Understanding and predicting nitrogen fluxes at the farm scale

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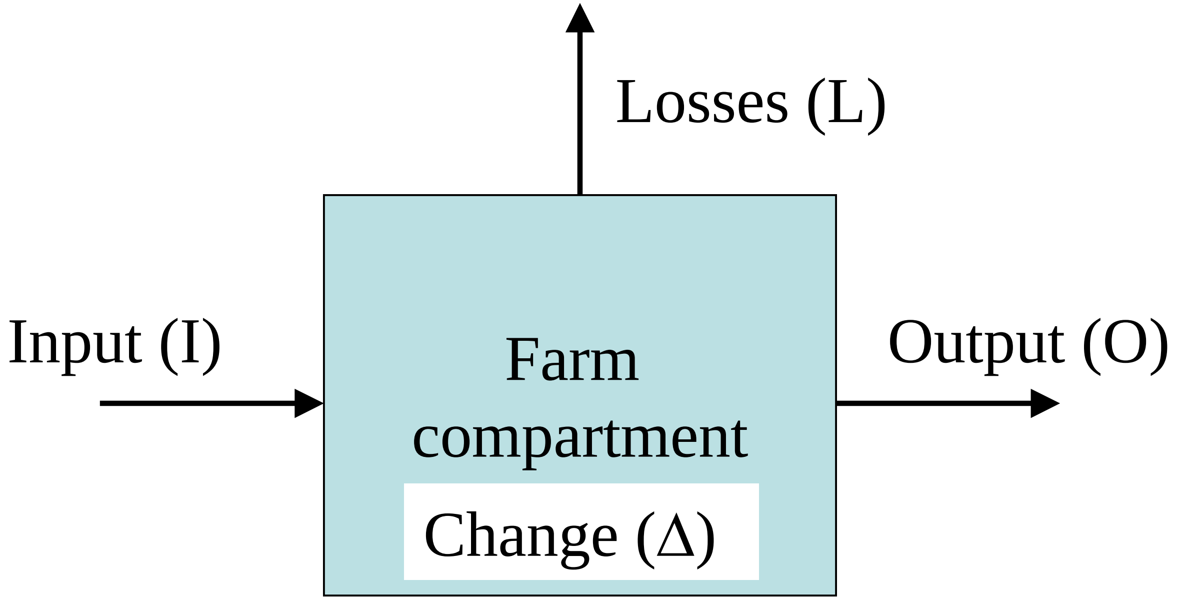
Nitrogen flows in farming systems

Agricultural systems have intensive N flows often leading to large emissions of reactive N to the surrounding environment.

The N fluxes and the effect of management on fluxes differ considerably between farm types (e.g. arable farm, pig farm, cattle farms).

Legislation is increasingly focusing on reducing emissions of several of the reactive N species simultaneously. Such reduction require farm management to be targeted at reducing emissions throughout the chain of N flows at farm scale.

The N balance concept

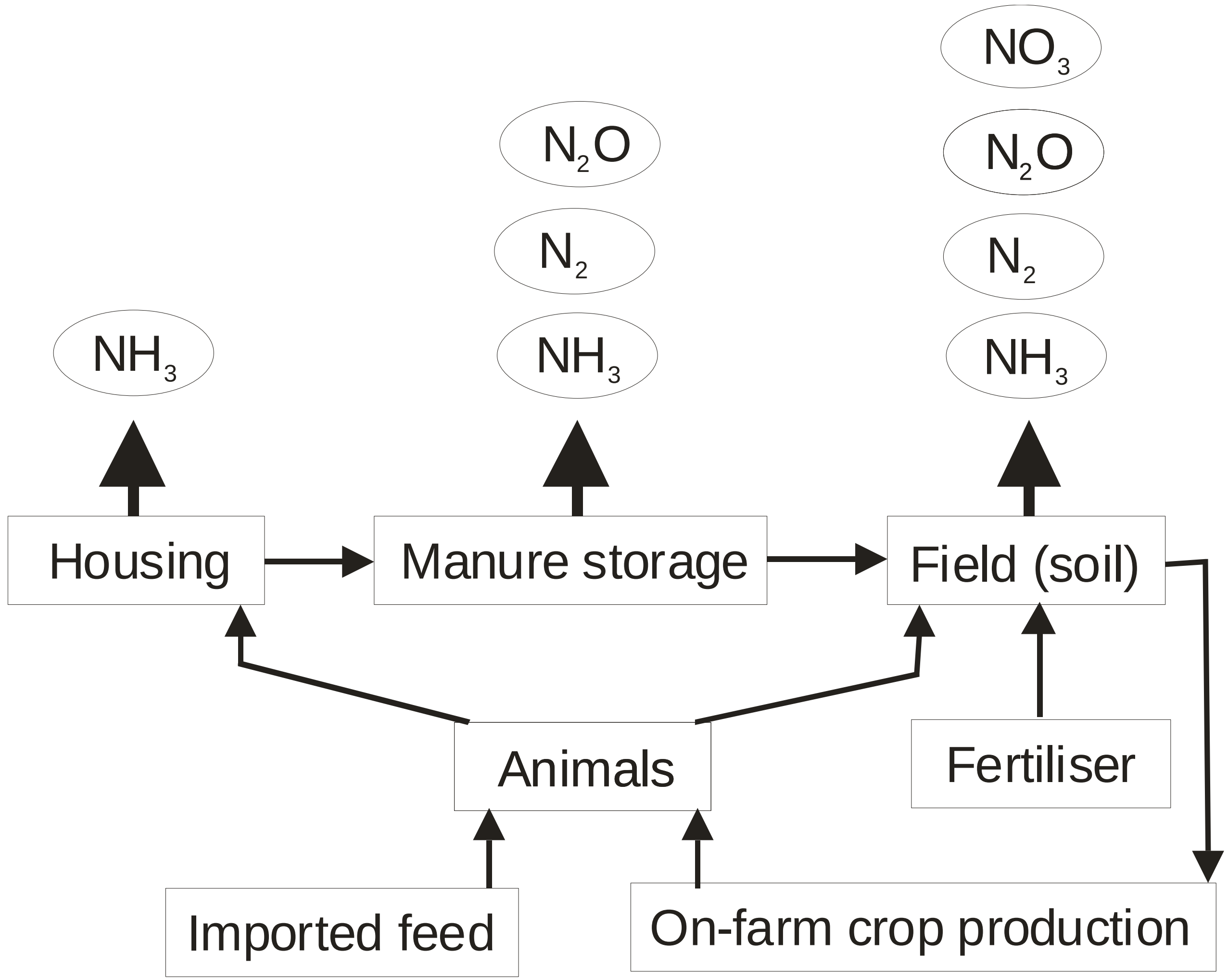


Surplus: $S = I - O = \Delta + L$

Efficiency: O/I

Losses: $L = S - \Delta$

Flows affecting farm N emissions



Scales of interest

- *Structural*: Different farm types and components differ considerably in terms of N cycling and emissions.
- *Spatial*: Farms are components of landscapes and affect N flows at landscape level (in atmosphere and water). Spatial heterogeneity in soils and cropping pattern at field and farm scale will affect emissions.
- *Temporal*: N flows and emissions are affected by the weather and by the prehistory of the soils.
- *Management*: The flows can be affected by management in all the different spatial contexts.

