“Energy use and energy efficiency in corn production in different fertilization strategies”

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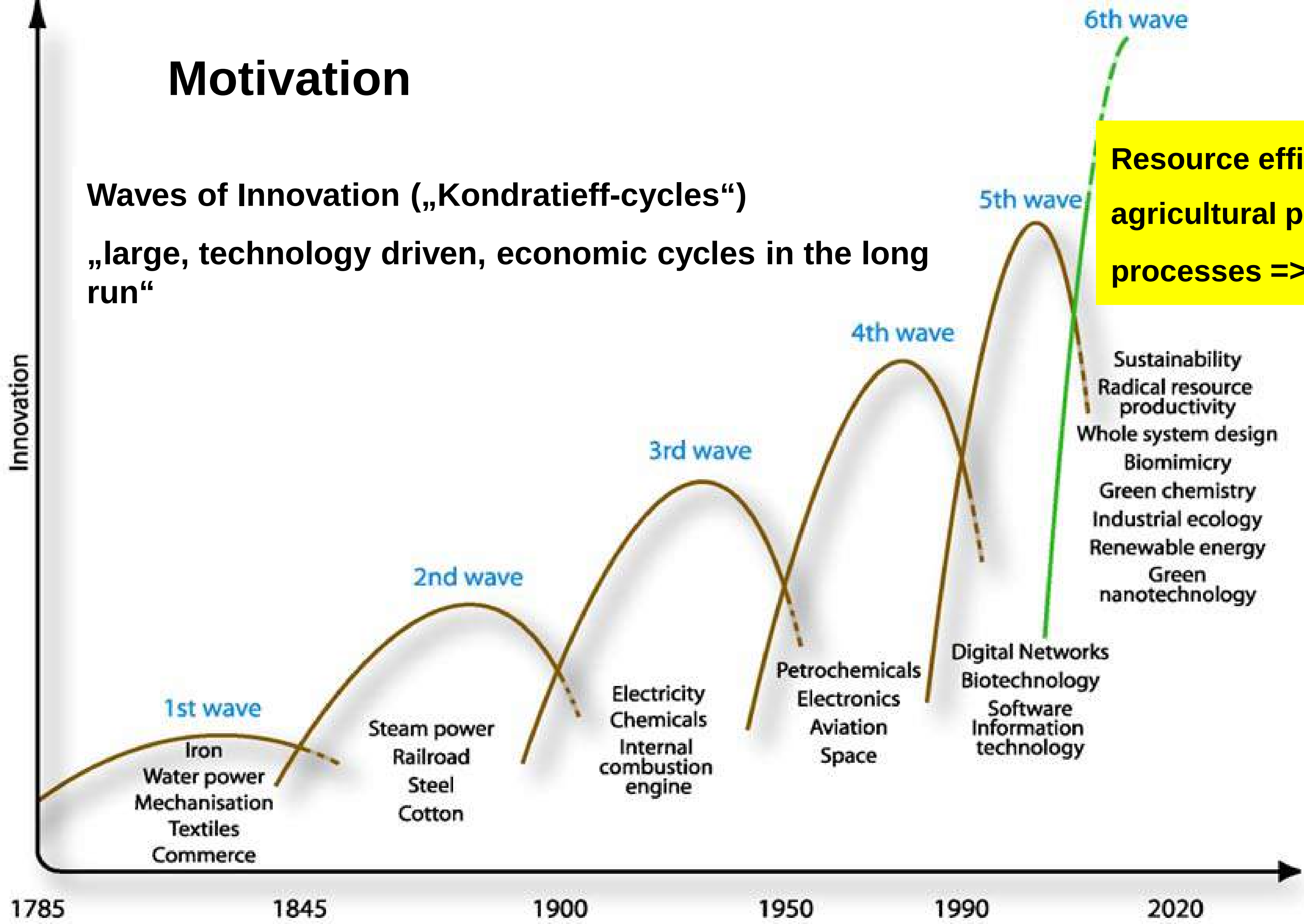
Motivation

Waves of Innovation („Kondratieff-cycles")

„large, technology driven, economic cycles in the long run"

Resource efficiency of agricultural production processes => η - Focus



Quelle: Vortrag von Ernst von Weizsäcker an der Veranstaltung „20 Jahre Ökosoziale Marktwirtschaft" am 15. Dezember 2009 in Wien

Agriculture - „solar energy harvester“

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$$6\,CO_2 + 12\,H_2O + PAR \xrightarrow[\text{+ 2782 kJ/mol}]{\text{Cholorophyll}} C_6H_{12}O_6 + 6\,O_2 + 6H_2O$$

PAR: Photosynthetically active radiation

Agriculture is a process to harvest photosynthetically stored solar energy for:

- ⇒ food
- ⇒ feed
- ⇒ energetic and material usage

Farm branch: crop production

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Input energy

Direct
fuel, heating oil, electricity

indirect:
process energie in „annual“ production facilities (fertilizers, pesticides, seeds)

Output energy

Crops for food and feed

straw

Output - Input

minimum: 50 GJ/ha

Tolerable range:
between: 5 und 15 GJ/ha

Extensive: < 8 GJ/ha

Intensive: > 8 GJ/ha

Soure: Hege U., & Brenner M., Kriterien umweltverträgliche Landbewirtschaftung/”**Criteria of environmentally compatible land management**”, Bayerische Landesanstalt für Landwirtschaft, 2004

Site-related factors (climate, soil)

Energy efficiency in plant production

Input of farm facilities (seeds, fertilizer, pesticide, etc.)

Mechanization (e.g. soil tillage)

Maize cropping

=> Maize area in Austria (2012): 219702 ha (24 % of arable land)

=> Average yield: 10.7 t/ha (Grüner Bericht, 2013)

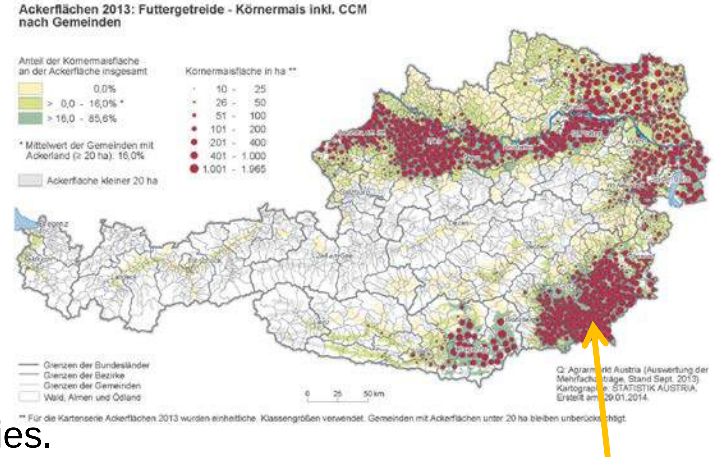
- Due to increasing energy prices, the **efficient use of technical energy** in cropping systems will be more important.
- **Direct energy** (fuel, heating oil electricity) und **indirect energy** (seed, fertilizer, herbicide and farm machinery) are **indicators for the production intensity**.
- A **high energy input** is correlated with **CO_2 - emission**.
- **Mineral nitrogen fertilizers** are **energy-intensive** and are responsible for **increasing cropping yields.**
- **Energy savings** between **36 % and 52 %:** Organic manure instead of mineral nitrogen fertilizer (McLaughlin et al. 2000).

Research objective:

To analyse the **energy use** and **energy-efficiency** in **corn production** (from seeding to drying harvested corn) **with different fertilization strategies** (mineral N fertilizer and organic fertilizer)**.**

Basic: Two long term fertilization field trials in South Sytria.

Two experimental sites in South Styria



„Wagna“ and „Wagendorf“ (5 km distance)

Location „*Wagna*“:

• Gravel terrace with sandy soil (55 % sand, 33 % silt and 12 % clay, 2,4 % humus) of the groundwater body „Westliches Leibnitzer Feld“

• Since 2007: corn field trial with 12 different nitrogen fertilization strategies.

• Block design with 6 replications

Location „Wagendorf“:

• Deep „Wagendorfer Terrace“ with silty soil (9 % sand, 72 % silt and 19 % clay, 2,4 % humus) with very high soil fertility („soil number“ near 100)

• Since 2008: corn field trial with 13 different nitrogen fertilization strategies.

• Block design with 4 replications

	2007	2008	2009	2010	2011	2012
Yearly mean temperature (° C)	10,4	10,4	10,2	9,6	11,0	11,2
Yearly precipitation (mm)	883	902	1312	1016	724	998

Source: ZAMG

N-fertilization rate

Nitrogen-rate **(kg N/ha)**	**„Wagna“** **2007-2012**	**„Wagendorf“** **2008-2012**
0		
90	45 kg N + 45 kg N as CAN [1]	45 kg N + 45 kg N as CAN
115	55 kg N + 60 kg N as CAN	55 kg N + 60 kg N as CAN
Pig slurry 1. Application: surface broadcast 2. Application: band spreading with trailing hoses	*2007: 146 kg N_{ff}* [2] *2008: 164 kg N_{ff}* *2009: 117 kg N_{ff}* Ø: 135 kg *2010: 142 kg N_{ff}* *2011: 115 kg N_{ff}* *2012: 124 kg N_{ff}*	*2008: 121 kg N_{ff}* *2009: 115 kg N_{ff}* *2010: 96 kg N_{ff}* Ø: 108 kg *2011: 115 kg N_{ff}* *2012: 94 kg N_{ff}*
145	55 kg N + 90 kg N as CAN	55 kg N + 90 kg N as CAN
175	55 kg N + 60 kg N + 60 kg N as CAN	55 kg N + 60 kg N + 60 kg N as CAN
210		70 kg N + 70 kg N + 70 kg N as CAN

[1] CAN: Calcium Ammonium Nitrate (27 % N)
[2] N_{ff}= 87 % from N_{total}
[3] Slurry amount between 23 and 45 m^3/ha
[4] Slurry amount between 29 and 58 m^3/ha

Energy-equivalents

	Farm facilities	Energy-equivalent	Source
Direct energy	Fuel, Heating oil	47.8 MJ/l	*CIGR, 1999*
	Electricity	12.0 MJ/kWh	*CIGR 1999*
Indirect energy	Mineral N-fertilizer	60.0 MJ/kg N	*CIGR, 1999*
	Mineral P-fertilizer	17.4 MJ/kg P_2O_5	*CIGR, 1999*
	Mineral K-fertilizer	13.1 MJ/kg K_2O	*CIGR, 1999*
	Synth. Herbizide	242.0 MJ/kg	*Hülsbergen 2008*
	Seed	100.0 MJ/kg	*Hülsbergen 2008, CIGR, 1999*
	Machinery	1956.0 MJ/ha	*Biedermann 2009*

CIGR: International Commission of Agricultural and Biosystems Engineering.

⇒ **Fuel consumption** was calculated with the fuel calculator from KTBL (Association for Technology and Structures in Agriculture, www.ktbl.de) for a used mechanisation with tractors of 90 and 120 Hp.

⇒ **Energy consumption for drying (continuous flow dryer)** was calculated with the basic data from Rossrucker (1977).

⇒ **Heat value of corn**: 18,6 MJ/kg DM (Hülsbergen 2008)

Energy efficiency indicators

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$$\textit{Energy intensity (MJ/kg)} = \frac{\text{Energy input (MJ/ha)}}{\text{Corn yield}_{(14\ \%\ \text{w.b.})}\ \text{(kg/ha)}}$$

$$\textit{Energy output/Energy input-Ratio} = \frac{\text{Energy output (MJ/ha)}}{\text{Energy input (MJ/ha)}}$$

$$\textit{Netto-energy output (GJ/ha)} = \textit{Energy output}_{Corn\ (14\%\ w.b.)}\ \textit{(GJ/ha)} - \textit{Energy input (GJ/ha)}$$

Mean Corn yield (kg/ha at 14 % w.b.)

Experimental site „Wagna“

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Different letters indicate significant differences (Student-Newman - Keuls Test, α = 0.05) between variants of a year.

Nitrogen-Rate (kg N/ha)	2007	2008	2009	2010	2011	2012	Mean	Mean increment
0	5491 ±3020	4715^{a} ±1712	5544^{a} ±1865	5091^{a} ±756	4494^{a} ±650	4861^{a} ±924	**5033^{a}** ±1624	
90	8563 ±1755	9892^{b} ±1.376	9138^{b} ±929	7708^{ab} ±1093	10110^{b} ±315	8504^{b} ±474	**8962^{b}** ±1313	+ 3929 kg (+ 78 %)
115	9181 ±2746	10669^{bc} ±921	10685^{bc} ±1563	8100^{ab} ±2198	10634^{b} ±1174	9818^{c} ±996	**9848^{b}** ±1875	+ 4815 kg (+ 96 %)
Pig slurry	8362 ±2669	9298^{b} ±2448	9273^{b} ±2023	7885^{ab} ±2130	10056^{b} ±865	8508^{b} ±912	**8897^{b}** ±1966	+ 3864 kg (+ 77 %)
145	9391 ±2.800	12305^{cd} ±1.631	11886^{c} ±945	8833^{b} ±3.374	11647^{b} ±1.876	10721^{cd} ±1.145	**10797^{c}** ±2380	+ 5764 kg (+ 115 %)
175	9283 ±828	13315^{d} ±498	12091^{c} ±694	8888^{b} ±1.394	11949^{b} ±1.080	11453^{d} ±580	**11163^{c}** ±1803	+ 6130 kg (+ 122 %)
Mean	**8378 ±2630**	**10032 ±3135**	**9769 ±2600**	**7751 ±2270**	**9807 ±2759**	**8978 ±2307**	**9117** ±2726	+ 4084 kg (+ 81 %)
Significance	*P=0.079*	*P=0.000*	*P=0.000*	*P=0.032*	*P=0.000*	*P=0.000*	***P=0.000***	

Mean Corn yield (kg/ha at 14 % w.b.)

Experimental site „Wagendorf“

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Different letters indicate significant differences (Student-Newman - Keuls Test, α = 0.05) between variants of a year.

Nitrogen-Rate (kg N/ha)	2008	2009	2010	2011	2012	Mean	Mean increment
0	13836 ±882	10009[a] ±1613	9042[a] ±1025	9995[a] ±924	10426[a] ±1305	**10662[a]** ±1993	
90	14581 ±511	14744[bc] ±351	12315[b] ±472	14150[bc] ±648	13300[b] ±228	**13818[bc]** ±1.014	+ 3156 kg (+ 30 %)
115	14815 ±727	14316[bc] ±482	13448[c] ±366	14555[bc] ±1083	13979[b] ±1173	**14223[c]** ±884	+ 3561 kg (+ 33 %)
Pig slurry	14443 ±343	13711[b] ±390	11990[b] ±703	13285[b] ±965	13257[b] ±804	**13337[b]** ±1020	+ 2675 kg (+ 25 %)
145	14310 ±811	15277[c] ±871	13686[c] ±713	15118[c] ±1.010	14033[b] ±742	**14485[c]** ±976	+ 3823 kg (+ 36 %)
175	14221 ± 415	15416[c] ±218	14095[c] ±734	15391[c] ±471	14048[b] ±858	**14634[c]** ±831	+ 3972 kg (+ 37 %)
210	14183 ±267	15380[c] ±481	13993[c] ±814	15102[c] ±395	13352[b] ±641	**14402[c]** ±908	+ 3740 kg (+ 35 %)
Mean	**14341 ±612**	**14122 ±365**	**12653 ±1800**	**13942 ±1918**	**13199 ±1433**	**13651 ±1715**	+ 2989 kg (+ 28 %)
Significance	*P=0.416*	*P=0.000*	*P=0.000*	*P=0.000*	*P=0.000*	*P=0.000*	

Drying energy from 22 % to 14 % w.b. (Experimental site „Wagna")

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Nitrogen-rate (kg N/ha)	mean wet corn yield (kg/ha)	Heating oil (l)	Electricity (kWh)	Energy consumption for drying (MJ/ha)
0	5654	**57**	20.9	2954
90	9884	**99**	36.6	5163
115	10856	**109**	40.2	5671
135 (pig slurry)	9849	**98**	36.4	5145
145	12018	**120**	44.5	6278
175	12421	**124**	46.0	6489

Dewatering: 9.3 kg/100 kg wet corn; **Heating oil consumption** in a continuous flow dryer with specific energy consumption of 900 kcal/kg H_2O: 1 Liter per 100 kg wet corn (Rossrucker, 1977).

