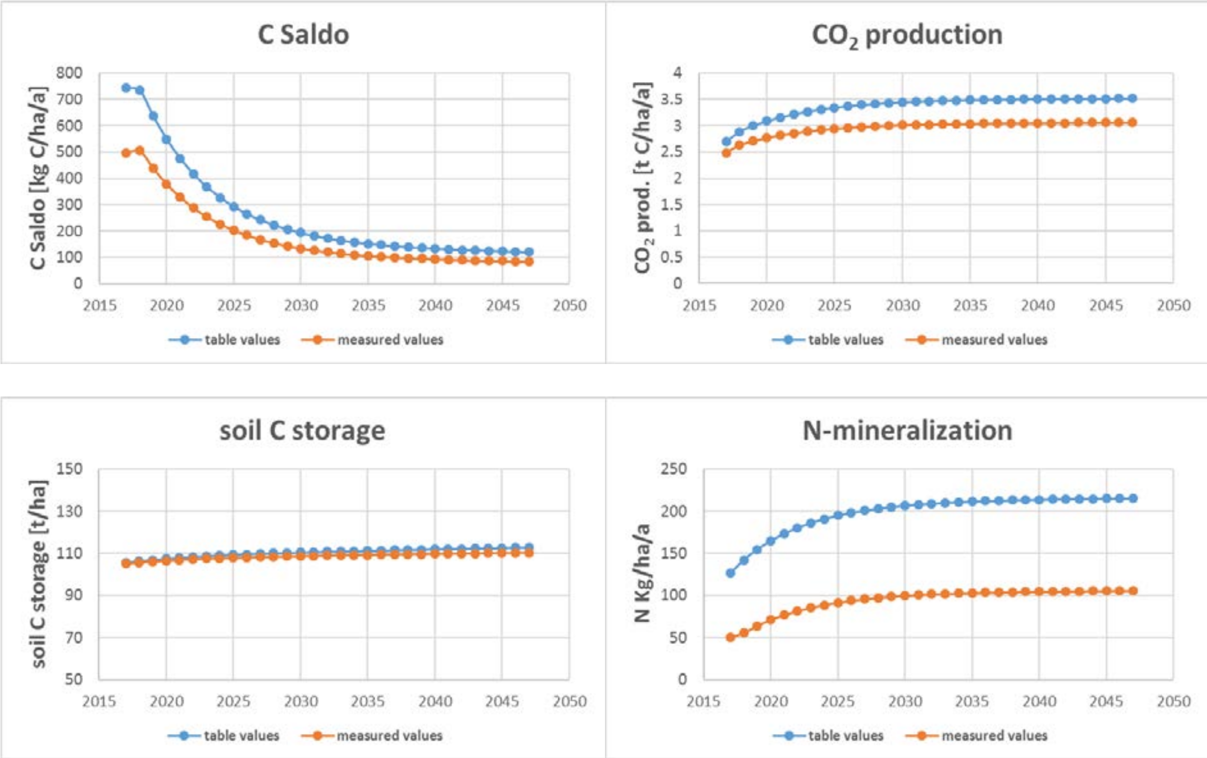

Figure 17. Simulated C saldo, CO_2 production, soil C storage and N-mineralisation of Farm LV6 arable land.

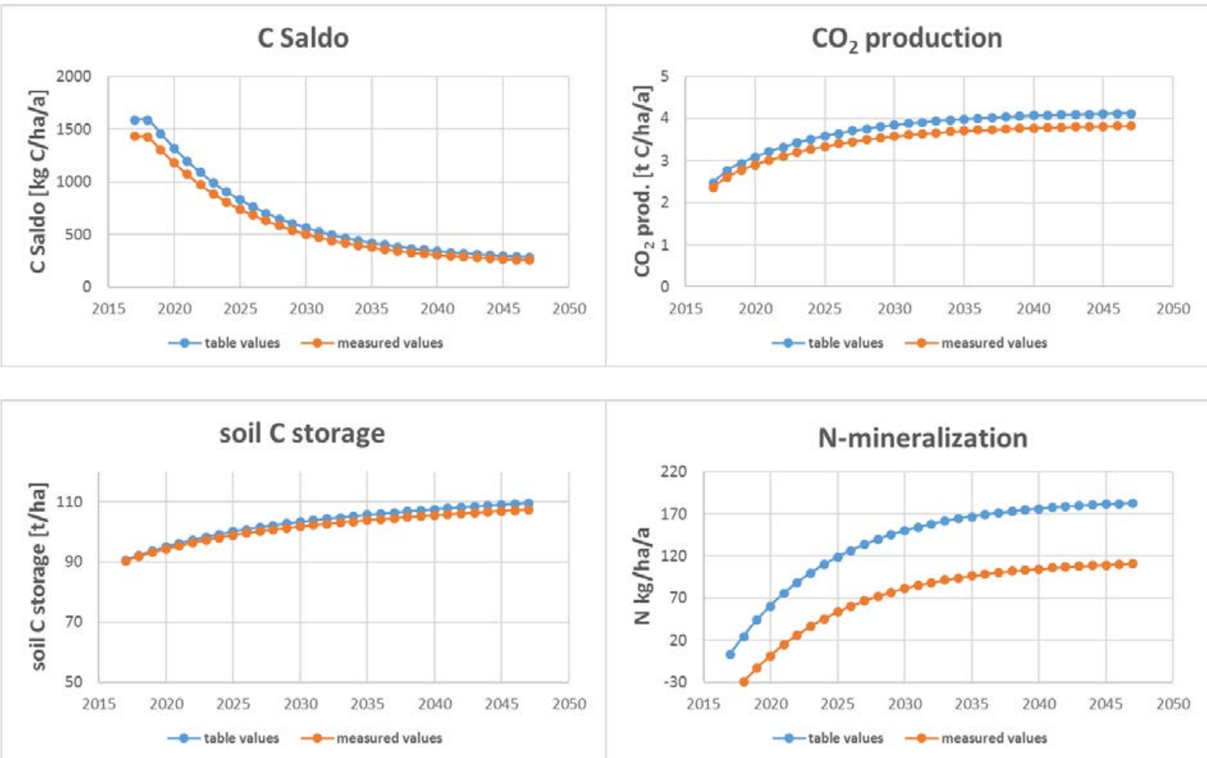

Figure 18. Simulated C saldo, CO_2 production, soil C storage and N-mineralisation of Farm LV6 grassland.

4.4.2.2. Results from the regional modelling

Fertilisation accuracy method

For the nitrogen fertilisation accuracy the whole country was used, only the most widespread crops with area above 2000 ha were included. The nutrient demand was based on average crop yield. The nitrogen content in FAOSTAT database the calculations are based on estimated animal number, which was higher than the national data, so the nitrogen content was recalculated based on actual data. The new data was based on the national level calculation tool developed in WP3. The comparison of new and old data shows considerable under fertilisation (**Table 56**).

Table 56. Summary of fertilisation accuracy method.

Crop	Acreage (1000 ha)	Nutrient demand, total (tons)	From manure ex storage (tons, based on **old manure data**)	Actual amounts of manure nutrients ex storage (tons, based on **new manure data**)	Under/over fertilisation (tons)	Over/under fertilisation, % of the nutrient demand
		N	N	N	N	N
TOTAL	888	67 753	34 966	21 897	-13 069	-19,29

CCB modelling

LV_Riga representing a region of Latvia. In 2017 white cabbage, buckwheat, spring and winter wheat, spring and winter rape, potato, cereal grain mix, spring and winter barley, oat, winter rye as well as pea fodder were grown in this region. Main textural class of soil according USDA is identified as a sandy loam; soil organic carbon content of soil is presumed to be 2%, the mean air temperature and precipitation is about 7°C respectively 706 mm (**Table 57**). This results in a BAT of 15.3 d (**Table 59**), which causes to a comparatively moderate turnover of organic matter in the soil.

Scenario 1 assumes 100% mineral fertiliser use and Scenario 2 replaces 60% of the nitrogen requirement with organic fertilisers of the quality from **Table 58**. In both cases, more carbon will be sequestered in the soil than is emitted into the atmosphere (***Figure 19***). However, in scenario 2, the C saldo and C storage level is higher and more carbon and nitrogen are mineralised.

Table 57. Soil and climate input data for the CCB model.

Corg (%) start value	2 (presumed)
Soil texture	Clay 16.21%; Silt 37.85%
Air Temperature (C°)	6.9
Precipitation (mm/yr)	706

Table 58. Utilised parameters (DM - Dry matter, N – Nitrogen, C - Carbon, CNR – C/N ratio) of manure from national references (table values).

	DM [%]	N [kg/t FM]	C [kg/t FM]	CNR
Table values	7.8	1.77	30.65	17.31

Table 59. Simulated Biologic active time (BAT) and Soil organic matter reproduction index = $C_{reproduction}$/BAT (REP_IX).

	BAT (d/a)	Rep_IX
Scenario 1	15.3	53,6
Scenario 2		91.1

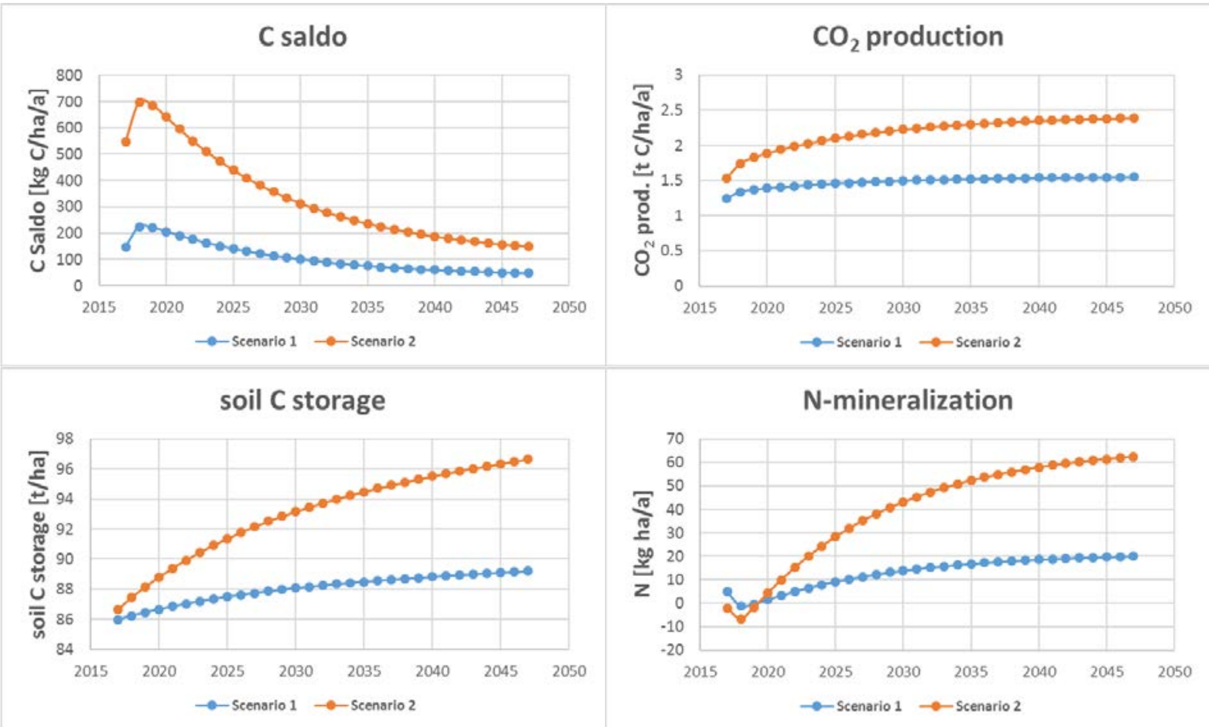

Figure 19. Simulated C saldo, CO_2 production, soil C storage and N-mineralisation of the LV_Riga region.

4.5. Lithuania

4.5.1. Comparison of the old and new manure data

<u>Ex storage manure data for fertilisation planning</u>

In Lithuania, fertilising plans are based on using of animal units. Definitions of animal units for different species are described in Environmental requirements for manure management (Decree 04/04/2018 No. D1-261/3D-200). Here one animal unit represents source of manure with 100 kg of total N per year. Conversions of animals to animal units and allowed amount of land for manure spreading are given in **Table 60**. This simplified system does not use amount of N in manure directly and therefor there are no official table values for nutrient content. It is possible to convert animal units to N concentration in manure by using values of manure amount per animal or per farm taken from different national norms and guidelines (for example Regulation for technological design of cattle buildings, 2009 and others) or from pilot farms. There are several published national sources with manure data (for example Developing a fertilisation plan 2002, Estimation of N and P in manure, 2017), they can be used as old table values for comparison as well. P is not considered in official decree and other published sources were used as old table values (**Table 61**).

Table 60. Conversions of animals to animal units and allowed amount of land for manure spreading

Animals	Number of animals per 1 AU	Number of AU per 1 animal	Allowed spreading area, ha
Sows (with weaners), boars	2.9	0.35	0.21
Piglets 7-32 kg (3 months)	100	0.01	0.006
Pigs 3-8 months	10	0.1	0.06
Pigs older than 8 months	9.1	0.11	0.065
Cows, bulls	1	1	0.59
Calves till 1 year	4	0.25	0.15
Cattle 1-2 years	1.4	0.7	0.41
Red deer	5	0.2	0.12
Sika deer	9	0.11	0.06
Bison	1.7	0.6	0.4
Sheep, goats	14	0.07	0.041
Horses older than 1 year	1	1	0.59
Foals till 1 year	2.5	0.4	0.24
Laying hens	140	0.007	0.0041
Broiler chickens	2500	0.0004	0.00024
Turkeys grown till 70 d.	157	0.0064	0.0038
Turkeys grown till 133 d.	75	0.0133	0.0078
Ducks	116	0.0086	0.0051
Geese	63	0.016	0.009
Rabbits (bucks and does with unweaned offspring)	40	0.025	0.015
Chinchilla	714	0.0014	0.00083
Minks / martens (older than 10 months)	40	0.025	0.015
Foxes (older than 10 months)	15	0.067	0.039
Ostriches (adult)	2.5	0.4	0.24
Laying quails	450	0.0022	0.0013
Broiler quails	4800	0.000208	0.00012

Table 61. Old and new ex storage manure data for total nitrogen (Tot-N) and total phosphorus (Tot-P), used as manure parameters in pilot farm scale (kg/ton of manure), and the percentage change between new and old values. Old data are based on conversion from animal units (for N) and the table values (for P, Estimation of N and P in manure, 2017, see text), and new data are based on the manure samples taken in WP2).

	Tot-N (kg/t)			Tot-P (kg/t)		
	Old	New	Diff.	Old	New	Diff.
Dairy cattle, slurry (Pilot farm 1)	3.3	3.8	+15.1%	0.7	0.62	-11.4%
Dairy cattle, solid manure (dung) (Pilot farms 2, 3, 4)	5.6	6.35	+13.4%	1.1	1.4	+27.3%
Beef cattle, deep litter (Pilot farms 5, 6)	10.5	7.2	-31.4%	1.35	1.34	-0.7%
Horses, solid manure (Pilot farm 8)	6.8	6.5	-4.4%	-	1.3	-
Broilers, deep litter (Pilot farm 11)	34.1	31.0	-9.1%	5.2	4.9	-5.8%
Sheep, deep litter (Pilot farm 9)	10.9	10.55	-3.2%	1.6	1.65	+3.1%
Goats, solid manure (dung) (Pilot farm 7)	8.9	9.5	+6.7	2.4	2.7	+12.5%

Ex animal manure data for atmospheric emission estimates

To be able to estimate changes in national atmospheric nitrogen emission estimates for animal husbandry, also new and old excretion values of total nitrogen (as kg/animal place/year) were compared. Currently in Lithuania, excretion values used in national emission inventories are calculated by Institute of Animal Science of LUHS under supervision of Ministry of Environment and are documented in national emission inventory reports. As new excretion data, values obtained from regional manure calculation tool developed in WP3 were used. The both data sets and the percentage change between them per animal category and manure parameter are presented in **Table 62**.

