Energy efficiency of field crops depending on the nitrogen fertilization based on IOSDV long-term field experiment and opportunities of IOSDV field experiment for energy analysis

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ENPOS Plant Production seminar
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IOSDV(Der **I**nternationale **O**rganische **S**tickstoff**d**auer-düngung**v**ersuch)

- IOSDV was established 1956 as a co-operation network under *International Union of Soil Science* soil-fertility working-group.

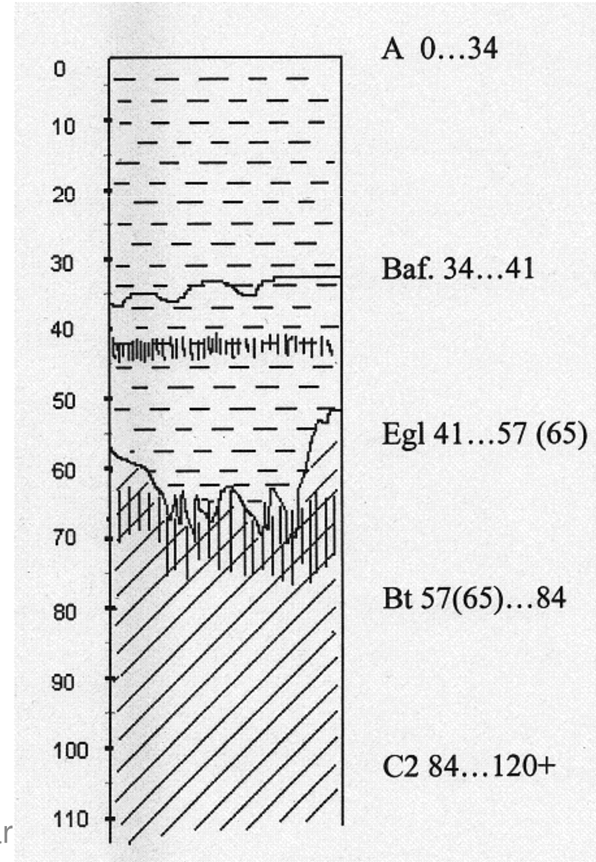
- 22 field experiments in 11 European countries
- The main idea:
  - study the yield response to the nitrogen fertilization
  - changes in soil condition

IOSDV in Estonia

- IOSDV Tartu field experiment in Eerika experimental station is established in 1989 (prof. emer. Paul Kuldkepp)

- Crop rotation: *spring wheat – spring barley – potato*

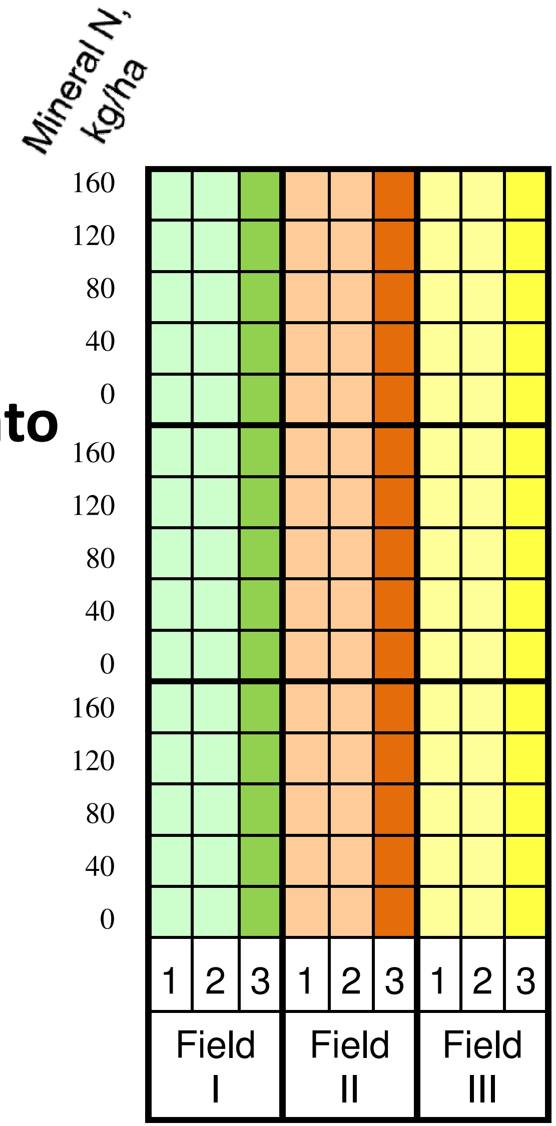
- Soil: sandy loam
  Fragi- Stagnic- Albeluvisol
  by WRB
  – ca 5,9 % Estonian soils (ca 70 % of those are arable *(Kokk, 1995)*



Factors

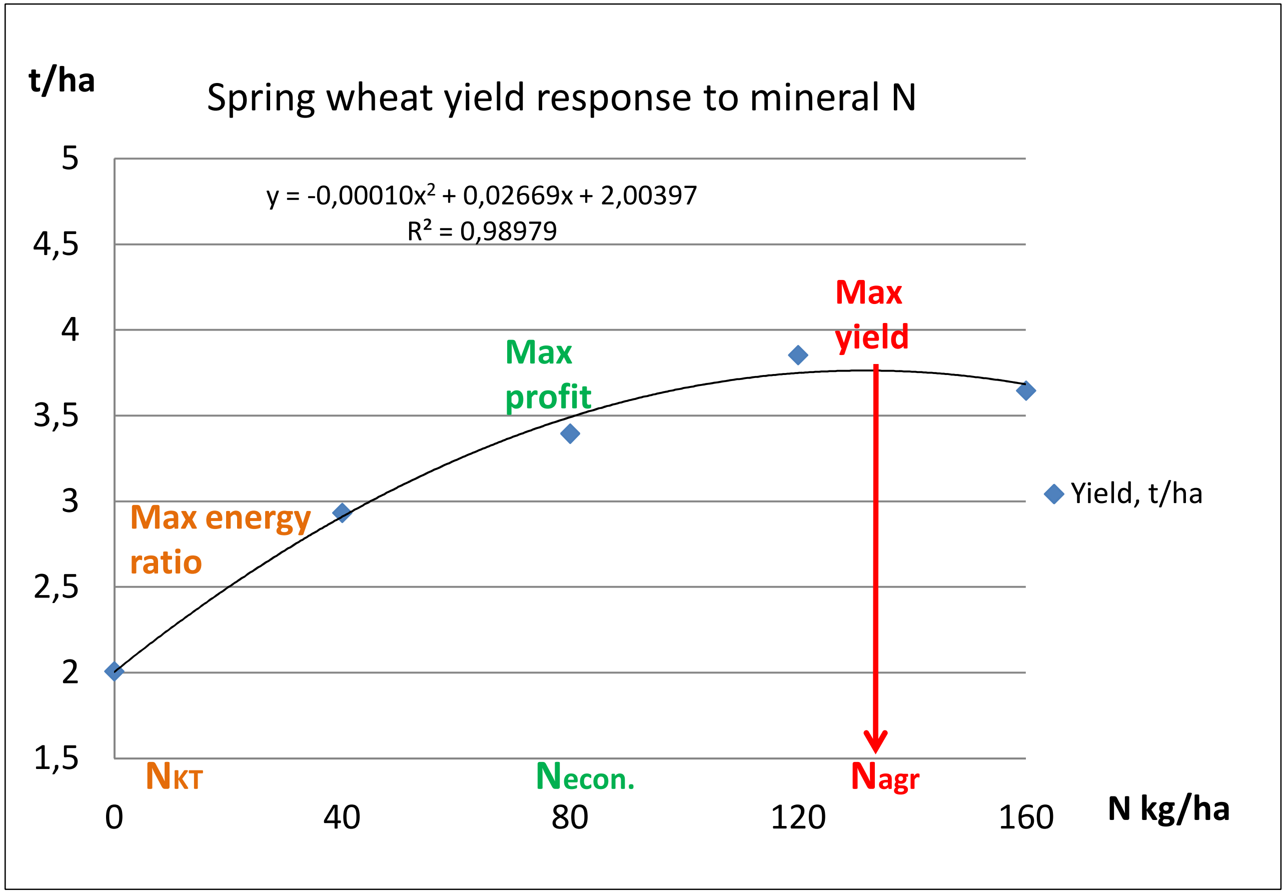
– Organic fertilisers
  - 1 - **Without organic fert.**
  - 2 - **Farmyard manure - 40 t/ha for potato**
  - 3 - Alternative organic fertilisers (beet leaves, straw, recultivation substance from oil shale semi-coke, red clover, residual from biogas and paper pulp production)

– Mineral fertilisers
  - **N rates 0, 40, 80, 120, 160 kg/ha**



Nitrogen – crop response curves

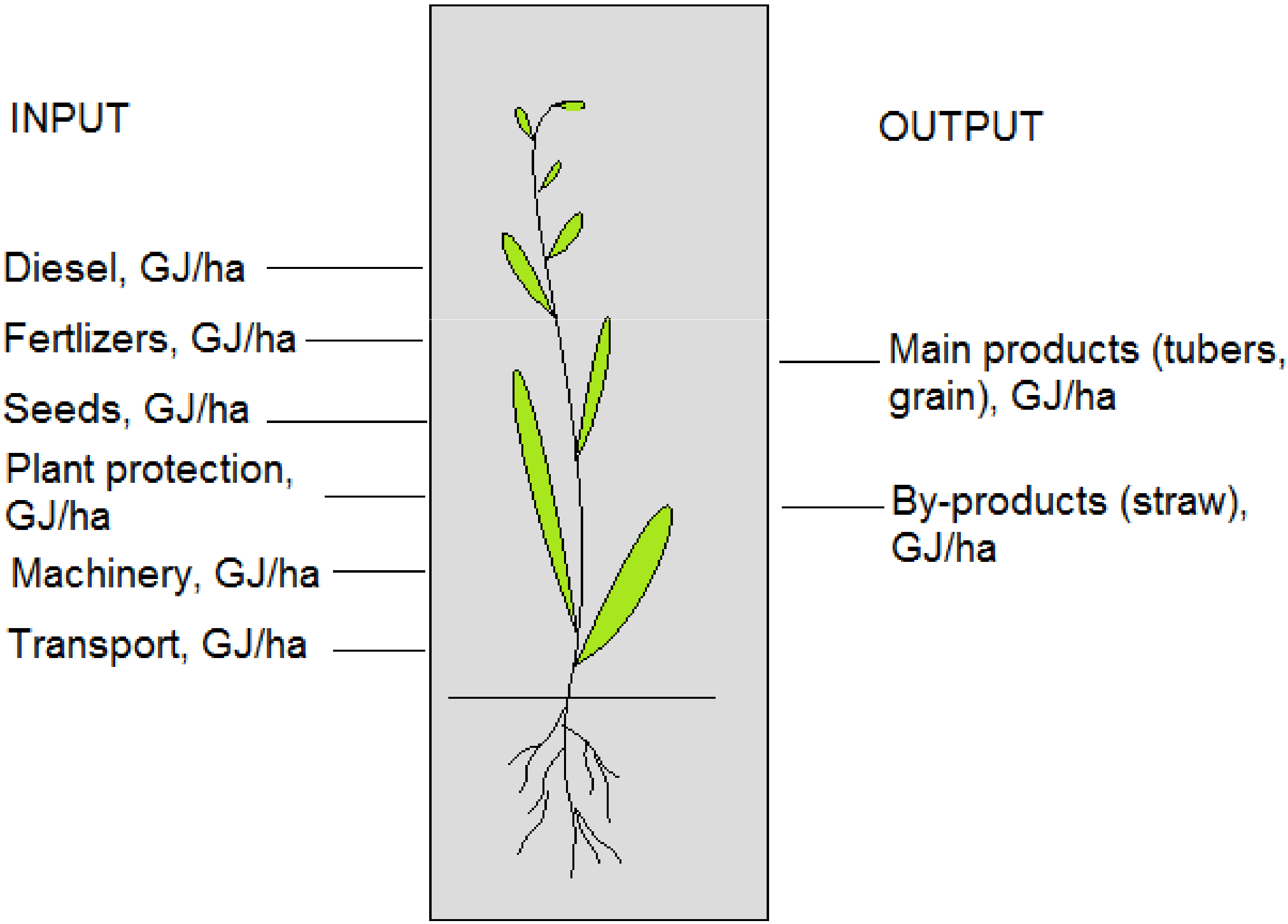
- Quadratic equation (polynom) - $Y=a_0+a_1x\pm a_2x^2$
- Optimization nitrogen fert - $N_{opt}=a_1/2a_2x$
  - agronomic,
  - economic,
  - energy.