Drying energy from 24 % to 14 % w.b. (Experimental site „Wagendorf")

Nitrogen-rate (kg N/ha)	mean wet corn yield (kg/ha)	Heating oil (l)	Electricity (kWh)	Energy consumption for drying (MJ/ha)
0	12138	**152**	55.8	7922
90	15584	**195**	71.7	10172
115	16087	**201**	74.0	10500
108 (pig slurry)	15082	**189**	69.4	9844
145	16403	**205**	75.5	10706
175	16603	**208**	76.4	10837
210	16388	**205**	75.4	10696

Dewatering: 11.6 kg/100 kg wet corn; **Heating oil consumption** in a continuous flow dryer with specific energy consumption of 900 kcal/kg H_2O: 1.25 Liter per 100 kg wet corn (Rossrucker, 1977).

Energy-Input (MJ/ha)

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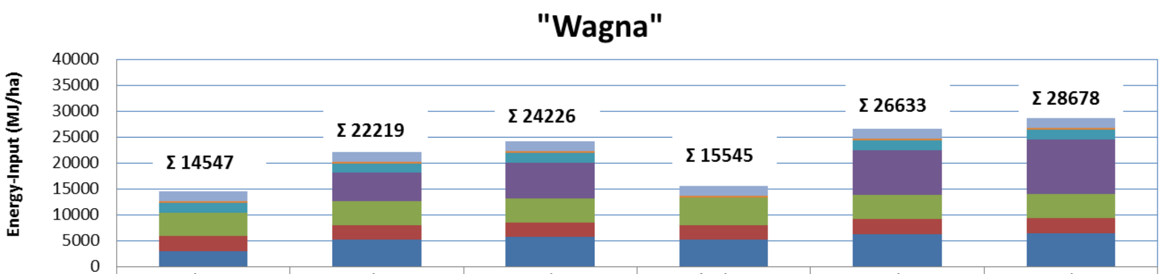
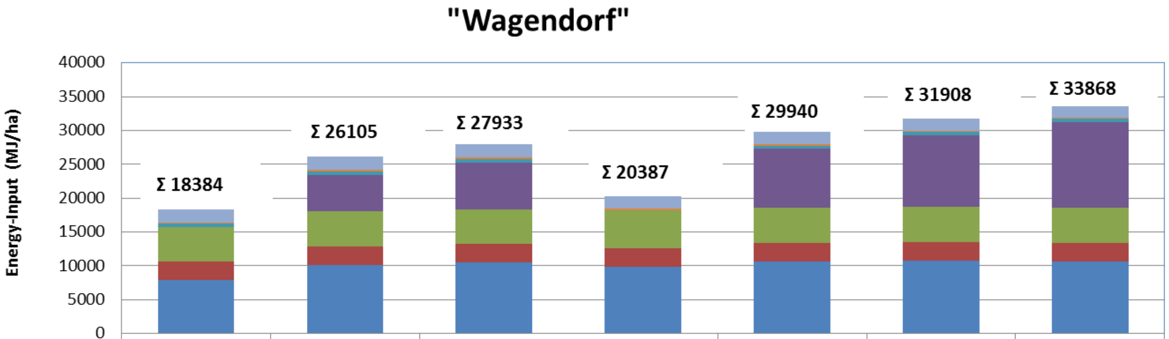


	0 kg N	(%)	90 kg N	(%)	115 kg N	(%)	Pig slurry	(%)	145 kg N	(%)	175 kg N	(%)
Machinery	1956	(13.4)	1956	(8.8)	1956	(8.1)	1956	(12.6)	1956	(7.3)	1956	(6.8)
Herbicide	335	(2.3)	335	(1.5)	335	(1.4)	335	(2.2)	335	(1.3)	335	(1.2)
Mineral-PK	1811	(12.4)	1811	(8.1)	1811	(7.5)	0	(0.0)	1811	(6.8)	1811	(6.3)
Mineral-N	0	(0.0)	5400	(24.3)	6900	(28.5)	0	(0.0)	8700	(32.7)	10500	(36.6)
Fuel	4636	(31.9)	4698	(21.1)	4698	(19.4)	5253	(33.8)	4698	(17.6)	4732	(16.5)
Seed	2856	(19.6)	2856	(12.9)	2856	(11.8)	2856	(18.4)	2856	(10.7)	2856	(10.0)
Drying	2954	(20.3)	5163	(23.2)	5671	(23.4)	5145	(33.1)	6278	(23.6)	6489	(22.6)



	0 kg N	(%)	90 kg N	(%)	115 kg N	(%)	Pig slurry	(%)	145 kg N	(%)	175 kg N	(%)	210 kg N	(%)
Machinery	1956	(10.6)	1956	(7.5)	1956	(7.0)	1956	(9.6)	1956	(6.5)	1956	(6.1)	1956	(5.8)
Herbicide	217	(1.2)	217	(0.8)	217	(0.8)	217	(1.1)	217	(0.7)	217	(0.7)	217	(0.6)
Mineral-PK	507	(2.8)	507	(1.9)	507	(1.8)	0	(0.0)	507	(1.7)	507	(1.6)	507	(1.5)
Mineral-N	0	(0.0)	5400	(20.7)	6900	(24.7)	0	(0.0)	8700	(29.1)	10500	(32.9)	12600	(37.2)
Fuel	5052	(27.5)	5123	(19.6)	5123	(18.3)	5639	(27.7)	5123	(17.7)	5161	(16.2)	5161	(15.2)
Seed	2730	(14.8)	2730	(10.5)	2730	(9.8)	2730	(13.4)	2730	(9.1)	2730	(8.6)	2730	(8.1)
Drying	7922	(43.1)	10172	(39.0)	10500	(37.6)	9844	(48.3)	10706	(35.8)	10837	(34.0)	10696	(31.6)

Energy efficiency at „Wagna“

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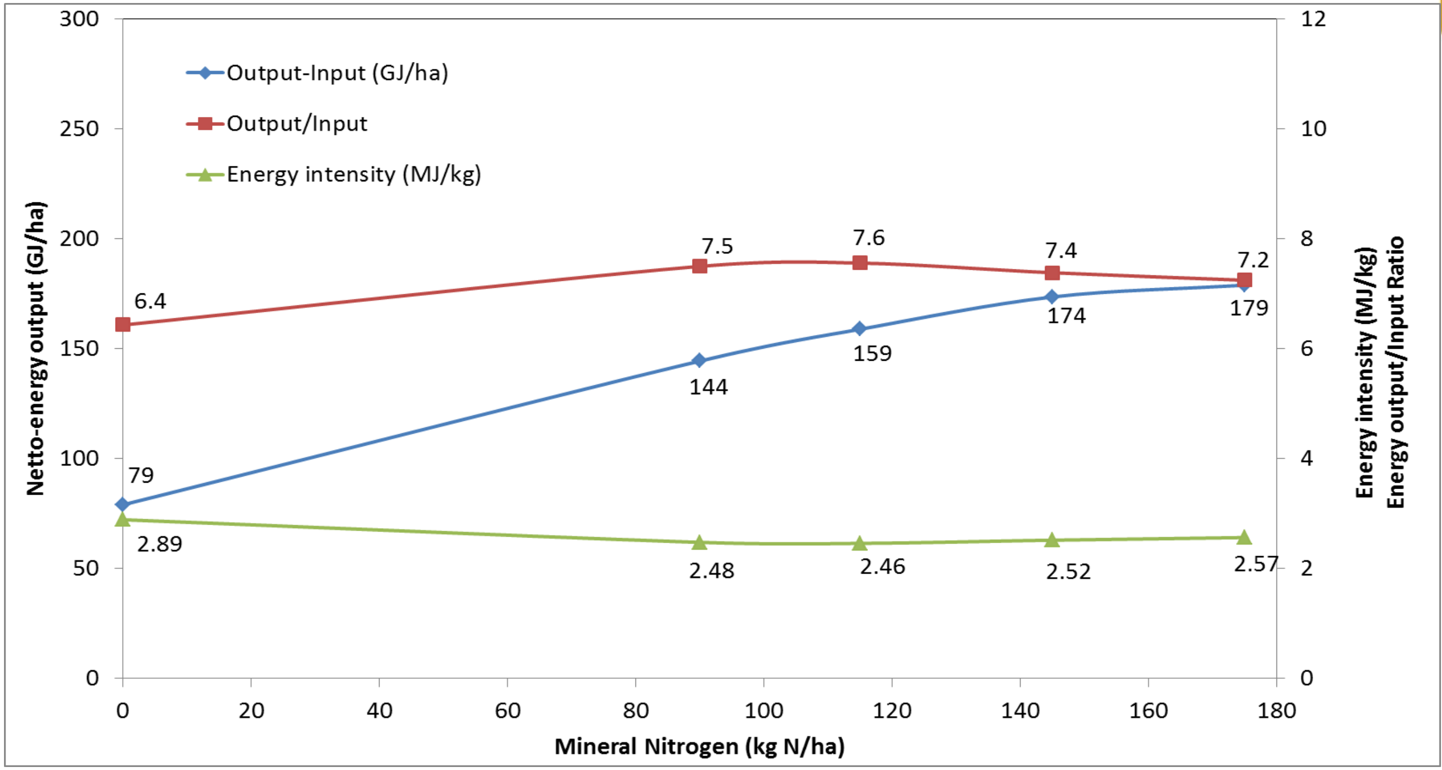

Organic Manure (pig slurry, Ø 135 kg N_{ff}):

Netto-energy output : 150 GJ/ha; Energy intensity : 1.75 MJ/kg; Energy output/Input-ratio: 10.6:1

Energy efficiency at „Wagendorf“

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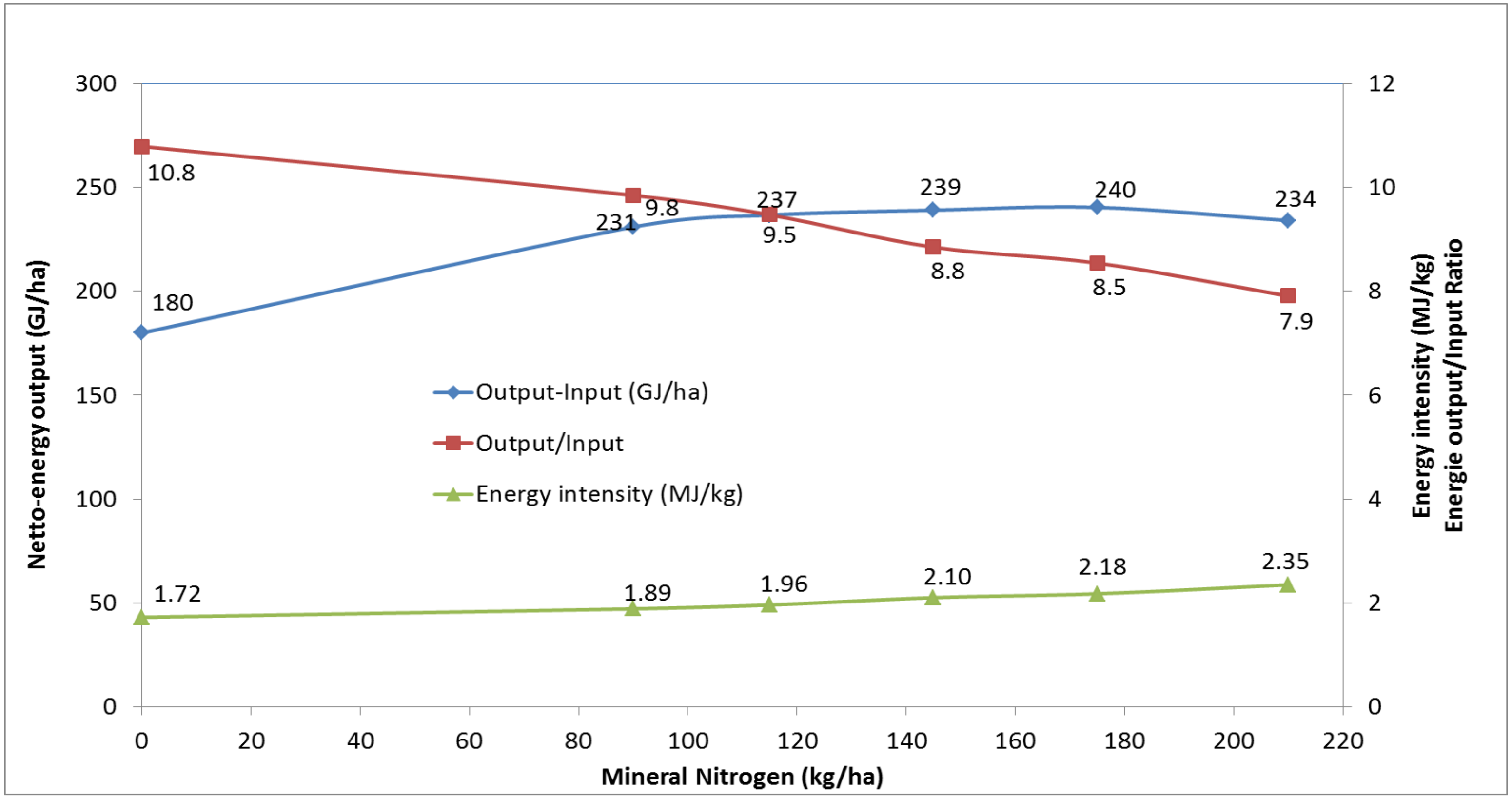

Organic Manure (pig slurry, Ø 108 kg N_{ff}):

Netto-energy output : 228 GJ/ha; Energy intensity: 1.53 MJ/kg; Energie output/Input-ratio: 12.2:1

Energy consumption per tonne corn (14 % w.b.)

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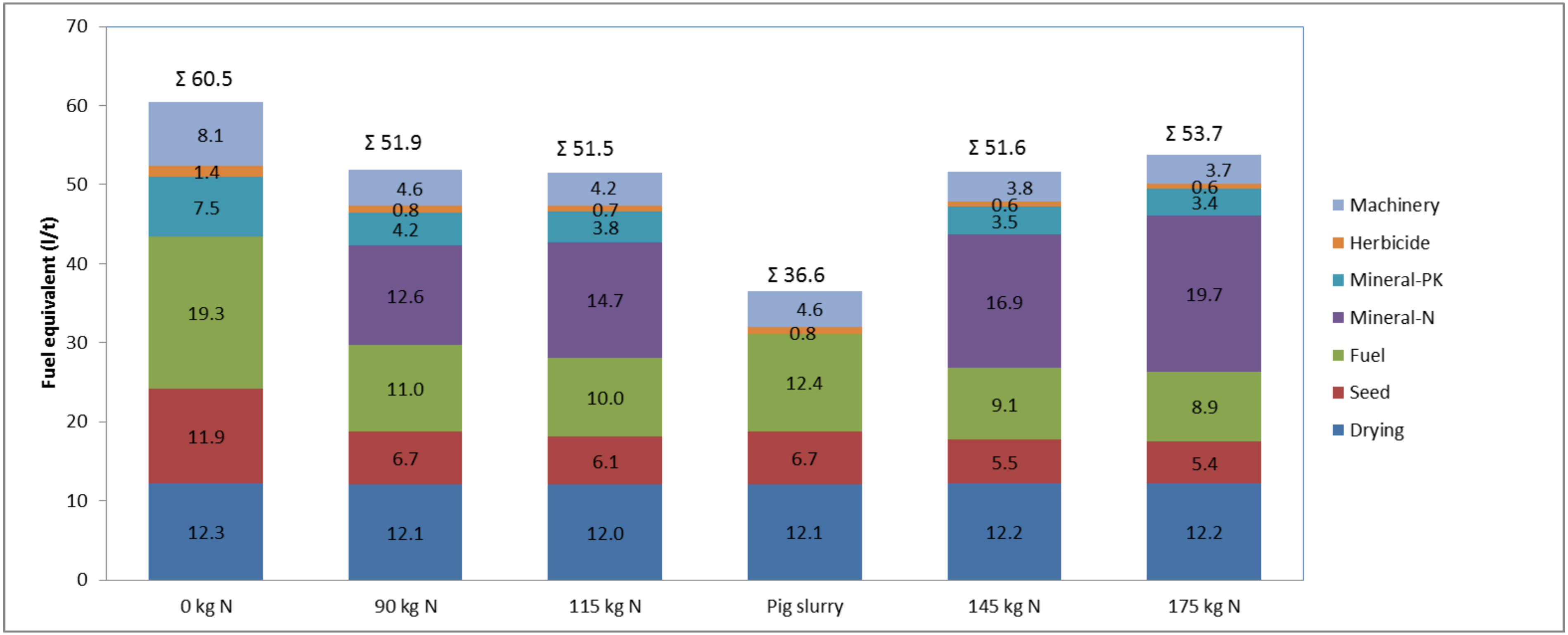
Liter Fuel equivalent per tonne corn

Experimental site „**Wagna**“



Energy consumption per tonne corn (14 % w.b.)