Table 62. Old and new excretion data (total nitrogen as kg/animal place/year) and the percentage changes between them, used in atmospheric emission estimation.

	Tot-N (kg/ap/yr)		
	Old	New	Diff. %
Dairy cattle	106.8	133.7	25.2
Non-dairy cattle	42.8	43.9	2.6
Horses	51.1	51.1	0.0
Swine	11.8	-	-
Goats	15.81	16.1	1.8
Layer hens	0.47	-	-
Broilers	0.51	0.4	-21.6
Turkeys	2.09	-	-
Ducks	0.4	-	-
Geese and other poultry	0.60	-	-
Rabbits	8.10	-	-
Minks, nutria	4.59	-	-
Foxes, polar foxes	12.09	-	-

4.5.2. Impacts of using the new manure data

4.5.2.1. Results from the pilot farm modelling

NBBM modelling

Data from four pilot farms were used to calculate the impacts of new manure tools to fertilisation and nutrient balances in the farm level (**Table 63.** Summary table for Lithuanian pilot farm results of NBBM modelling.). Based on that, the impacts on nitrogen and phosphorus leaching risk were estimated, based on the methods described in chapter 3. In the Lithuanian case, the NBBM mode for N efficiency factors was used. Some yields of cereals and grasses were taken from Lithuanian sources (Magilevičius, 2009; Lukoševičius and Šiuliauskas, 2017) other data and yield response to fertilisation functions were based on the Finnish studies (default parameters).

For all farms, table values were used as old manure data, and farms' new manure analysis results from this study were used as new manure data (see chapter 4.5.1). When introduced new manure data, the balance of nitrogen and phosphorus decrease slightly. Relative change in nitrogen leaching risk after introducing new manure data is -0.01%.

Table 63. Summary table for Lithuanian pilot farm results of NBBM modelling.

Animal type	Manure type	Farm acreage (ha)	% of acreage received manure	Basis of manure application rates		Average nutrient balances with old manure data (present actual; kg/ha)			Average nutrient balances with new manure data (new actual; kg/ha)			Difference between "new" and "present" nutrient balances (%)			Difference in leaching risk (from "present" to "new", %)
				Old manure data	New manure data	Ntot	Nplant	Ptot	Ntot	Nplant	Ptot	Ntot	Nplant	Ptot	Nplant
Dairy cattle	Slurry	208.4	100%	Table values	Farm's new manure analysis	38.9	11.2	18.5	44.8	17.6	15.6	15%	57%	-16%	1%
Dairy cattle	Solid+urine	40.5	100%	Table values	Farm's new manure analysis	87.6	-75.6	97.4	18.8	-136.6	75.4	-79%	-81%	-23%	0%
Beef cattle	Deep litter	100.0	100%	Table values	Farm's new manure analysis	91.2	23.4	6.2	104.3	42.5	6.6	14%	82%	6%	-4%
Horse	Solid+urine	121,7	100%	Table values	Farm's new manure analysis	20.5	-103.3	18.7	-83.3	-177.0	2.9	-506%	-71%	-84%	0%
		Received manure:										**Weighted averages:**			
		470.6 ha	100%									-1.4%		-0.3%	-0.01%

CCB modelling

Farm LT1 represents Lithuanian dairy production system. In 2017 spring wheat, field bean and maize were grown on the farm. The textural class of soil according USDA is identified as a silty clay; soil organic carbon content of soil is presumed to be 2%, the mean air temperature and precipitation is about 8°C respectively 650 mm (**Table 64**). This results in a BAT of 17.8 d (**Table 66**), which causes to a comparatively moderate turnover of organic matter in the soil.

Table 64. Soil and climate input data for the CCB model.

Corg (%) start value	2.0 (presumed)
Soil texture	Clay 55%; Silt 25%
Air Temperature (C°)	8.3
Precipitation (mm/yr)	650

The table values and measured values of manure quality are very different (**Table 65**). At a same CN ratio, the measured values of N and C lower and of DM higher than of table values. This results in a lower Rep_IX (**Table 66**) and therefore to a lower C saldo as well as to a less CO_2 production and N mineralisation (***Figure 20***) by using measured values of manure quality. However, the soil C storage is more or less on the same level.

Table 65. Utilised parameters (DM - Dry matter, N – Nitrogen, C - Carbon, CNR – C/N ratio) of manure from national references (table values) and measurements of laboratories (measured values).

Cattle slurry	DM [%]	N [kg/t FM]	C [kg/t FM]	CNR
Table values	4.16	5.30	44.64	8.42
Measured values	8.90	3.79	31.95	8.42

Table 66. Simulated Biologic active time (BAT) and Soil organic matter reproduction index = $C_{reproduction}$/BAT (REP_IX).

	BAT (d/a)	Rep_IX
Table values	17.8	44.8
Measured values		38.5

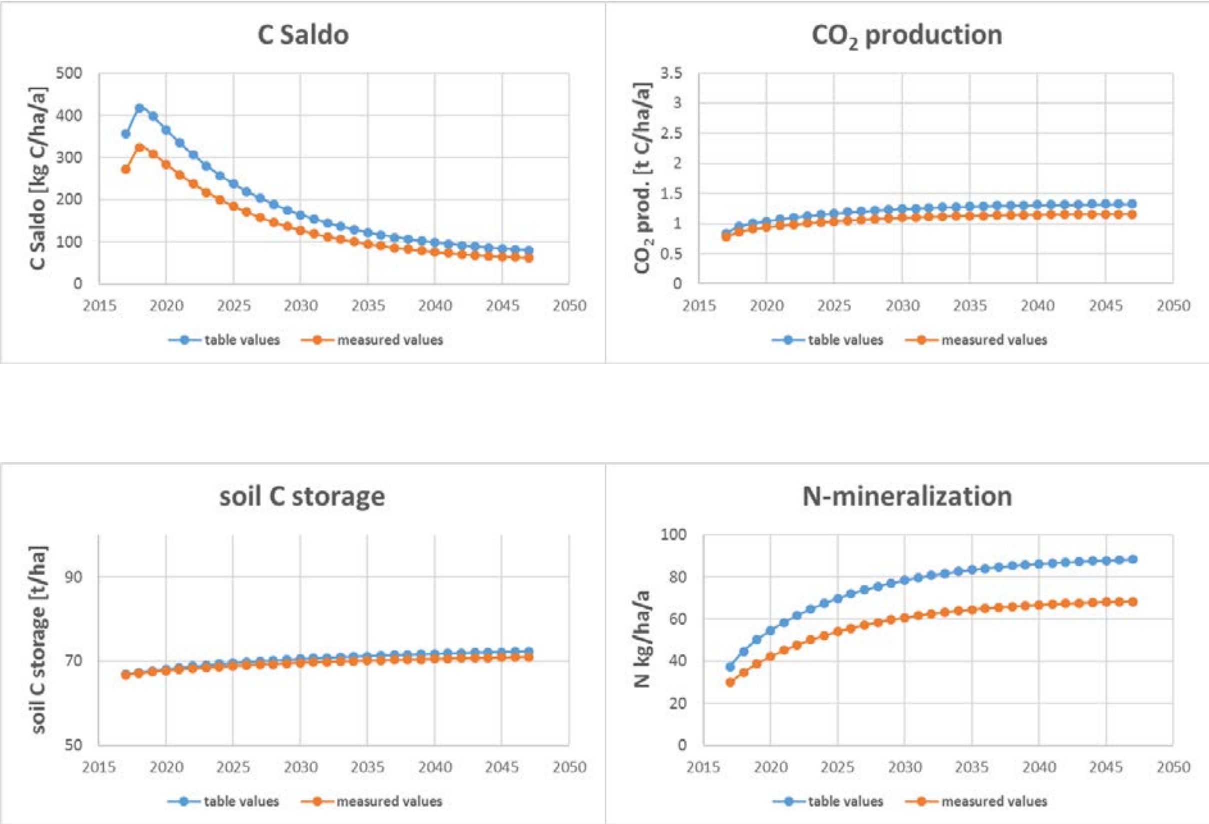

Figure 20. Simulated C saldo, CO_2 production, soil C storage and N-mineralisation of Farm LT1.

Farm LT5 produces organic beef cattle. In 2017 clover grass and pea fodder were grown on the farm. Three quarters of the area is grassland. The textural class of soil according USDA is identified as a loamy sand; soil organic carbon content of soil is presumed to be 2%, the mean air temperature and precipitation is about 7°C respectively 792 mm (**Table 67**). This results in a BAT of 29.3 d for plowed arable land and 19.1 for grassland (**Table 69**), which causes to a comparatively fast turnover of organic matter in the soil.

Table 67. Soil and climate input data for the CCB model.

Corg (%) start value	2.0 (presumed)
Soil texture	Clay 10%; Silt 20%
Air Temperature (C°)	7.3
Precipitation (mm/yr)	792

The table values and measured values of manure quality are very different (**Table 68**). Excluding CN ratio all measured values are significantly higher than table values. This results in a higher Rep_IX (**Table 69**) and therefore to a higher C saldo as well as to a stronger CO_2 production and N mineralisation (***Figure 21*** & ***Figure 22***) by using measured values of manure quality. However, the soil C storage is more or less on same level.

Table 68. Utilised parameters (DM - Dry matter, N – Nitrogen, C - Carbon, CNR – C/N ratio) of manure from national references (table values) and measurements of laboratories (measured values).

Beef solid	DM [%]	N [kg/t FM]	C [kg/t FM]	CNR
Table values	20.50	4.79	66.01	13.77
Measured values	64.40	5.71	78.57	13.77

Table 69. Simulated Biologic active time (BAT) and Soil organic matter reproduction index = $C_{reproduction}$/BAT (REP_IX).

	BAT (d/a) (arable land)	Rep_IX (arable land)	BAT (d/a) (grassland)	Rep_IX (grassland)
Table values	29.3	45.7	19.1	138.4
Measured values		51.8		149.4

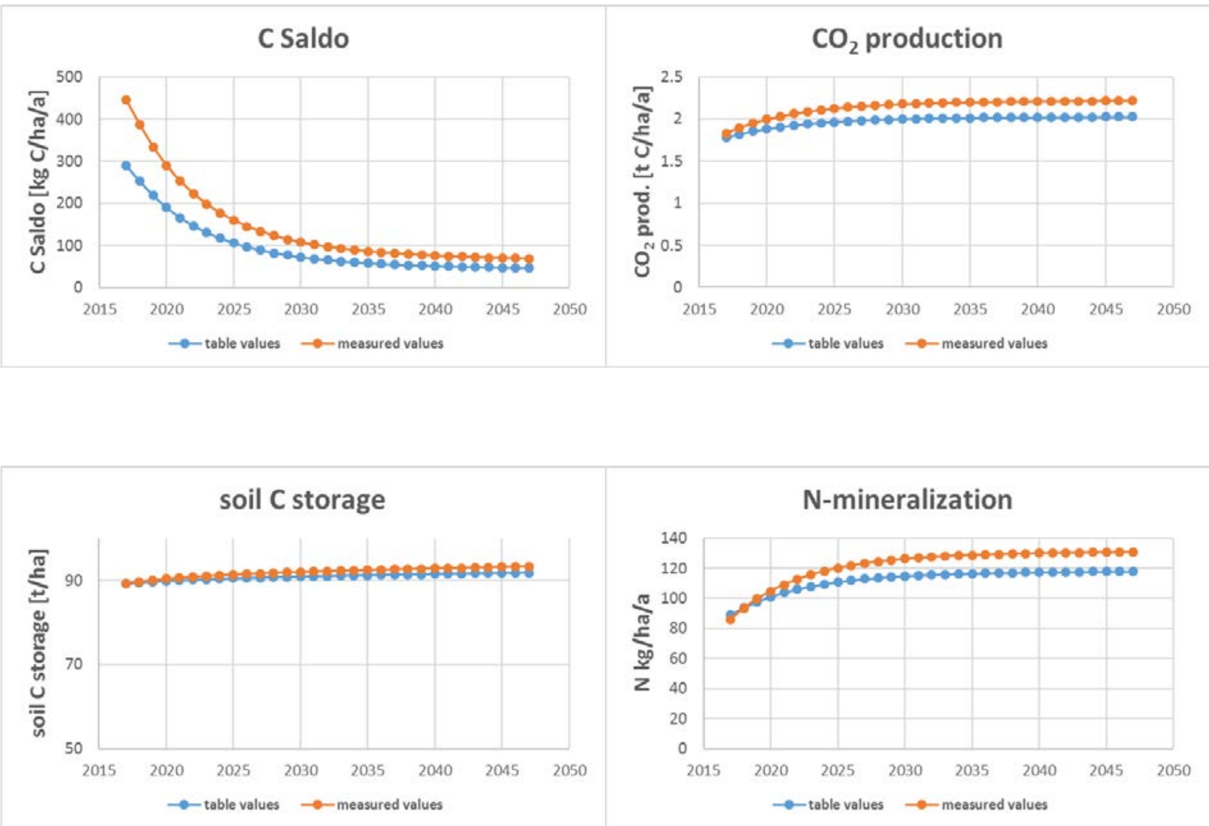

Figure 21. Simulated C saldo, CO_2 production, soil C storage and N-mineralisation of Farm LT5 arable land.

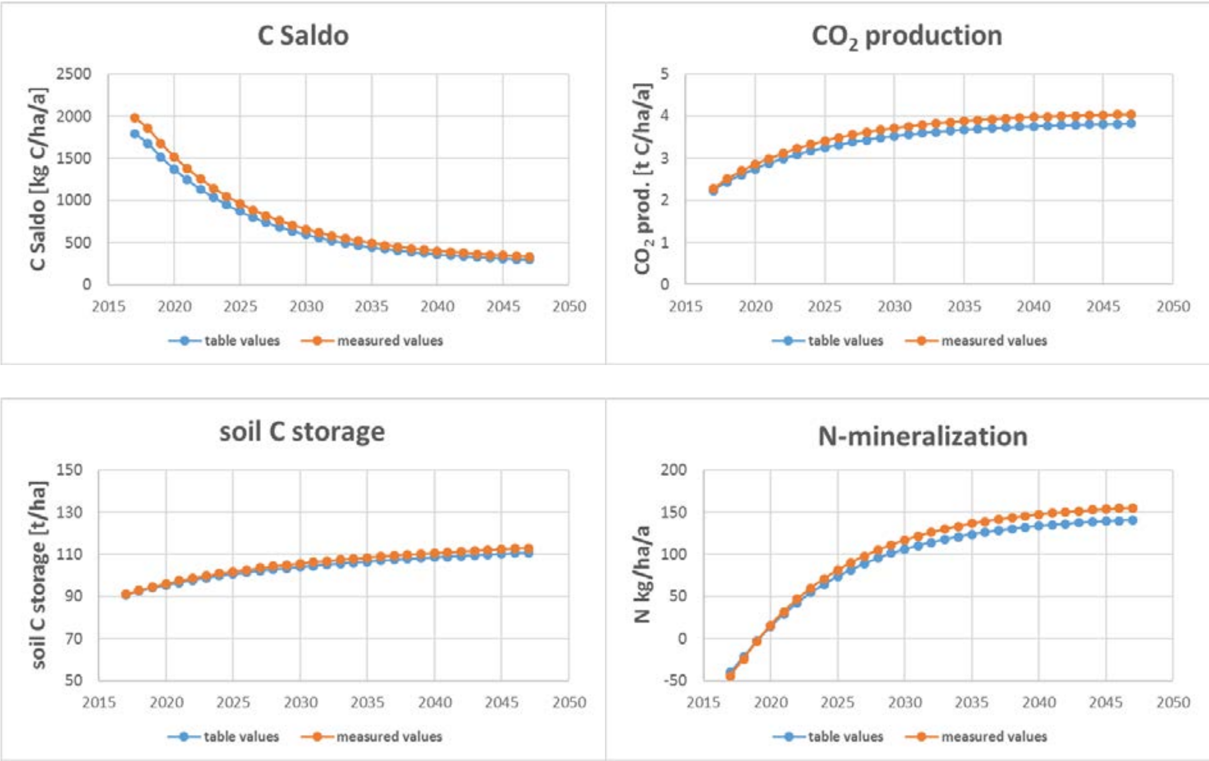

Figure 22. Simulated C saldo, CO_2 production, soil C storage and N-mineralisation of Farm LT5 grassland.