Energy parameters

ENERGY GAIN (ES)	OUTPUT - INPUT
ENERGY RATIO (KT)	OUTPUT/INPUT
COMPLEX INDEX Relative importance of every single plot compared to the best plot value was found for ES and KT and then summarized.	Combines *energy ratio* and *energy gain* (max value=2)

Method of energy balancing - Hülsbergen *et al.* (2001)



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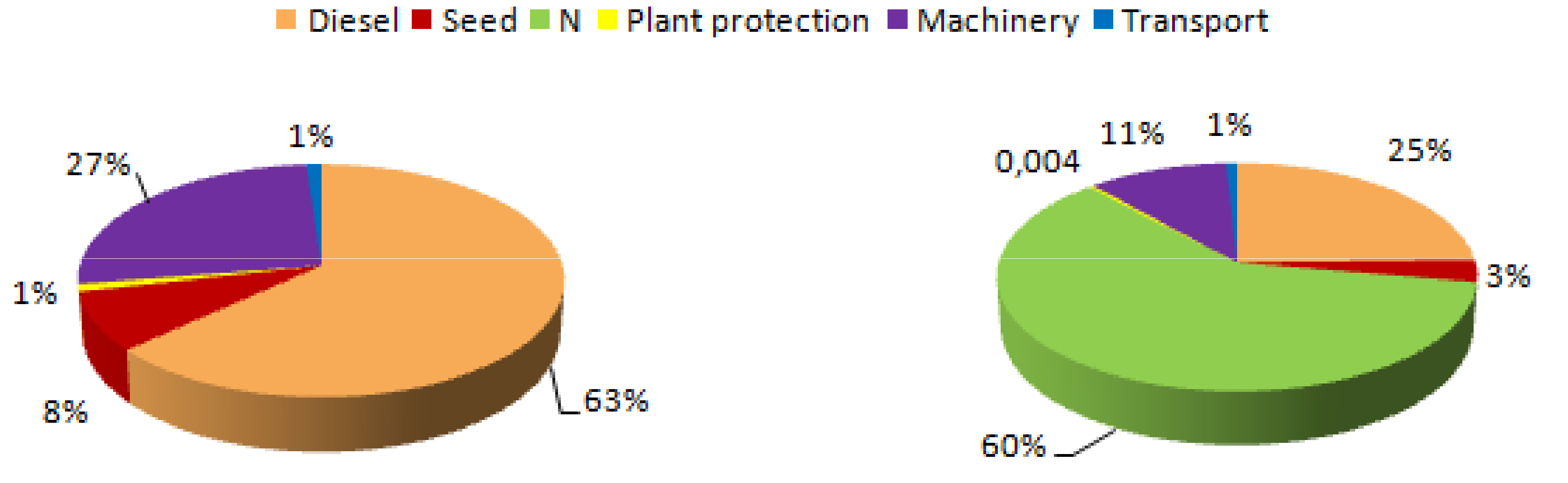
Energy equivalents

	Unit	Energy equivalent	Reference
Diesel	MJ kg^{-1}	39,6	Reinhardt (1993)
Fertilizers			
N (min. fert.)	MJ kg^{-1}	35,3	Appl (1997) (32,2-45)
N (org. fert.)		$0,43*N_{min}$	Schilling (1987)
P (min. org. fert.)	MJ kg^{-1}	36,2	Kaltschmitt ja Reinhardt (1997)
K (min. org. fert.)	MJ kg^{-1}	11,2	Kaltschmitt ja Reinhardt (1997)
Plant protection agents			Green (1987)
Herbicides	MJ kg^{-1}	288	
Fungicides	MJ kg^{-1}	196	
Insecticides	MJ kg^{-1}	237	
Seed			Kalk *et al.* (1995)
Spring wheat	MJ kg^{-1}	5,5	
Spring barley	MJ kg^{-1}	5,5	
Potato	MJ kg^{-1}	1,3	
Machinery	MJ kg^{-1}	108	Kalk, Hülsbergen (1996)
Transport	MJ t^{-1} km^{-1}	6,03	Müller (1989)

Results

Energy *input* for cereals



3,5 GJ/ha (N0)

9,3 GJ/ha (N160)

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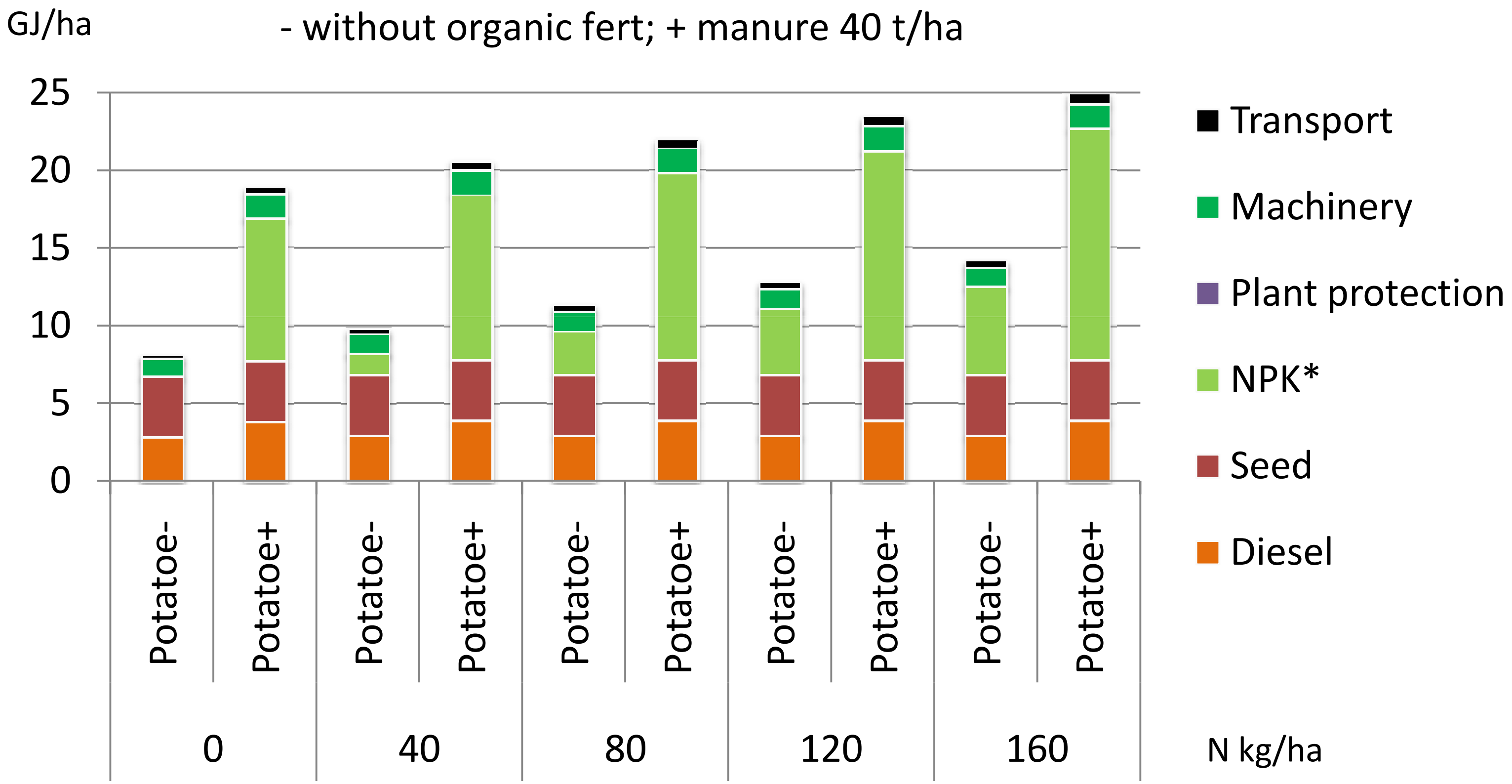
Energy *input* for potato