Liter Fuel equivalent per tonne corn

Experimental site „**Wagendorf**“

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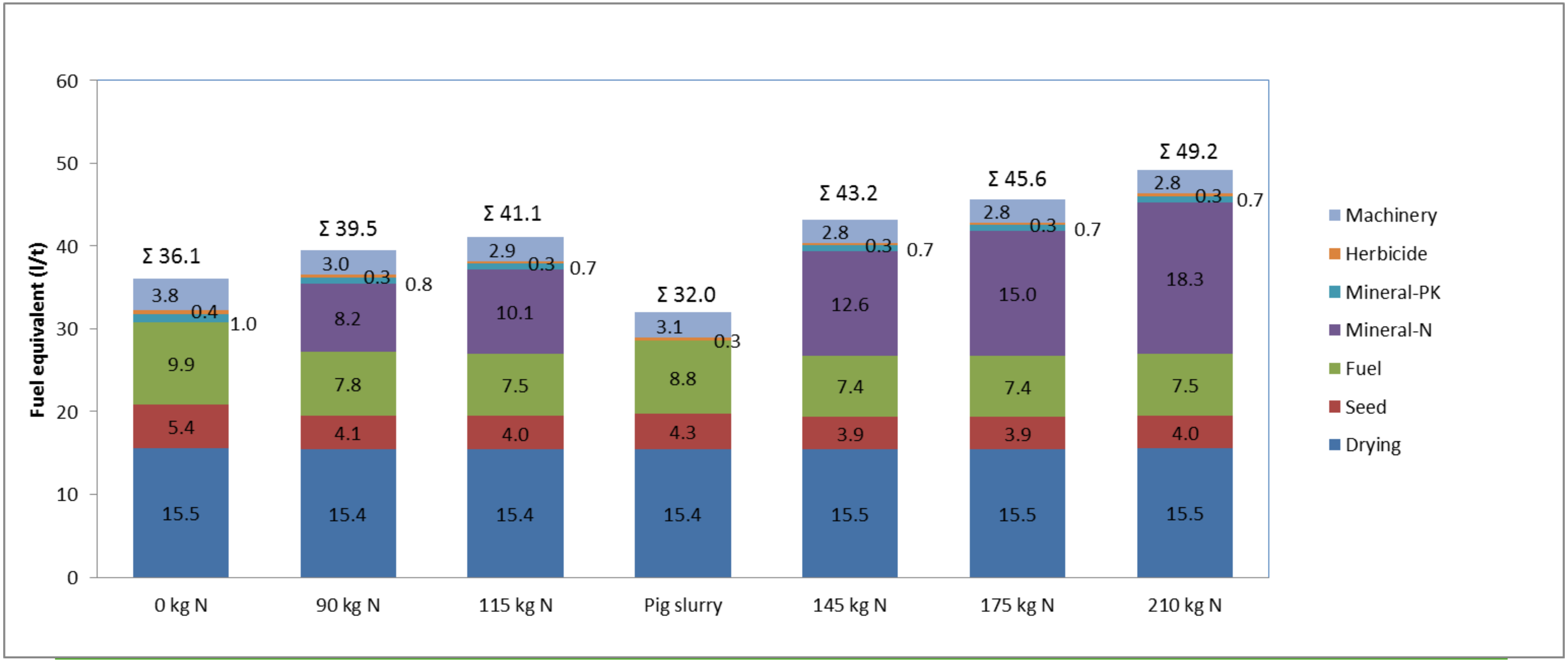

Conclusion

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- The **site with its soil and climate conditions** had a large influence on **energy efficiency in corn production**.
- The **nitrogen mineralisation for the organic matter** at the very fertile site Wagendorf caused **high corn yields**.
- An additional **soil organic matter and nitrogen balance** can bring further insight, with which mineral N fertilization rate the humus-content can be sustainably stabilized.
- The **liquid organic manure treatment** reached **the highest energy efficiency.**
- Highest energy efficiency in the **mineral nitrogen fertilization treatment:** "**Wagna": at 90 and 115 kg** N/ha; **"Wagendorf "** zero treatment (0 kg N/ha).
- **Measurements for reduction of fossil energy use in grain maize**:

  => Location adapted nitrogen fertilizer - preferably with **organic manure**

  => Use of **renewable energy sources** (heat from biomass district heating supply systems of biogas plants) for **maize grain drying**.
- Holistic evaluation with **integration of LCA, nitrogen balance, humus balance** could bring deeper insight of **ecological sustainability** of maize cropping.

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Thank you for your attention

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Farm branch: crop production

Input energy

Direct
fuel, heating oil, electricity

indirect:
process energie in „annual“ production facilities (fertilizers, pesticides, seeds)

Output energy

Crops for food and feed

straw

balance = Output - Input

minimum: 50 GJ/ha

Tolerable range:
between: 5 und 15 GJ/ha

Extensive: < 8 GJ/ha

Intensive: > 8 GJ/ha

Soure: Hege U., & Brenner M., Kriterien umweltverträgliche Landbewirtschaftung/”**Criteria of environmentally compatible land management**”, Bayerische Landesanstalt für Landwirtschaft, 2004

Energy-equivalent

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		Energy-equivalent	Source
Direct-use Energy			
	Diesel, Heating oil	44.3 MJ/l	*CIGR, 1999*
	Electricity	12 MJ/kWh	
Indirect-use Energy			
Fertilizers	Nitrogen	60 MJ/kg N	*CIGR, 1999*
	Phosphorus	14 MJ/kg P_2O_5	
	Potassium	12 MJ/kg K_2O	
Pesticides	Herbicide	250 MJ/kg[1)]	*CIGR, 1999*
	Fungicide	180 MJ/kg[1)]	
	Insecticide	300 MJ/kg[1)]	
Seed	Cereals	15 MJ/kg	*CIGR, 1999* *Hülsbergen, 2008*
	Corn hybrid	100 MJ/kg	
	Potato	93 MJ/kg	
	Oil seed rape	200 MJ/kg	
	Sunflower	20 MJ/kg	
	Sugarbeet	54 MJ/kg	
	Soybean	34 MJ/kg	
Machinery	Farm size (50 ha)	3000 MJ/ha	*Biedermann 2009*
	Farm size (100 ha)	1700 MJ/ha	
	Farm size (200 ha)	1170 MJ/ha	

In a **questionnaire** basic farm description (size, crop rotation,...), the **amount of used facilities (**fuel, pesticides, fertilizer, and seed) and the **yearly harvested crops** were recorded for the cropping **season 2011**.

Description of the analysed farms

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	RO 1	RO 2	SK 1	SK 2	SRB 1	SRB 2	A 1
Location	Transylvanian Plateau A	Transylvanian Plateau B	Kolinany	Risnovce	Sremska Mitrovica	Novi Sad	Ansfelden
Arable land (ha)	400	600	1112	1266	115	450	368
Mean temperature (°C)	8.4	9.0	9.7	10.3	11.0	11.5	9.1
Precipitation (mm)	628-733	557-600	631	550-600	650-700	550-600	848
Average field size (ha)	8.0	10.0	39.5	27.0	5.0	8.5	8.8
Soil	clay-silty, chernozem	clay-silty, chernozem	brown soil type	brown soil type	clay-silty chernozem	clay-silty chernozem	silty loam; brown soil type
Soil tillage	with plough	with plough	with plough	with plough	with plough	Plough-less	Plough-less

Energetic parameters for the energetic evaluation of the production systems

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(CIGR 1999, Hülsbergen 2008, Naghiu et al. 2003)

a.) Energy Ratio = Eo/Ei

b.) Energy Intensity (MJ/kg) = Ei/Y

c.) Fuel Intensity (l/t) = Fl/Y

d.) Net Energy Gain (GJ/ha) = Eo-Ei

e.) Energy Productivity (kg/MJ) = Y/Ei

f.) Energy Efficiency Index (%) η_E

$$\eta_E = \frac{E_o - E_i}{E_o}$$

[%]
where:
Ei - Energy input (fuel, seeds, fertilizer, pesticide, farm machinery); MJ/ha
Eo: Energy output of the harvested crop; MJ/ha
Y: harvested crop; kg/ha

Mean Fuel consumption (l/ha)

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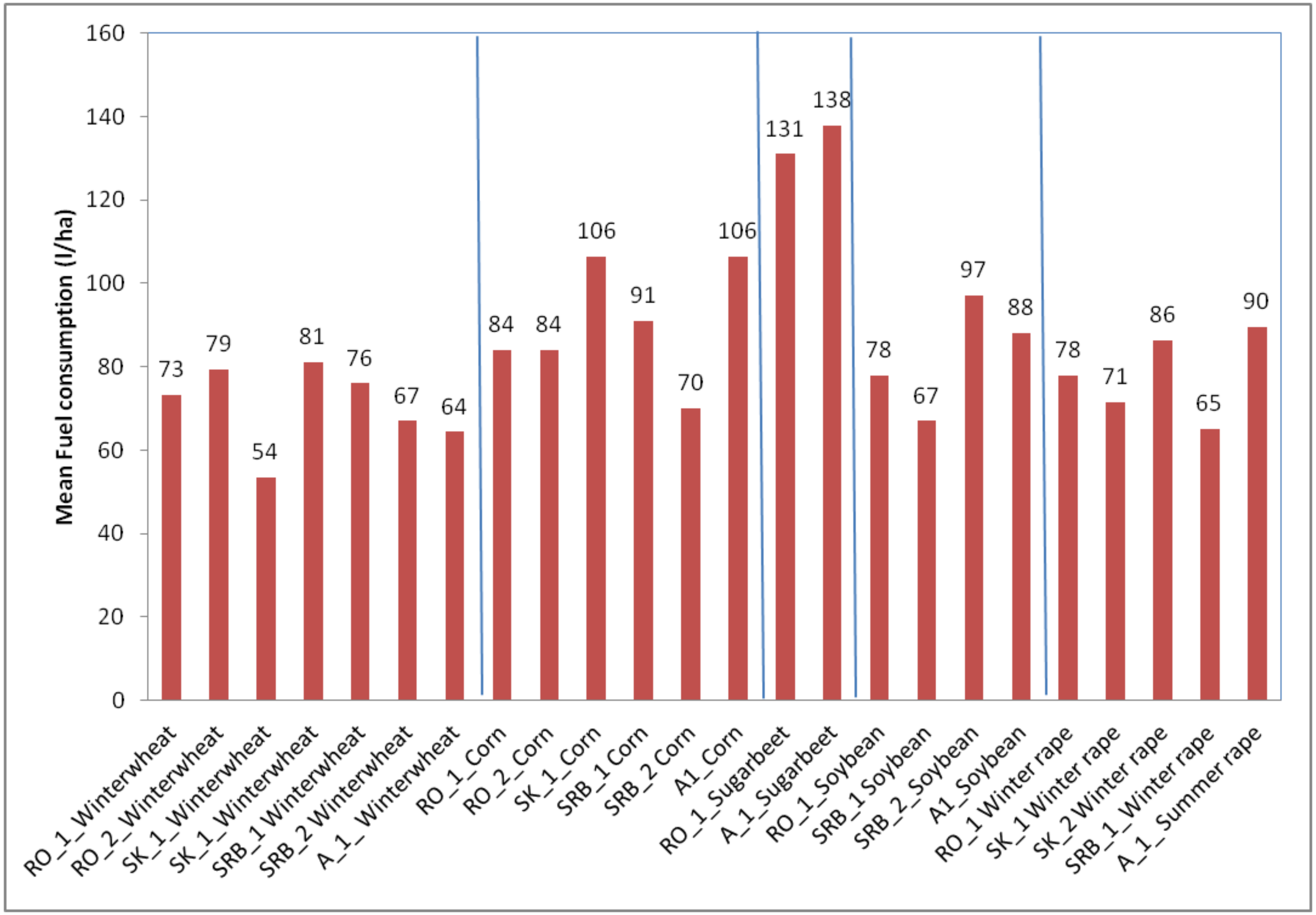

Mean Fuel intensity (l/t)

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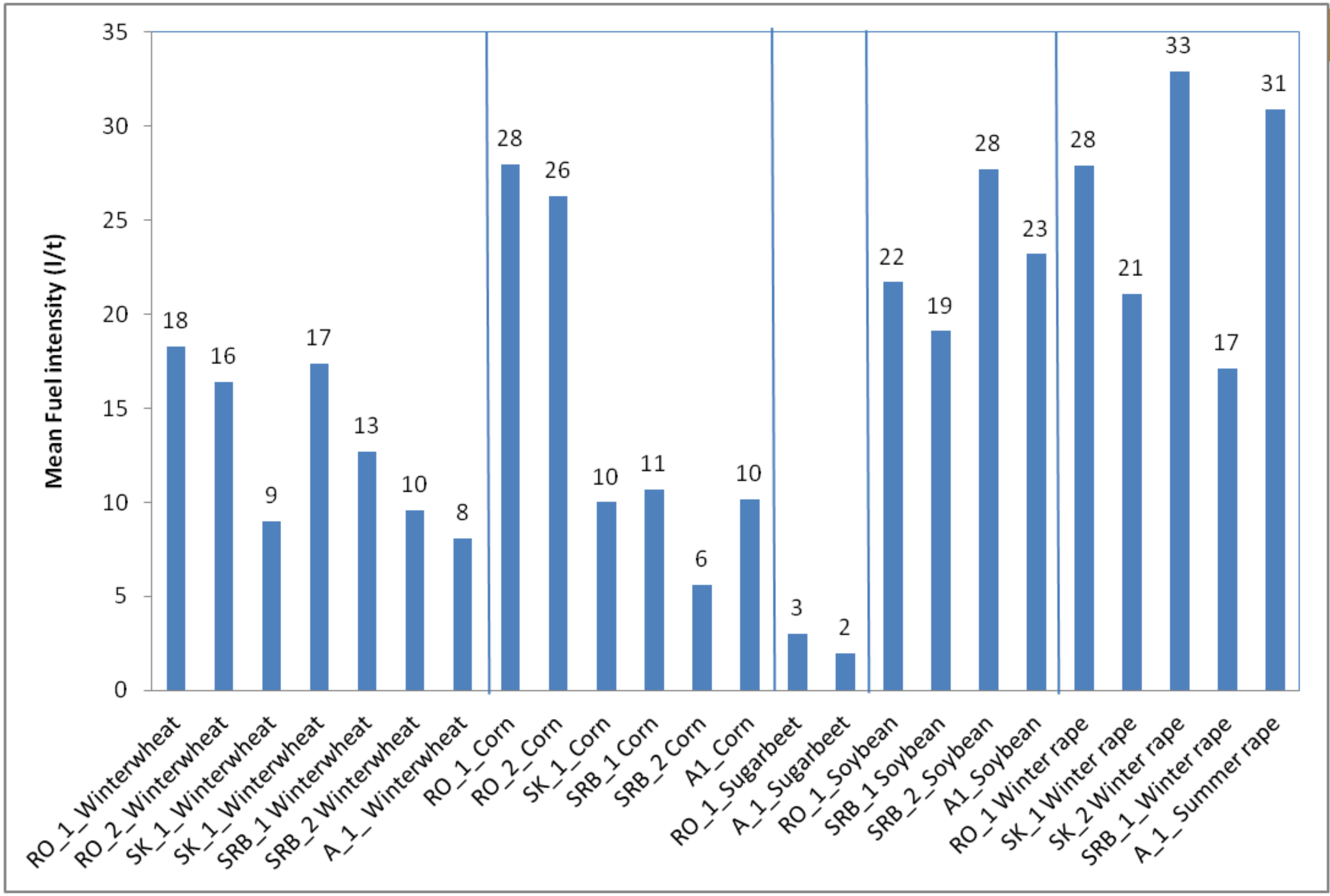