4.5.2.2. Results from the regional modelling

CCB modelling

LT_Region representing a region of Lithuania. In 2017 triticale, spring and winter wheat, spring and winter rye, spring and winter barley, field bean, oat, cereal grain mix, maize, pea, lupine, sugar beet, spring and winter rape, fodder beet, maize, potato as well as buckwheat were grown in this region. Main textural class of soil according USDA is identified as a silty clay; soil organic carbon content of soil is presumed to be 2%, the mean air temperature and precipitation is about 8°C respectively 840 mm (**Table 70**). This results in a BAT of 15.1 d (**Table 59**), which causes to a comparatively moderate turnover of organic matter in the soil.

Scenario 1 assumes 100% mineral fertiliser use and Scenario 2 replaces 60% of the nitrogen requirement with organic fertilisers of the quality from **Table 71**. In both cases, more carbon will be sequestered in the soil than is emitted into the atmosphere (***Figure 23***). However, in scenario 2, the C saldo and C storage level is higher and more carbon and nitrogen are mineralised.

Table 70. Soil and climate input data for the CCB model.

Corg (%) start value	2 (presumed)
Soil texture	Clay 45%; Silt 30%
Air Temperature (C°)	7.63
Precipitation (mm/yr)	839.5

Table 71. Utilised parameters (DM - Dry matter, N – Nitrogen, C - Carbon, CNR – C/N ratio) of manure from national references (table values).

	DM [%]	N [kg/t FM]	C [kg/t FM]	CNR
Table values	8.9	3.79	31.95	8.42

Table 72. Simulated Biologic active time (BAT) and Soil organic matter reproduction index = $C_{reproduction}$/BAT (REP_IX).

	BAT (d/a)	Rep_IX
Scenario 1	15.1	26.3
Scenario 2		40.3

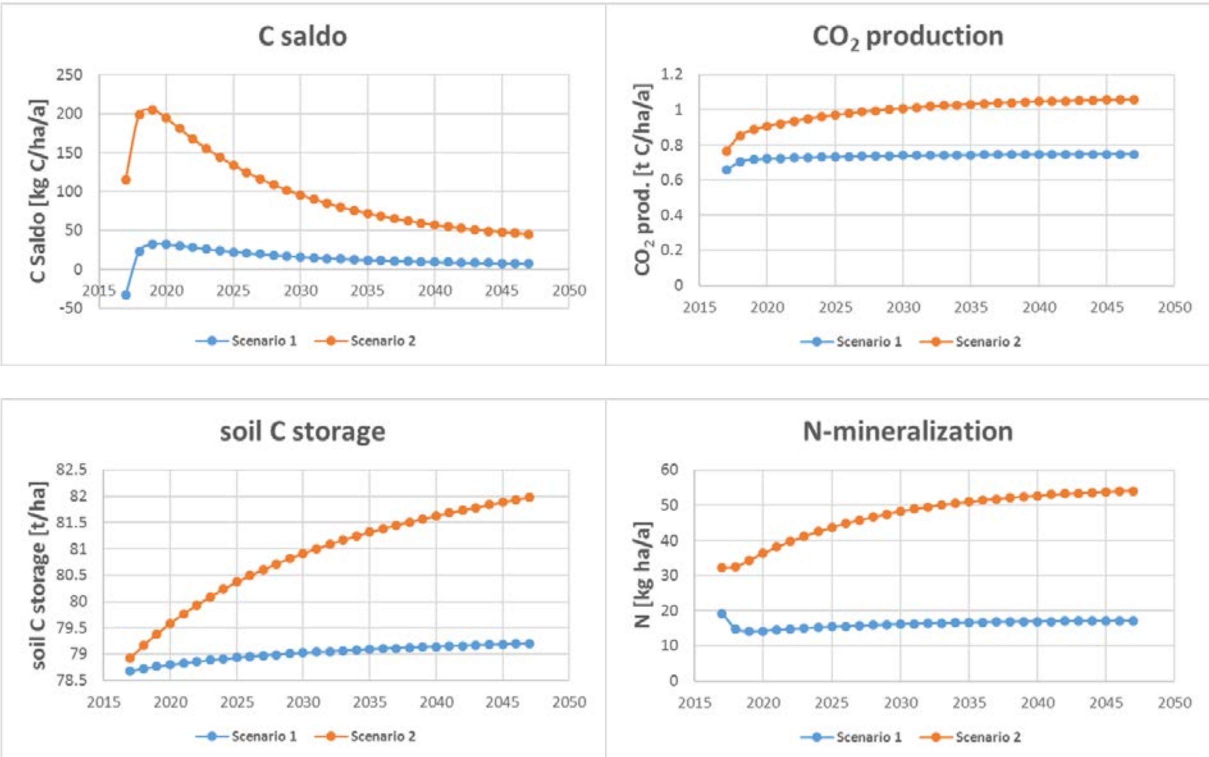

Figure 23. Simulated C saldo, CO_2 production, soil C storage and N-mineralisation of the LT_Region.

4.6. Poland

4.6.1. Comparison of the old and new manure data

Ex storage manure data for fertilisation planning

In Poland, old (table) values are based on Ordinance of the Council of Ministers of 5 June 2018 on the adoption of the 'Action programme for the reduction of water pollution caused by nitrates from agricultural sources and prevention of further pollution' – 'Nitrate Program' (Journal of Laws 2018 item 1339), what is related to the Water Act. Table values do not contain neither N soluble nor ammonia N data, and nitrogen fertilisation planning is based on manure N efficiency factors. For fertilisation purposes farmers can use table values or their own manure analyse results. As old N manure data the table values from 'Nitrate Program' was taken. As old P manure data, the table values from a database of The National Research Institute of Animal Production was used. The new data are represented by the results obtained in laboratory analyses of *Ex storage* samples taken from pilot farms (**Table 73**).

For the national level table values from 'Nitrate Program" were used as old manure data, and values calculated with regional calculation tool in WP3 (Tier 2) were used as a new manure data (**Table 74**). Calculations were conducted based on the Polish standard excretion values published in national emission inventory report.

Table 73. Polish old and new ex storage manure data for total nitrogen (Tot-N), and total phosphorus (Tot-P), used as manure parameters in pilot farm scale (kg/ton of manure), and the percentage change between new and old values.

	Tot-N (kg/t)			NH_4-N (kg/t)			Tot-P (kg/t)		
	Old	New	Diff.	Old	New	Diff.	Old	New	Diff.
Cattle solid manure (Pilot farm PL 7)	3.10	4.77	+54%	n/a	n/a	n/a	0.45	0.99	+120%
Cattle urine (Pilot farm PL 7)	3.20	1.92	-40%	n/a	n/a	n/a	0.44	0.09	-79%
Pig solid manure (Pilot farm PL 1)	4.20	4.90	+17%	n/a	n/a	n/a	0.60	0.99	+66%
Pig urine (Pilot farm PL 1)	4.60	1.72	-63%	n/a	n/a	n/a	0.87	0.06	-93%
Poultry solid manure (Pilot farm PL 2)	24.70	27.10	+10%	n/a	n/a	n/a	3.07	4.30	+40%

Notes: Sources of manure data are explained in the text.

Table 74. Polish old and new ex storage manure data used as manure parameters in national scale. Old data are based on the table values (Nitrate Program; see text) and new data are based on the calculation tool developed in WP3.

	Tot-N (kg/t)			NH_4-N (kg/t)			Tot-P (kg/t)		
	Old	New	Diff.	Old	New	Diff.	Old	New	Diff.
Cattle solid manure	3.10	2.60	-16%	n/a	0.20	n/a	0.45	1.20	+166%
Cattle slurry	4.00	4.10	+3%	n/a	0.16	n/a	0.55	0.90	+63%
Cattle urine	3.20	n/a	n/a	n/a	n/a	n/a	0.44	n/a	n/a
Pig solid manure	4.20	5.40	+29%	n/a	0.13	n/a	0.60	1.00	+67%
Pig slurry	4.60	4.90	+7%	n/a	0.17	n/a	0.87	0.70	-20%
Pig urine	4.60	n/a	n/a	n/a	n/a	n/a	0.87	n/a	n/a
Sheep solid manure	8.10	n/a	n/a	n/a	n/a	n/a	1.37	n/a	n/a
Goat solid manure	8.18	n/a	n/a	n/a	n/a	n/a	1.59	n/a	n/a
Horse solid manure	3.05	n/a	n/a	n/a	n/a	n/a	0.26	n/a	n/a
Laying hen solid manure	20.70	n/a	n/a	n/a	n/a	n/a	2.06	n/a	n/a
Broiler solid manure	24.70	n/a	n/a	n/a	n/a	n/a	3.07	n/a	n/a
Turkey solid manure	41.05	n/a	n/a	n/a	n/a	n/a	3.73	n/a	n/a

Notes: Sources of manure data are explained in the text.

Ex animal manure data for atmospheric emission estimates

Estimation of changes in national atmospheric nitrogen emission was not possible to conduct due to lack of data on animal feeding at the regional/country level (use in Tier 3 of regional calculation tool), which were necessary to the calculation of new emission data. In Poland, current N excretion rates, NH_3, NO_2, CH_4 and volatile solids emissions are calculated by National Centre for Emission Management (KOBiZE) and published in national emission inventory report.

4.6.2. Impacts of using the new manure data

4.6.2.1. Results from the pilot farm modelling

NBBM modelling

For calculation of the impacts of new manure tools to fertilisation and nutrient balances at the farm level the data from three pilot farms was taken. Using this data, the impacts on nitrogen and phosphorus leaching risk were estimated, based on the methods described in chapter 3. In the Polish case, the NBBM mode for N efficiency factors was used. For crop yields, farm specific values were used.

Manure application averagely covers 58% of the total area of the pilot farms. For the pilot farms, different sources for old and new manure data were used (see chapter 4.6.1). When new manure data were implemented, the level of change in nutrient balances at farm level depends on the difference between old and new manure data and the share of fields where manure is applied.

If the nutrient content of manure is currently underestimated, the introduction of new manure data will reduce the fertilisation rate and nutrient balance, and vice versa. However, the model assumes that only mineral fertilisation is corrected if it is necessary to adjust fertilisation due to changes in the nutrient composition of the manure. For dairy cow and fattening pig Polish pilot farms, the manure analyse results showed much higher content of total nitrogen (17-63%) and total phosphorus (66-120%) in manure samples, compared to table values, while in case of broiler farm the differences were small, 9% and 40% for N and P, respectively. When using these values in the model for balance calculations and adjusting the fertilisation plan, lower amount of nitrogen and phosphorus by mineral fertilisers need to be used for expected yield, and both element's balance decrease.

In the case of Polish pilot farms, the change in risk of nitrogen leaching due to introducing new manure data varies between -2% and 0% (**Table 75**). It was not possible to indicate the change in risk of phosphorus leaching because the change in STP concentration, which is needed for this calculation (cf. chapter 3.1.3), could not be estimated for Polish pilot farms from methodology reasons (different STP analysis method). However, based on P-balance calculations it was estimated that the introduction of new manure data will reduce phosphorus balances, which in turn will reduce the risk of phosphorus leaching in the long term. It must be kept in mind that the risk values describe only the effect of introducing the new manure data.

Table 75. Summary table for Polish pilot farm results of NBBM modelling.

Animal type	**Manure type**	**Farm acreage (ha)**	**% of acreage received manure**	**Basis of manure application rates**		**Average nutrient balances with old manure data (present actual; kg/ha)**			**Average nutrient balances with new manure data (new actual; kg/ha)**			**Difference between "new" and "present" nutrient balances (%)**			**Difference in leaching risk (from "present" to "new", %)**	
				Old manure data	**New manure data**	**N_{tot}**	**N_{avail}**	**P_{tot}**	**N_{tot}**	**N_{avail}**	**P_{tot}**	**N_{tot}**	**N_{avail}**	**P_{tot}**	**N_{avail}**	**P (10 yrs)**
Dairy cattle	Solid+urine	112.8	35.5	Table values	Farm's new manure analysis taken by CDR	81.3	50.2	9.6	70.2	39.1	6.8	-14%	-22%	-29%	-2%	n.a.
Broilers	Deep litter	96.5	60.6	Table values	Farm's new manure analysis taken by CDR	73.4	8.2	15.5	72.7	7.5	14.6	-1%	-9%	-6%	0%	n.a.
Fattening pigs	Solid	136.2	74.7	Table values	Farm's new manure analysis taken by CDR	61.0	30.9	-11.7	51.9	21.9	-15.7	-15%	-29%	-35%	-1%	n.a.
		345.5														
		Received manure:										**Weighted averages:**				
		200.3 ha	58%									-7.7	-16.7	-18.5	-0.8	

CCB modelling

Farm PL7 is a dairy farm. In 2017 clover grass, spring barley, cereal grain mix, spring wheat, triticale, winter wheat and maize were grown on the farm. One third of the area is grassland area. The textural class of soil according USDA is identified as a sandy loam; soil organic carbon content of soil amounts 0.95%, the mean air temperature and precipitation is about 8°C respectively 623 mm (**Table 76**). This results in a BAT of 28.9 d for arable land and 18.0 d for grassland (**Table 78**), which causes to a comparatively fast turnover in arable land and moderate turnover in grassland of soil organic matter.

Table 76. Soil and climate input data for the CCB model.

Corg (%) start value	0.95
Soil texture	Clay 15.23%; Silt 14.46%
Air Temperature (C°)	8.3
Precipitation (mm/yr)	623

The table values and measured values of manure quality are different (**Table 77**). CN ratio and DM content of measured values are lower and N as well as C content higher than table values. This all together results in a higher Rep_IX (**Table 78**) and therefore to a higher C saldo as well as to a stronger CO_2 production and N mineralisation (***Figure 24*** & ***Figure 25***) by using measured values of manure quality. However, the soil C storage is more or less on same level.

Table 77. Utilised parameters (DM - Dry matter, N – Nitrogen, C - Carbon, CNR – C/N ratio) of manure from national references (table values) and measurements of laboratories (measured values).