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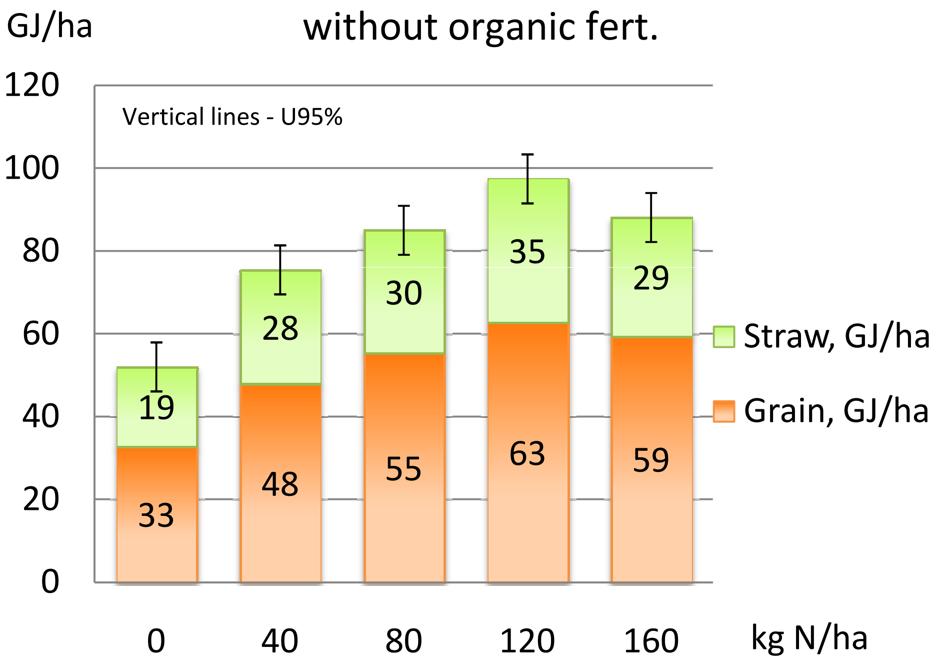
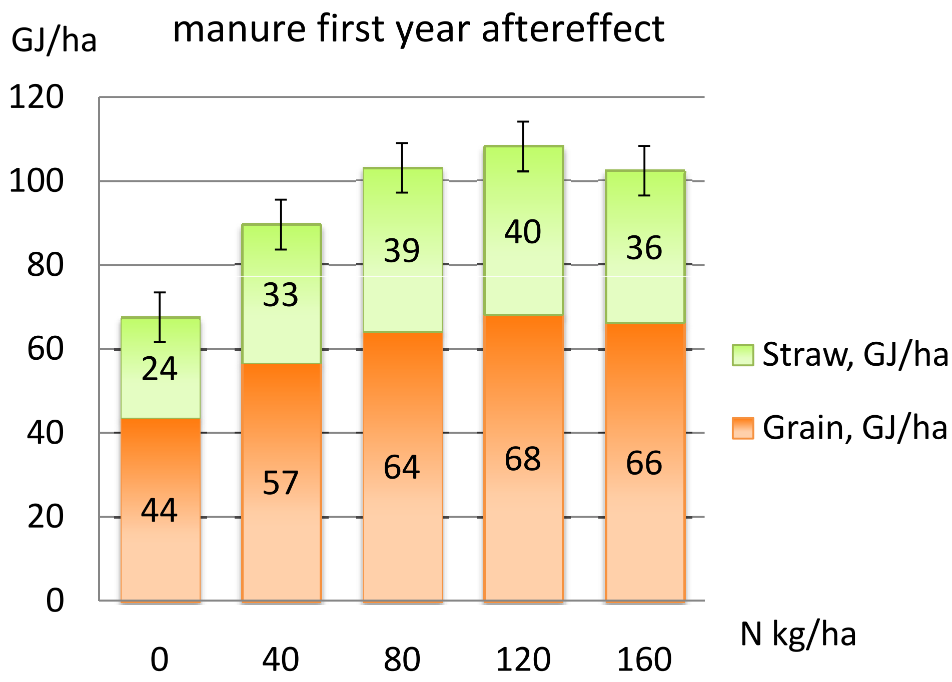
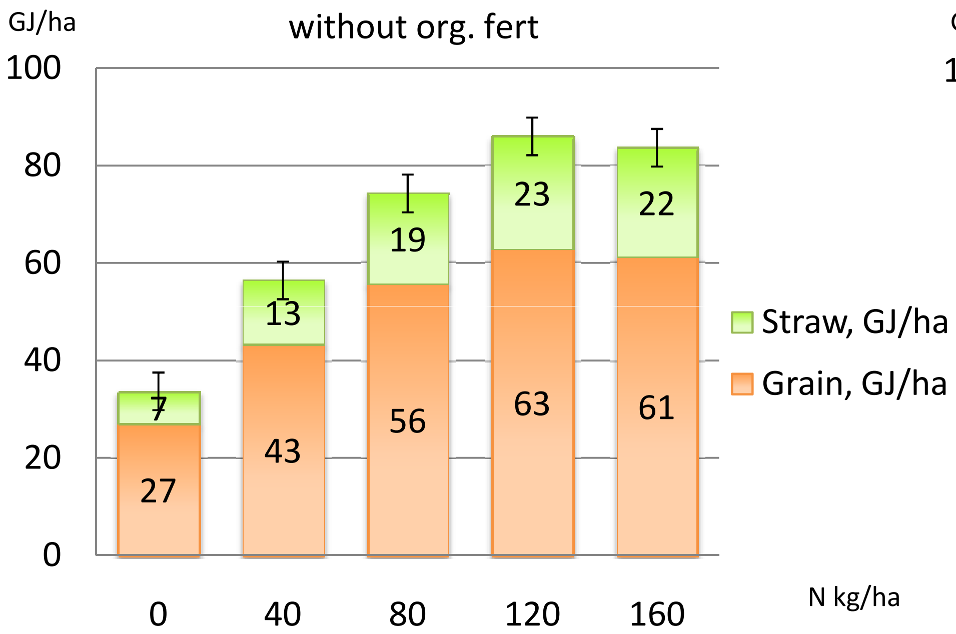
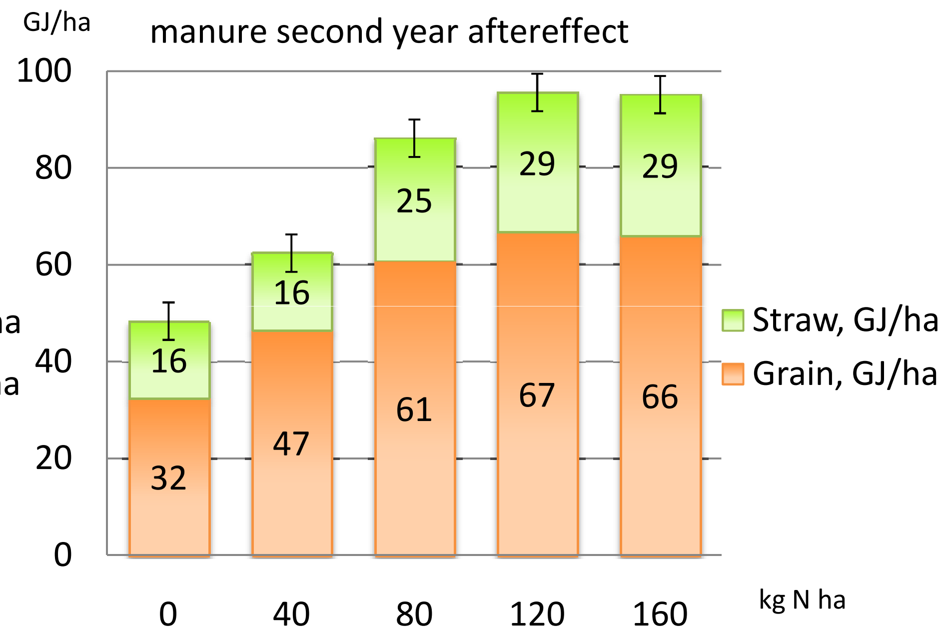
Spring wheat *energy yield*, GJ/ha