Crop specific data for wheat production on seven arable farms

	Romania		Slovak Republic		Serbia		Austria
	RO 1	RO 2	SK 1	SK 2	SRB1	SRB 2	A1
Location	Transylvanian Plateau A	Transylvanian Plateau B	Kolinany	Risnovce	Sremska Mitrovica	Novi Sad	Ansfelden
Arable land on the farm (ha)	400	600	1112	1266	115	450	368
Winterwheat area (ha)	**20**	**76**	**177**	**155**	**38**	**120**	**185**
Mean Fuel consumption (l/ha)	73.2	79.4	53.5	81.1	76.0	67.0	64,4
N-fertilizer (kg N/ha)	30	37.5	145	145	160	207	164
Herbicide (kg/ha)	2	1.15	1.20	0.4	0.35	2.50	3.20
Fungicide (kg/ha)	-	-	1.10	1.0	0.50	-	3.82
Insecticide (kg/ha)	-	-	0.1	0.1			
Seed (kg/ha)	230	230	223	200	200	240	190
Organic manure (t/ha)	15	20	-	-	-	-	-
Mean yield (kg/ha)	4.000	4.850	5.920	4.657	6.000	7.000	8.000

Energy analysis for winter-wheat production

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	Romania		Slovak Republic		Serbia		Austria
	RO 1	RO 2	SK 1	SK 2	SRB1	SRB 2	A1
Location	Transylvanian Plateau A	Transylvanian Plateau B	Kolinany	Risnovce	Sremska Mitrovica	Novi Sad	Ansfelden/ Linz
Arable land (ha)	400	600	1112	1266	115	450	368
Winterwheat (ha)	**20**	**76**	**177**	**155**	**38**	**120**	**185**
Yield (kg/ha)	4.000	4.850	5.920	4.657	6.000	7.000	8.000
Energy ratio	5.05	5.58	6.51	5.09	4.91	4.82	7.08
Energy intensity (MJ/kg)	3.19	2.89	2.81	3,59	2.62	3.17	2.27
Fuel intensity (l/t)	18.3	16.4	9.0	17.4	12.70	9.60	8.06
Net energy gain (GJ/ha)	51.67	64.10	91.69	68.49	74.54	84.56	110.64
Energy productivity (kg/MJ)	0.31	0.34	0.36	0.28	0.32	0.31	0.44
Energy efficiency index (%)	80.2	82.1	84.6	80.4	79.6	79.3	85.9

Energy saving through targeted or reduced application of farm facilities

- **Manure management** (e.g. Treatment and application with low trace gas emissions)

- **Organic Farming** (Biological N-fixation)

- **„Precision farming"**

  Steering Assistance Systems, Automatic Guidance Systems

  Variable Rate Technology (e.g.: sensorbased fertilization systems)

Thank you for your attention

Gerhard Moitzi

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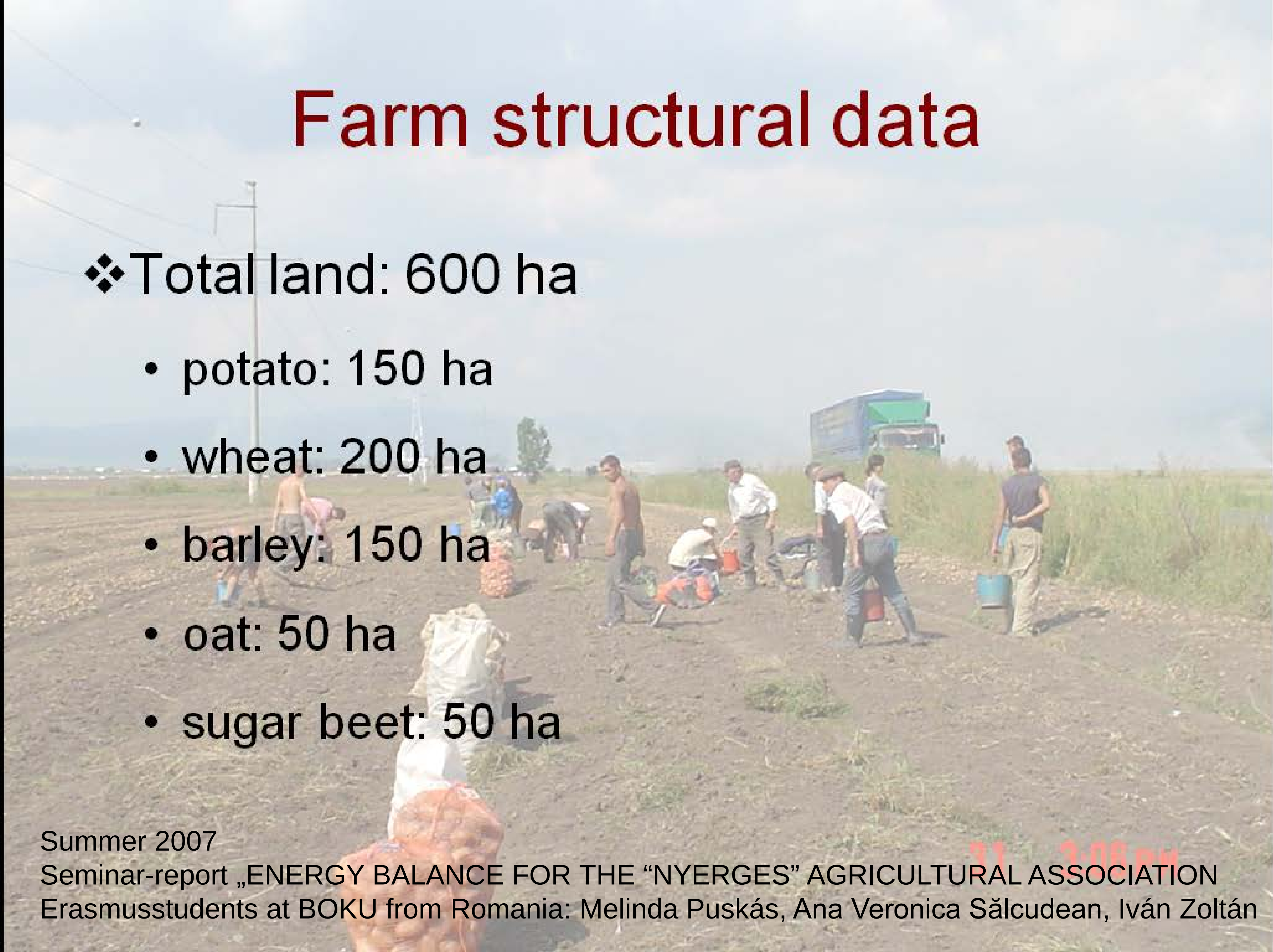
Die Ernte: Vicent van Gogh; 1888; Van Gogh Ausstellung in der Albertina; Wien



Farm structural data

- Total land: 600 ha
  - potato: 150 ha
  - wheat: 200 ha
  - barley: 150 ha
  - oat: 50 ha
  - sugar beet: 50 ha

Machinery usage

- 6 tractors with 65 Hp
- 1 tractor with 150 Hp (Zetor)
- 2 trucks (6 t capacity)

Fuel Consumption

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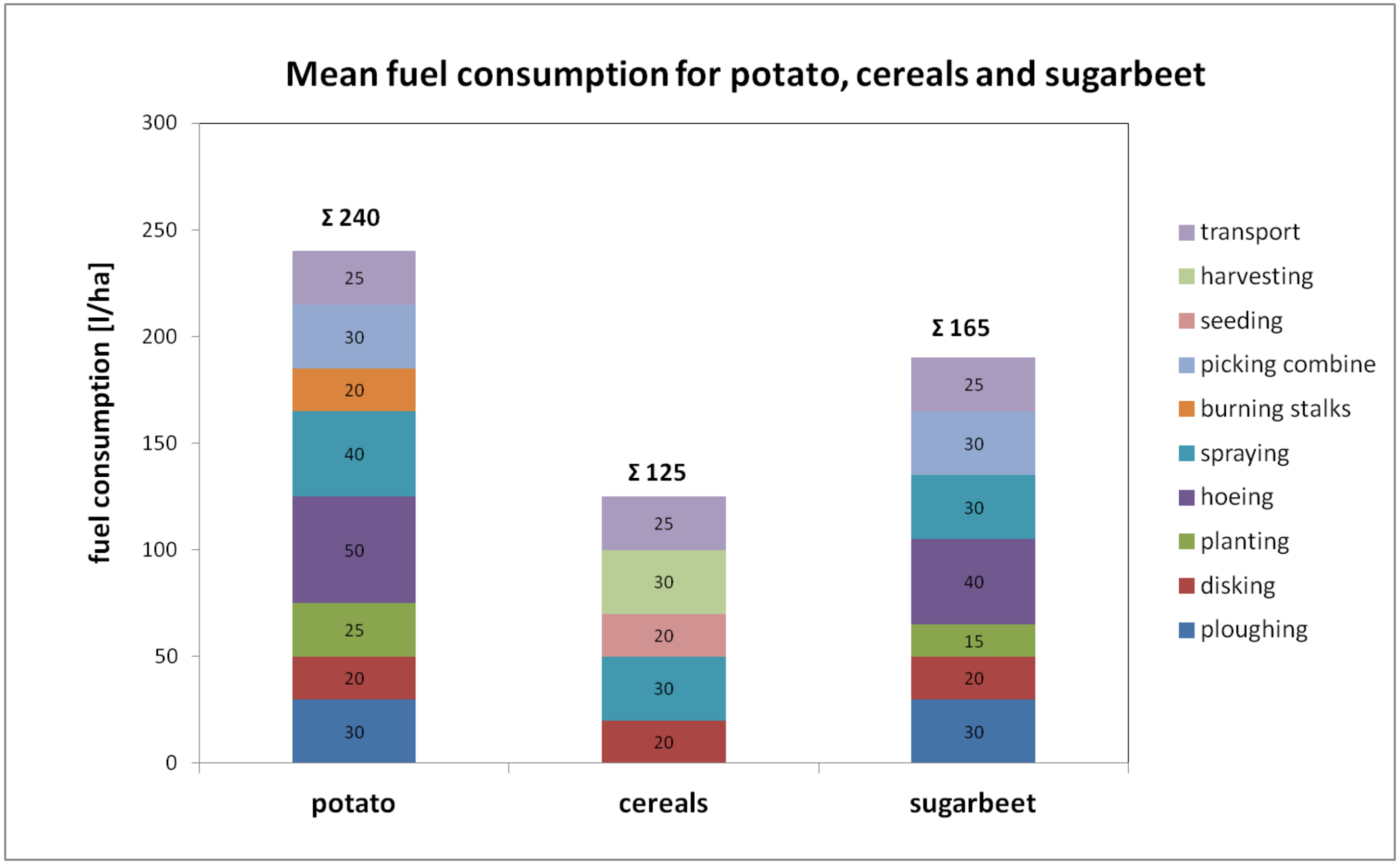

Data from the Seminar-report „ENERGY BALANCE FOR THE “NYERGES” AGRICULTURAL ASSOCIATION
Erasmusstudents at BOKU from Romania: Melinda Puskás, Ana Veronica Sălcudean, Iván Zoltán

CASEE
Central and South Eastern Europe

Direct and indirect energy input

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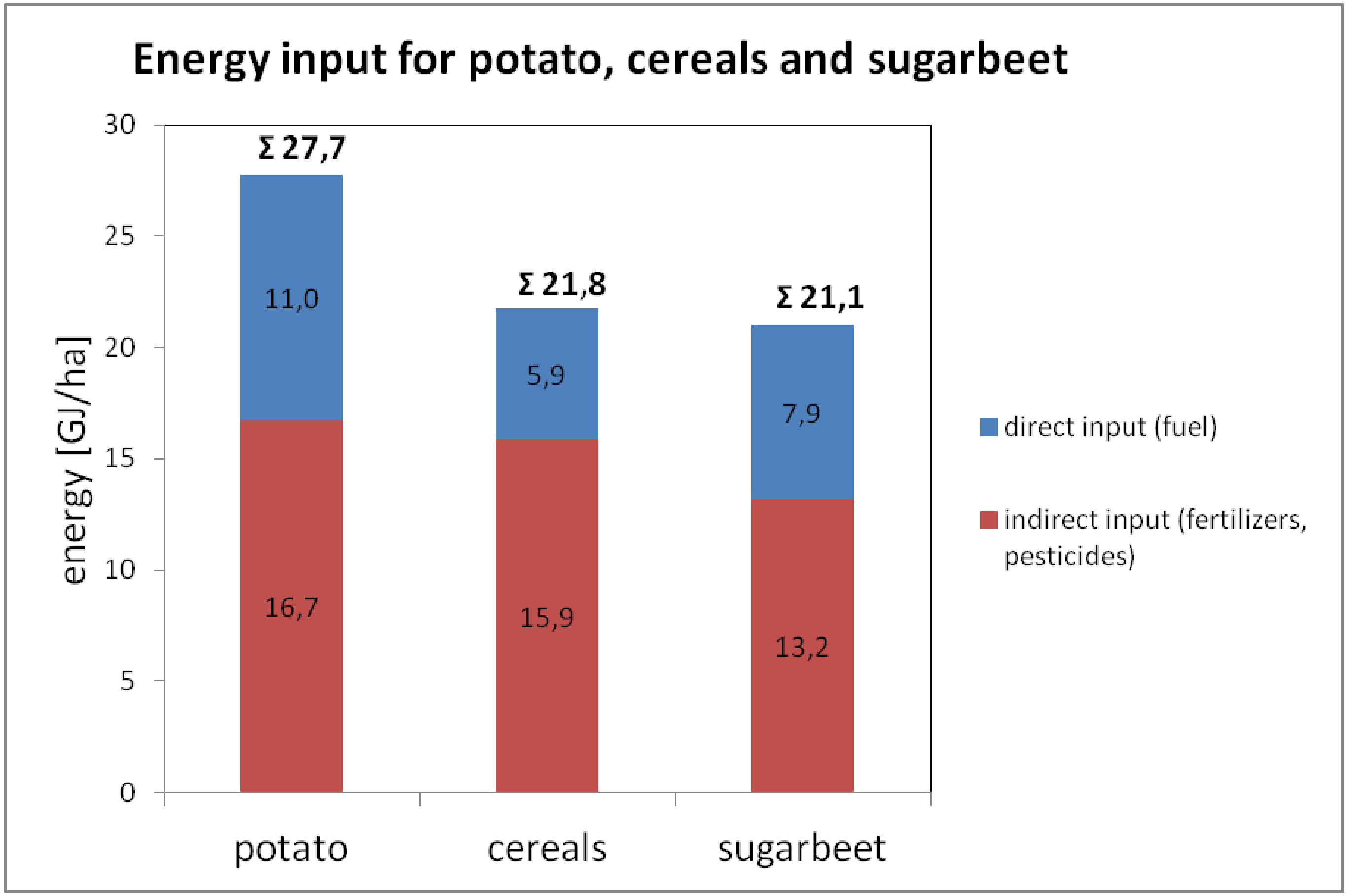

Data from the Seminar-report „ENERGY BALANCE FOR THE "NYERGES" AGRICULTURAL ASSOCIATION
Erasmusstudents at BOKU from Rumania: Melinda Puskás, Ana Veronica Sălcudean, Iván Zoltán