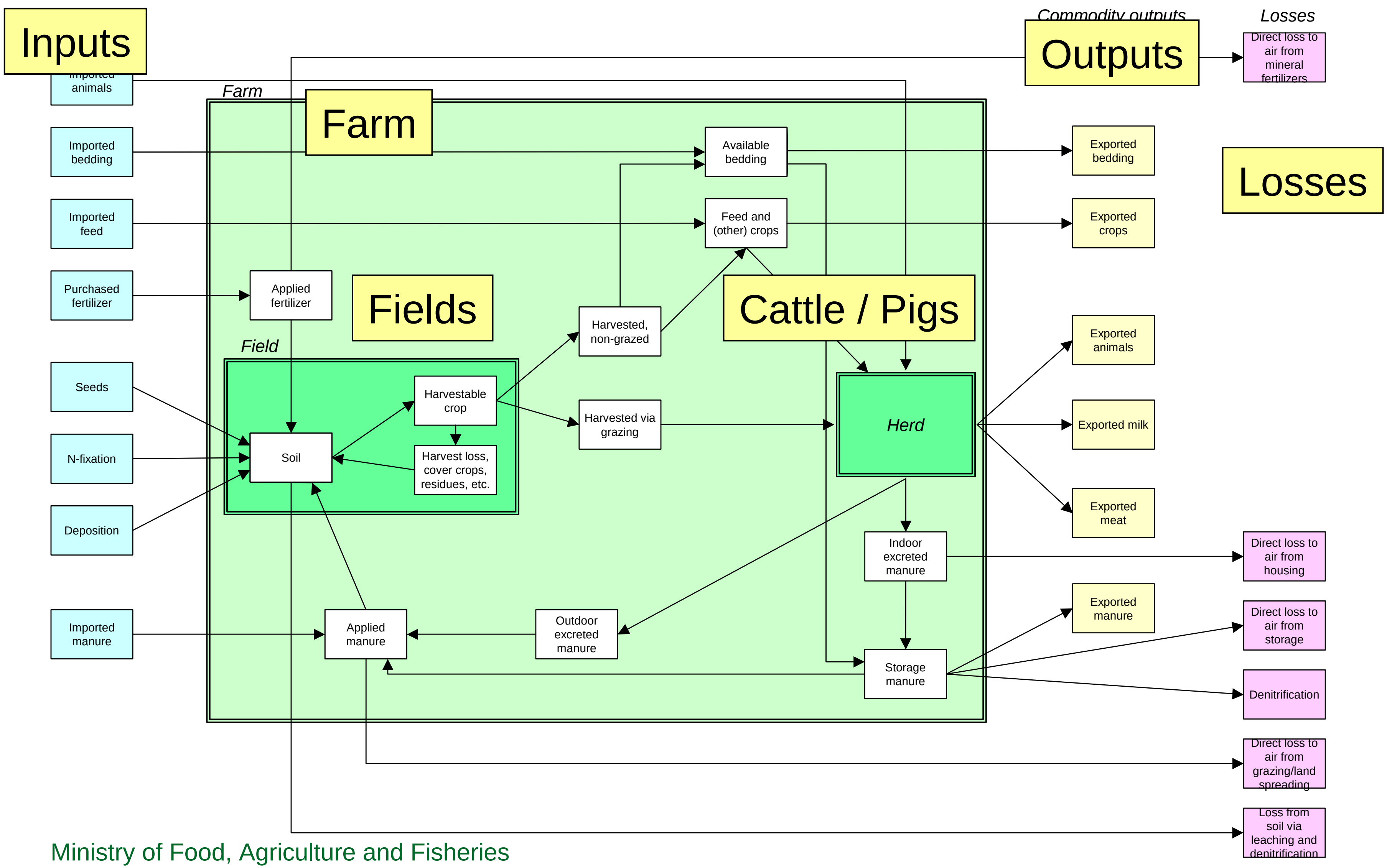
Modelling farm flows and emissions

- *Static models*: Focuses on the structural aspects of the farm (e.g.: Farm-N tool).
- *Dynamic models*: Focuses on structural and dynamic aspects of the farm (e.g.: FASSET and FarmGHG).
- *Landscape*: Focuses on spatial and dynamic aspects of farms and their interaction with other landscape components (e.g.: NitroScape).

The Farm-N tool (available at www.farm-n.dk)

- A whole-farm model of N flows
- Focuses on the interactions between crop and livestock production
- Static model, results represent an average situation
- Deterministic; same input produces same output
- Underlying assumption: Nutrient quota used to regulate management