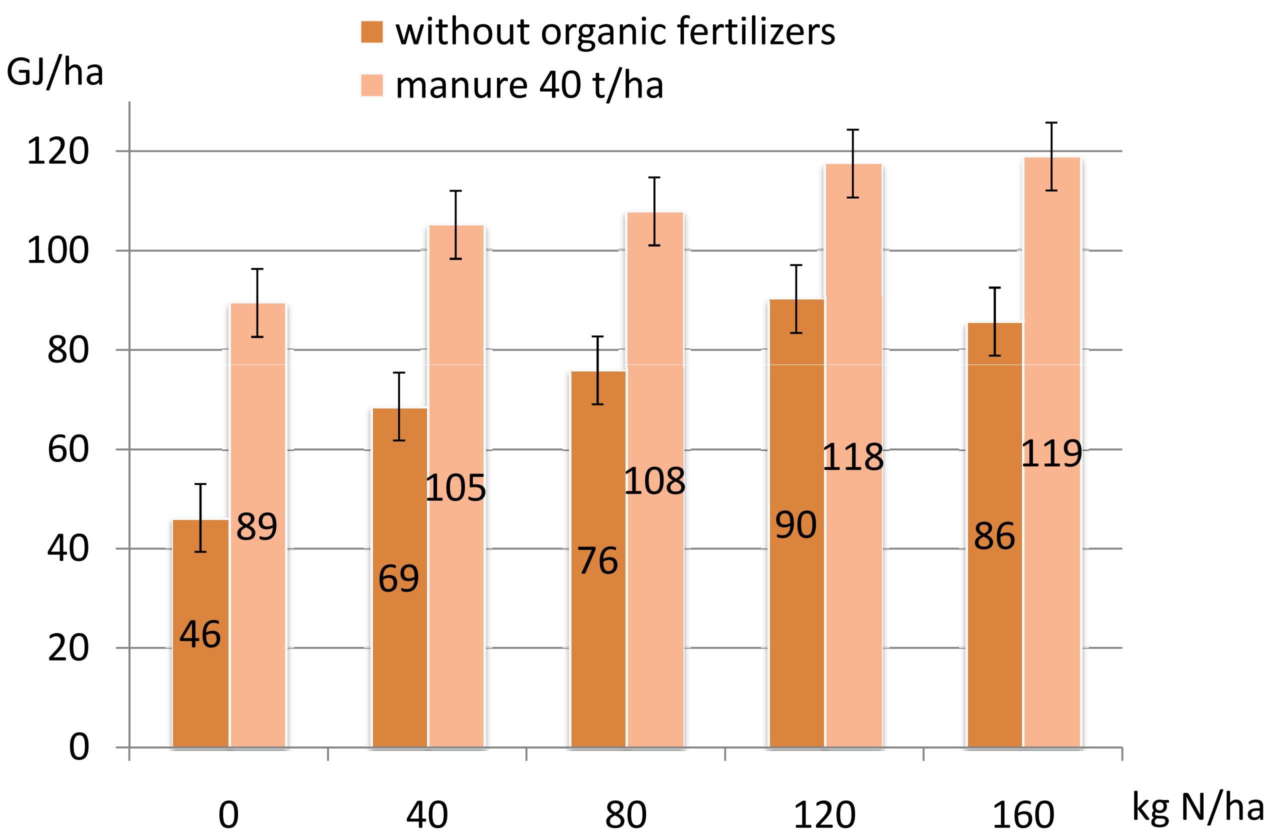


Barley *energy yield*, GJ/ha

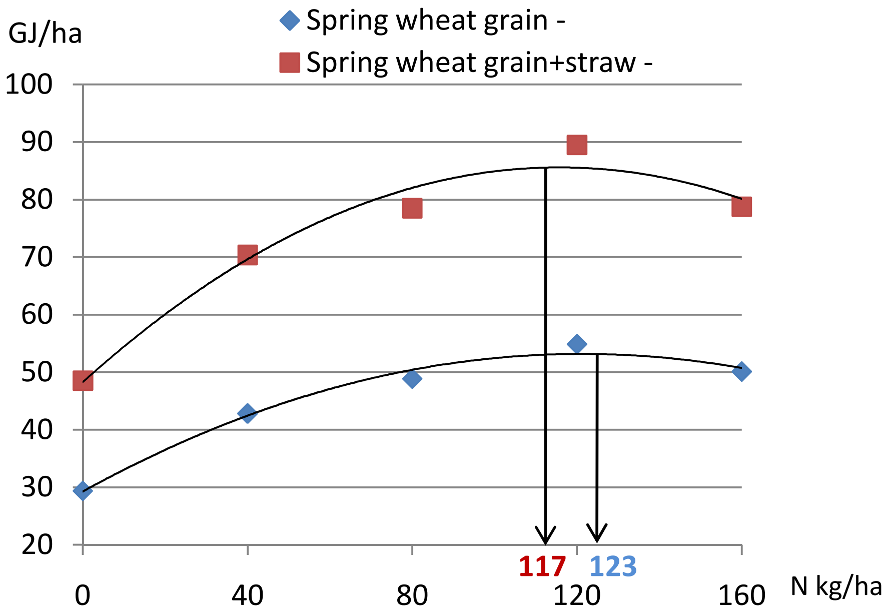


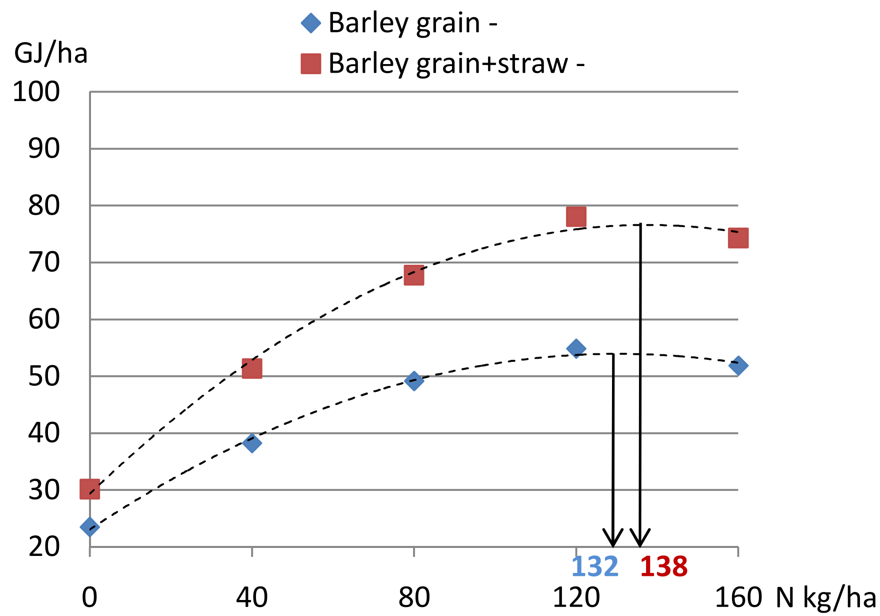


Potato *energy yield*, GJ/ha



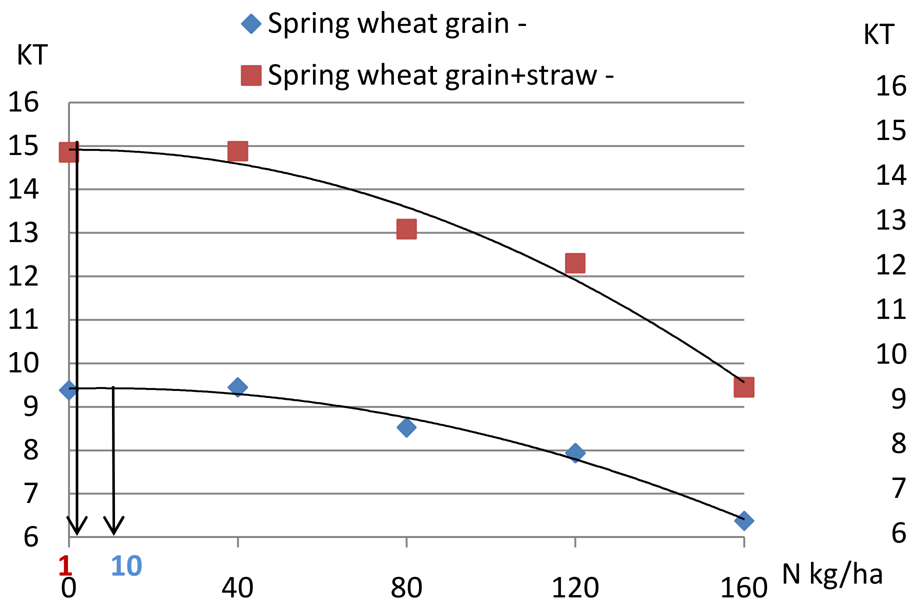
Energy gain (output-input)

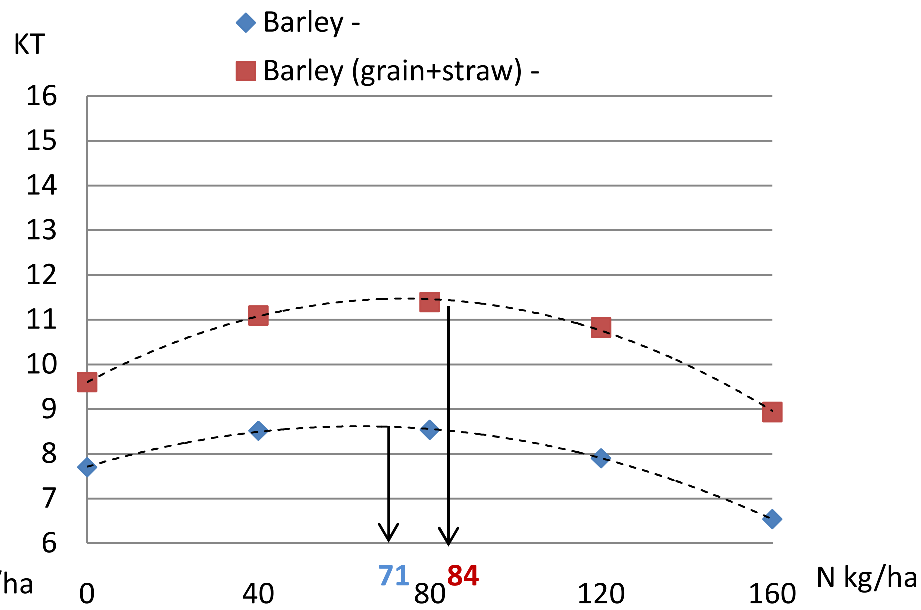




- Grain+straw – higher *energy gain* values
- Considering grain – *energy gain* is similar for both cereals (different on low N rates)
- Optimal N rates depend on crop
- N_{opt} – similar to N_{agr}

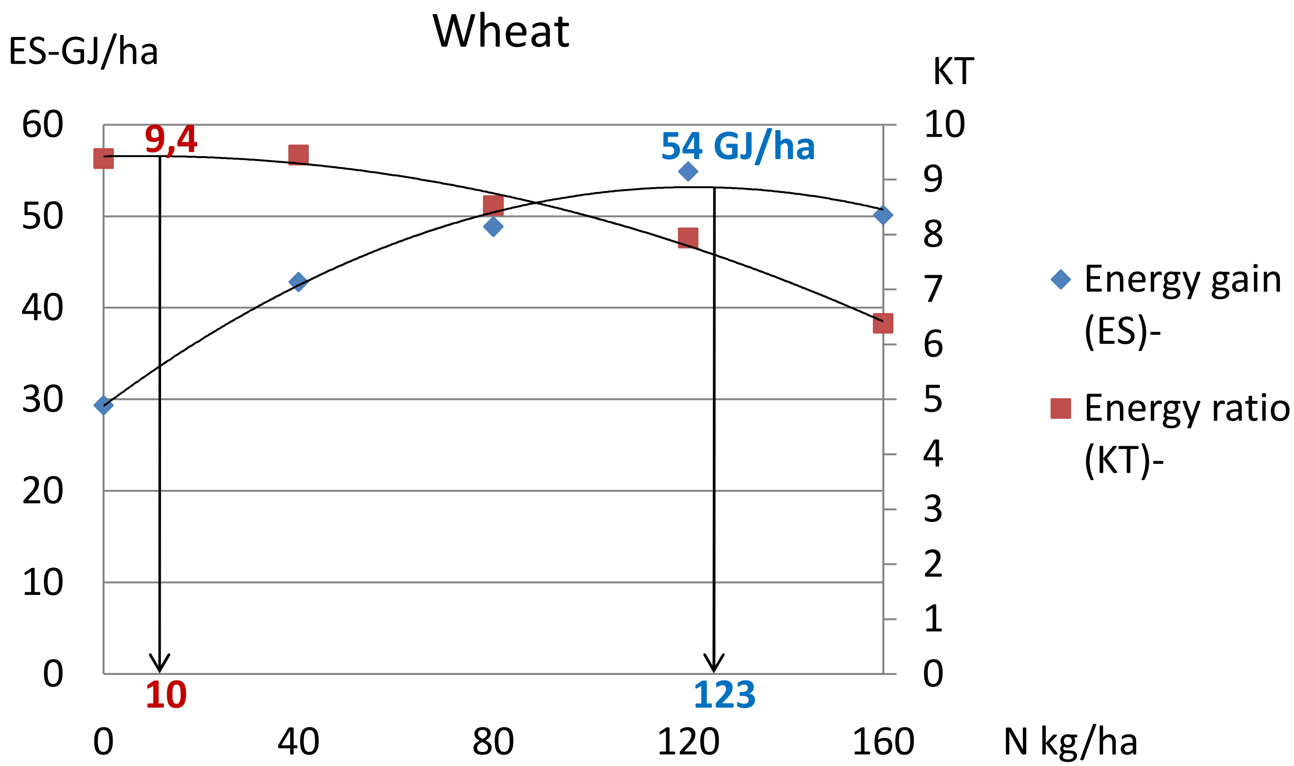
Energy ratio (output/input)





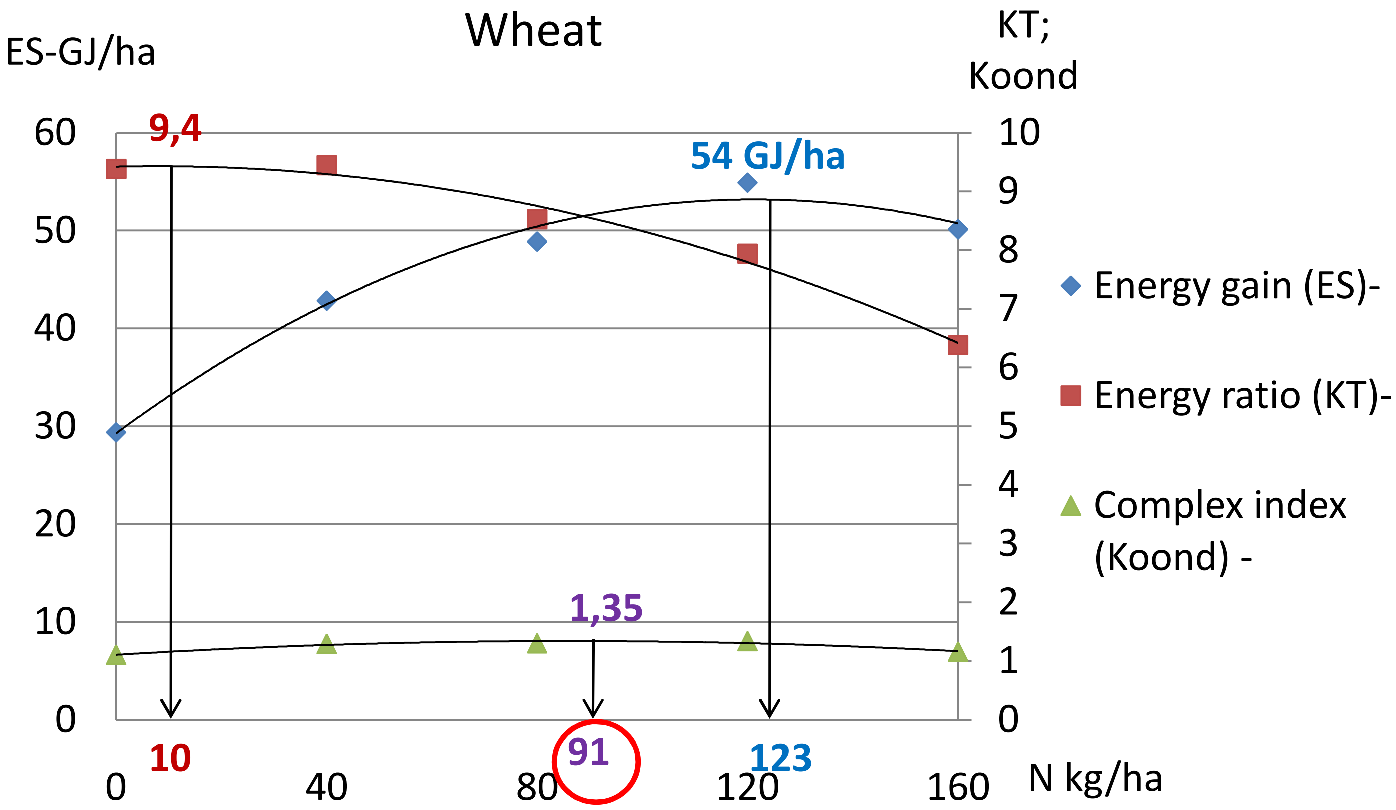
- Lower for barley – differences decreased with N rate increase.
- Straw increased the energy ratio, more for wheat.
- Lower N_{opt} norms than for optimizing energy gain.