Cattle man. (solid)	**DM [%]**	**N [kg/t FM]**	**C [kg/t FM]**	**CNR**
Table values	27.00	3.40	102.06	30.00
Measured values	20.70	5.06	133.93	26.48

Table 78. Simulated Biologic active time (BAT) and Soil organic matter reproduction index = $C_{reproduction}$/BAT (REP_IX).

	BAT (d/a) (arable land)	**Rep_IX (grassland)**	**BAT (d/a) (grassland)**	**Rep_IX (grassland)**
Table values	28.9	50.9	18.0	112.4
Measured values		60.5		120.9

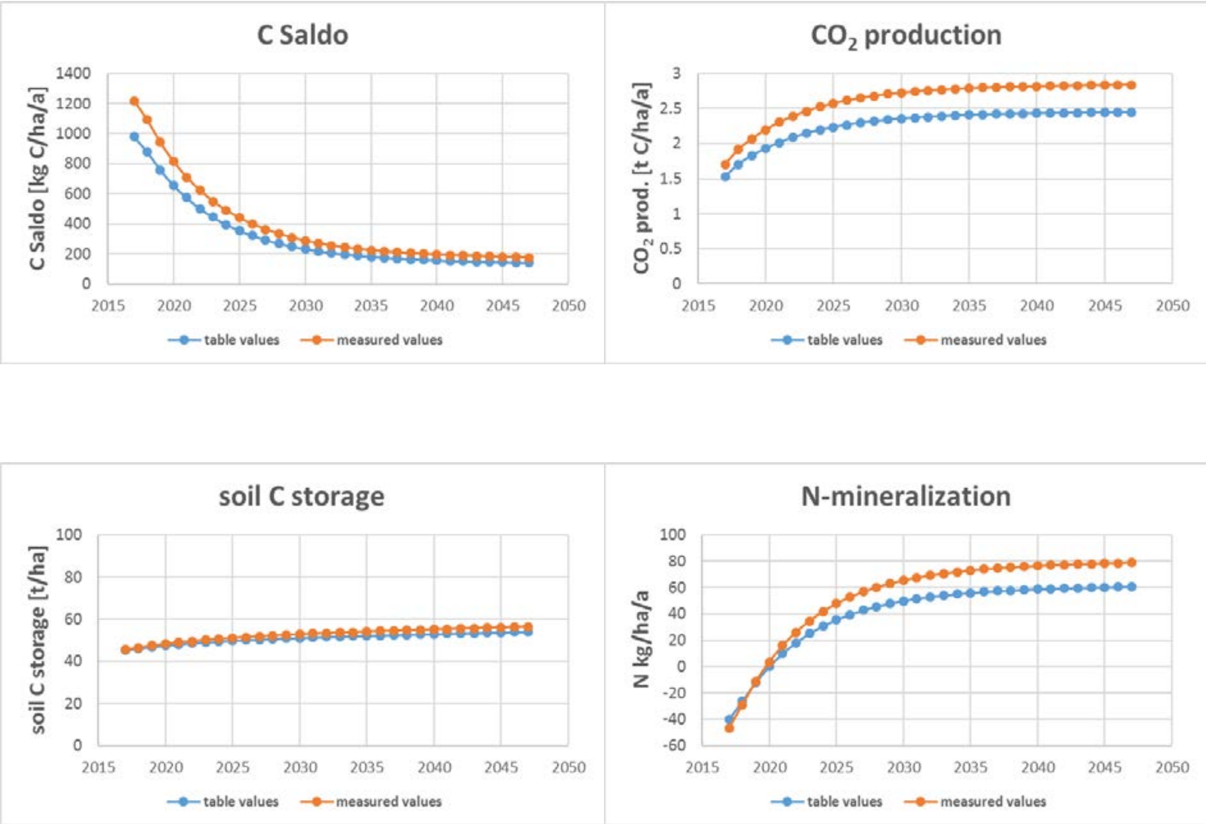

Figure 24. Simulated C saldo, CO_2 production, soil C storage and N-mineralisation of Farm PL7 arable land.

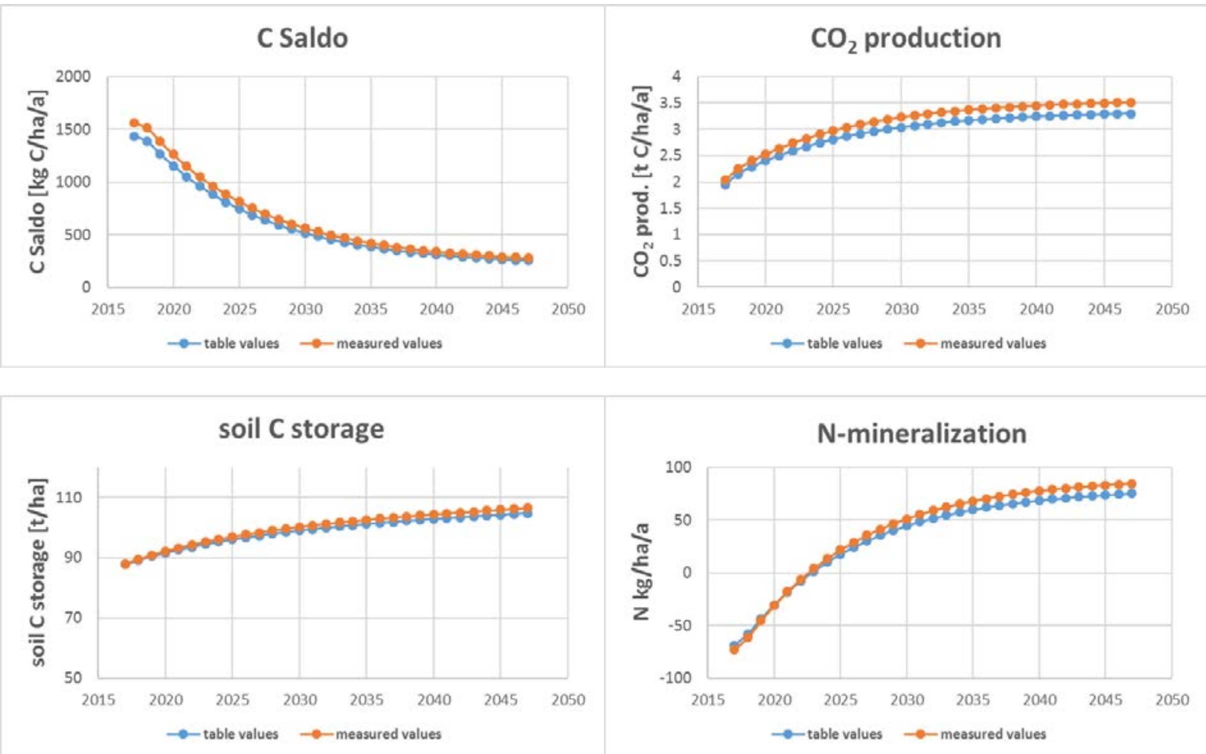

Figure 25. Simulated C saldo, CO_2 production, soil C storage and N-mineralisation of Farm PL7 grassland.

4.6.2.2. Results from the regional modelling

CCB modelling

PL_Mazowickie representing a region of Poland. In 2017 field bean, spring and winter wheat, winter rye, spring and winter barley, triticale, cereal grain mix, maize, potato, winter rape as well as sugar beet were grown in this region. Main textural class of soil according USDA is identified as a sand; soil organic carbon content of soil is presumed to be 2%, the mean air temperature and precipitation is about 9°C respectively 623 mm (**Table 79**). This results in a relatively high BAT of 39.6 d (**Table 81**), which causes to a comparatively very fast turnover of organic matter in the soil.

Scenario 1 assumes 100% mineral fertiliser use and Scenario 2 replaces 60% of the nitrogen requirement with organic fertilisers of the quality from **Table 80**. Scenario 1 shows a negative trend of carbon storage and in the scenario 2 the carbon content increases over time (***Figure 26***). However, in scenario 2, also the C saldo and C storage level is higher and more carbon and nitrogen are mineralised.

Table 79. Soil and climate input data for the CCB model.

Corg (%) start value	2 (presumed)
Soil texture	Clay 8.84%; Silt 9.83%
Air Temperature (C°)	8.9
Precipitation (mm/yr)	623

Table 80. Utilised parameters (DM - Dry matter, N – Nitrogen, C - Carbon, CNR – C/N ratio) of manure from national references (table values).

	DM [%]	**N [kg/t FM]**	**C [kg/t FM]**	**CNR**
Table values	20.7	5.06	133.93	26.48

Table 81. Simulated Biologic active time (BAT) and Soil organic matter reproduction index = $C_{reproduction}$/BAT (REP_IX).

	BAT (d/a)	**Rep_IX**
Scenario 1	39.6	14.3
Scenario 2		29.3

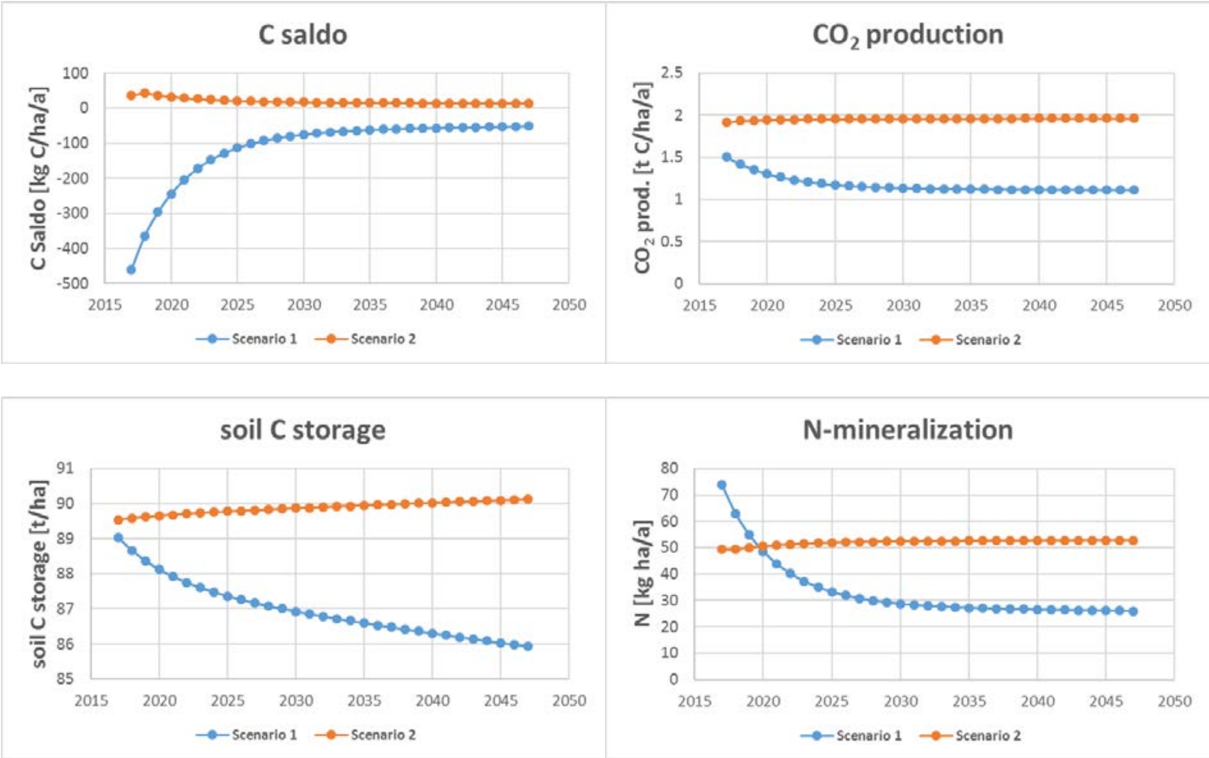

Figure 26. Simulated C saldo, CO_2 production, soil C storage and N-mineralisation of the PL_Mazowickie region.

4.7. Russia

4.7.1. Comparison of the old and new manure data

There are several official reference documents with reference values of manure nutrient content in Russia (**Table 82**).

Table 82. Russian official reference documents for manure properties.

Title of reference document	year	use cases	Remarks
RD APK 3.10.15.01-17 Guidelines for designing systems for removing, processing, disinfection, storage and application of animal and poultry manure	2017	Used for creation and reconstruction of farms (Calculation of storage sizes, amount of needed equipments and required area of fields).	Describes the properties of excrement (ex animal manure) for cattle, pigs and poultry. Reference losses of nitrogen and dry matter are also presented, depending on the degree of composting of manure.
RD APK 1.10.15.02-17 Guidelines for technological design of systems for removal and preparation for application of animal and poultry manure	2017	Used for creation and reconstruction farms (Calculation of storage sizes, amount of needed equipments and required area of fields).	Describes the properties of excrement (ex animal manure) for cattle, pigs and poultry. Reference losses of nitrogen are presented for storage, composting and application of manure.
Guidelines for determining the nutrient balance of nitrogen, phosphorus, potassium, humus, calcium	2000	Used by agronomists for planning of doses of organic fertilisers.	Describes the properties of organic fertilisers (ex storage manure) for cattle, pigs and poultry.

These documents are used when new agricultural installations (farms) or plants (parts of farms) are founded, organizing work with manure and determining doses of organic fertilisers. These documents were developed at state research institutes and approved by the Ministry of Agriculture of Russia.

Reference data from RD-APK 3.10.15.01-17 were used as old (existing) data for ex animal manure; reference data from "Guidelines for determining the nutrient balance" were used as existing data for ex storage manure. New data were obtained by sampling on pilot farms, their chemical analysis and taking the median values of the results. The results of the statistical analysis of new data for ex animal manure are shown in **Table 83**.

To compare old and new data, they were converted to same unit - the percentage of nutrients in dry matter. The comparison of old and new data for total nitrogen and total phosphorus is presented in **Table 84** and in **Table 85**.

It should be noted that the most reliable (in terms of the number of samples taken) are new data on cattle manure; for pig manure, on the contrary, the small number of samples taken does not allow us to confirm their relevance to the existing situation.

Table 83. New data for ex animal manure.

indicator	Minimum value	**Median value**	Maximum value	Average value	Standard deviation	Dispersion	Standard error
Dairy cows, semi-solid manure							
Dry matter, %	9.70	**14.80**	20.55	15.29	2.35	5.53	0.61
Total N, kg/t	1.60	**3.10**	4.30	3.13	0.60	0.36	0.15
Total P, kg/t	0.36	**1.20**	2.10	1.18	0.44	0.19	0.11
Dairy cows, solid manure							
Dry matter, %	16.70	**26.90**	54.40	28.00	11.13	123.85	3.71
Total N, kg/t	2.80	**4.60**	9.80	4.96	2.24	5.03	0.75
Total P, kg/t	0.70	**1.45**	2.10	1.53	0.48	0.23	0.16
Heifers, calves							
Dry matter, %	13.75	**16.43**	18.30	16.48	1.64	2.68	0.67
Total N, kg/t	2.70	**3.13**	4.05	3.15	0.49	0.24	0.20
Total P, kg/t	1.05	**1.30**	1.95	1.40	0.36	0.13	0.15
Laying hens							
Dry matter, %	23.70	**47.40**	61.80	44.30	19.24	370.11	11.11
Total N, kg/t	11.50	**13.50**	16.70	13.90	2.62	6.88	1.51
Total P, kg/t	1.20	**3.80**	4.50	3.17	1.74	3.02	1.00

Table 84. Comparison of old and new data of ex animal manure for total N.