Nitrogen flow on farm



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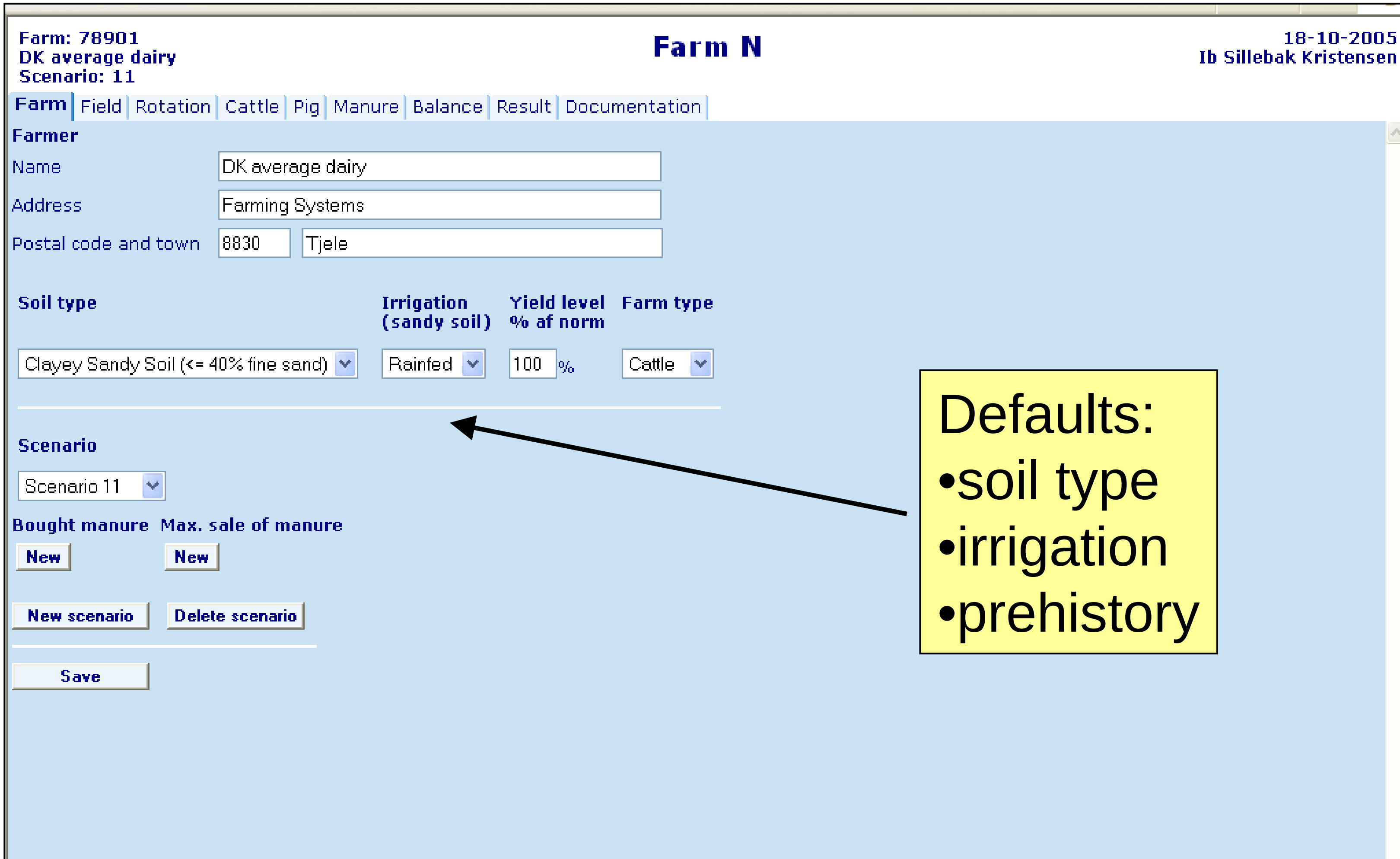
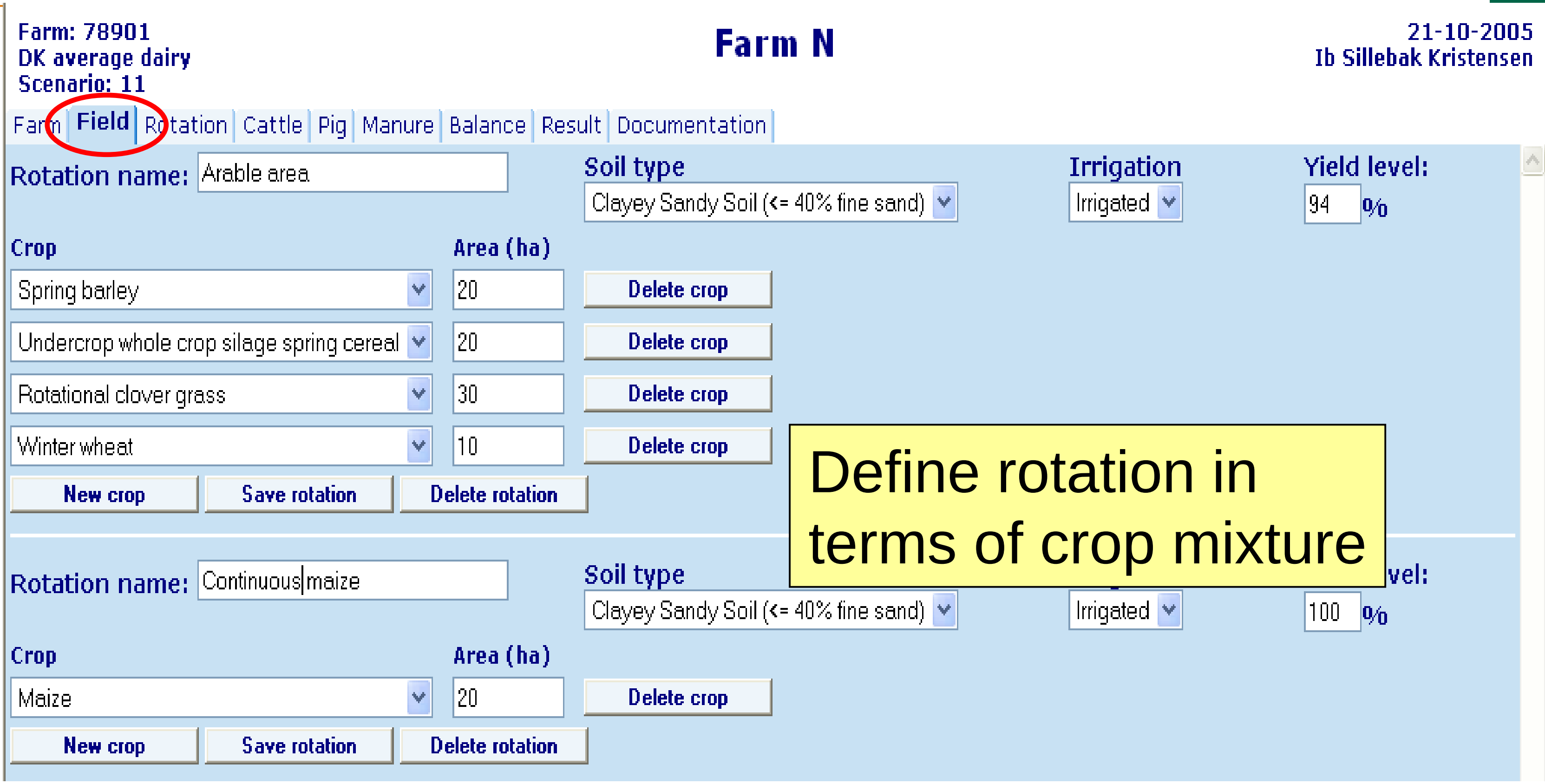
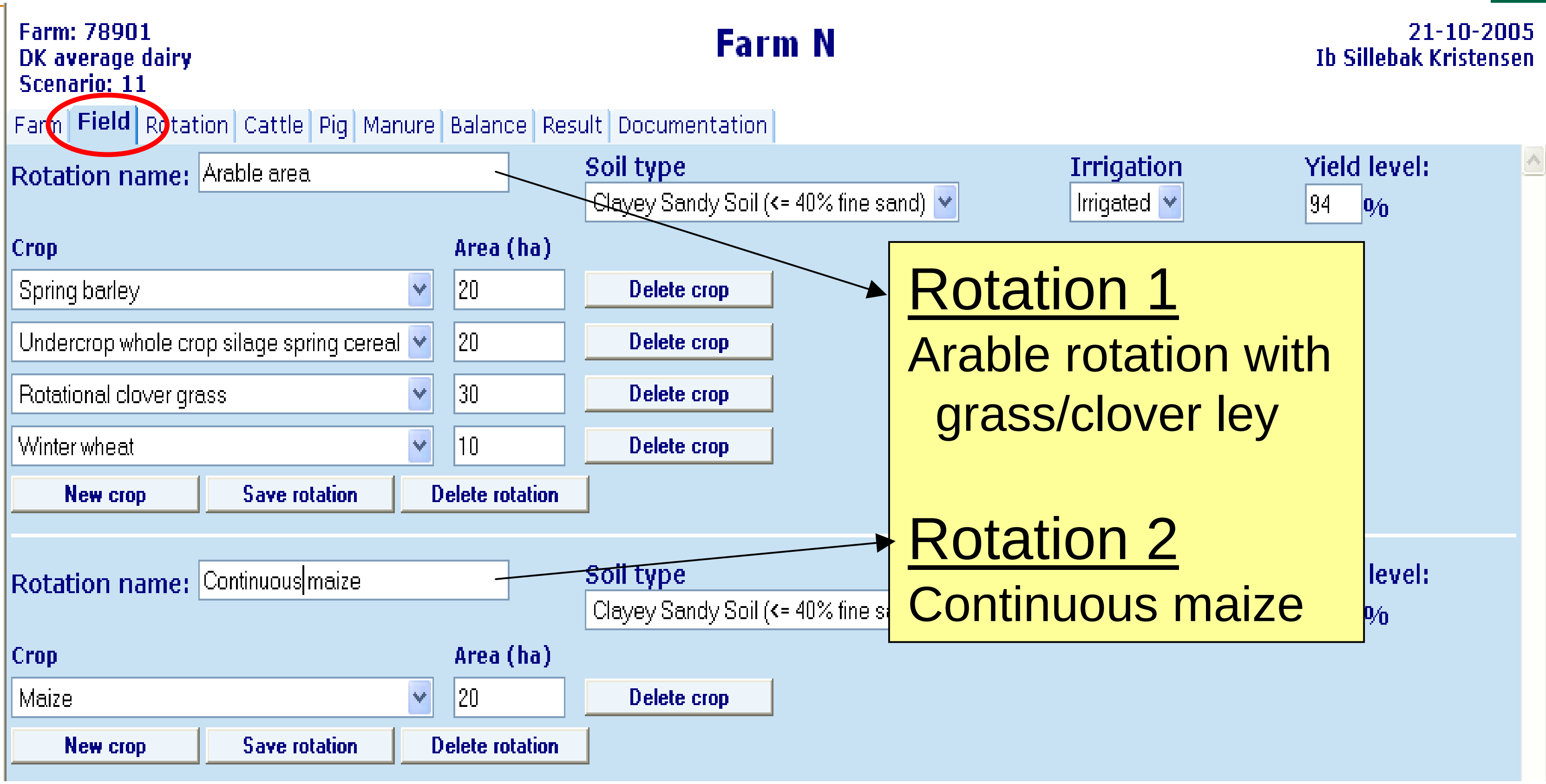


Defaults:
- soil type
- irrigation
- prehistory

Field


Farm: 78901
DK average dairy
Scenario: 11
Farm N
21-10-2005
Ib Sillebak Kristensen
Farm
Field
Rotation
Cattle
Pig
Manure
Balance
Result
Documentation
Rotation name: Arable area
Soil type
Clayey Sandy Soil (<= 40% fine sand)
Irrigation
Irrigated
Yield level:
94 %
Crop
Area (ha)
Spring barley
20
Delete crop
Undercrop whole crop silage spring cereal
20
Delete crop
Rotational clover grass
30
Delete crop
Winter wheat
10
Delete crop
New crop
Save rotation
Delete rotation
Define rotation in terms of crop mixture
Rotation name: Continuous maize
Soil type
Clayey Sandy Soil (<= 40% fine sand)
Irrigated
100 %
Crop
Area (ha)
Maize
20
Delete crop
New crop
Save rotation
Delete rotation