Energy efficiency

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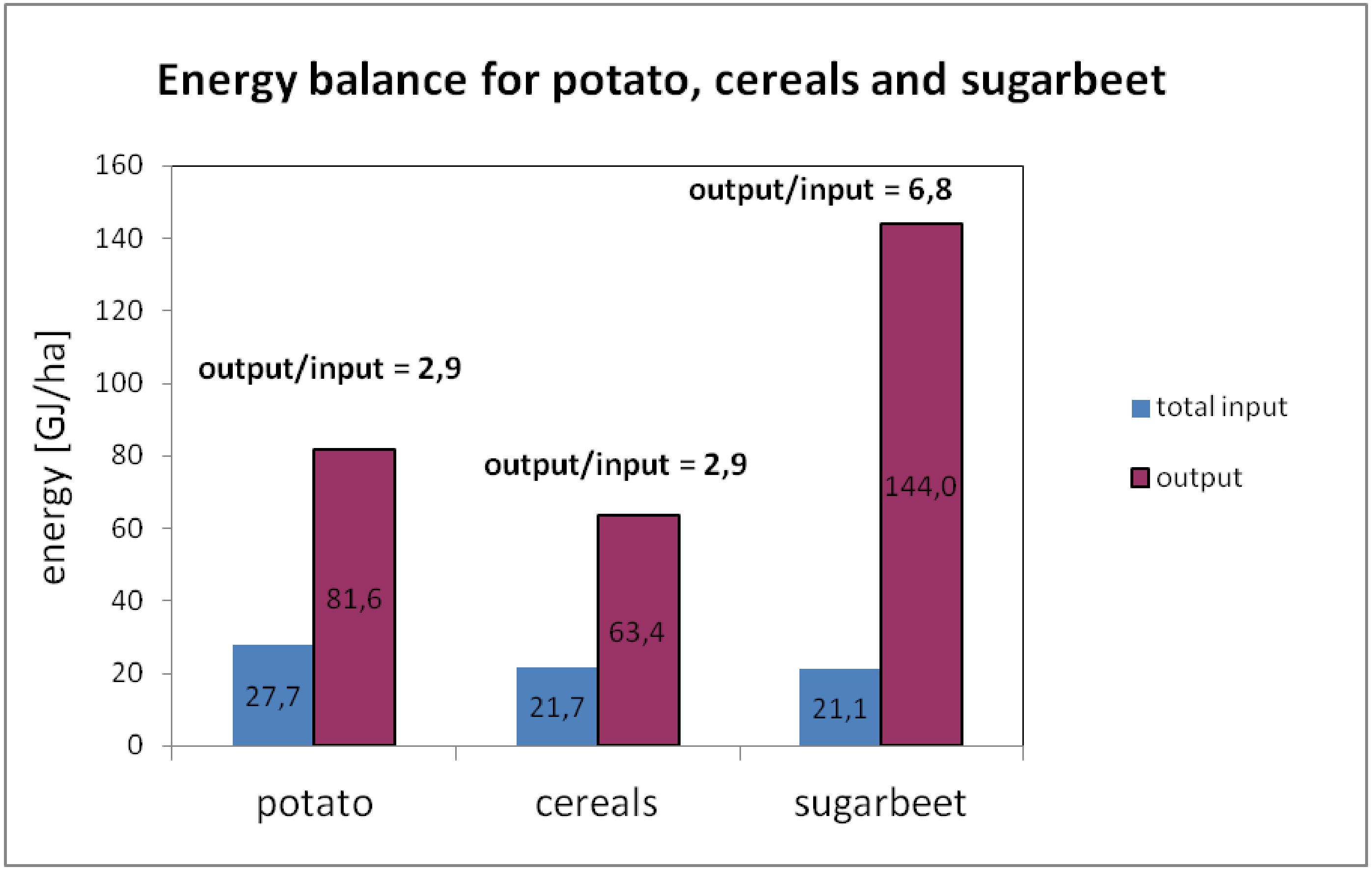

Data from the Seminar-report „ENERGY BALANCE FOR THE “NYERGES” AGRICULTURAL ASSOCIATION
Erasmusstudents at BOKU from Rumania: Melinda Puskás, Ana Veronica Sălcudean, Iván Zoltán

"Mechanization and Energy use in selected arable farms in Central and South Eastern Europe"

CASEE
Central and South Eastern Europe

University of Natural Resources and Life Sciences, Vienna
Department of Sustainable Agricultural Systems
Division of Agricultural Engineering

Project-timeline: 12th April 2012 – 15th February 2013

Grant amount: 4.500 €

Involved partners:

- USAMV - University of Agricultural Sciences and Veterinary Medicine Cluj-Napoca (**Rumania**)
- The Slovak Agricultural University in Nitra (**Slovakia**) => Prof. Dr. L. Nozdrovicky
- University of Novi Sad (**Serbia**)
- University of Natural Resources and Life Sciences, BOKU-Vienna (**Austria**)

Central and South Eastern Europe

Brief description of project content

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1. Selected arable farms are analysed via on-farm survey according:

⇒ **Kind of mechanisation**

⇒ **Farm facility inputs** (Fuel, fertilizer, pesticides, etc)

⇒ **Crop rotation with yields**

2. Calculating of the fuel intensity (l/ha) and energy efficiency (Output/Input-Ratio)

3. Potential energy saving strategies (without and with investment) are identified.

⇒ **Soil tillage systems** are focused **deeper** and **if possible fuel consumption for selected soil tillage operations are measured volumetrically.**

.

4. Potential of integration of biobased fuels (e.g. canola or sunflower oil, FAME) are analysed.

⇒**The vision is an fuel autarkic farm.**

CO_2-enrichment in the atmosphere

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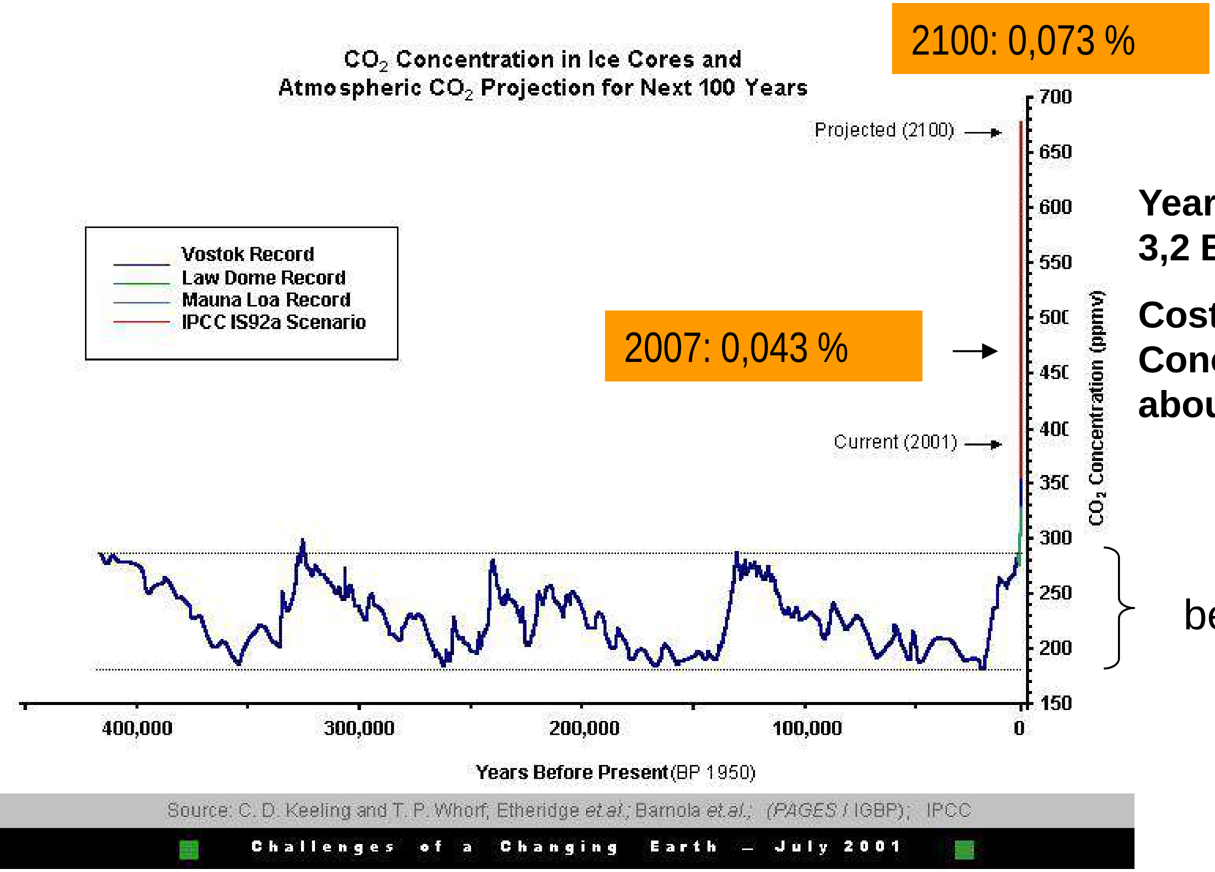
⇒ Greenhouse Gases GHG (**CO_2, CH_4, N_2O**)

⇒ 80 % of the global energy consumption is based on crude oil, coal and natural gas

⇒ CO_2-emission factor: ~3 kg CO_2/kg fossil liquid fuel



Yearly carbon enrichment in the atmosphere: 3,2 Billion Tonnes C

Costs of the stabilisation of the CO_2-Concentration (between 500 and 550 ppm): about 1 % of the global GDP

between: 0,02 und 0,03 %

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CO_2-mitigation strategie

„energy efficiency“

renewable energy

biomass utilization

Bad efficiency in energy conversion

(3,4 : 1)

State of Art

=> Increasing in traffic
=> Limitation in crude oil resources

Improvement in energy efficiency:
- 20 % reduction of primary energy till 2020
- 20 % increase of energy efficiency

Targets in EC

Biofuel promotion
Till 2010: 5,75 % biofuel share
Till 2020: min. 10 % biofuel share

Agriculture - „solar energy harvester“

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Division of Agricultural Engineering

Cholorophyll + 2782 kJ/mol

$$6\ CO_2 + 12\ H_2O + PAR \longrightarrow C_6H_{12}O_6 + 6\ O_2 + 6H_2O$$

PAR: Photosynthetically active radiation

Agriculture is a process to harvest photosynthetically stored solar energy for:

⇒ food

⇒ feed

⇒ energetic and material usage

Energy – input in agriculture

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Direct enery input:

= Direct usage of secondary energy:

fuel, heating oil: heat value: 35,2 MJ/l => 2,6 kg CO_2/l;
261 g CO_2/kWh

Electricity: Ø Austria 439 g CO_2/kWh => 2020: 220 g CO_2/kWh
Ø EC: 652 g CO_2/kWh

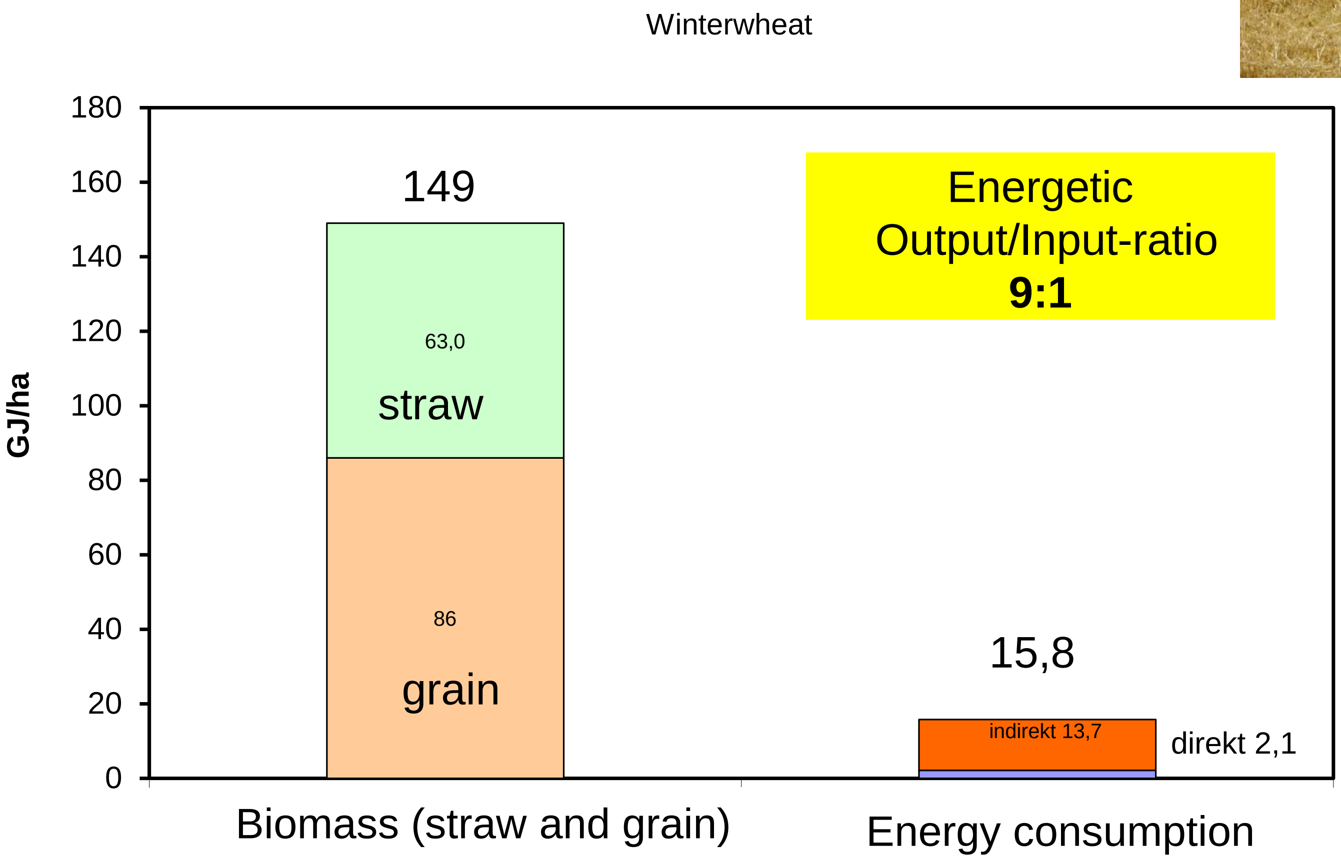
Indirect energy input:

= Secondary energy for production of farm facilities:

- Fertilicer: z.B. NAC (39 MJ/kg N); Urea (48 MJ/kg N);
- Herbicide: Ø 259 MJ/kg
- Fungicide: Ø 177 MJ/kg
- Insecticide: Ø 296 MJ/kg
- PE-foils: 76,8 MJ/kg
- Machinery: 50 - 70 MJ/kg
- Seed: z. B. WW_{konv}: 2,8 MJ/kg; WW_{biol}: 1,52 MJ/kg

Agriculture as solar energy harvester

Expertimental site: Gross Enzersdorf in Lower Austria



Grain - yield: 5500kg

Straw - yield: 4000 kg

Energy use and energy efficiency in corn production in different fertilization strategies