	Old data, % in dry matter.	New data, % in dry matter.	Difference, %
Cattle manure, ex animal, semi-solid	3.20	2,09	-34,7%
Cattle manure, ex storage, semi-solid	2.00	0,81	-59,5%
Pig manure, ex animal	6.00	2,24	-62,7%
Pig manure, ex storage	2.30	3,26	+41,7%
Poultry manure, ex animal	6.20	2,84	-54,2%
Poultry manure, ex storage	3.33	3,66	+9,9%

Table 85. Comparison of old and new data of ex animal manure for total P.

	Old data, % in dry matter.	New data, % in dry matter.	Difference, %
Cattle manure, ex animal, semi-solid	0.785	0.810	+3.2%
Cattle manure, ex storage, semi-solid	0.349	0.720	+106.3%
Pig manure, ex animal	1.395	0.655	-53.0%
Pig manure, ex storage	0.760	1.420	+86.8%
Poultry manure, ex animal	1.526	0.800	-47.6%
Poultry manure, ex storage	1.977	2.160	+9.3%

4.7.2. Impacts of using the new manure data

4.7.2.1. Results from the pilot farm modelling

NBBM modelling

To assess the impacts of the use of new data, the NBBM tool was used, which allows modelling the risks of nutrient leaching, depending on the nutrient content of organic fertilisers, their doses, crops grown and their productivity. The situation was simulated for two pilot agricultural enterprises - dairy agricultural enterprises, which use three types of organic fertilisers: semi-solid cattle manure and two types of solid cattle manure (**Table 86**). The cultivation data of the pilot farms are presented in **Table 87** and in **Table 88**.

Table 86. Comparison of old and new manure data used in NBBM modelling.

	Old data		New data	
Manure type	**Total N, kg/t**	**Total P, kg/t**	**Total N, kg/t**	**Total P, kg/t**
Solid manure #1	5.99	1.34	9.8	1.30
Solid manure #2	5.78	1.29	4.6	1.90
Semi-solid manure	4.50	0.50	3.1	0.90

Table 87. Description of the fields of the pilot farm #1.

	Area, hectares	Crop	Manure type	Amount of manure per ha (t)
Field #1	87.0	Spring barley	Solid manure #1	28.1
Field #2	120.9	Oats	Solid manure #1	28.1
Field #3	9.1	Oats	Semi-solid manure	37.3
Field #4	60.0	Potatoes	Semi-solid manure	37.3
Field #5	131.0	Fodder grassland for hay	Semi-solid manure	37.3
Field #6	484.0	Fodder grassland for silage	Semi-solid manure	37.3
Field #7	650.0	Fodder grassland for silage	Semi-solid manure	37.3
Total	1542.0			

Table 88. Description of the fields of the pilot farm #2.

	Area, hectares	Crop	Manure type	Amount of manure per ha (t)
Field #1	390.0	Spring barley	Solid manure #2	16
Field #2	10.0	Potatoes	Solid manure #2	110
Field #3	260.0	Fodder grassland for silage	Solid manure #2	19
Field #4	1059.0	Fodder grassland for silage		
Total	1729.0			

Table 89 and **Table 90** present the results of modelling changes of nutrients balance for pilot farms. For the first pilot farm, updating data of nutrient content in manure led to significant increase for total and available nitrogen, which leads to increased risk of leaching. For the total and available phosphorus, the opposite situation was observed - its balance has decreased, which also reduces the risks of leaching.

For the second pilot farm, updating data of nutrient content in manure led to slight decrease for nitrogen balance, and consequently risk of nitrogen leaching is decrease too, and more significant decrease for phosphorus balance and, accordingly, risk of leaching is decrease too.

Table 89. Results of the simulation of changes in balances for the pilot farm #1.

Total N	Plant available N	Total P	Plant available P
121%	26%	-6%	-6%
INCREASE nutrient balances and nutrient leaching risk		DECREASE nutrient balances and nutrient leaching risk	

Table 90. Results of the simulation of changes in balances for the pilot farm #2.

Total N	Plant available N	Total P	Plant available P
-1%	0%	-8%	-8%
DECREASE nutrient balances and nutrient leaching risk		DECREASE nutrient balances and nutrient leaching risk	

CCB modelling

Farm RU8 is a cattle farm. In 2017 potato, winter barley and oat were grown on the farm. Only a tenth of the area is arable land. Other area is grassland. The textural class of soil according USDA is identified as a sandy loam; soil organic carbon content of soil amounts 2.22%, the mean air temperature and precipitation is about 5°C respectively 671 mm (**Table 91**). This results in a BAT of 10.2 d for plowed arable land and 7.1 for grassland (**Table 93**), which causes to a comparatively slow turnover of soil organic matter.

Table 91. Soil and climate input data for the CCB model.

Corg (%) start value	2.22%
Soil texture	Clay 17%; Silt 45%
Air Temperature (C°)	4.6
Precipitation (mm/yr)	671

The table values and measured values of manure quality are more or less similar (**Table 92**). Only the N content is different. Cattle solid manure has a higher value and cattle slurry a lower value of measured samples. This all together results in a comparable Rep_IX (**Table 93**) and to similar C saldo, CO_2 production and soil C storage (***Figure 27*** & ***Figure 28***) by using measured values or table values of manure quality. Only the nitrogen mineralisation is different by using table or measured values (***Figure 27*** & ***Figure 28***). In general, the C content of manure are very high which leads to an increased C storage over time both in arable land and grassland.

Table 92. Utilised parameters (DM - Dry matter, N – Nitrogen, C - Carbon, CNR – C/N ratio) of manure from national references (table values) and measurements of laboratories (measured values).

Cattle solid	**DM [%]**	**N [kg/t FM]**	**C [kg/t FM]**	**CNR**
Table values	30.00	5.99	210.00	35.06
Measured values	31.50	9.80	207.90	21.21
Cattle slurry	**DM [%]**	**N [kg/t FM]**	**C [kg/t FM]**	**CNR**
Table values	15.00	4.50	130.05	28.89
Measured values	14.90	3.10	126.65	40.85

Table 93. Simulated Biologic active time (BAT) and Soil organic matter reproduction index = $C_{reproduction}$/BAT (REP_IX).

	BAT (d/a) (arable land)	**Rep_IX (arable land)**	**BAT (d/a) (grassland)**	**Rep_IX (grassland)**
Table values	10.5	398.9	7.1	637
Measured values		394.5		626

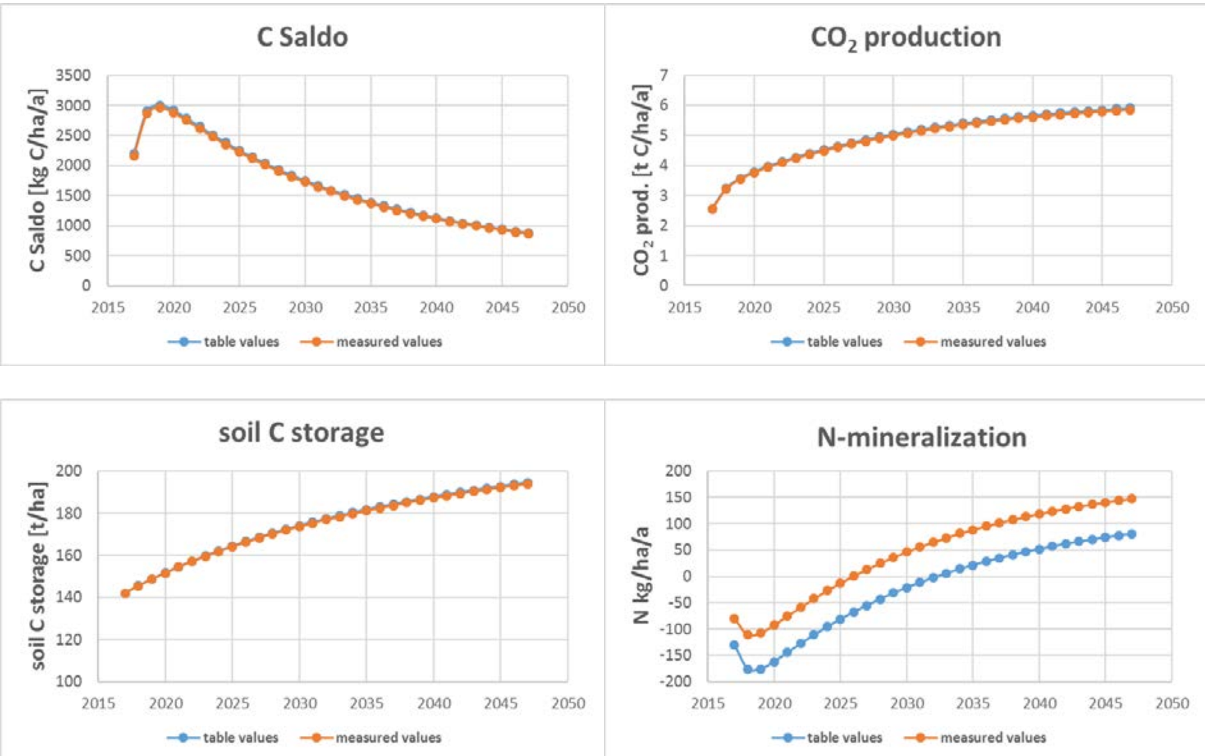

Figure 27. Simulated C saldo, CO_2 production, soil C storage and N-mineralisation of Farm RU8 arable land.

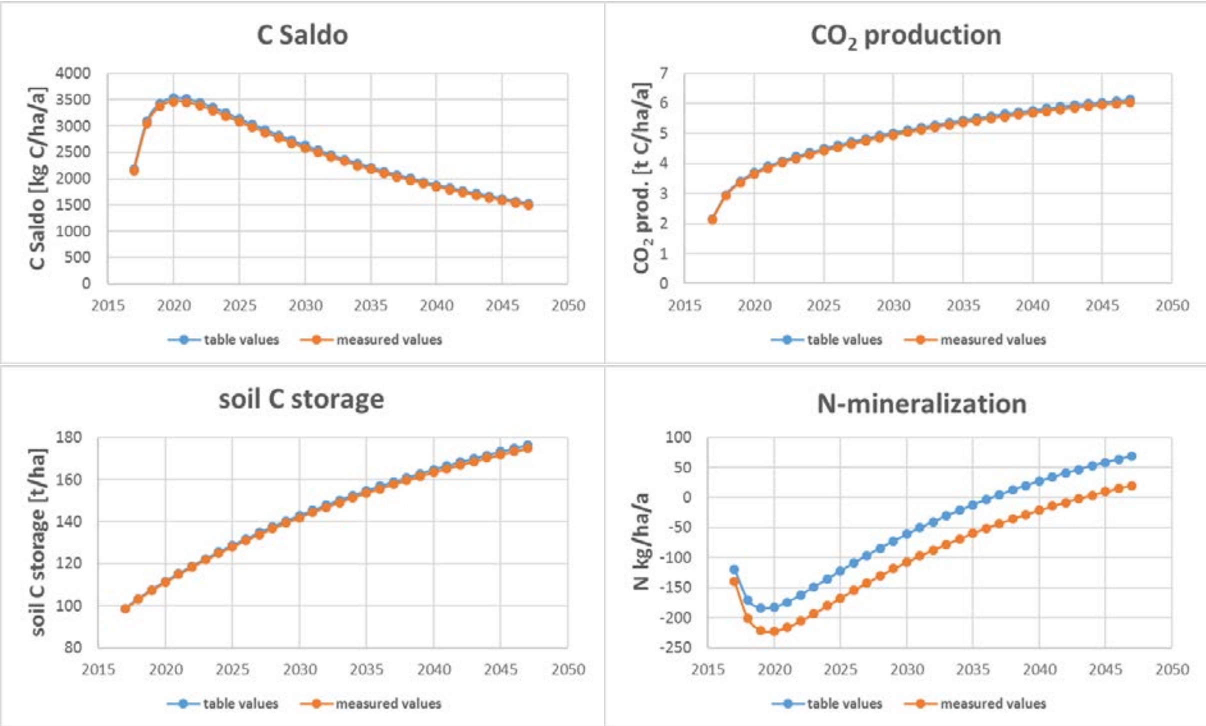

Figure 28. Simulated C saldo, CO_2 production, soil C storage and N-mineralisation of Farm RU8 grassland.

4.7.2.2. Results from the regional modelling

<u>Changes in estimates of national atmospheric emissions originating from manure</u>

Currently, the Russian Federation reports on emissions in the framework of relevant international treaties. Russia is a party to the Convention on Long-range Transboundary Air Pollution. Under the Convention, the Ministry of Natural Resources of Russia annually submits a report on emissions of major air pollutants from all pollution sources (including manure management systems - NH_3, NO). It should be noted that the inventory of air pollutants considers only the European part of Russia. Fulfilling its obligations under the agreement on Greenhouse Gases, Russia reports the results of the inventory of greenhouse gases, which contain data on emissions from agriculture - CH_4 and N_2O. This reporting is carried out for the whole country.

Emission inventories are carried out according to EMEP/EEA emission inventory guidebook 2016.3.B Manure management, and 2006 IPPC Guidelines for national Greenhouse Gas Inventories.

In this project, emissions were calculated for the Leningrad Region, on the basis of the collected source data in accordance with the emission inventory guidelines, adapted to Russian conditions. Within the framework of the Baltic Sea problems and the project, information on the Leningrad region, (and not for the whole country - Russian Federation,) are more interesting.

Calculation of agricultural emissions is currently carried out using Tier1 method; emission values are defined as the product of tabular emission factor and the number of animals of the corresponding category.

In **Table 94**, the results of the following steps for estimation of atmospheric emissions originating from manure (for Leningrad region) are presented:

- Step1: calculation NH_3, N_2O, NO emissions using Tier1 according the EMEP/EEA air pollutant emission inventory Guidebook 2016 for Leningrad region (old emissions factor, old emission estimates)
- Step 2: comparison data on Nex, TAN from table 3.9 of EMEP Guidebook for different animal category with the project result (WP3) and calculation of the percentage differences between them (Quote from GB “The default Tier 1 EFs for NH_3 have been calculated using the Tier 2 default NH_3-N EFs for each stage of manure management (see section 3.4) and default activity data on N excretion, the proportions of TAN in excreta and, if appropriate, the length of the grazing period”)
- Step 3: re-calculating TIER 1 Emission factor for different animal categories using the percentage differences calculated in step 2 (=>new emission factors)
- Step 4: calculation new NH_3, N_2O, NO emissions with new emissions factors

Emission factor was changed only for dairy cows because it was not possible to obtain new N excretion values for other animal types. Because of this, the old emission estimates were used as the new ones for these animal categories. As can be seen from **Table 94**, The new emission factors for dairy cow are 20% higher than the old ones. This is because the new tot-N excretion rate per animal (134 kg N/head/yr) is 20% higher than the one presented in the table 3.9 of EMEP emission inventory guidebook. However, as the emissions of the other animal categories remain unchanged, the increase in NH_3, N_2O and NO emission estimates for Leningrad region is 2-4%, depending on the pollutant.

Table 94. Results of calculation old and new NH_3, N_2O and NO emission estimates for Leningrad region 2017.