ES vs KT



Max net energy yield (*energy gain*) vs min pressure to the environment (*energy ratio*)

Energy gain, energy ratio → *COMPLEX INDEX*



Optimum N rate, kg/ha

	Spring wheat (+ by-products)	Barley (+ by-products)
Agronomy	**135**	**145**
Energy gain (ES)	**123**	**138**
Energy ratio (KT)	**10**	**84**
COMPLEX INDEX (Koond)	**91**	**107**

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Effect of manure

Energy ratio calculated at optimum N rate		
	Energy ratio (KT)	
	Without organic fert.	Manure
Crop rotation (*potato-spring wheat-barley*)	10,2	8,4

Conclusion

- Results depend on used methodics. They are specific to the experimental site (soil conditions and used agrotechnology).
- Energy parameters depend on crop.
- For cereals better energy parameters were gained using mineral fertilizers on the backround of organic!
- New complex index – fertilizers recomendations consider both important characteristics - maximizing net energy yield and minimizing pollution to the environment!

Further opportunities of IOSDV field experiment for energy analysis

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Soil fertility and productivity

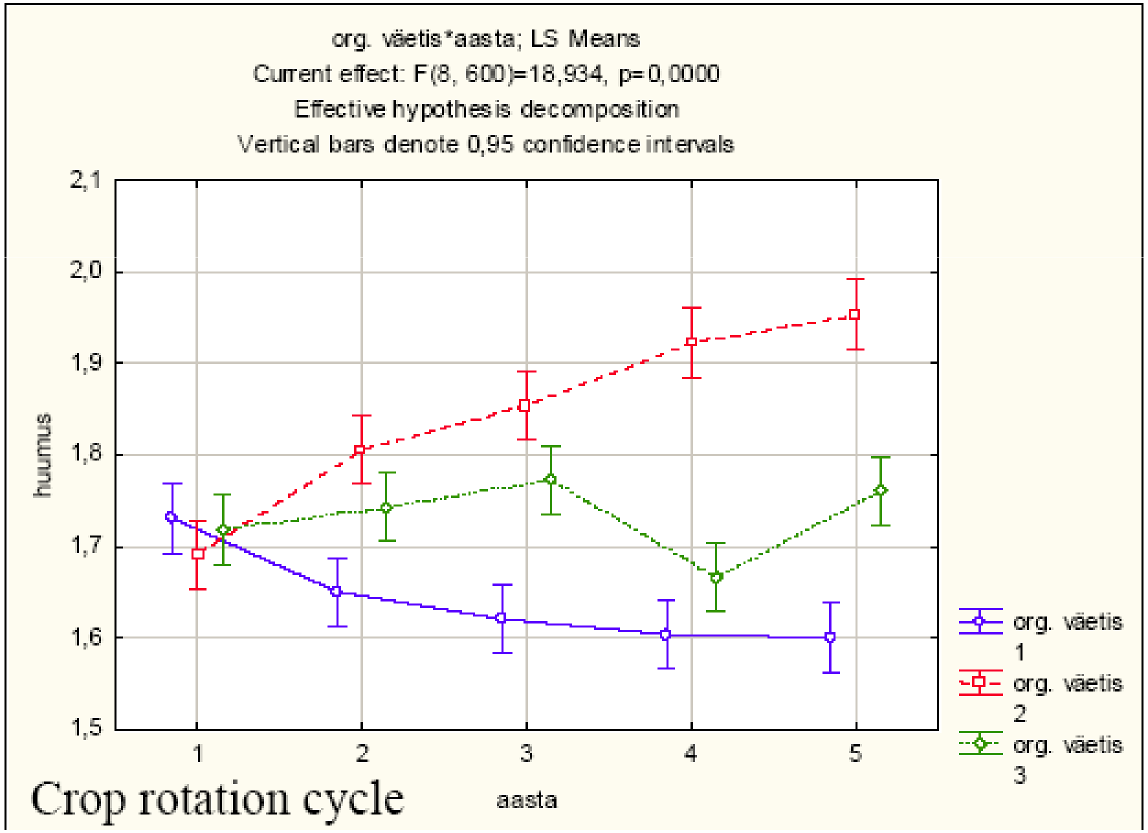
- In some cases energy ratio is the highest at low-input crop production practices
- But problems can arise with
  - Soil quality and fertility (how to estimate?)
  - Long-term productivity (yield level)
  - Yield quality

Only long-term trends are meaningful!

Work Package 2.3.3. Upkeeping the production capacity of fields

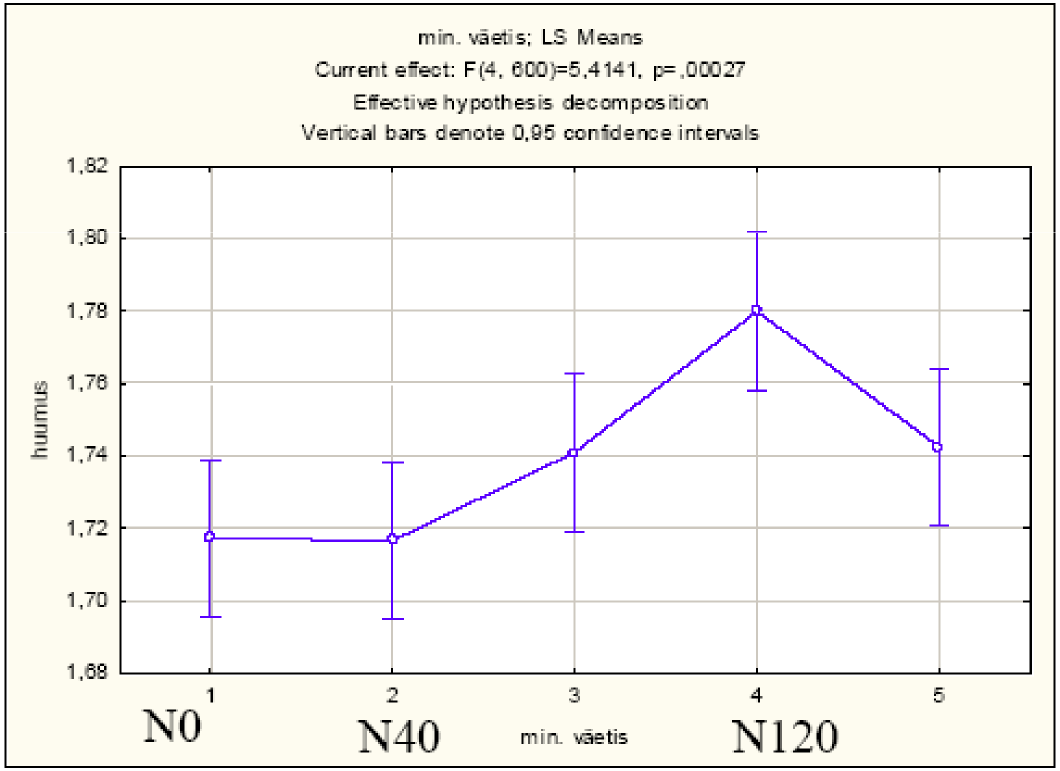
Organic fertilizers

Changes in soil humus content after 5 crop rotations (15 years) without organic fert. (1), farmyard manure (2) ja straw+beat-tops (3)