Field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Delete crop
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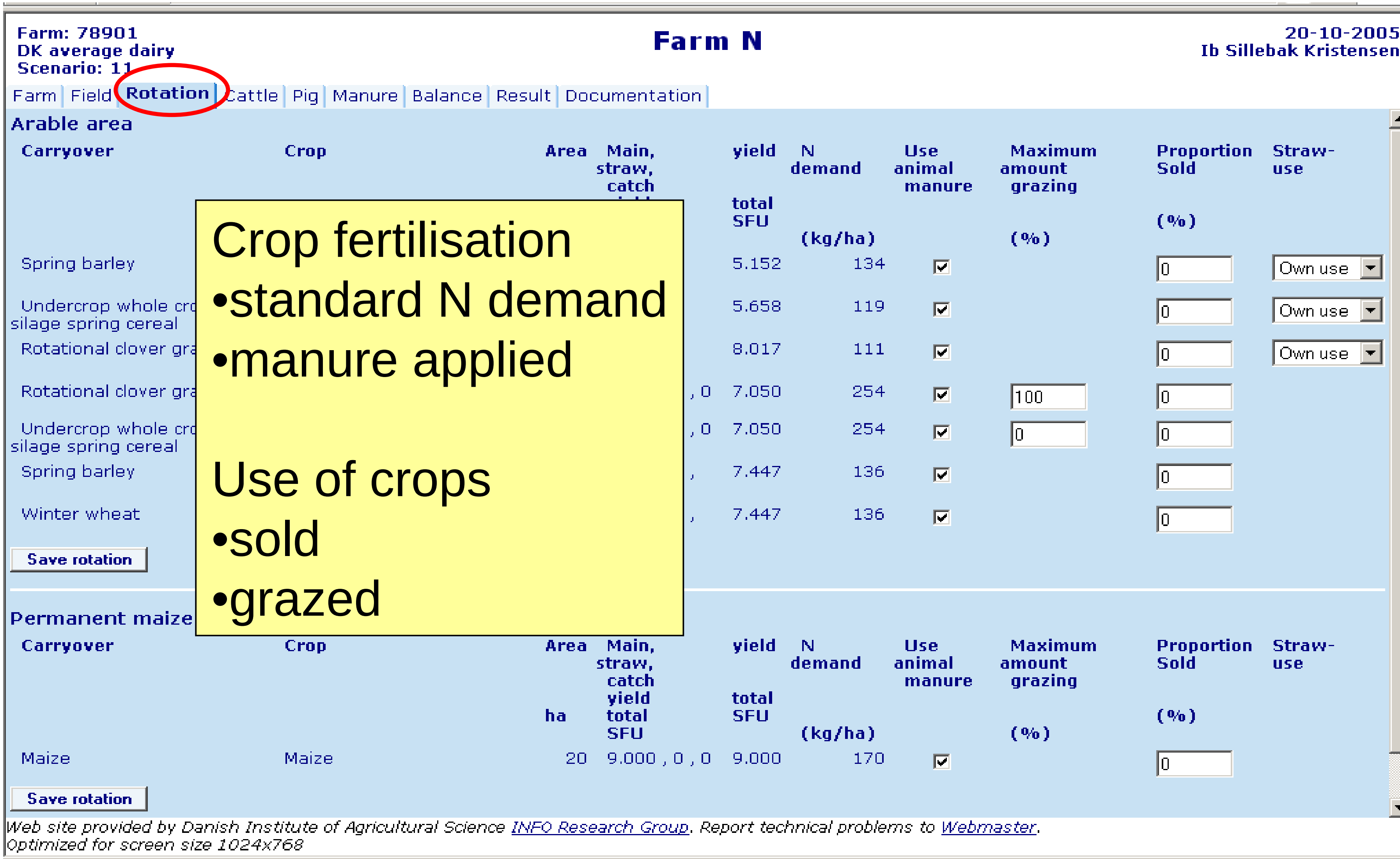
30
Delete crop
Winter wheat
10
Delete crop
New crop
Save rotation
Delete rotation
Rotation 1
Arable rotation with grass/clover ley
Rotation 2
Continuous maize
Rotation name:
Continuous maize
Soil type
Clayey Sandy Soil (<= 40% fine s
level:
%
Crop
Area (ha)
Maize
20
Delete crop
New crop
Save rotation
Delete rotation

Crop rotation



Farm: 78901
DK average dairy
Scenario: 11

Farm N

20-10-2005
Ib Sillebak Kristensen

Farm | Field | Rotation | Cattle | Pig | Manure | Balance | Result | Documentation

Arable area

Carryover	Crop	Area	Main, straw, catch	yield total SFU	N demand (kg/ha)	Use animal manure	Maximum amount grazing (%)	Proportion Sold (%)	Straw-use
Spring barley				5.152	134	☑		0	Own use
Undercrop whole cro silage spring cereal				5.658	119	☑		0	Own use
Rotational clover gra				8.017	111	☑		0	Own use
Rotational clover gra			, 0	7.050	254	☑	100	0	
Undercrop whole cro silage spring cereal			, 0	7.050	254	☑	0	0	
Spring barley			,	7.447	136	☑		0	
Winter wheat			,	7.447	136	☑		0	

Save rotation

Crop fertilisation
- standard N demand
- manure applied

Use of crops
- sold
- grazed

Permanent maize

Carryover	Crop	Area ha	Main, straw, catch yield total SFU	yield total SFU	N demand (kg/ha)	Use animal manure	Maximum amount grazing (%)	Proportion Sold (%)	Straw-use
Maize	Maize	20	9.000 , 0 , 0	9.000	170	☑		0	

Save rotation

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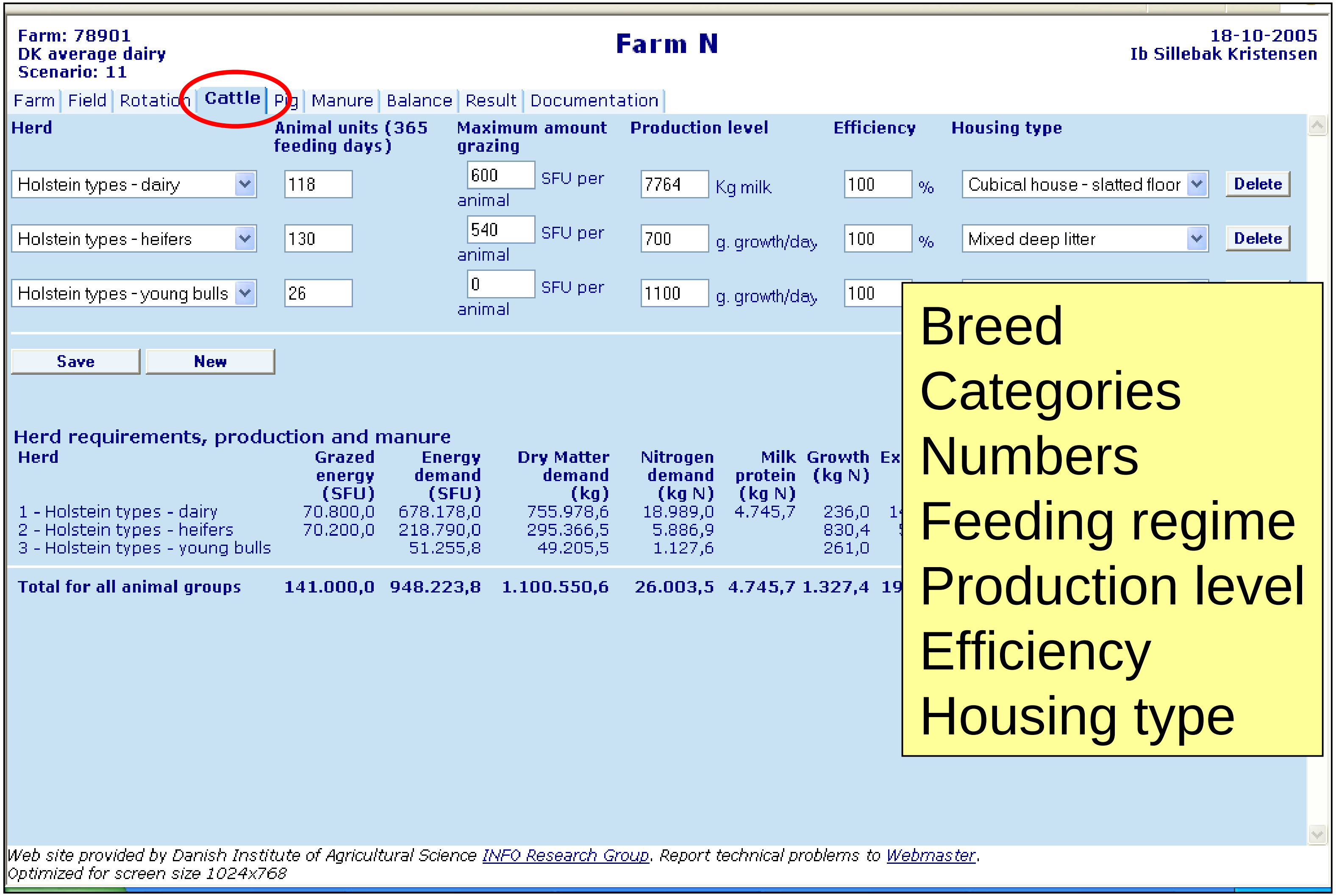
Cattle