	NH_3					N_2O					NO				
	EF NH_3 (kg/head/yr)			NH_3 (t/yr)		EF N_2O (kg/head/yr)			N_2O (t/yr)		EF NO (kg/head/yr)			NO (t/yr)	
Source	Old	New	Diff.	Old	New	Old	New	Diff.	Old	New	Old	New	Diff.	Old	New
Dairy Cows	34.0	40.8	+20%	2730.2	3276.2	0.84	1.01	+20%	67.5	80.94	0.236	0.283	+20%	18.95	22.71
Other cattle	11.3	11.3	-	1128.6	1128.6	0.34	0.34	-	34.9	34.88	0.144	0.144	-	14.77	14.77
Swine	10.1	10.1	-	1803.9	1803.9	0.04	0.04	-	7.144	7.144	0.204	0.204	-	36.43	36.43
Sheep	1.4	1.4	-	48.16	48.16	0.08	0.08	-	2.752	2.752	0.008	0.008	-	0.275	0.275
Layers	0.48	0.48	-	4612.8	4612.8	0.02	0.02	-	192.2	192.2	0.0002	0.0002	-	1.922	1.922
Other Poultry	0.22	0.22	-	4158	4158	0.02	0.02	-	378	378	0.004	0.004	-	75.6	75.6
Total				**14482**	**15028**				**682.4**	**695.9**				**147.9**	**51.8**

CCB modelling

RU_Volosovsky representing a region of Russia. In 2017 field grass, clover-grass, potato and pea were grown in this region. Main textural class of soil according USDA is identified as a lay loam; soil organic carbon content of soil amounts 2.9%, the mean air temperature and precipitation is about 4°C respectively 687 mm (**Table 95** and **Table 25**). This results in a relatively low BAT of 8.9 d (**Table 97**), which causes to a comparatively slow turnover of organic matter in the soil.

Scenario 1 assumes 100% mineral fertiliser use and Scenario 2 replaces 60% of the nitrogen requirement with organic fertilisers of the quality from **Table 96**. Scenario 1 shows a more or less constant carbon level and in the scenario 2 the carbon content increases over time (**Figure 29**). However, in scenario 2, also the C saldo and C storage level is higher and more carbon and nitrogen are mineralised.

Table 95. Soil and climate input data for the CCB model.

Corg (%) start value	2.9
Soil texture	Clay 35%; Silt 35%
Air Temperature (C°)	4.2
Precipitation (mm/yr)	687

Table 96. Utilised parameter (DM- Dry matter, N – Nitrogen, C- Carbon, CNR – CN-ratio) of manure from national references (table values).

	DM [%]	**N [kg/t FM]**	**C [kg/t FM]**	**CNR**
Table values	14.9	3.10	126.65	40.85

Table 97. Simulated Biologic active time (BAT) and Soil organic matter reproduction index = $C_{reproduction}$/BAT (REP_IX).

	BAT (d/a)	**Rep_IX**
Scenario 1	8.9	118.2
Scenario 2		351.9

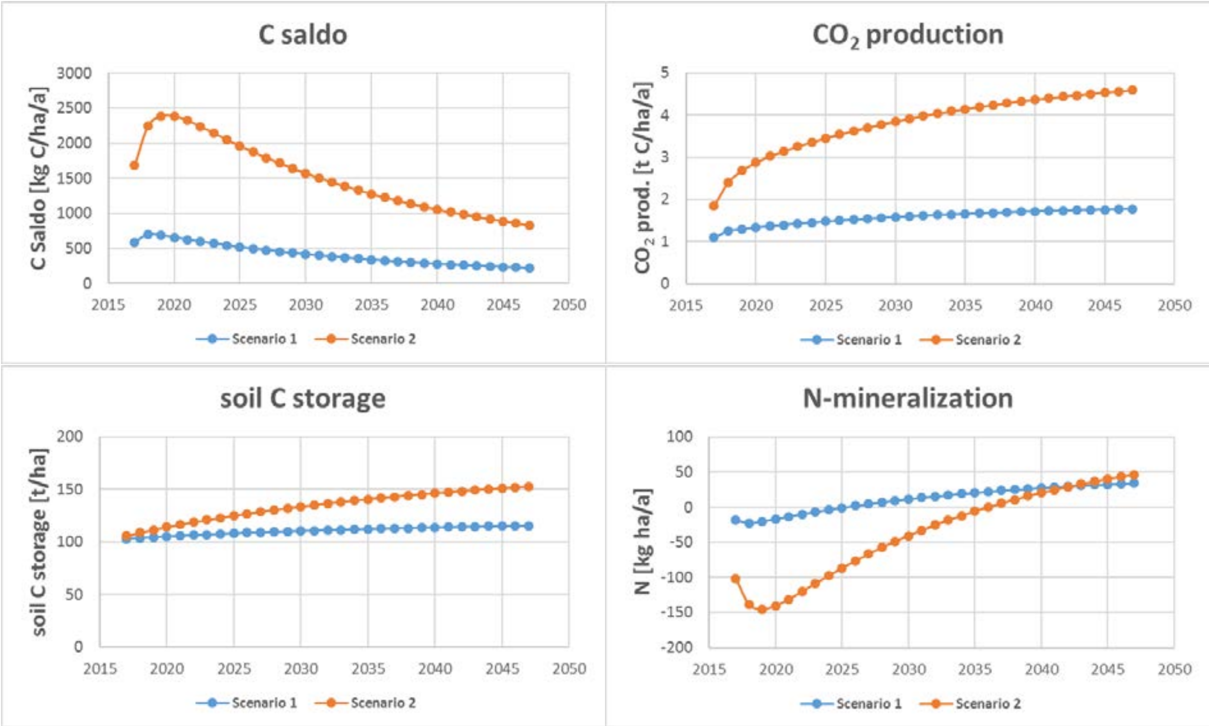

Figure 29. Simulated C saldo, CO_2 production, soil C storage and N-mineralisation of the RU_Volosovsky region.

4.8. Sweden

4.8.1. Comparison of the old and new manure data

The table values for nutrient content in manure that are used as old data in the NBBM-model originate from Börling et. al. (2018). These table values or farm-specific values from barn balances are commonly used in different Swedish advisory calculation tools for fertilisation planning. The table values are also available in Swedish legislation, i.e. *Ordinance (1998:915) on environmental considerations in agriculture and The provisions of the Swedish Board of Agriculture (SJVFS 2004:62) on environmental concerns regarding plant nutrients*.

Ex storage manure data for fertilisation planning

Sampling and analysis of manure was made at five Swedish pilot farms within this project. The analysis results were used as new data in the NBBM-model. The samples were taken during spring 2018. The calculated values for nutrient content in manure from WP3 (within this project) were also used as new data for two of the farms. Two of the pilot farms hold dairy cows (slurry), one slaughter pigs (slurry), one integrated pig production (slurry and deep litter) and one for broilers (deep litter).

Manure analysis results from the two dairy farms show lower nutrient concentrations than the table values for both nitrogen and phosphorus, but higher proportions of soluble nitrogen. Corresponding values calculated in WP3 for pilot farm 1 were close to the table values for total nitrogen and phosphorus, but the ammonium nitrogen concentration was higher (**Table 98**).

For the two pig farms, analysed values for nutrient content of both total and soluble nitrogen were higher than the table values. The analysed concentration of phosphorus was lower than the table value at the farm with slurry, but higher at the farm with deep litter.

For the deep litter, (broiler manure, pilot farm 5), both analysed and calculated nutrient concentrations were lower than the table values.

Table 98. Difference in nutrient concentrations according to table values ("Table"), results from manure sampling and analyses ("Analysis") and calculated from farm-specific barn balance in WP3 ("WP3"). Analysed values used are average values from manure samples taken during spring 2018.

	Tot-N (kg/t)			**NH_4-N (kg/t)**			**Tot-P (kg/t)**		
	Table	Analysis	WP3	Table	Analysis	WP3	Table	Analysis	WP3
Dairy cow, slurry (Pilot farm 1)	4.3	4.11	4.28	1.8	2.5	2.57	0.56	0.53	0.60
Dairy cow, slurry (Pilot farm 2)	4.3	3.72		1.8	2.2		0.56	0.35	
Pig, slurry (Pilot farm 3)	3.6	4.69	2.34	2.4	3.4	1.75	0.63	0.57	0.46
Pig, deep litter (Pilot farm 4)	4.8	6.66	4.69	0.48	0.87	1.17	1.5	2.68	1.78
Poultry, deep litter (Pilot farm 5)	38	28.55	25.72	7.6	7.7	6.43	8.6	5.83	7.22

Data from three of the five pilot farms were used in the NBBM model to calculate the difference in nutrient balances and risk of nitrogen leaching between table values and manure analysis results. Two of these pilot farms were also used to calculate the difference between table values and values calculated in WP3.

4.8.2. Impacts of using the new manure data

4.8.2.1. Results from the pilot farm modelling

NBBM modelling

Some adjustments were been made in the Swedish calculations of the NBBM model. Guideline values for nitrogen application rates needed for different yield levels were taken from the Swedish recommendations for fertilisation and liming 2019 (Börling et al., 2018). These recommendations reflect the economically optimal application rates and are based on results from Swedish field trials and are available for different regions with different climate. The recommended N application rates were adapted to a straight line by linear regression and the regression equation used to estimate the harvest level. For all crops where these recommendations were available for different yield levels, the r^2 value for the regression line was higher than 0.99, except for rye in central part of Sweden where the r^2 value was 0.96. For other crops the standard yields for which the recommendations are given have been used.

The crop production plans used were taken from the farms, but for different years for different farms. For pilot farm 1 the plan for 2018 was used, for pilot farm 2 the plan for 2014 was used and for pilot farms 4 and 5 we have used the plans for 2017. In these fertilisation plans calculated or analysed values for nutrient content of manure have already been used.

Results when manure analysis results were used

At pilot farm 1 and 2 the manure analysis results showed lower concentrations of total nitrogen and phosphorus and a higher concentration of plant available nitrogen in the manure compared to table values. This indicates that the manure on these farms is more diluted than the table values indicate. To compensate for this, the farmer would need to increase the amount of manure per hectare. Since the concentration of plant available nitrogen seems to be higher in the manure it would be possible to reduce the mineral fertiliser dose in the fields where manure is applied. However, if the amount of manure applied per hectare is increased the manure will not cover as many hectares as assumed and larger acreage will have to rely on mineral fertilisers. So, with the knowledge of a higher concentration of plant available nitrogen in the manure, the farmer can adapt the fertilisation, and this will lead to a more efficient use of manure. And even if a larger acreage will be fertilised with mineral fertiliser it's likely that the total use of mineral fertiliser will decrease (see **Table 99**).

At farm 5 the manure analysis results also showed lower concentration of total nitrogen and phosphorus, but the concentration of plant available nitrogen is the same compared to table values. This indicates that the manure on this farm also is less concentrated than the table values indicate. To compensate for this the farmer would need to increase the amount of manure per hectare. But since the concentration of plant available nitrogen is the same as in the table values it is not advisable to reduce the dose of mineral fertiliser. This will probably result in an increased use of mineral fertilisers on this farm, but also a more adapted fertilisation according to the crop's requirements.

Results when calculations of nutrient content in manure from WP3 were used

When adjusting the fertilisation plan to the nutrient content in manure calculated in WP3 instead the results change a little bit (see **Table 100**). For pilot farm 1, there are no difference in concentrations of total nitrogen and phosphorus when we compare table values with results from the calculation tool. But as for analysed values the concentration of plant available nitrogen is higher. If the farmer fertilised according to this scenario, the amount of manure spread would be the same. But since the concentration of plant available nitrogen is higher the amount of mineral fertliser could be decreased.

For pilot farm 5, the calculated total and plant available nitrogen as well as the phosphorus concentration in manure are lower than the table values. To compensate this, the farmer would need to increase the amount of manure per hectare or increase the mineral fertiliser dose.

Table 99. Summary table for Swedish pilot farm results of NBBM modelling comparing table values and manure analysis results.

Animal type	Manure type	Farm acreage (ha)	% of acreage received manure	Basis of manure application rates		Average nutrient balances with old manure data (present actual; kg/ha)			Average nutrient balances with new manure data (new actual; kg/ha)			Difference between "new" and "present" nutrient balances (%)			Difference in leaching risk (from "present" to "new")
				Old manure data	New manure data	Ntot	Nsol	Ptot	Ntot	Nsol	Ptot	Ntot	Nsol	Ptot	Nsol (%)
Dairy cow	Slurry	137.5	43%	Table values	Farm's new manure analysis taken by Rise	53.8	36.9	-3.3	48.9	32.8	-3.1	-9%	-11%	5%	-3%
Dairy cow	Slurry	164.9	53%	Table values	Farm's new manure analysis taken by Rise	127.0	90.6	0.9	119.0	82.7	1.4	-7%	-9%	56%	-3%
Poultry	Deep litter	839.2	44%	Table values	Farm's new manure analysis taken by Rise	76.3	8.6	-3.6	76.0	8.3	-3.6	0%	-4%	0%	0%

Table 100. Summary table for Swedish pilot farm results of NBBM modelling comparing table values and calculated manure properties (WP3).

Animal type	Manure type	Farm acreage (ha)	% of acreage received manure	Basis of manure application rates		Average nutrient balances with old manure data (present actual; kg/ha)			Average nutrient balances with new manure data (new actual; kg/ha)			Difference between "new" and "present" nutrient balances (%)			Difference in leaching risk (from "present" to "new")
				Old manure data	New manure data	Ntot	Nsol	Ptot	Ntot	Nsol	Ptot	Ntot	Nsol	Ptot	Nsol (%)
Dairy cow	Slurry	137.5	43%	Table values	Values calculated in WP3	55.3	37.4	-2.6	49.9	32.8	-2.5	-10%	-12%	6%	-3%
Poultry	Deep litter	839.2	44%	Table values	Values calculated in WP3	67.1	6.2	0.9	69.3	8.3	0.9	3%	34%	0%	0%

CCB modelling

Farm S1 represents Swedish dairy production. In 2017, winter wheat and spring barley were grown on the farm. Half of the area is grassland area. The textural class of soil according to USDA is identified as a silty clay; soil organic carbon content of soil amounts to 3.904%, the mean air temperature is about 8°C and the annual precipitation 780 mm (**Table 101**). This results in a BAT of 18.7 d for arable land and 10.1 d for grassland (**Table 103**), which causes to a comparatively moderate turnover of soil organic matter.

The table values and measured values of manure quality are similar (**Table 102**). This results in a comparable Rep_IX (**Table 103**) and similar C saldo, CO_2 production, soil C storage and N mineralisation (***Figure 30*** & ***Figure 31***) by using measured values or table values of manure quality. The soil C storage increases, especially in grassland but also in arable land.

Table 101. Soil and climate input data for the CCB model.

C_{org} (%) start value	3.904
Soil texture	Clay 45%; Silt 27.5%
Air temperature (°C)	7.7
Precipitation (mm/yr)	780

Table 102. Utilised parameters (DM - Dry matter, N – Nitrogen, C - Carbon, CNR – C/N ratio) of manure from national references (table values) and measurements of laboratories (measured values).

Cattle slurry	**DM [%]**	**N [kg/t FM]**	**C [kg/t FM]**	**CNR**
Table values	9.00	4.30	34.92	8.12
Measured values	7.50	4.10	33.30	8.12

Table 103. Simulated Biological active time (BAT) and Soil organic matter reproduction index = $C_{reproduction}$/BAT (REP_IX).