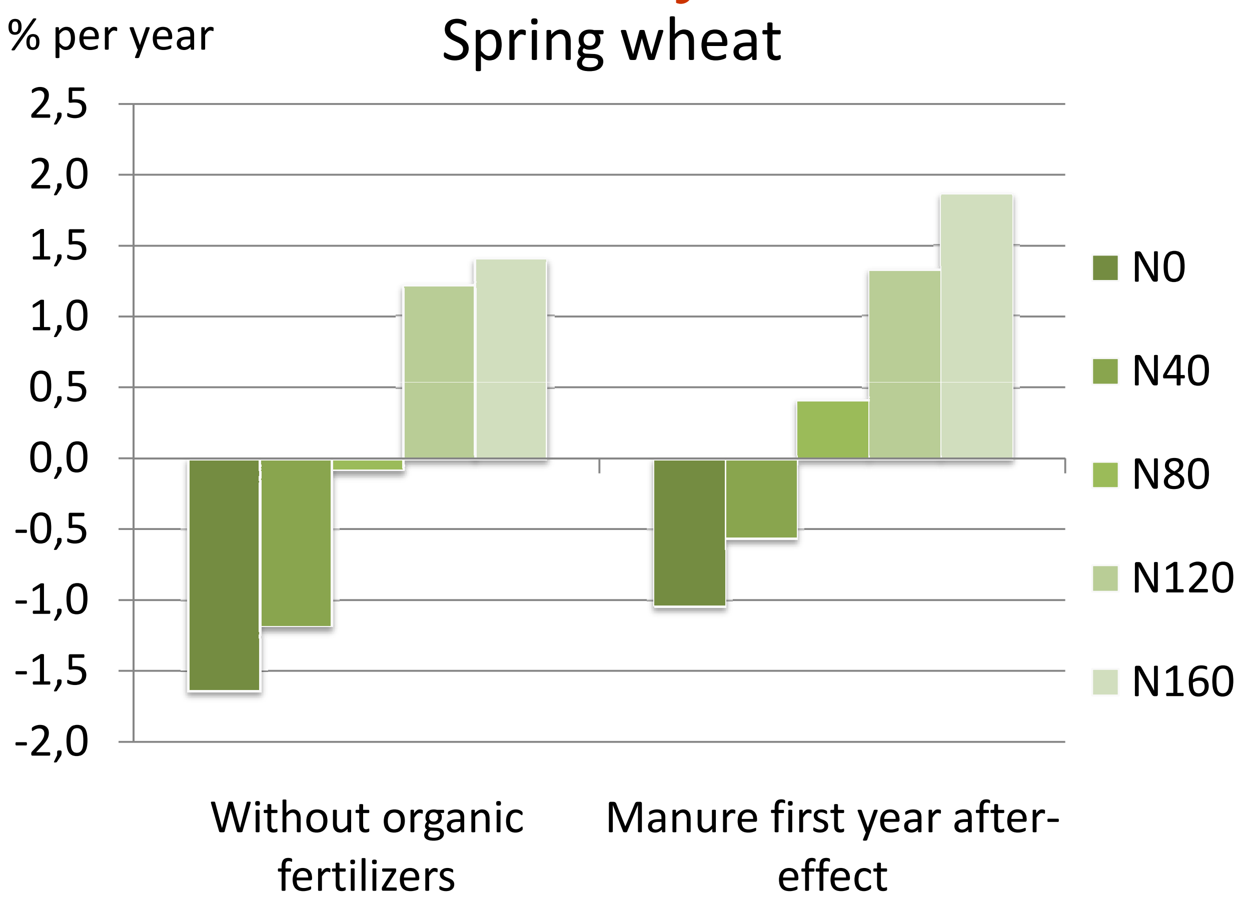


Mineral fertilizers

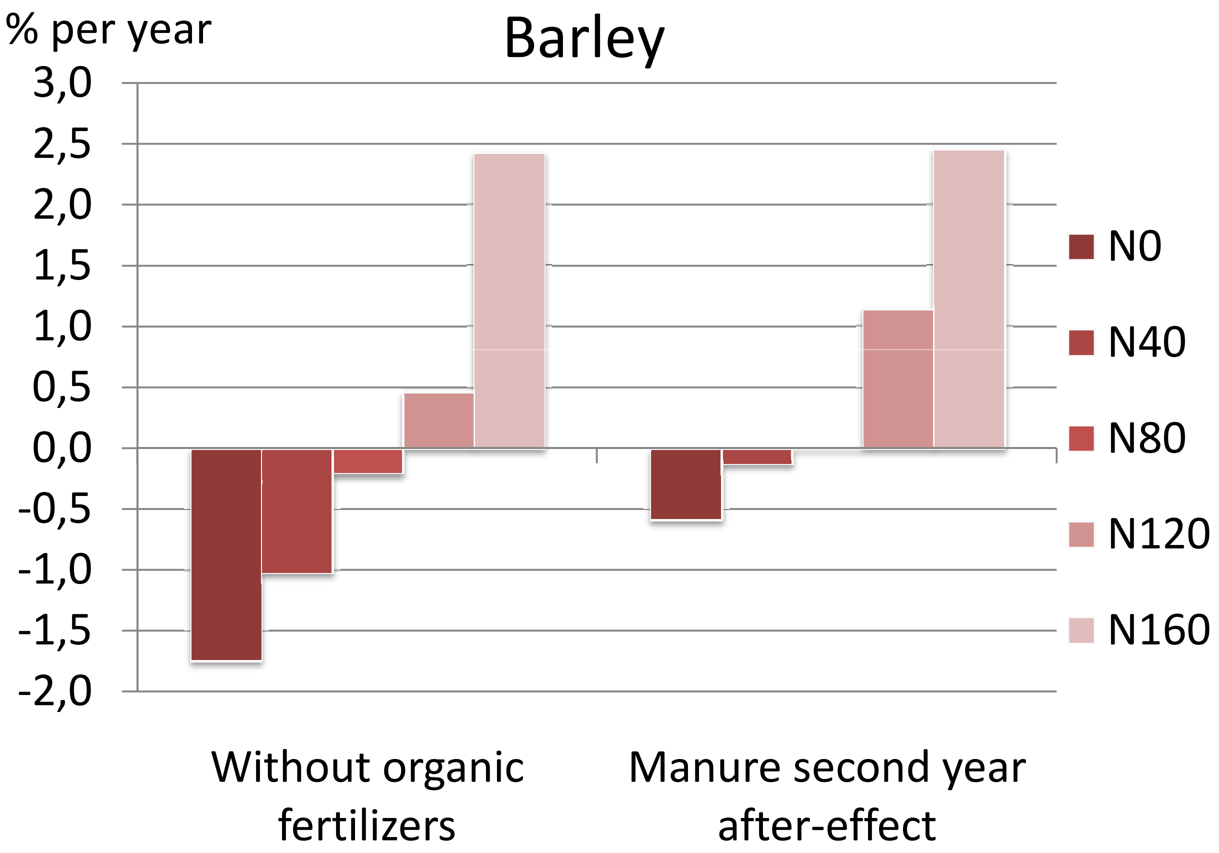
Humus content after 5 crop rotations in different levels of mineral fertiliser (N_0, N_{40}, N_{80}, N_{120}, N_{160})



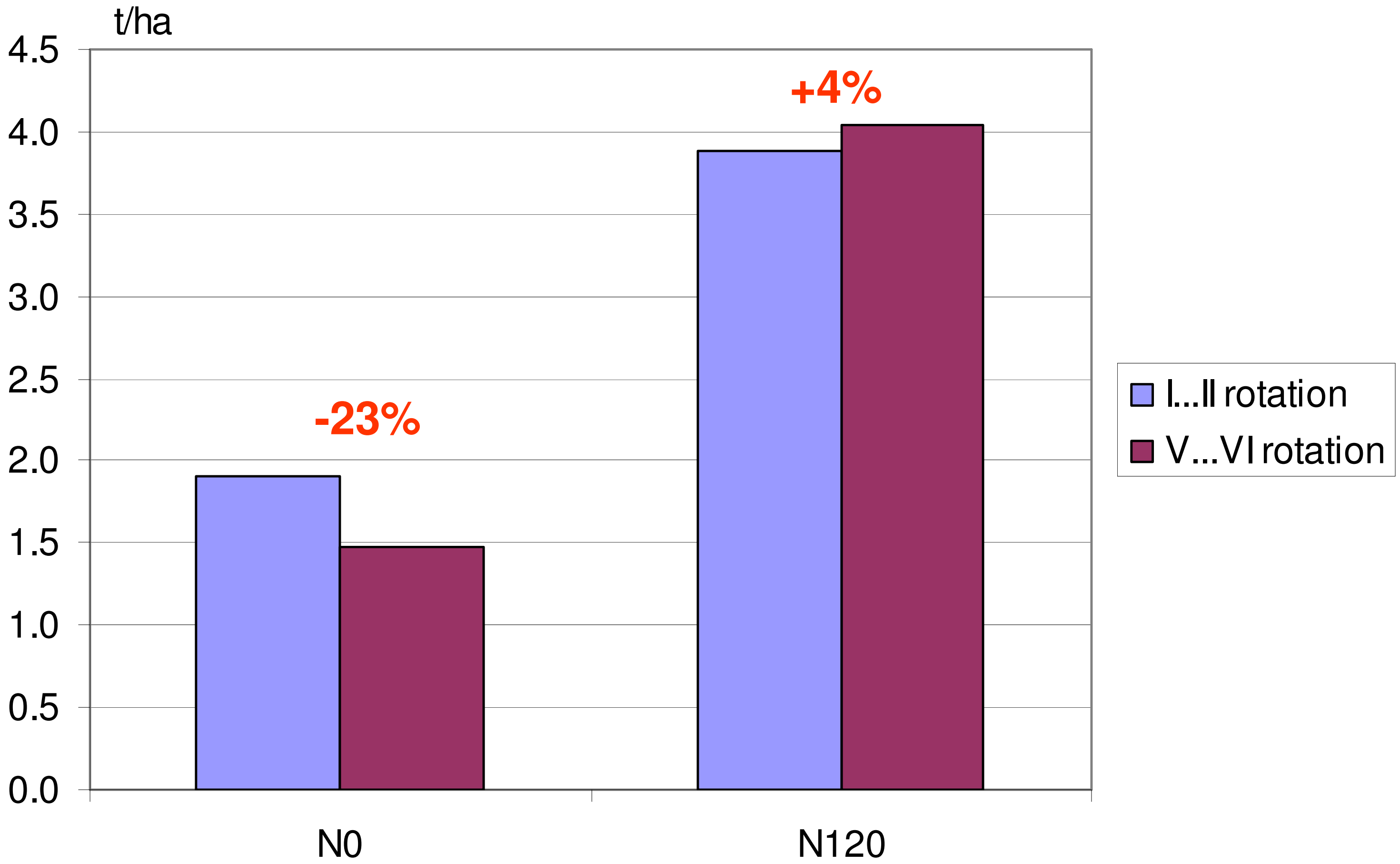
Annual change rate (%) in grain yield over 18 years



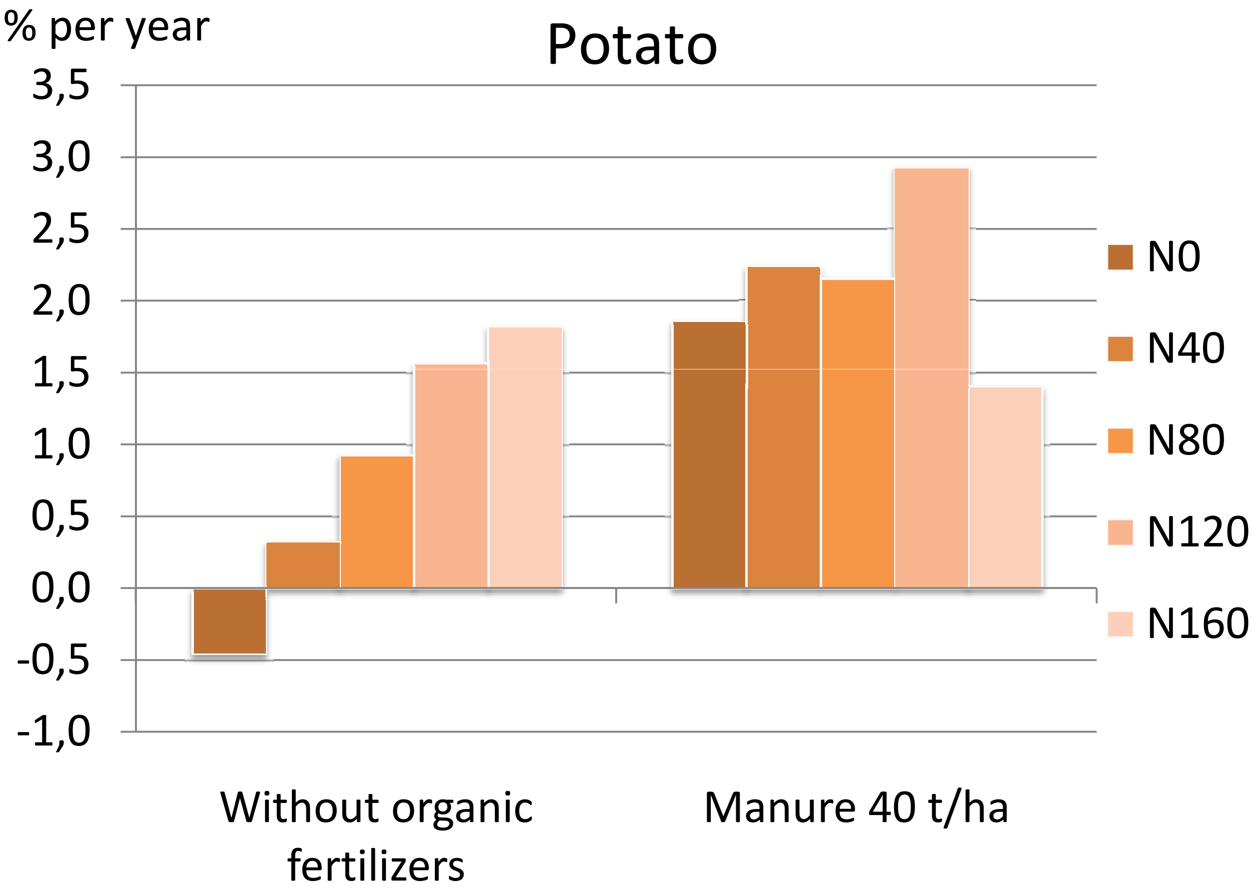
Annual change rate (%) in grain yield over 18 years