Farm: 78901
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Herd
Animal units (365 feeding days)
Maximum amount grazing
Production level
Efficiency
Housing type
Holstein types - dairy
118
600 SFU per animal
7764 Kg milk
100 %
Cubical house - slatted floor
Delete
Holstein types - heifers
130
540 SFU per animal
700 g. growth/day
100 %
Mixed deep litter
Delete
Holstein types - young bulls
26
0 SFU per animal
1100 g. growth/day
100
Save
New
Herd requirements, production and manure
Herd
Grazed energy (SFU)
Energy demand (SFU)
Dry Matter demand (kg)
Nitrogen demand (kg N)
Milk protein (kg N)
Growth (kg N)
1 - Holstein types - dairy 70.800,0 678.178,0 755.978,6 18.989,0 4.745,7 236,0
2 - Holstein types - heifers 70.200,0 218.790,0 295.366,5 5.886,9 830,4
3 - Holstein types - young bulls 51.255,8 49.205,5 1.127,6 261,0
Total for all animal groups 141.000,0 948.223,8 1.100.550,6 26.003,5 4.745,7 1.327,4
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Breed
Categories
Numbers
Feeding regime
Production level
Efficiency
Housing type

Pigs

Farm: 78901
DK average dairy
Scenario: 15

Farm N

18-10-2005
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Sows

Number of year sows	Number of live piglets per sow	Weight at weaning	Feed amount	Protein content	Stable type - pregnant sows	Stable type - lacta sows
140 number	23,2 number	7,2 kg	1340 SFUpigs	149,8 g/SFUpigs	Single-housed, fully-slatted	Boxed, partially-sl

New

Piglets and Finishing pigs

Type	Produced animals	Start weight	End weight	Feed amount per animal	Protein content	Stable type	
Piglets	3200 number	7,2 kg	30 kg	47 SFUpigs	164,3 g/SFUpigs	Fully slatted floor	Delet
Finishing pigs	3151 number	30 kg	102 kg	201 SFUpigs	158,3 g/		Delet

New

Save

Herd requirements, production and manure

Herd	Energy demand (SFU)	Nitrogen demand (kg N)	Growth (kg N)	Excretion (kg N)	Excretion - faeces (kg N)	
1 - Sows	187.600,0	4.496,4	771,3	3.725,1	899,3	
2 - Finishing pigs	633.351,0	16.041,5	6.220,1	9.821,4	3.208,3	
3 - Piglets	150.400,0	3.953,7	1.943,0	2.010,7	672,1	
Total for all animal groups	**971.351,0**	**24.491,6**	**8.934,4**	**15.557,3**	**4.779,7**	**10.777,5**

Categories
Numbers
Feeding regime
Production level
Housing type

Intermediate calculations

- Animals
  - feed demand
  - N excretion
- Housing & storage
  - addition of bedding
- Fields
  - optimum crop rotation
  - plant-available N required
  - optimised manure use
  - mineral fertiliser applied
  - crop production

Farm-N uses fixed N efficiencies in the animal production

Animal category	N efficiency (%)
Dairy cows	26
Heifers	15
Bulls	23
Sows with piglets	17
Piglets	49
Slaughter pigs	38

Farm N surplus = Import - Export

- Import (input)
  - feed imported
  - livestock imported
  - mineral fertiliser and manure
  - N fixation
  - seed
  - atmospheric deposition
- Export (output)
  - livestock products (meat, milk)
  - crop products (grain, straw, hay)
  - manure exported

Results

Farm: 78901
DK average dairy
Scenario: 11

Farm N

20-10-2005
Ib Sillebak Kristensen

Farm | Field | Rotation | Cattle | Pig | Manure | Balance | **Result** | Documentation

Farm scale

Input (kg N)	per ha	total				total	per ha	Output (kg N)
Mineral fertiliser	55,7	5.566,5	->		->	0,0	0,0	Cash crops
Manure bought	0,0	0,0	->		->	0,0	0,0	Piglets sold
Feed bought	111,6	11.162,0	->		->	1.327,4	13,3	Cattle meat
Straw bought	0,0	0,0	->		->	4.745,7	47,5	Milk
Pigs bought	0,0	0,0	->		->	0,0	0,0	Manure sold
Seed	1,1	111,7	->		->	728,3	7,3	Feed sold
N fixation	31,5	3.150,0	->		->	0,0	0,0	Finishing pigs sold
Atmospheric deposition	15,0	1.500,0	->					
Total input	214,9	21.490,1	->		->	6.801,3	68,0	Total output

Farm N-surplus: 14.688,8 kg N 146,9 kg N per ha
Area : 100,0 ha
Herd : 184,8 livestock units

Distribution of N-surplus

	total kg N	per ha kg N per ha
Ammonia lost, housing	1.355,2	13,6
Ammonia lost, storage	832,2	8,3
Denitrification, storage	112,0	1,1
Ammonia lost, grazing	215,9	2,2
Ammonia lost, spreading manure	995,4	10,0
Ammonia lost, spreading mineral fertiliser	167,0	1,7
Denitrification, soil	1.164,1	11,6
Soil pool change	5.505,6	55,1
N leaching	4.341,4	43,4

Distribution of estimated N surplus

- Ammonia volatilisation estimated from emission factors
- Denitrification (N_2+N_2O) in housing and manure storage estimated from emission factors
- Denitrification (N_2+N_2O) in soils estimated from emission factors (SimDen model)
- Soil N change estimated from a simple dynamic SOM model
- Nitrate leaching = farm N surplus – (other losses + change in soil N).
- Nitrate leaching may alternatively be estimated from an empirical N leaching model (e.g.: N-LES).