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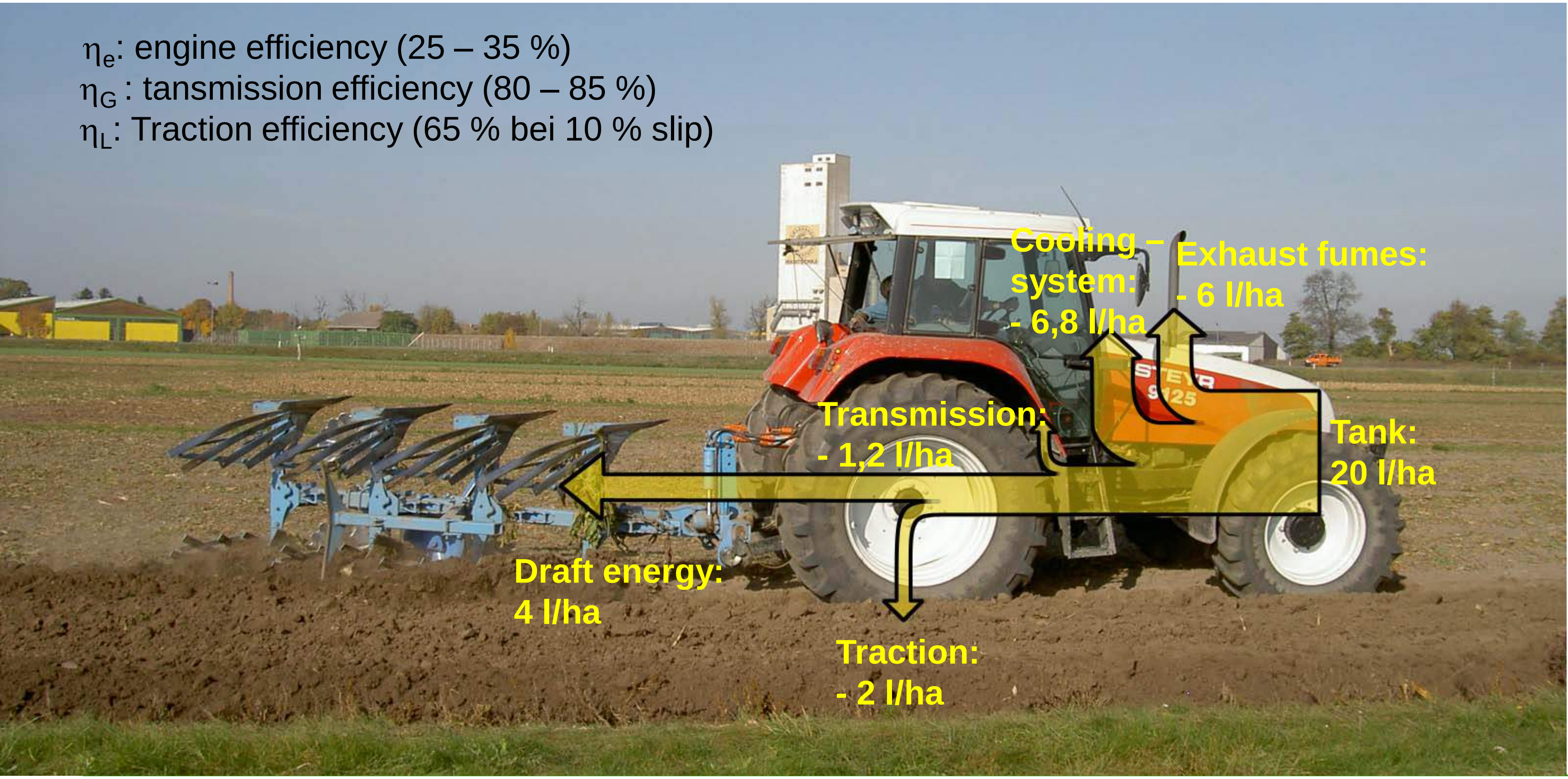
Energyflow in a tractor

$$\eta_{ges} = \eta_e \times \eta_G \times \eta_L$$

η_e: engine efficiency (25 – 35 %)
η_G : tansmission efficiency (80 – 85 %)
η_L: Traction efficiency (65 % bei 10 % slip)



Fuel consumption in soil tillage

➢ **Soil tillage can be an large energy consumer:**
=> 1 cm soil tillaged → approx. 100 m^3 or 150 t/ha must be moved

=> per 1 cm ploughing depth ⟶ **0.5 – 1.5l/ha**

➢ Transmission of drawbar power via the interface wheel and soil surface is affected by the efficiency of traction:

tractor-releated factors:

weight, number of driven axle, kind of tyre, inflation pressure etc.

soil-releated factors:

surface hardness, soil moisture content etc.

Efficiency of traction

Experimental farm of BOKU in Gross Enzersdorf (Lower Austria)

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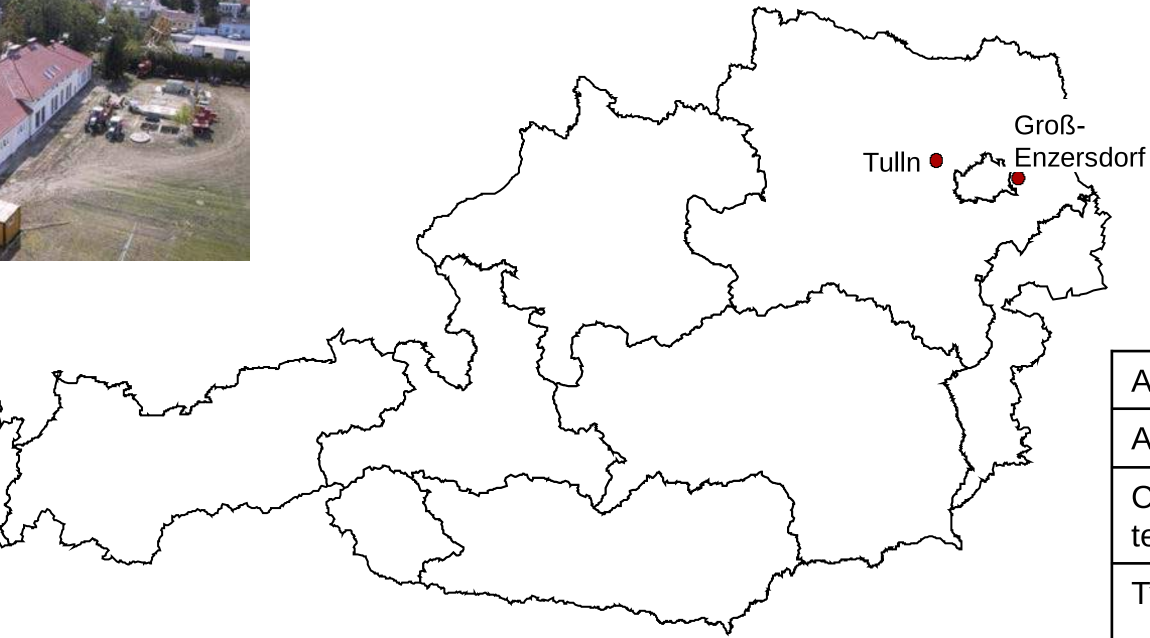

Average temperature	9.5 °C – 10 °C
Average rainfall	500 – 600 mm
Classification of soil texture	loamy clay
Type of soil	Gleyc Chernozem And pure Chernozem

Tractor with measurement equipment

Process parameter	Measurement engineering
Vehicle speed (v)	Radar sensor: generates a rectangular signal (130 pulses/m = 27,8 Hz/(km/h))
Wheel speed (v_0)	Transmission sensor (inductively transducer), generates a alternative current (0.4 - 3.8 V), rectified with diode rectifier
Engine speed (n_M) Position lifting system	Inductive sensor: generates a rectangular signal: 0-12 V > 50 % = 12 V, < 50 % = 0 V
Fuel consumption (B)	Flow-meter (PLU 116 H), inductive displacement sensor generates a digital rectangular signal (22 - 2800 Hz)

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3

11

12

13

Linkage from fuel filter

Linkage to fuel injection pump

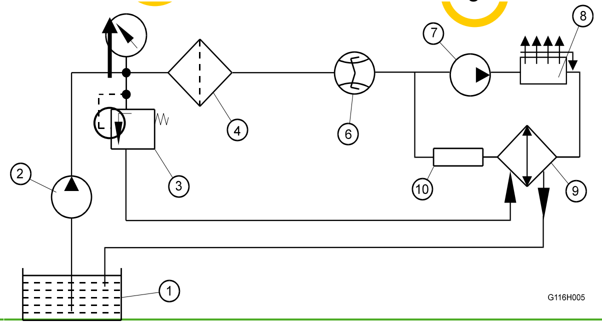
9

Linkage from injection pump (leak diesel)

Linkage to tank

7

6



Steyr 9125a

- Power: 92 kW (DIN)
- 6 stroke diesel engine with direct injection and exhaust turbo super charger
- Capactiy: 6600 cm^3
- Nominal rotation speed: 2300 rev/min
- Constant power range between 1900 – 2300 rev/min
- Gear box: 4 step power shift, forward/reverse group, main transmission 6 gears (synchronized). total: 24 forward and 24 reverse speeds
- weight: 5465 kg

1 tank
2 pre pump
3 pressure controller with manometer
4 pre filter
6 flowmeter PLU 116H
7 pump
8 injection pump
9 fuel/fuel-heat exchanger
10 control for leak flow
11 air bubble releaser
12 power supply
13 digital rectangular signal

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Soil tillage Systems	Description
Conventional tillage with plough ***(Conventional 1)***	Heavy cultivator for Stubble field skimming (3 m, 5 cm) 2x4-mouldboard plough (1,6 m, 25 cm) Power harrow (3 m, 5 cm) Seeding machine (3 m, 3 cm)
Conventional tillage with heavy cultivator and subsoiler ***(Conventional 2)***	Heavy cultivator for Stubble field skimming (3 m, 5 cm) Subsoiler[1)] (3 m, 35 cm) Heavy cultivator (3 m, 20 cm) Power harrow (3 m, 5 cm) Seeding machine (3 m, 3 cm)
Conventional tillage –integrated *Every four years: plough instead of cultivator* ***(Conventional 3)***	Heavy cultivator for Stubble field skimming (3 m, 5 cm) Heavy cultivator (3 m, 10 – 15 cm) Resp. 2x4-mouldboard plough (1,6 m, 25 cm) Power harrow (3 m, 5 cm) Seeding machine (3 m, 3 cm)
Conservation tillage – mulch seeding ***(Conservation 1)***	Heavy cultivator for Stubble field skimming (3 m, 5 cm) Heavy cultivator (3 m, 8 cm) Seeding machine (3 m, 3 cm)
Conservation tillage – direct seeding ***(Conservation 2 – No tillage)***	Direct drilling machine with disc coulters (3 m, 2 cm)


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Mean measured technical process parameter for different field operations

Field operations	Fuel consumption [l/ha] in the field operation	Technical performance [ha/h]	Working time requirement for one turning event [sec.]	Fuel consumption [l/h] at turning
Ploughing (25 cm)	18.8	1.03	35	5.0
Subsoiling (35 cm)	9.4	2.16	30	5.8
Cultivating (20 cm)	9.4	2.19	26	5.0
Cultivating (8 cm)	6.7	2.71	23	5.0
Power harrowing	8.6	2.31	22	5.6
Seeding	6.3	2.46	33	5.3
Stubble field skimming	5.6	2.85	21	5.0

Fuel consumption of the different soil tillage systems for winter wheat cropping

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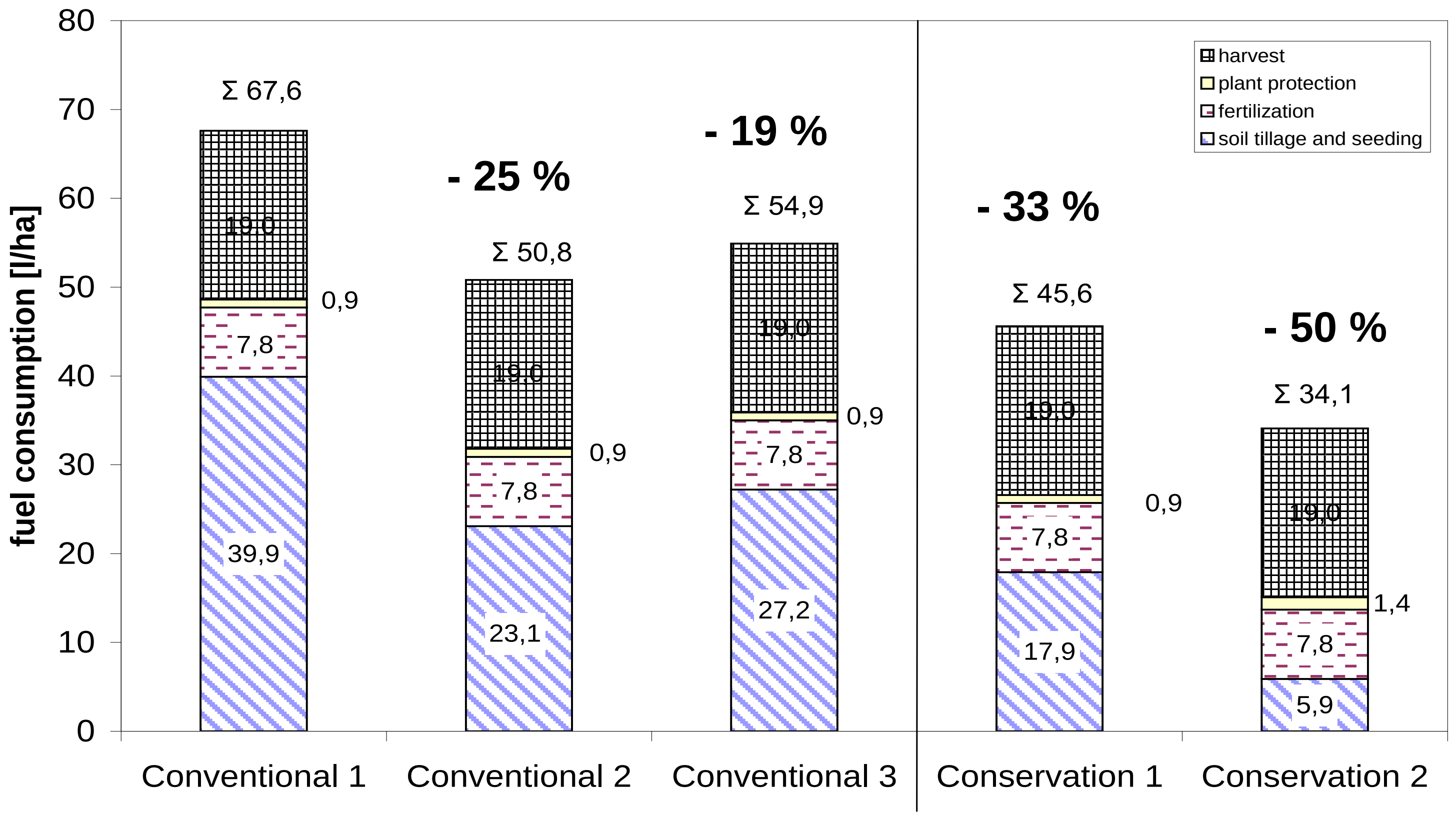

Fuel consumption for fertilization, plant protection and harvest is calculated by means of data from The Association for Technology and Structures in Agriculture (KTBL)

Energy analysis for wheat production in different soil tillage systems

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	Conventional tillage			Conservation tillage	
	1	2	3	1	2
Direct Energy input [MJ•ha-1]	**2380**	**1788**	**1932**	**1605**	**1200**
Fuel for soil tillage (figure 1)	1404	813	957	630	208
Fuel for fertilizer application	275	275	275	275	275
Fuel for pesticide application +1 *glyphosate* application in Conservation tillage 2	32	32	32	32	49
Fuel for harvest (combine)	669	669	669	669	669
Indirect Energy input [MJ•ha-1]	**7042**	**7030**	**7013**	**7033**	**7109**
Seeds (160 kg•ha-1)	880	880	880	880	880
Fertilizers (Ø 120 kg N•ha-1)	4874	4874	4874	4874	4874
Herbicides + 1 *glyphosate* application (2 l•ha-1) Conservation tillage 2	675	675	675	675	805
Machine	612	600	583	603	550
Total Energy input [MJ•ha-1]	**9422**	**8818**	**8945**	**8638**	**8609**
Direct Energy:Indirect Energy	**25:75**	**20:80**	**22:78**	**19:81**	**14:86**
Wheat yield*) [kg•ha-1], 89 % DM	**4636**	**4788**	**4969**	**4842**	**5117**
Energy output_grain [MJ•ha-1]	**72964**	**75347**	**78205**	**76198**	**80539**
Energy intensity [Input_MJ•kg-1 wheat]	**2.03**	**1.84**	**1.80**	**1.78**	**1.68**
Fuel intensity [l fuel•t-1 wheat]	**14.58**	**10.60**	**11.04**	**9.41**	**6.66**
Output-Input = Net energy [MJ•ha-1] (grain)	**63542**	**66529**	**69260**	**67560**	**72230**
Output/Input = Energy efficiency (grain)	**7.70**	**8.54**	**8.74**	**8.82**	**9.69**