	BAT (d/a) (arable land)	**Rep_IX (arable land)**	**BAT (d/a) (grassland)**	**Rep_IX (grassland)**
Table values	18.7	80.9	10.1	179.2
Measured values		80.4		178.0

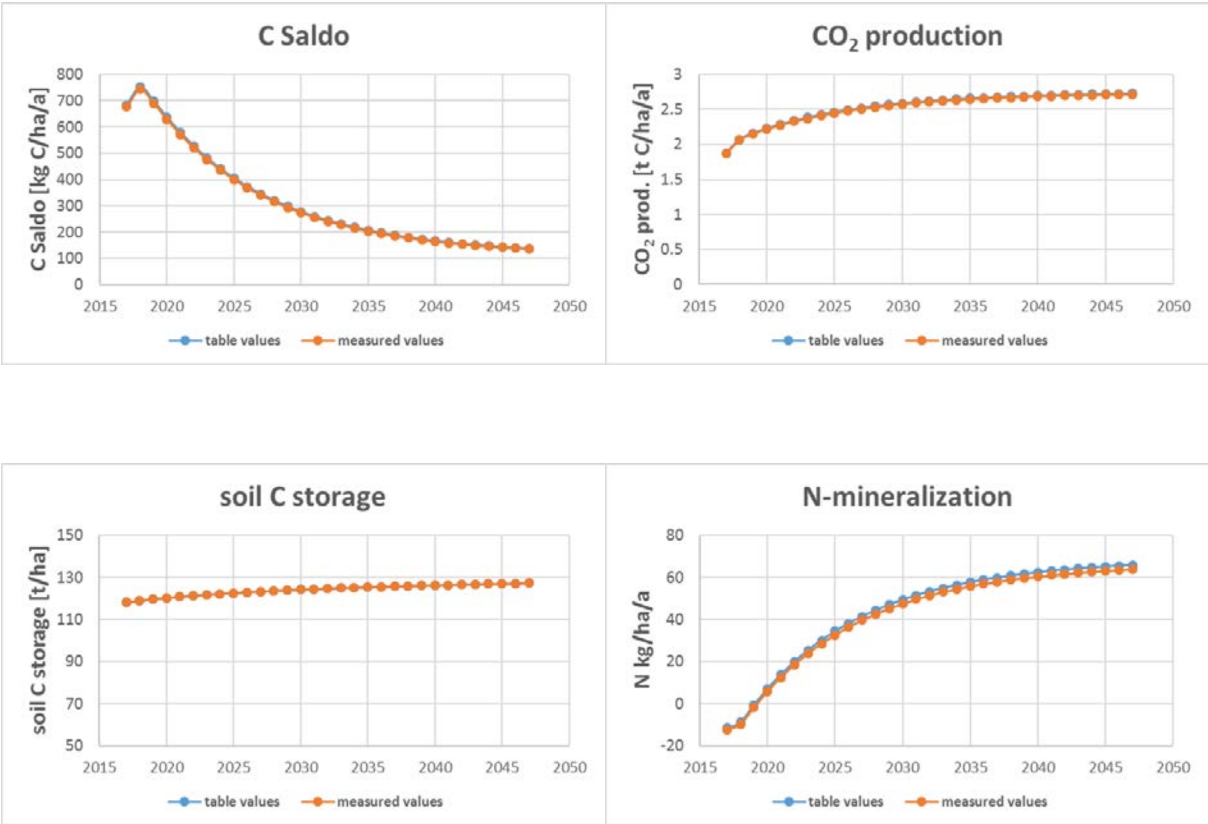

Figure 30. Simulated C saldo, CO_2 production, soil C storage and N mineralisation of farm S1, arable land.

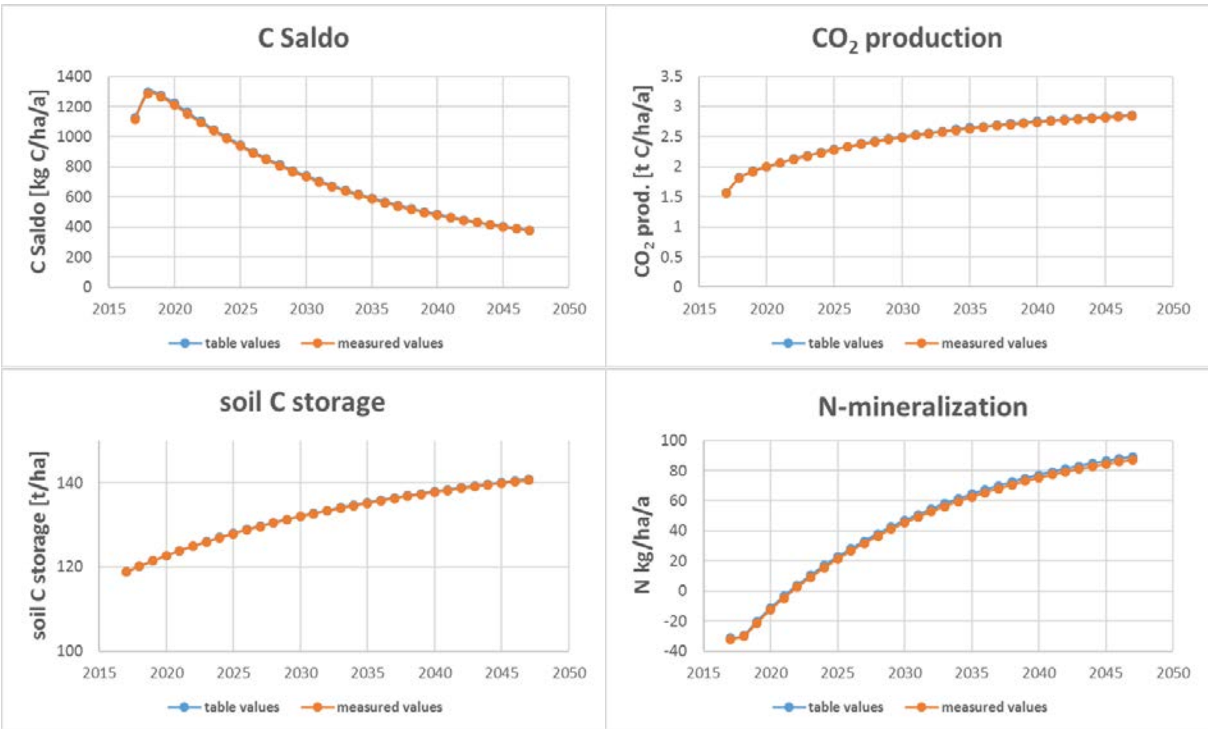

Figure 31. Simulated C saldo, CO_2 production, soil C storage and N mineralisation of farm S1, grassland.

Farm S4 is a pig farm. In 2017 spring barley, winter wheat, oats and field beans were grown on the farm. A tenth of the area is grassland. The textural class of soil according to USDA is identified as a loam; soil organic carbon content of soil amounts 3.2%, the mean air temperature is about 7°C and the annual precipitation 490 mm (**Table 104**). This results in a BAT of 21.0 d for arable land and 12.3 d for grassland (**Table 106**), which causes a comparatively moderate turnover of soil organic matter.

Table 104. Soil and climate input data for the CCB model.

C_{org} (%) start value	3.2
Soil texture	Clay 20.64%; Silt 39.68%
Air temperature (°C)	7
Precipitation (mm/yr)	490

The table values and measured values of manure quality are very different (**Table 105**). At the same C/N ratio, the measured values of N and C are twice as large. This results in a higher Rep_IX (**Table 106**) and therefore to a higher C saldo, CO_2 production and N mineralisation (***Figure 32*** & ***Figure 33***) by using measured values of manure quality. However, the soil C storage of arable land and grassland is more or less on the same level.

Table 105. Utilised parameters (DM - Dry matter, N – Nitrogen, C - Carbon, CNR – C/N ratio) of manure from national references (table values) and measurements of laboratories (measured values).

Pig slurry	**DM [%]**	**N [kg/t FM]**	**C [kg/t FM]**	**CNR**
Table values	6.00	2.69	11.10	4.12
Measured values	5.30	5.20	21.41	4.12

Table 106. Simulated Biological active time (BAT) and Soil organic matter reproduction index = $C_{reproduction}$/BAT (REP_IX).

	BAT (d/a) (arable land)	**Rep_IX (arable land)**	**BAT (d/a) (grassland)**	**Rep_IX (grassland)**
Table values	21.0	61.9	12.3	132.1
Measured values		65.0		138.8

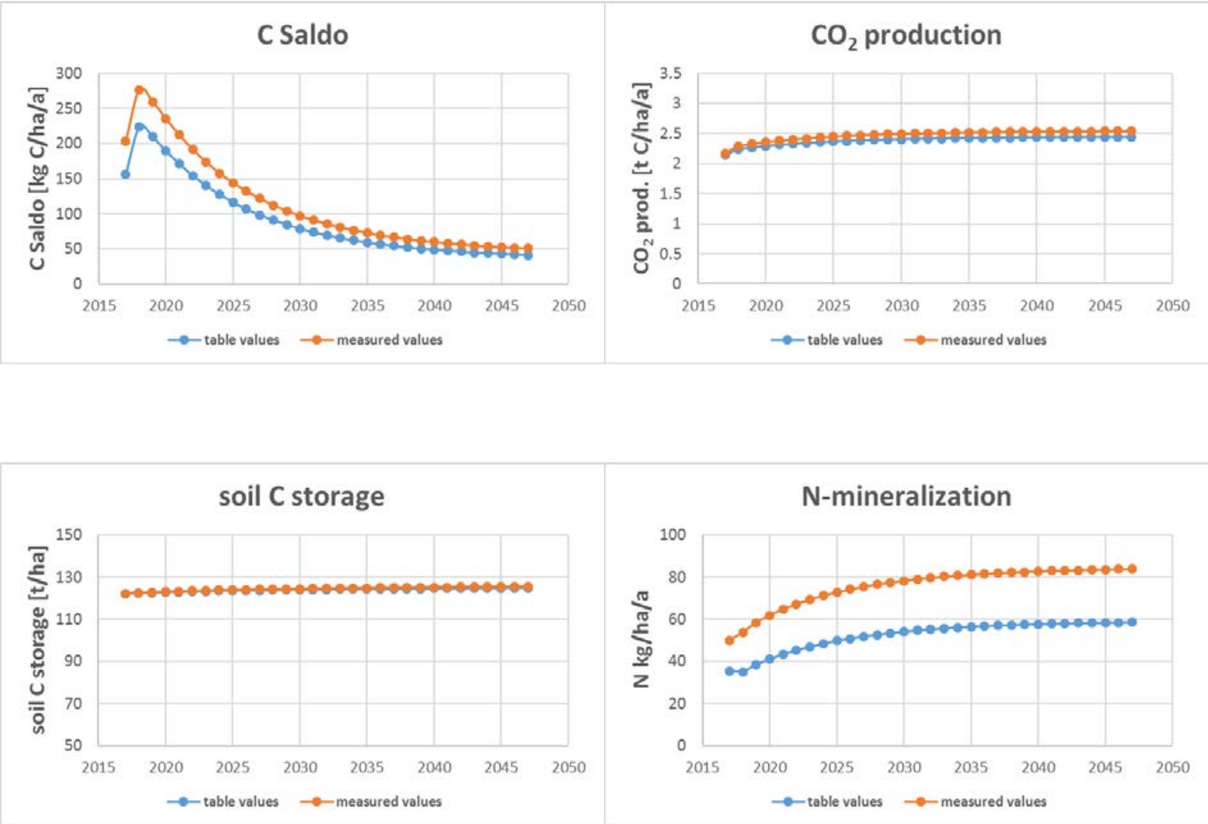

Figure 32. Simulated C saldo, CO_2 production, soil C storage and N mineralisation of farm S4, arable land.

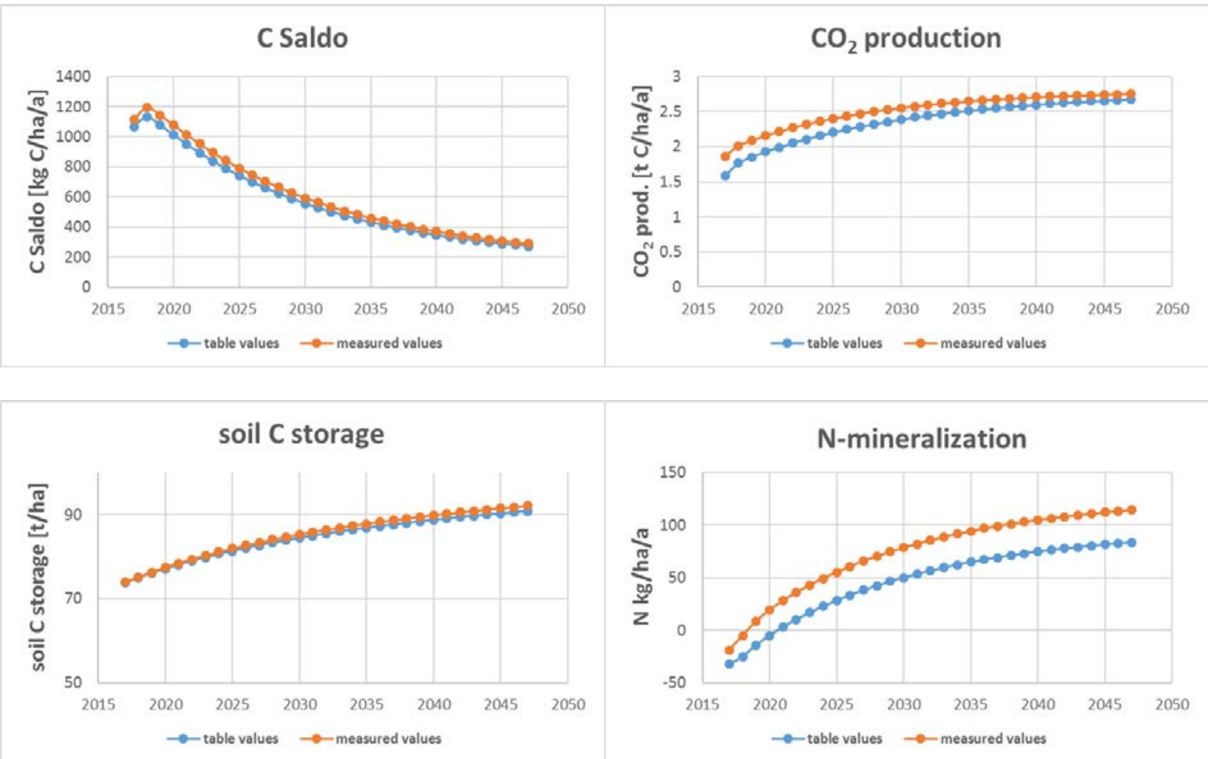

Figure 33. Simulated C saldo, CO_2 production, soil C storage and N mineralisation of farm S4, grassland.

4.8.2.2. Results from the regional modelling

CCB modelling

SE_GMB[2] represents a region with mixed landscape in southern Sweden. In 2017 oats, maize, spring and winter wheat, winter rye, spring and winter barley, flax, triticale, cereal grain mix, spring and winter rape, potatoes, sugar beet, peas as well as field beans were grown in this region. Main textural class of soil according USDA is identified as a loamy sand; soil organic carbon content of soil is presumed to be 2%, the mean air temperature and precipitation is about 8°C respectively 527 mm (**Table 107**). This results in a relatively high BAT of 26 d (**Table 109**), which causes to a comparatively fast turnover of organic matter in the soil.

Scenario 1 assumes 100% mineral fertiliser use and Scenario 2 replaces 60% of the nitrogen requirement with organic fertilisers of the quality from **Table 108**. Scenario 1 shows a more or less constant carbon level and in the scenario 2 the carbon content increases over time (***Figure 34***). However, in scenario 2, also the C saldo and C storage level is higher and more carbon and nitrogen are mineralised.