Distribution of Farm gate N-surplus = 147 kg N/ha

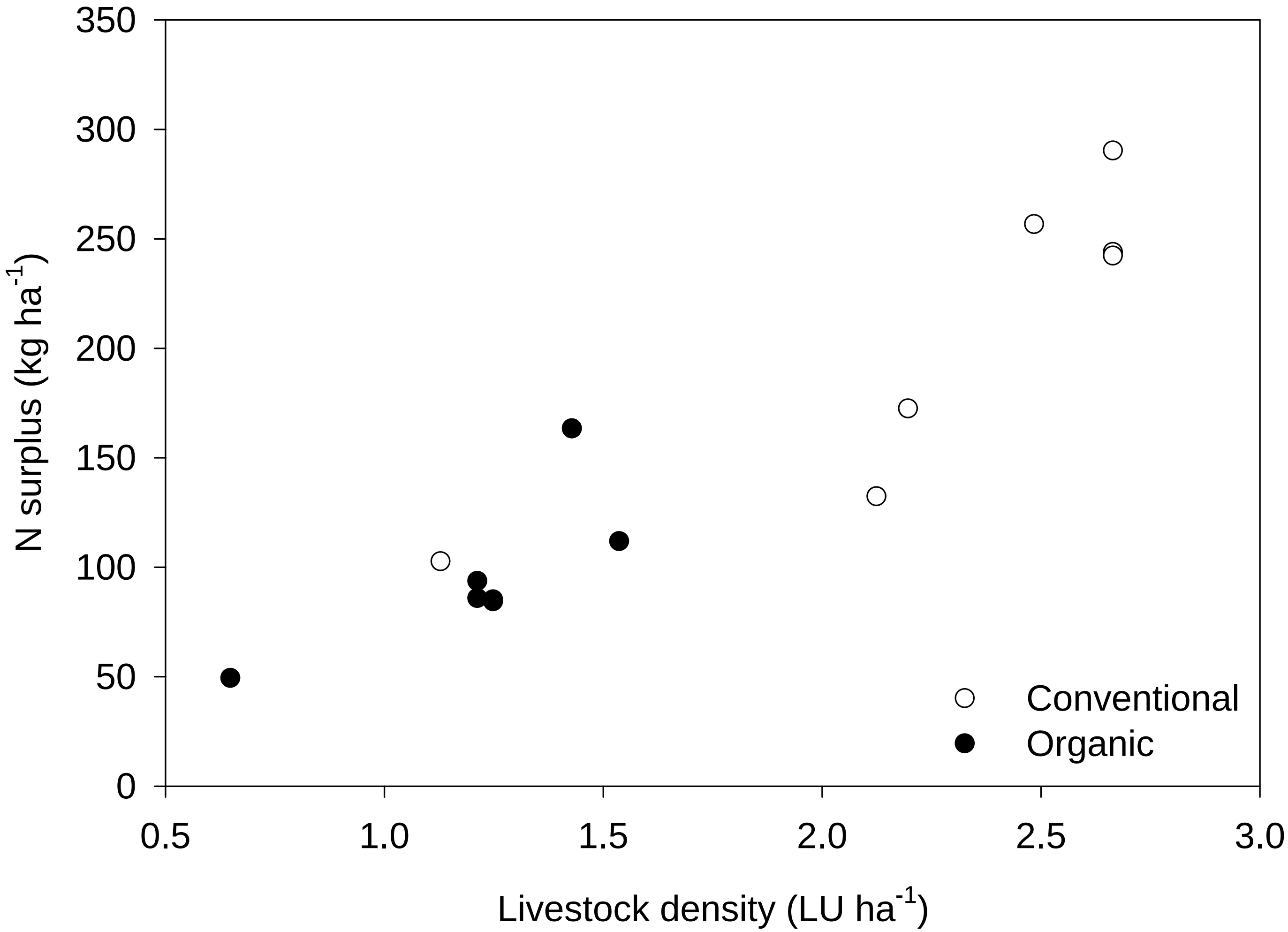
Distribution of N-surplus

	total	per ha	
	kg N	kg N per ha	Lost of input
Ammonia lost, housing	1.355,2	13,6	7%
Ammonia lost, storage	832,2	8,3	4%
Denitrification, storage	112,0	1,1	5%
Ammonia lost, grazing	215,9	2,2	7%
Ammonia lost, spreading manure	995,4	10,0	6%
Ammonia lost, spreading mineral fertiliser	167,0	1,7	3%
Denitrification, soil	1.164,1	11,6	4%
Soil pool change	5.505,6	55,1	
N leaching	4.341,4	43,4	

The FarmGHG farm model (www.agrsci.dk/jpm/jeo)

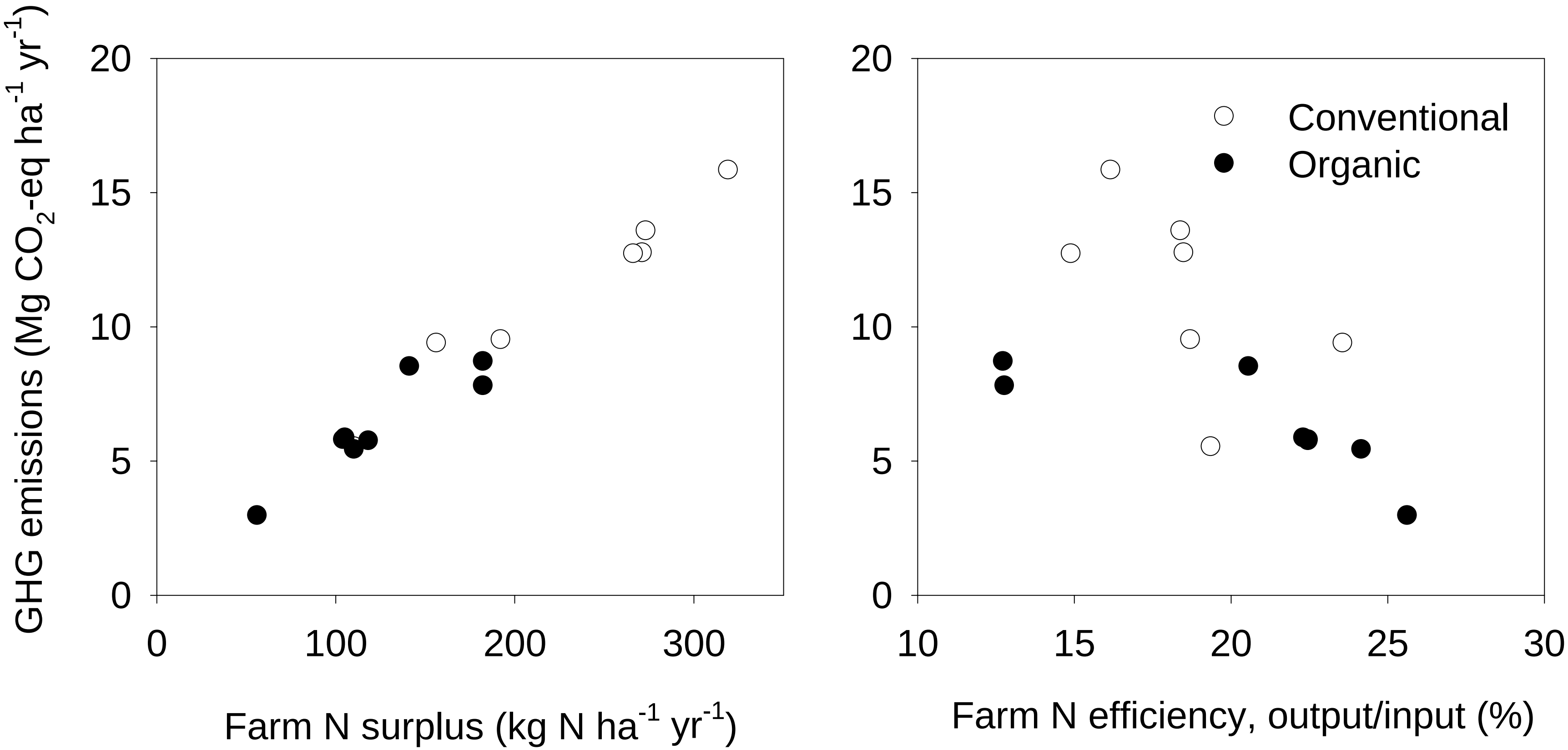
- A whole-farm model of N flows and greenhouse gas emissions
- Focuses on estimation of measures (management and technological) of reducing greenhouse gas emissions.
- Semi-dynamic model, uses monthly time steps, but results represent an average situation
- Deterministic
- A combination of emission factors and dynamic effects on N flows and emissions is used
- The model has been applied to European dairy farming systems (organic and conventional)