Trends in barley yield
(rotation without organic fertilisers)



Annual change rate (%) in potato yield over 18 years



Alternative fertilizers

- Beet leaves + straw
- Recultivation substance from oil shale semi-coke
- Biogas digestate
- Aspen pulp mill waste

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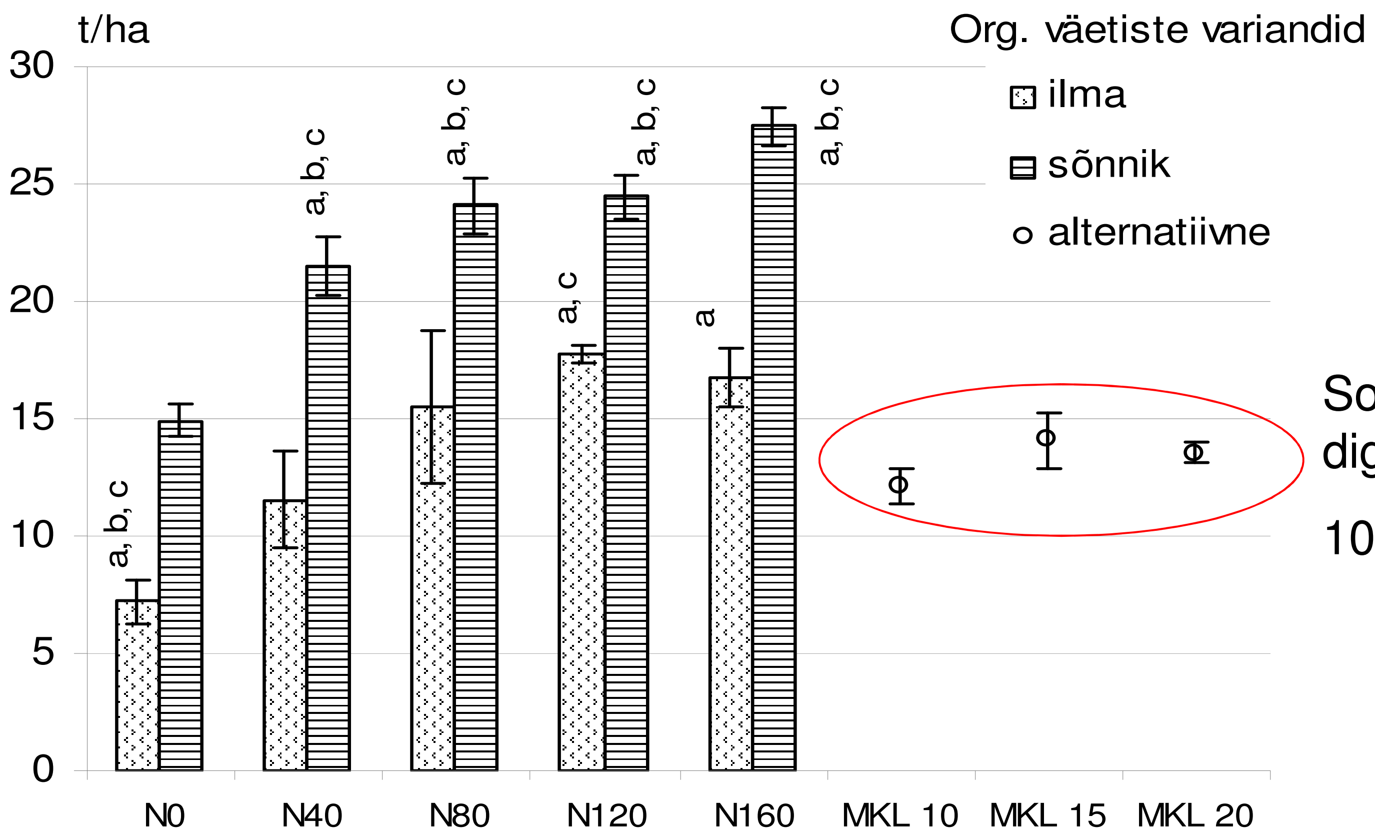
Potato yield in 2008

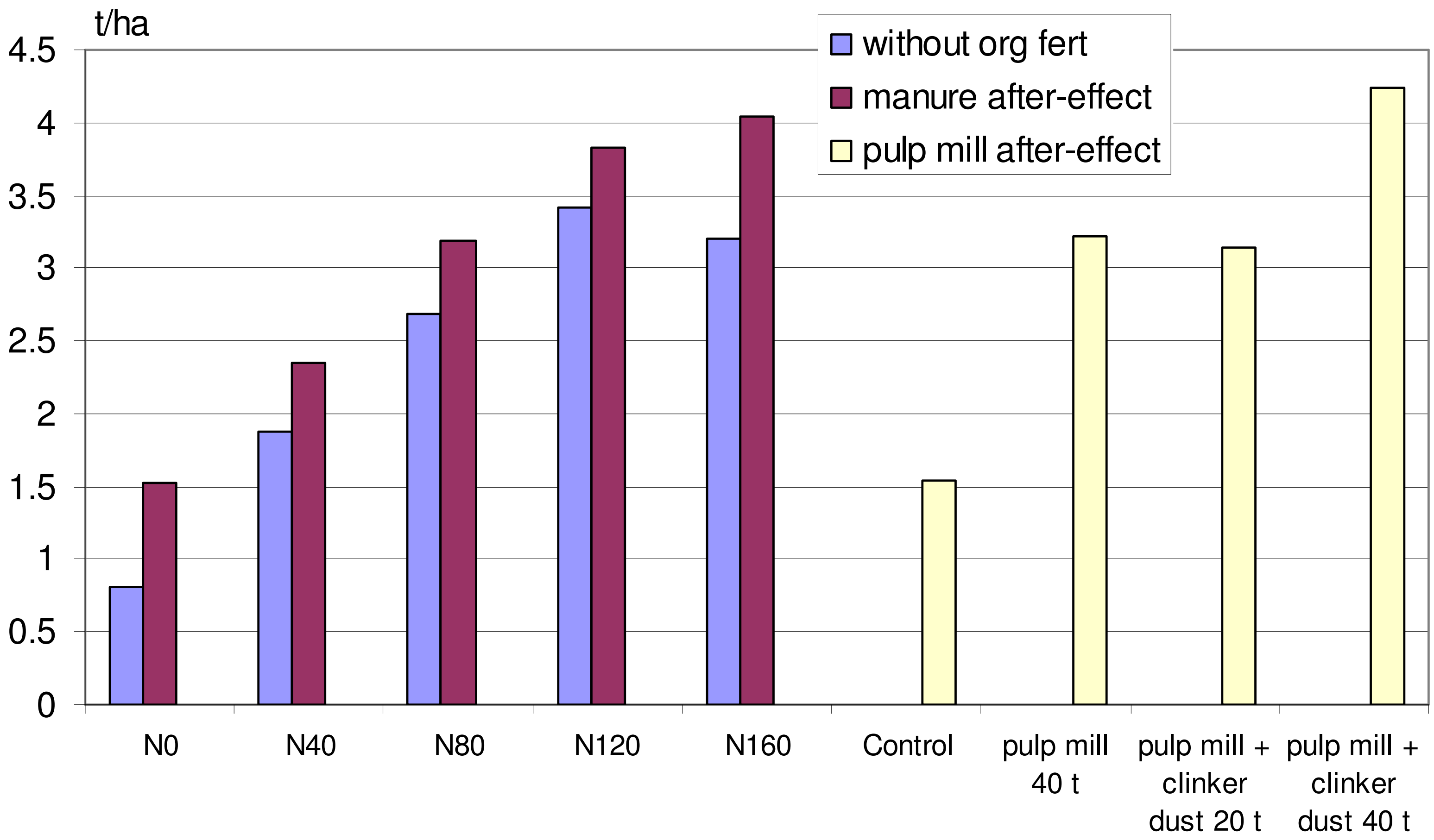


Solid biogas digestate (pig slurry)

10, 15 or 20 t/ha

Equal effect compared with traditional dairy manure (ca 40 t/ha) to the yield
Energy analysis is still missing