Table 107. Soil and climate input data for the CCB model.

C_{org} (%) start value	2 (presumed)
Soil texture	Clay 11%, Silt 26%
Air temperature (°C)	8.2
Precipitation (mm/yr)	527

Table 108. Utilised parameters (DM - Dry matter, N – Nitrogen, C - Carbon, CNR – C/N ratio) of manure from national references (table values).

	DM [%]	**N [kg/t FM]**	**C [kg/t FM]**	**CNR**
Table values	6.8	3.95	30.94	7.83

Table 109. Simulated Biological active time (BAT) and Soil organic matter reproduction index = $C_{reproduction}$/BAT (REP_IX).

	BAT (d/a)	**Rep_IX**
Scenario 1	26	31.4
Scenario 2		44.9

[2] Götalands mellanbygder

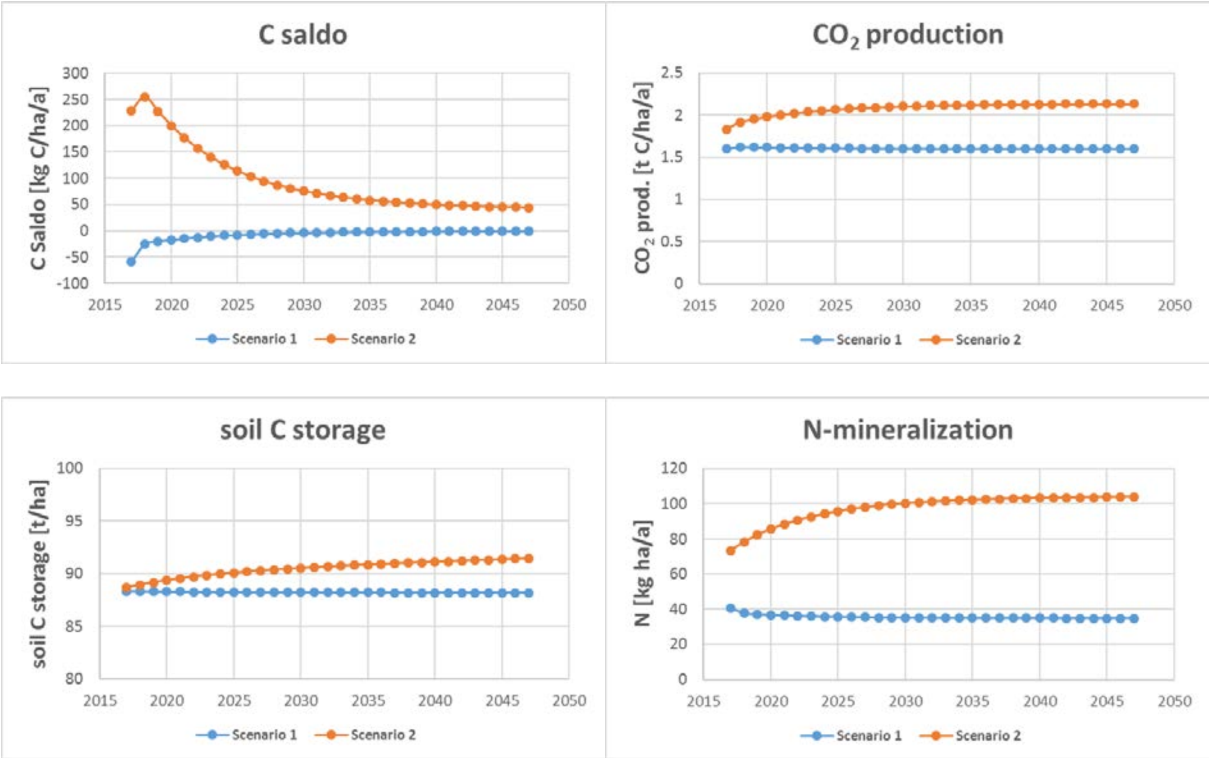

Figure 34. Simulated C saldo, CO_2 production, soil C storage and N mineralisation of the SE-GMB region.

5. Nutrient balances at farm/regional level

The nutrient balance, here a field balance, is the comparison of nutrient supply and nutrient offtake on the arable land or grassland of a farm or region. Nutrients are added to the field in the form of crop residues, seed bound N, atmospheric N, nitrogen binding from legumes as well as mineral and organic fertilisers. In the case of liquid and solid manure, the nutrient losses in the categories stable, storage and spreading must be considered. For this purpose, national table values, simulation results from models (see WP3 report) or measurements according to verified regulations (see WP2 report) can be used. N offtake and thus N output is determined by yields of crops or grassland, which are sold or be fed. The N saldo of the field balance equates to the difference between the N-inputs and the N-output to the utilised agricultural area (UAA). The control value for the nutrient balances for nitrogen should be have a maximum of 60 kg nitrogen per hectare over a three-year average.

The nutrient balances of pilot farms were compared using table values and measured values (**Table 110**). Sometimes the table values are higher and sometimes lower than the measurements. The balance also changes in accordance with the change in the N input via organic fertilisers according to table values or measurements, since all other accounting variables remain the same. The difference of table values and measurements and thus of N saldo is up to 114 kg N / ha (Farm LV 6, **Table 110**). According to the table values, 7 field balances have a positive surplus of up to 60 kg N/ha, 4 field balances have a negative balance and 15 of the 26 field balances have a higher surplus of up to 186 kg N/ha. According to the measurements, 8 field balances have a positive surplus of up to 60 kg N/ha, 5 field balances have a negative balance and 13 of the 26 field balances have a higher surplus of up to 205 kg N/ha. This means that most of balances are above the obligatory limit. Since only a part of the area of the farms was simulated for one year, the average surplus should be in the limit. In addition, the yields achieved in 2017 could be lower as normal due to the drought. Therefore, the N offtake could be lower than normal. Since many assumptions had to be made for the pilot, the results can only be interpreted with uncertainties.

Table 111 shows the nutrient balances (field balance) of example regions of the different BSR countries. In scenario 1, all fertilisers are covered by mineral fertilisers. In scenario 2, 60% of the fertilisers are substituted by Organic fertilisers. The N saldo remains the same. Except for the Russian region, all field balances remain below the limit of 60 kg N / ha. In two regions is a nitrogen deficit. For a balanced field balance more N should be added in these regions. Since many assumptions had to be made for the regions, the results only give a general survey.

Table 110. Different nutrient balances (field balance) considering i) table values and ii) measured values of pilot farms calculated by CCB model

Description			N-Input [N kg/ha]								N-Output [N kg/ha]	Saldo [N kg/ha]	
Country	Farm	Site des.	Mineral fertiliser	Organic fertiliser (table values)	Organic fertiliser (measured)	by-products left on field	N-fixation (sym.)	N-Fixation (asym.)	Atmospheric N2	Seed bound N	N-Offtake	N Saldo (table values)	N Saldo (measured values)
Estonia	EE 1	A	100	126	110	0	0	5	5	3	78	161	145
Finland	FI 1	G	147	40	33	0	0	5	4	1	22	175	168
	FI 2	A	112	64	71	0	13	5	6	4	120	84	91
	FI 2	G	186	10	11	0	0	5	6	1	137	71	72
	FI 3	A	84	64	70	0	0	5	6	3	154	8	14
	FI 3	G	136	94	102	0	0	5	6	1	115	127	135
Germany	DE 1	A	105	73	21	1	0	5	15	1	124	76	24
	DE 1	G	0	77	22	0	0	10	15	1	80	23	-32
	DE 3	A	140	156	148	8	0	5	19	2	198	132	124
	DE 3	G	97	126	120	0	0	5	19	1	110	138	132
	DE 4	A	190	82	128	20	0	5	19	3	163	156	202
Latvia	LV 2	A	42	93	88	0	0	5	5	2	238	-91	-96
	LV 4	A	119	117	27	21	0	5	6	3	176	95	5
	LV 6	A	88	205	91	0	0	5	6	2	177	129	15
	LV 6	G	48	136	60	0	0	5	6	1	168	28	-48
Lithuania	LT 1	A	0	77	55	0	24	10	4	5	131	-11	-33
	LT 5	A	0	81	97	0	194	10	4	4	107	186	202
	LT 5	G	0	96	114	0	0	10	4	1	120	-9	9
Poland	PL 7	A	138	45	67	0	107	5	10	2	169	138	160
	PL 7	G	0	25	37	0	0	10	10	1	216	-170	-158
Russia	RU 8	A	0	163	228	8	0	10	6	4	51	140	205
	RU 8	G	0	168	116	0	0	10	6	1	72	113	61
Sweden	SE 1	A	70	47	45	18	0	5	5	3	102	46	44
	SE 1	G	57	54	51	0	0	5	5	1	103	19	16
	SE 4	A	63	28	55	13	13	5	4	4	126	4	31
	SE 4	G	44	35	68	0	0	5	4	1	29	60	93

A = arable land; G = grassland

Table 111. Nutrient balances (field balance) of two scenarios of example regions calculated by CCB model

country	Region	Scenario	Mineral fertiliser	Organic fertiliser	by-products left on field	N-fixation (sym.)	N-Fixation (asym.)	Atmospheric N_2	Seed bound N	N-offtake	N Saldo
EE	Jogeva	1	99	0	7	7	5	5	3	108	18
		2	40	59	7	7	5	5	3	108	18
FI	Varsinais-Suomi	1	110	0	0	3	5	5	3	105	21
		2	44	66	0	3	5	5	3	105	21
DE	Ostholstein	1	231	0	5	3	5	16	3	229	34
		2	92	139	5	3	5	16	3	229	34
LV	Riga	1	90	0	8	5	5	5	3	104	12
		2	36	54	8	5	5	5	3	104	12
LT	Region	1	69	0	0	11	5	4	3	124	-32
		2	28	41	0	11	5	4	3	124	-32
PL	Mazowieckie	1	58	0	3	2	5	10	3	84	-3
		2	23	35	3	2	5	10	3	84	-3
RU	Volosovsky	1	140	0	0	1	5	6	1	25	128
		2	56	84	0	1	5	6	1	25	128
SE	GMB	1	123	0	14	4	5	9	3	141	17
		2	49	74	14	4	5	9	3	141	17

Scenario 1 = 100% Mineral fertiliser

Scenario 2 = 40% Mineral fertiliser and 60% Organic fertiliser

6. Conclusions and recommendations

Knowing the properties of manure and using that information together with crop, expected yield, N delivery from the soil and other farming conditions to obtain site specific fertilisation recommendations is important to avoid over and under fertilisation. Optimised fertilisation reduces the risk of nutrient losses to the waters and improves nutrient utilisation. Rational utilisation and recycling of nutrients also reduces the need to use non-renewable resources necessary for production of inorganic fertilisers. It also has an impact on the economic efficiency of production. In addition, when using organic fertilisers, the carbon pool is increasing in the soil or protected respectively.

Nutrient balances on field level indicate the difference between nutrients given as fertilisers and those removed from the field with harvested crops. Too large nutrient surpluses lead to an increased risk of nutrient leaching. Too small or negative balances indicate under-fertilisation which may cause lower yields and soil nutrient depletion. Lower yields due to deficiency of one nutrient also leads to lower utilisation of other nutrients. However, in the case of phosphorus, it may be necessary to apply less P than removed by the crop if the content of plant available phosphorus in the soil is too high as a result of long periods of excessive phosphorus fertilisation. For this reason, it is advisable to conduct regular soil analyses.

The regional concentration of livestock production poses challenges for efficient manure utilisation. If the arable area suitable for manure application is not close enough, the applied nutrient amounts and further nutrient balances may become too high on the fields used for manure application. The problem is exacerbated if the characteristics of the manure are not well known. If the knowledge base is incomplete, it will also be difficult to find solutions to the nutrient problem.

A good knowledge base is a prerequisite for good decisions. The Manure Standards project has shown that better manure information can have a big impact, for example, on the environmental impact of manure utilisation. The project has also shown that obtaining better manure information can be challenging. It is challenging especially for solid and semi-solid manure. The inhomogeneous nature of non-pumpable manure makes it difficult to take representative samples.

On the other hand, estimating the properties of manure using mass balance calculations is also difficult, since e.g. gaseous losses are very case- and circumstance-specific. High uncertainties in, for example, the estimation of water evaporation and amounts of technical water added give rise to uncertainty in the results of the calculation, i.e. in the amounts of manure produced, DM content and nutrient concentrations.

It is also possible to use different methods in parallel. One option at the farm level would be to use national manure data (table values) at the same time with the farm's own manure analysis or farm-specific barn balance calculation results. Using these two sources as the basis for fertilisation could reduce the risk of incorrect application rates of manure nutrients, for example due to failed manure sampling.

The accuracy of the manure quantity and quality data has also a significant impact on the countries' estimates of greenhouse gas, ammonia and other air pollutant emissions (and compliance with emission reduction obligations), and on nutrient balance calculations. Improving the reliability and accuracy of emission estimates is crucial for all countries in assessing the impacts of emission reduction techniques on emissions.

A short summary of the main characters of the different old (existing) and new (suggested by this project) manure tools is presented in **Table 112**.

Table 112. Properties of old and new manure tools.

Attribute		**Old tool 1:** Table values	**Old tool 2:** Manure analysis	**New tool 1:** Manure analysis, precise manure sampling	**New tool 2:** Farm specific manure calculation tool	**New tool 3:** Regional manure calculation tool (for new table values)
Accuracy	Pros:		Compared to table values give more accurate information on manure properties	More representative samples give more accurate results	The accuracy is better than of the regional normative manure values.	Possibly better than the old table values but depends on the method the old values are produced.
	Cons:	Does not take into account the heterogeneity of manure between farms.	Poor sampling may not give representative results. Depends on the sampling method used.		The biggest problem is how to obtain farm-specific input data which take into account the production conditions and techniques on the farm.	Regional normative manure does not take into account the variations in production conditions and techniques between farms
Costs	Pros:	No direct costs for farmers but might cause indirect costs due to non-optimal use of manure and mineral fertilisers		More representative samples may help farmers to reduce fertilisation costs.	No direct costs for farmers if the calculation tool is free of charge. Possibly, costs for purchasing of mineral fertilisers may be reduced.	No direct costs for farmers
	Cons:	Using table values which are not representative may cause excessive or sub-optimal use of mineral fertilisers.	Sampling and analysing manure cause direct and indirect costs for farmers. Poor sampling may cause over- or under-use of mineral fertilisers.	More precise manure sampling and analysing cause extra direct and indirect costs for farmers.	Causes indirect costs due to extra work.	Using new table values which are not representative may cause excessive or sub-optimal use of mineral fertilisers.
Practicality	Pros:	Do not require any actions from the farmers. Simple to use, especially if the values are as default values in the fertilisation planning tool.				New manure data are calculated by authorities using average regional feeding and manure management data. No actions from farmers are required. These 'new table values' are simple to use especially if the values are as defaults in the fertilisation planning tool.
	Cons:		Requires actions (sampling and sending to the laboratory) from the farmers in certain intervals. The new values must be entered to the fertilisation planning tool.	More precise manure sampling requires more work from farmers.	Requires extra work to collect and enter feeding and manure management data to the calculator and keeping this data up to date. The output values must be entered to the fertilisation planning tool.	To calculate regional manure data, data on feeding and manure management must be collected from farmers => farmers are expected to take part in the surveys.

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