Farm N surplus increases with livestock density



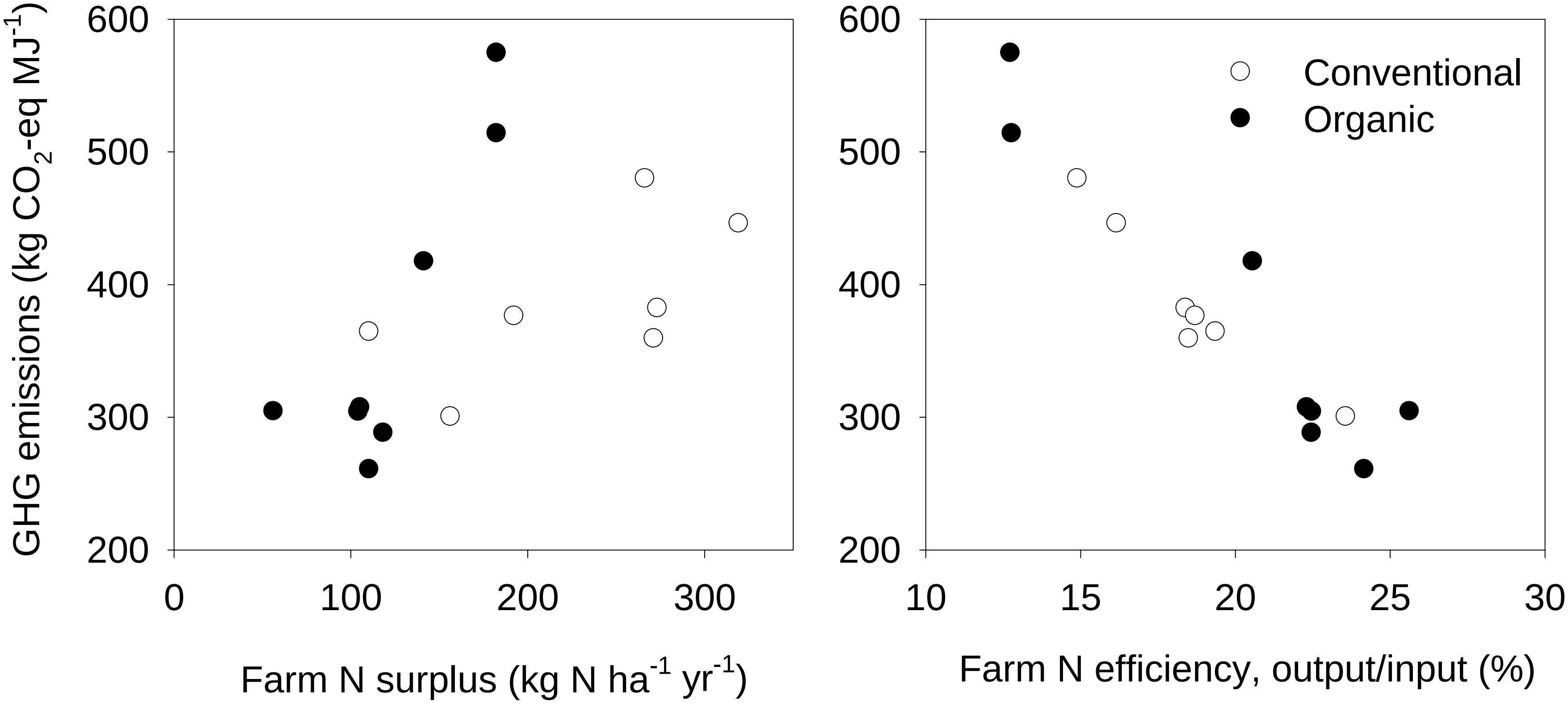
FarmGHG model

Emissions per area



FarmGHG model

Emissions per unit of energy exported



FarmGHG model

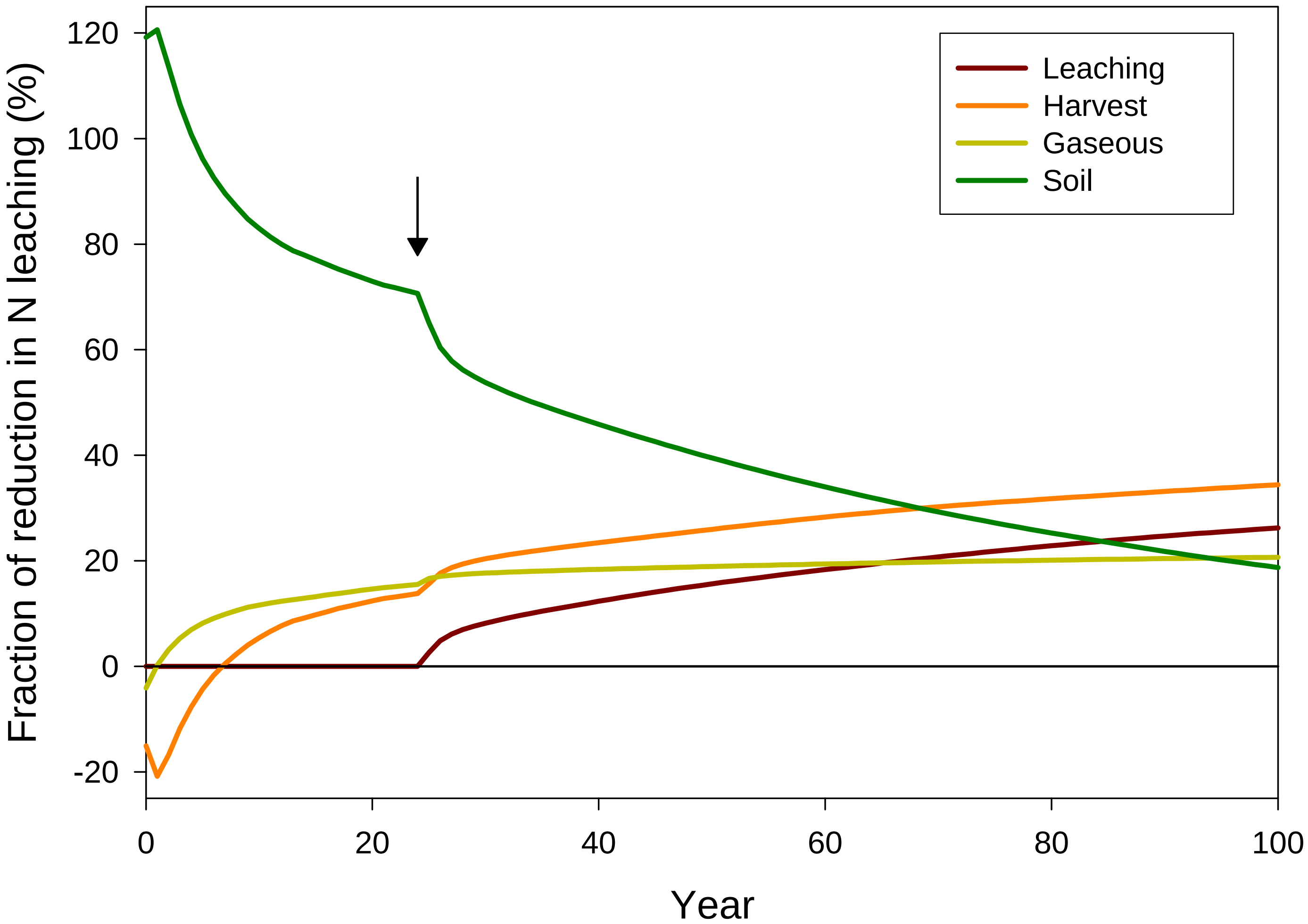
The FASSET farm model (www.fasset.dk)

- A whole-farm model of C and N flows and farm production
- Focuses on estimation of farm management effects on C and N flows, in particular of emissions of reactive N species.
- Dynamic model, uses daily time steps, and results depend on actual soil and climatic conditions
- Deterministic
- The flows and emissions are mostly simulated through mechanistic modelling of the physical and biological systems involved.