*) mean wheat yield from the year 1998, 2000, 2002, 2004, 2007 and 2009

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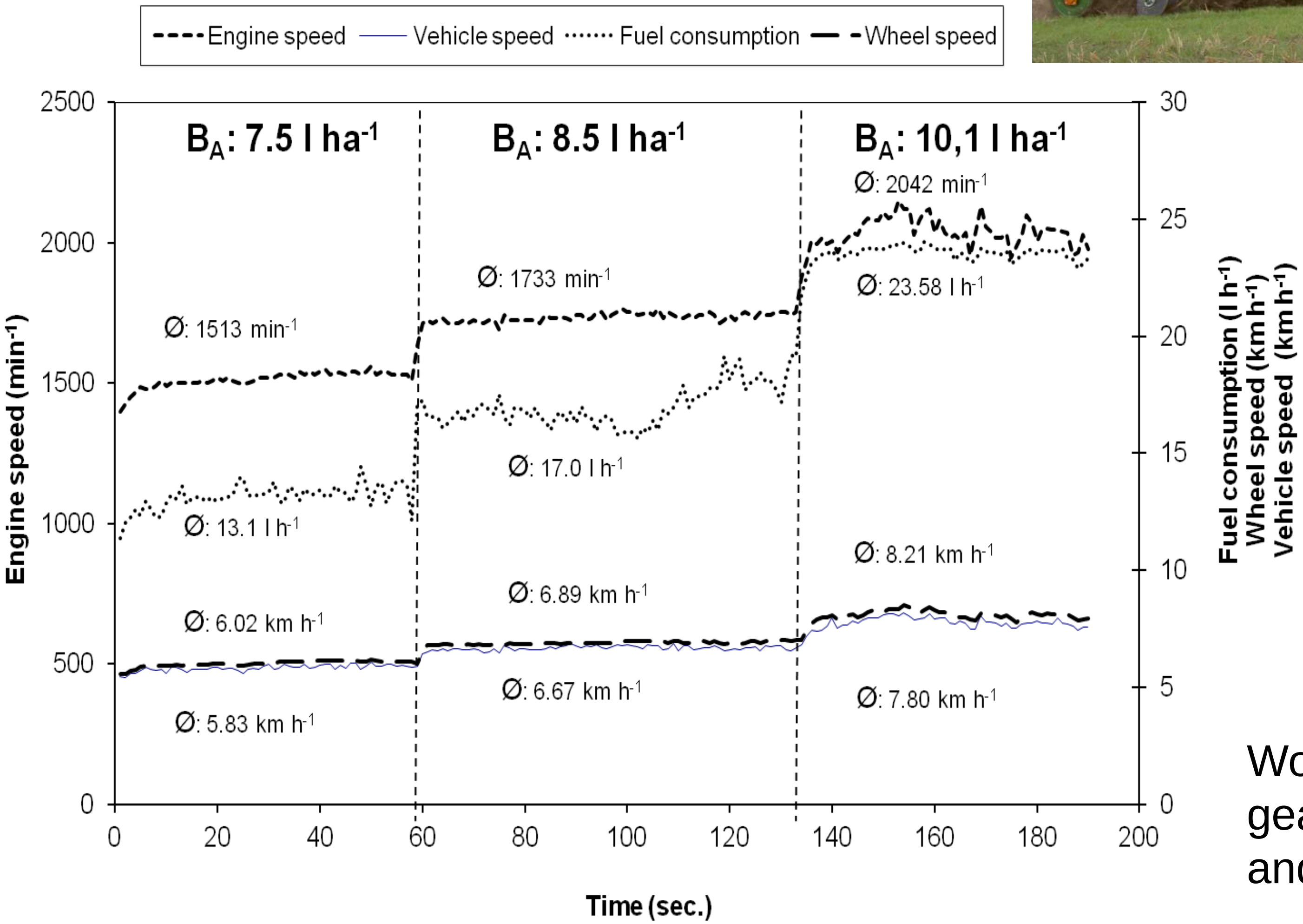
Conclusions

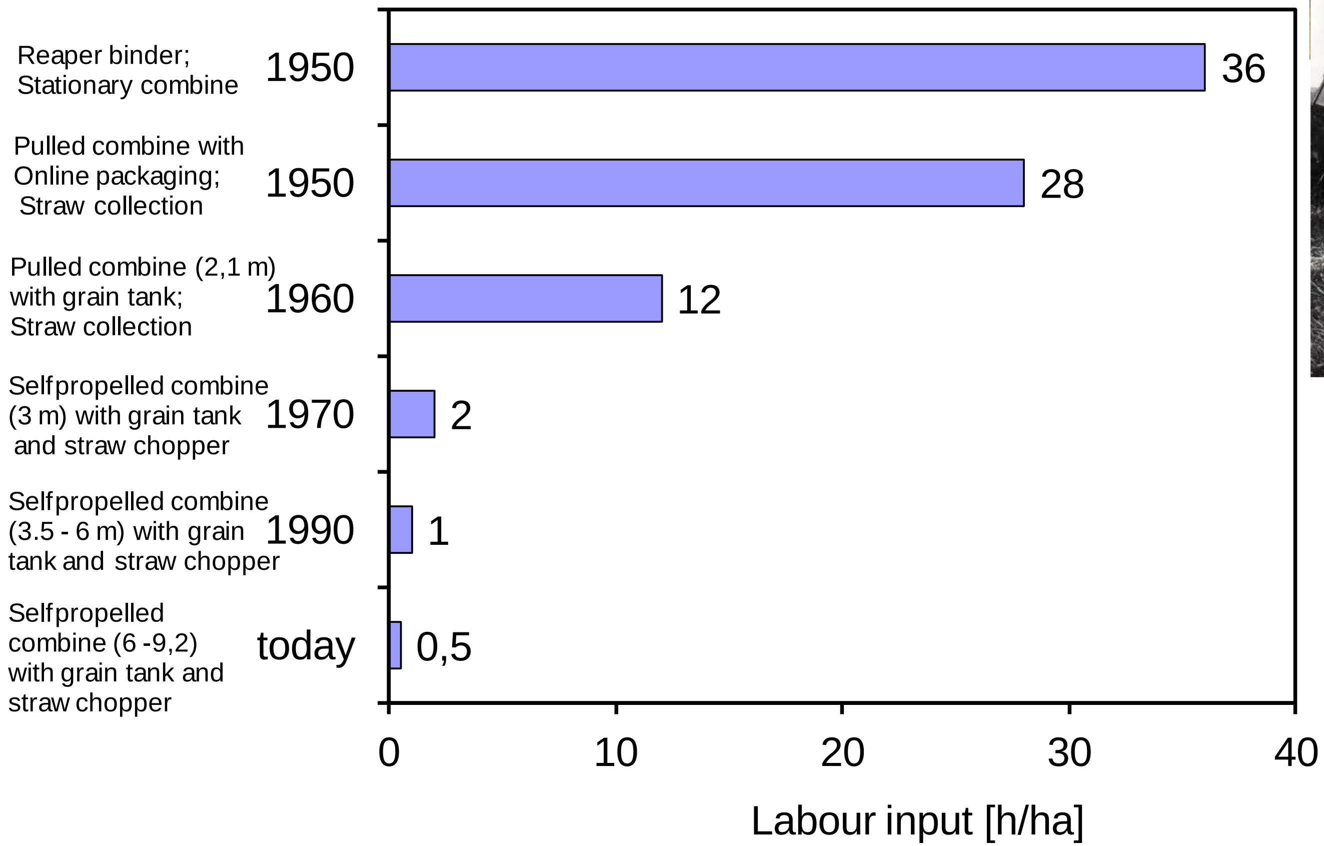
- **Fuel consumption** in cereal cropping is significantly influence by the **soil tillage system.**
- **Conservation soil tillage systems** save fuel and increase the water storage capacity in the soil.
- The shift from soil tillage systems with plough to conservation tillage systems **reduces the direct energy input and improves the energy efficiency.**

Influence of the engine operating point (controlled via engine speed) at cultivation



Working depth 15 cm. gear adjustment: 3. gear and 3. powershift.

Labour input for wheat - harvesting



Source: Bertram; in Flur und Furche 3/2006

Classification of soil tillage systems according intensity and soil covering

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Bodenbearbeitungs- u. Bestellverfahren		Arbeitsabschnitte: Grundbodenbearbeitung	Arbeitsabschnitte: Saatbettbereitung	Arbeitsabschnitte: Saat	Bodenbedeckung nach Saat
Konventionelle Bodenbearbeitung	wendend		oder		bis 15% oder 560 kg/ha
	nicht wendend		oder		15 - 30% oder 560 - 1120 kg/ha
Konservierende Bodenbearbeitung	**Mulchsaat** nicht wendend	oder	oder / oder		> 30 % oder > 1120 kg/ha
		oder			
	Streifensaat streifenweise Lockerung bis 1/3 Reihenweite				
	Direktsaat keine Bodenbearbeitung				

Bild 2: Einteilung der Bodenbearbeitungsverfahren

Nach Loibl & Köller (**Landtechnik Sonderheft 2006**)

Cultivating vs. Ploughing

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Heavy-cultivator (subsoiler) with star distributer and cracker rolls:
working width: 3.0 m
working depth: 15 cm

2 x 4 mouldboard plough – two-way-rear mounted:
working width: 1.7 m
working depth: 15 cm

Real speed: 7,2 km/h

Field performance: 2,2 ha/h

Fuel consumption: 8 l/ha

Real speed: 6,8 km/h

Field performance: 1,2 ha/h

Fuel consumption: 14 l/ha

Soil tillage operations

Location „Gross Enzersdorf“ (soil texture: silty loam)

4-wheel driven tractor: 92 KW

measurement of fuel consumption: volumetric with high performance flow-meter

Conventional Tillage (CT)




Reduced Tillage (RT)



No Tillage (NT)

Location „Tulln“ (soil texture: loamy clay)

4-wheel driven tractor: 110 KW

measurement of fuel consumption: volumetric in three repetitions

Conventional Tillage (CT)



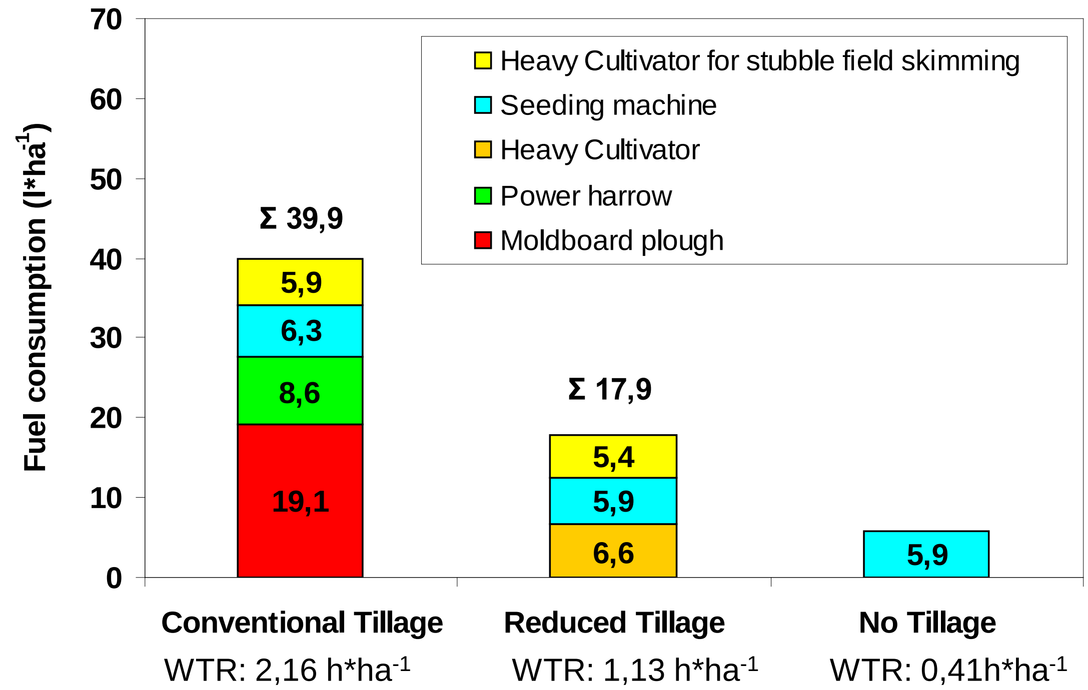
Reduced Tillage (RT)


No Tillage (NT)

Results: fuel consumption

Location: „Gross Enzersdorf“

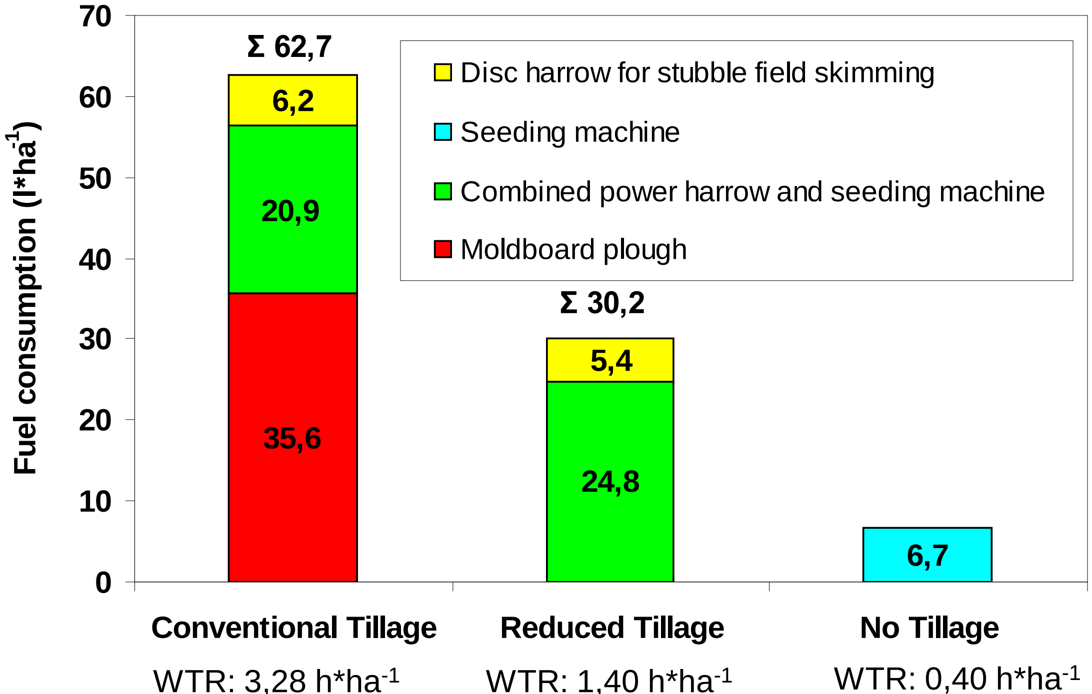
(soil texture: silty loam)



WTR: Working Time Requirement

Location: „Tulln“

(soil texture: loamy clay)