Barley yield in 2009



Other examples

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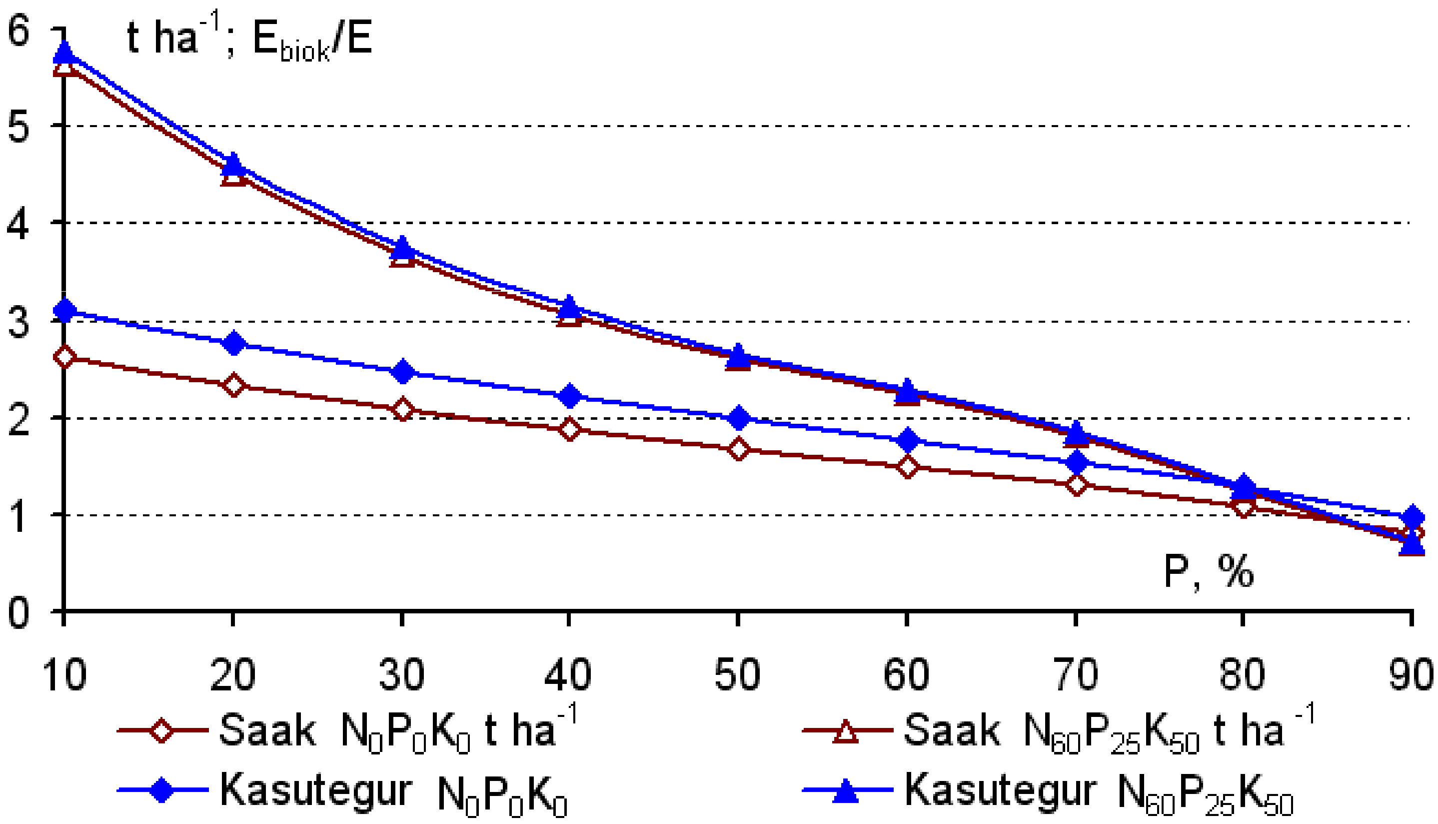
Probability of energy ratio for rye (blue line in graph)



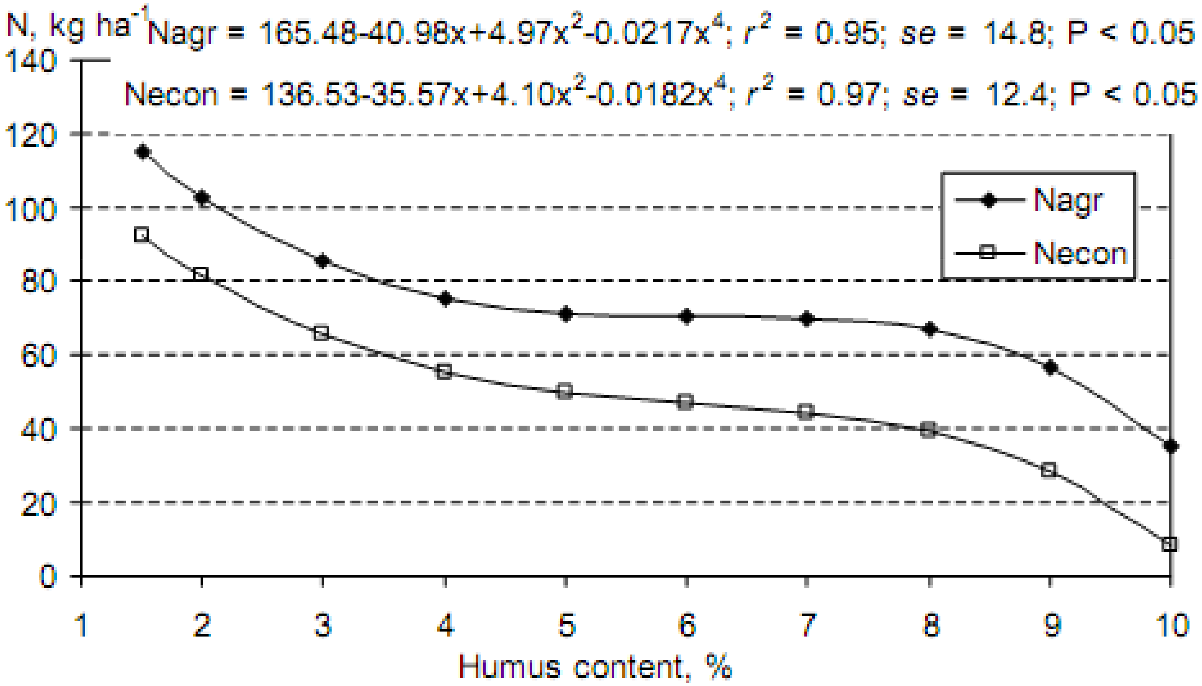


Fig. 2. Agronomically (Nagr) and economically (Necon) effective nitrogen fertiliser norms for barley depending on soil humus content.

Astover et al. 2006

Need for improved methods

- Energy input for organic fertilizers
  - Usually equal based on nutrient contents with mineral fertilizers but what could be alternative approach?
- Other inputs that should be considered
  - grain drying etc.
- Energy eqvivalents for complex fertilizers?

Econometric methods – efficiency

- Applicable also for energy analysis but still rarely used
- The non-parametric method
  Data Envelopment Analysis (DEA)
- DEA uses mathematical programming to produce a linear best practice frontier over the data and then calculates efficiency measures relative to this frontier. The objective of DEA is to determine the relative efficiency of each farm (decision unit).

Farm energy efficiency, DEA approach

Energy saving (MJ/ha) from different sources if recommendations of study are followed

Inputs	Present use, MJ/ha	Target use, MJ/ha	Energy saving, MJ/ha	Contribution of input to savings, %
Human	2291.3	2081.9	209.4	19.1
Diesel	2694.4	2434.7	259.7	23.7
Seed	1152.9	956.2	196.7	18
FYM	62.2	37.3	24.9	2.3
Fertilizers	2875.1	2517.4	357.7	32.7
Machinery	360.8	315.4	45.4	4.2
Total input energy, MJ/ha	**9436.8**	**8343**	1093.8	100

Chauhan et al. 2006

Farm energy efficiency, DEA approach

The actual and suggested values of energy use from different sources for inefficient farmers (based on BCC Model)

Farmer number	Pure technical efficiency	Actual energy use, MJ/ha						Target energy use, MJ/ha						% saving
		Human	Diesel	Seeds	FYM	Fertilizer	Machinery	Human	Diesel	Seeds	FYM	Fertilizer	Machinery	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
2	0.9771	1842.8	3943.5	726.5	7.4	2071.0	449.9	1800.6	3148.6	709.9	7.2	2023.6	439.6	10.1
3	0.9626	1944.8	3032.5	908.1	6.7	2331.0	347.9	1872.0	2919.1	874.1	6.5	2243.8	334.9	3.7
5	0.9638	1895.8	3336.5	817.3	7.4	2537.0	380.8	1827.2	2953.6	787.7	7.1	2150.2	367.0	9.8
7	0.9510	1909.7	3125.6	1089.7	5.9	2300.0	507.1	1816.2	2972.5	1035.9	5.6	2187.4	386.6	6.0
8	0.9415	2082.5	3606.7	1089.7	5.9	2047.0	413.1	1795.3	3158.7	908.1	5.6	1927.2	360.8	11.8
9	0.9366	1990.8	3943.5	726.5	6.7	2481.0	450.9	1864.7	3109.6	680.5	6.3	2139.4	422.3	14.3
10	0.8866	2203.7	3526.6	1089.7	7.1	2047.0	405.1	1780.3	3055.6	942.6	6.3	1814.9	349.3	14.3
11	0.8779	2266.2	3405.7	1017.0	7.1	2320.0	392.0	1809.0	2990.0	892.9	6.2	2036.8	344.2	14.1
12	0.9769	1945.7	3405.7	871.8	5.9	1979.0	391.1	1810.3	3179.2	851.7	5.8	1933.4	375.2	5.2
15	0.9610	1781.2	3561.5	1037.8	6.4	2331.0	407.7	1711.8	3103.6	958.0	6.2	2240.1	391.8	7.8
17	0.9681	1841.5	3225.6	1089.7	7.4	1852.0	367.1	1782.8	2980.4	978.8	6.8	1793.0	355.4	5.8
20	0.9545	1924.7	3325.6	1017.0	5.3	2648.0	382.1	1837.0	3174.1	970.7	5.1	2265.5	364.7	7.4
22	0.9986	1977.3	2715.2	1037.8	6.4	2331.0	736.3	1933.2	2711.3	1036.3	6.4	2327.6	310.9	5.4
26	0.9502	1941.7	3325.6	1017.0	5.3	2320.0	382.1	1845.0	3159.9	961.0	5.0	2204.4	363.1	5.0
29	0.9886	2156.8	3336.5	726.5	7.4	2331.0	381.8	1923.3	2879.6	718.2	7.3	2304.4	377.4	8.2
30	0.9383	1946.8	3336.5	908.1	6.7	2331.0	551.8	1826.7	3130.7	852.1	6.3	2187.3	444.9	7.0
31	0.9467	1957.2	3018.2	1037.8	6.4	2655.0	347.3	1853.0	2857.5	979.0	6.1	2513.6	328.8	5.4
32	0.9322	1924.8	3336.5	908.1	7.4	2537.0	381.8	1794.4	3004.0	846.6	6.9	2041.1	355.9	11.5
33	0.9894	1842.3	3205.4	908.1	7.4	1852.0	366.8	1822.8	3005.0	898.5	7.3	1832.4	362.9	3.1
37	0.9882	2190.5	2186.1	908.1	8.1	3846.0	513.7	2164.6	2160.2	897.4	8.0	3206.3	250.7	10.0
39	0.7757	2671.1	2604.5	1452.9	59.3	3846.0	674.8	2072.1	2020.4	911.2	46.0	2983.5	266.4	26.6
40	0.9399	2329.4	1976.4	1162.3	79.1	3531.0	230.3	2189.5	1857.7	954.5	73.3	3230.8	216.5	8.4
41	0.9477	2510.4	2171.0	908.1	12.4	3846.0	624.9	2379.0	2057.4	860.6	11.8	3354.2	242.0	11.6
42	0.8975	2383.0	2120.5	1089.7	101.9	4557.0	246.3	2138.9	1903.3	931.5	66.7	3205.4	221.1	19.4
43	0.7827	2324.2	2852.6	1210.8	107.1	3846.0	329.0	1819.1	2232.6	742.2	19.2	2967.2	257.5	24.7
44	0.9786	2722.3	1870.4	1362.1	14.8	5551.0	221.7	2664.1	1830.4	1005.1	14.5	3594.2	215.3	20.6
45	0.8707	2476.2	2301.7	1245.4	105.9	5551.0	267.2	2156.1	2004.2	816.1	49.3	3024.4	232.7	30.7
51	0.9683	2273.3	1978.4	1135.1	111.2	2557.0	229.4	2201.3	1913.3	1099.2	103.1	2476.0	222.1	3.3

Chauhan et al. 2006

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Thank You for Attention!