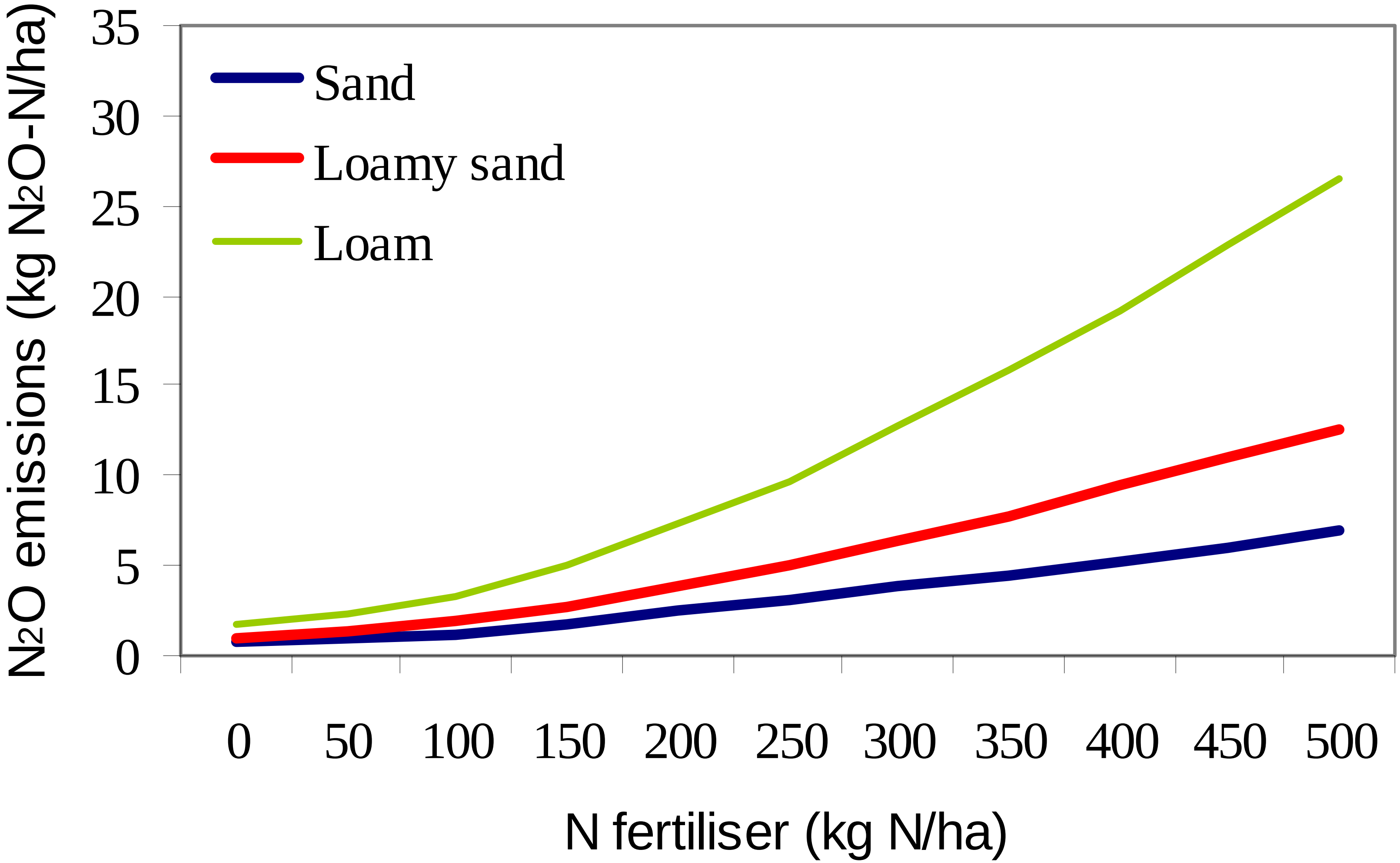
Examples of management options to reduce N losses

- Change in feeding of cattle and pigs, e.g. reduced use of N-rich concentrates, addition of essential amino acids.
- Cover on slurry tanks
- Anaerobic digestion of slurry (biogas)
- Slurry injection
- Reduced fertiliser N rates
- Better timing of fertiliser and manure applications
- Growing of catch crops
- Reduced tillage

The fate of N-savings from catch crop changes over time



N_2O emissions from grazed grassland



Simple or complex models?

- Simple models
  ☺ few inputs, readily obtained
  ☺ low parameter error
  ☹ high model error
  ☹ reflects average management
- Complex models
  ☹ many inputs, readily obtained
  ☹ high parameter error
  ☺ low model error
  ☺ can reflect wide range of management

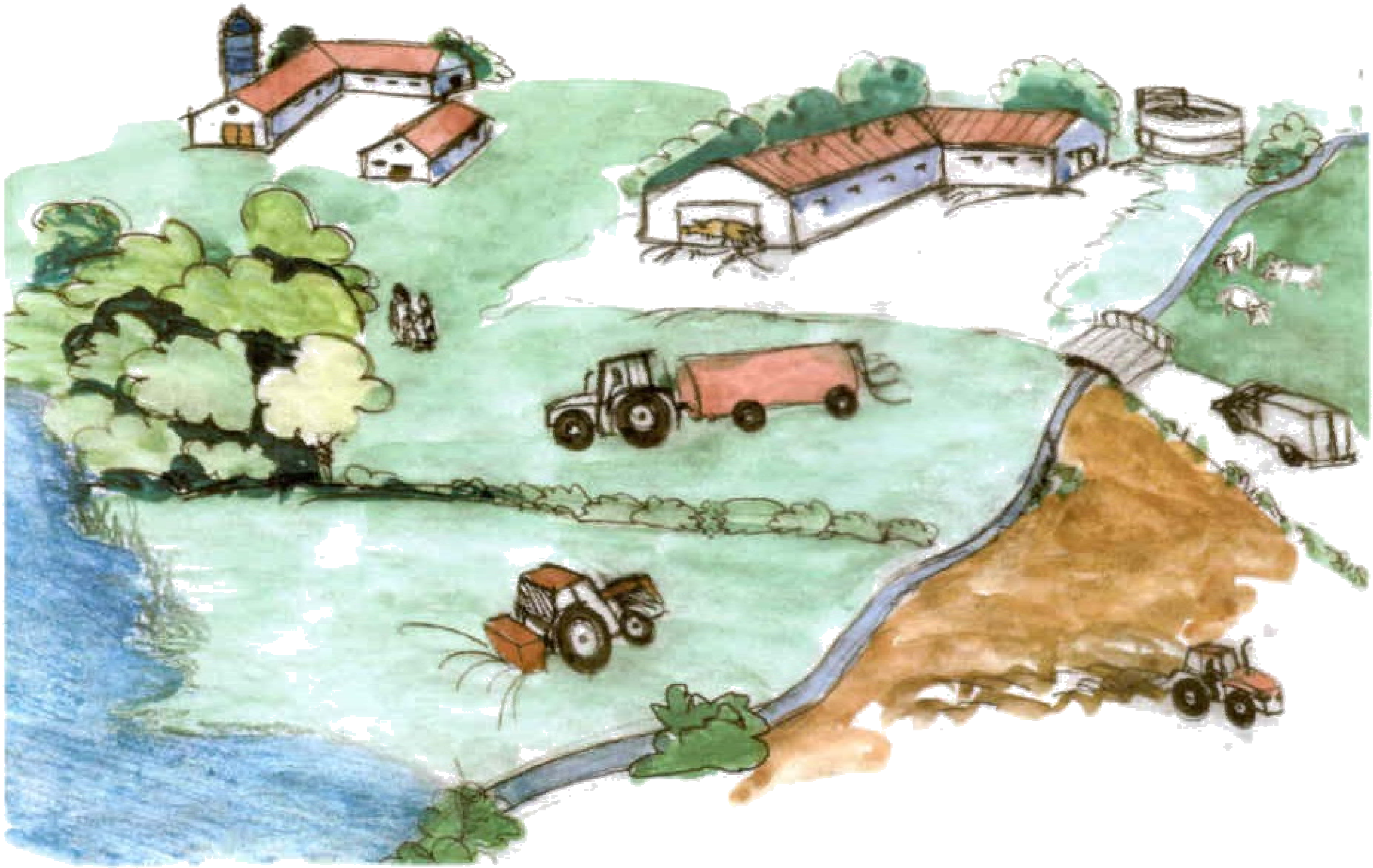
Which models to apply?

- Prediction of management effects on farm N flows and emissions
  - dynamic models
  - reflect the underlying processes affected
- Prediction of farm N flows and emissions at landscape scale
  - simple (empirical and static) models
  - limited amount of good quality data available

Conclusions

- N losses from farming systems are particular large from livestock systems with low N-efficiencies in the livestock production
- Farm N flows and emissions are often best predicted using simple (empirical and static) models
- Farm N flows and emissions are often best understood using dynamic models, which represent both structural and temporal scales
- To properly represent the need for future targeted regulations of farm N emissions, farm models will need to consider interactions within the landscape

Thanks for your attention



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