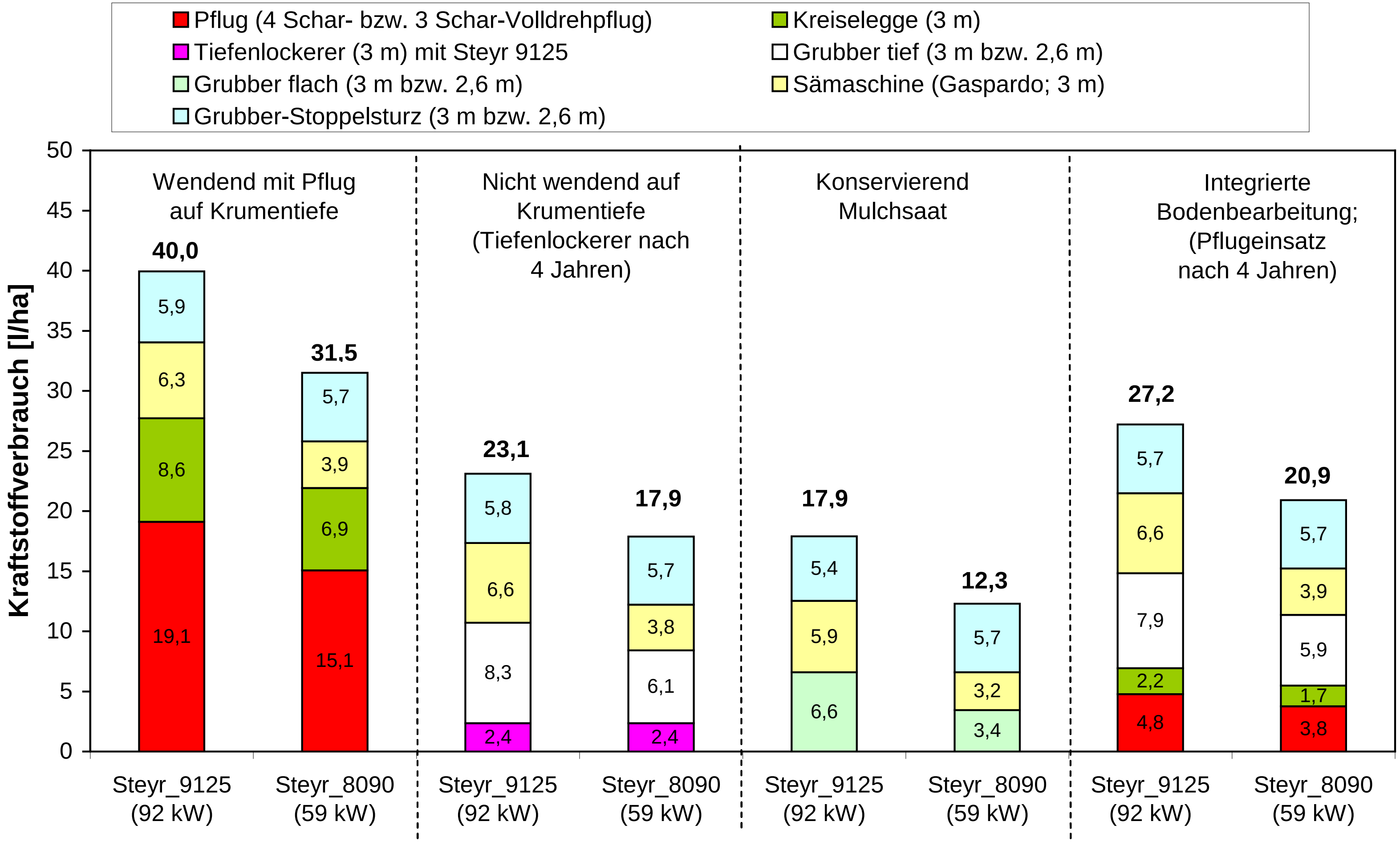


WTR: Working Time Requirement

Kraftstoffverbrauch bei unterschiedlichen Bodenbearbeitungssystemen und Mechanisierung

University of Natural Resources and

Winterweizenanbau, Standort Groß Enzersdorf

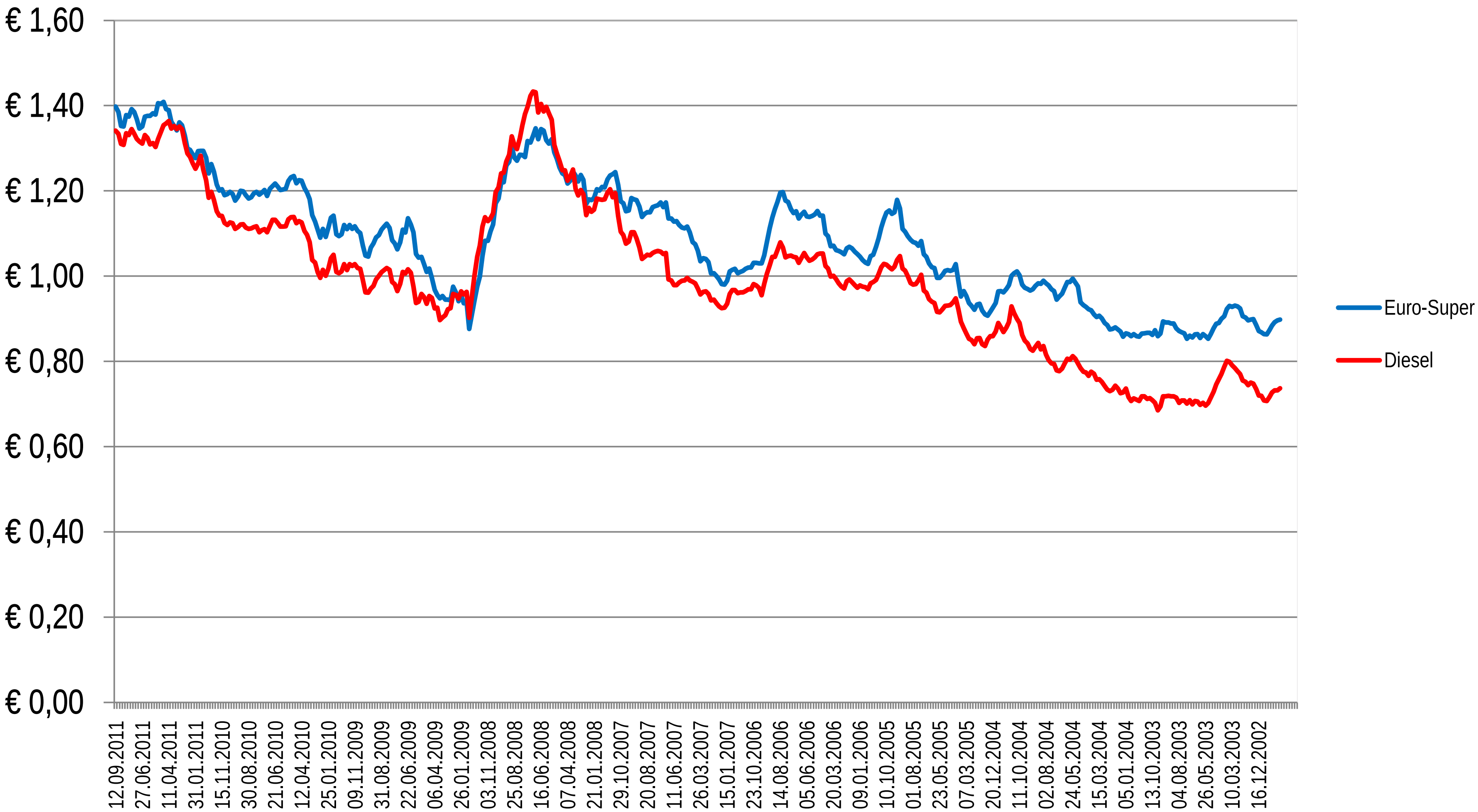


kg CO_2	*104,7*	*82,4*	*60,5*	*47,8*	*46,8*	*32,2*	*71,2*	*54,7*

Kraftstoffverbrauchsmessungen an der Versuchswirtschaft der BOKU in Groß Enzersdorf

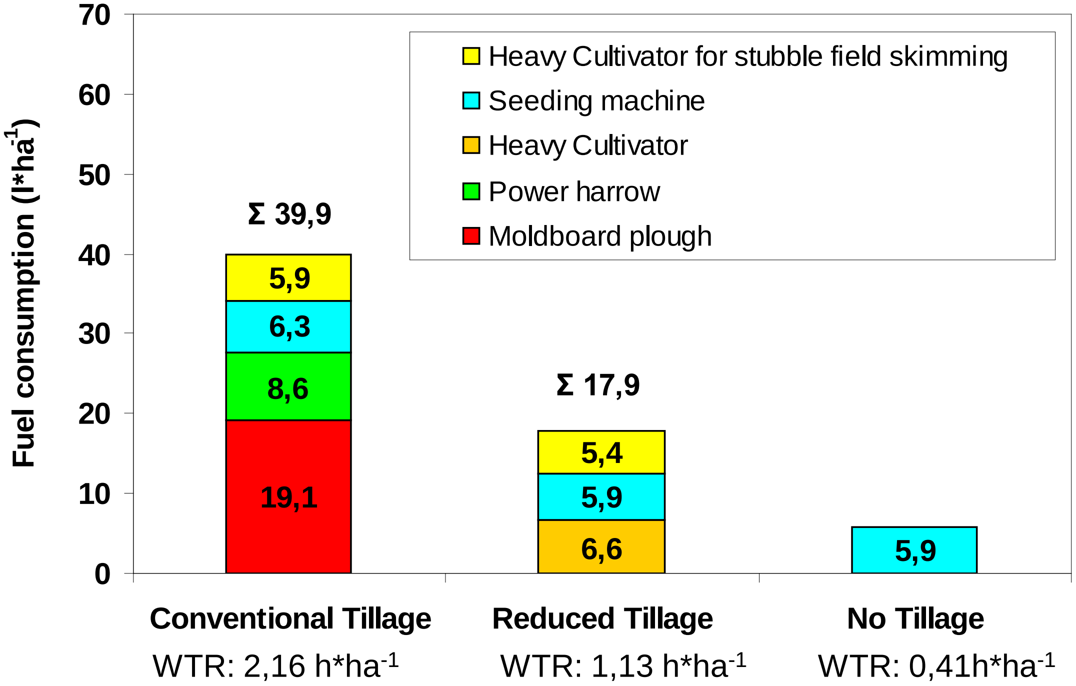
Fuel prices since 2002

Datasource: Austrian Ministry of Economy



1 € = 1.40 CAD

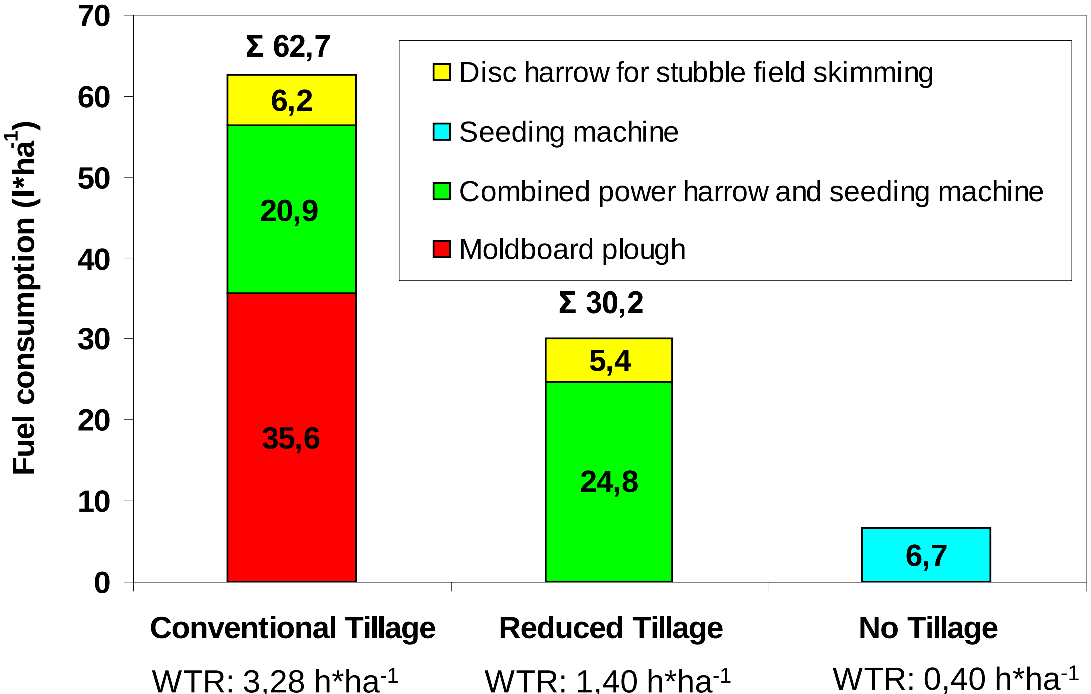
Results: fuel consumption



Location: „Gross Enzersdorf“

(soil texture: silty loam)

WTR: Working Time Requirement



Location: „Tulln“

(soil texture: loamy clay)

WTR: Working Time Requirement

CO_2-emission factors:

Energy
Digestion – Ruminant
N-Fertilization

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Emission source	Mean CO_2-Emission factor	range
Energy – fuel (Diesel)	**2,6 kg CO_2/l** ***0,08 kg/MJ***	**very low**
Energy - electricity	**439 g CO_2/kWh** ***0,12 kg/MJ***	**large:** depends on energy-mix China: 1447 g CO_2/kWh Ø – EU: 652 g CO_2/kWh A: 2020 Ziel 220 g CO_2/kWh
Ruminant - digestion - Methane* (CH_4)	**230 g CO_2**/kg TM-Aufnahme**	**large:** depends on feed stuff; 10 – 40 g CH_4/kg DM-Intake
Agricultural soils – Nitrous oxide* (N_2O)	**3,7 kg CO_2**/kg $N_{gedüngt}$**	**Very large:** International emission factor(IPCC): 0,0125 kg N_2O-N/kg N

* Treibhauspotenzial von Methan ist 23mal und von Lachgas 296mal höher als von Kohlendioxid; ** als CO_2-Äquivalente umgerechnet

Soil tillage system and soil water storage

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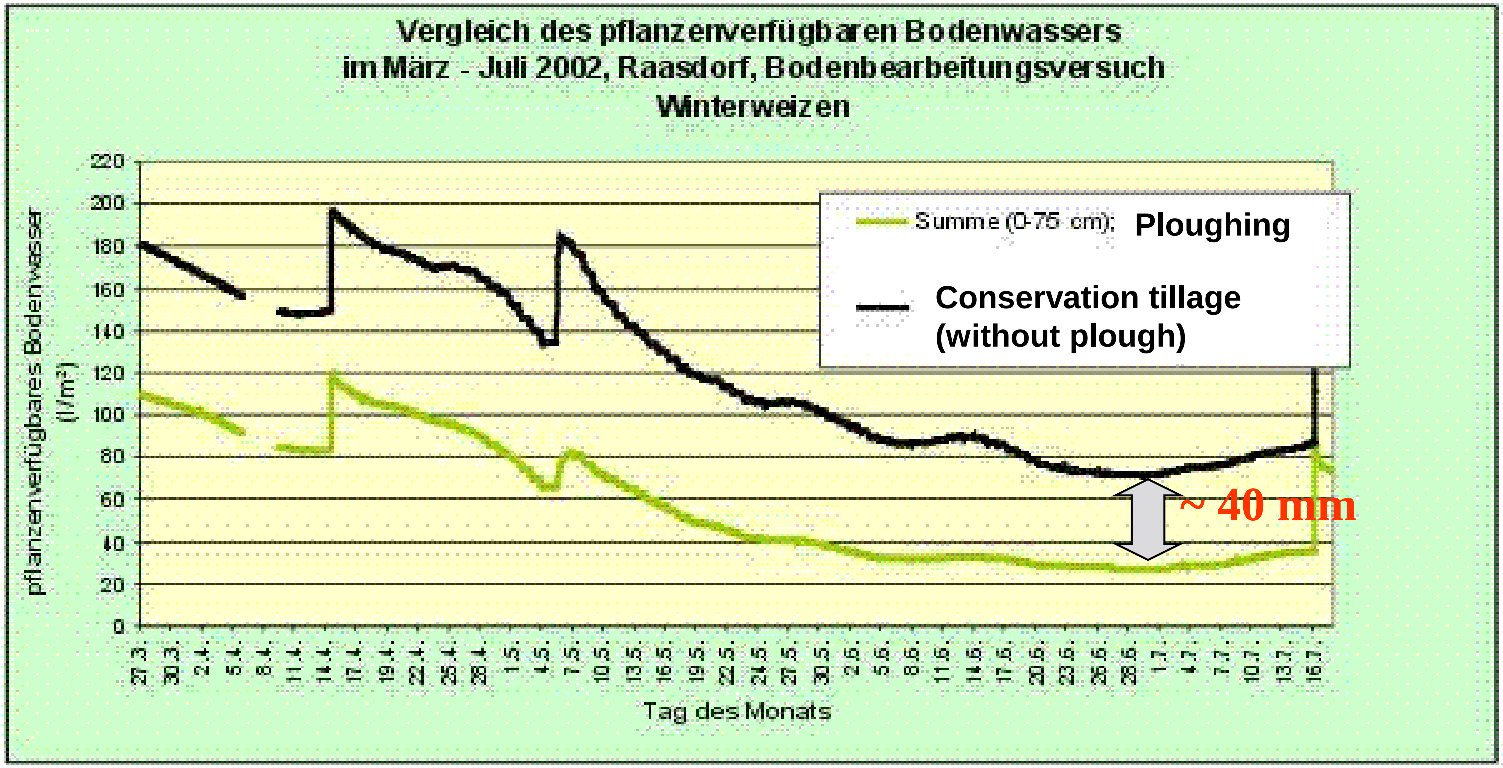

Mittlere Transpiration über die Pflanze:

8 l/m² und Tag

Impact of soil cultivation on soil water storage (Eitzinger et al., 2004)

Overview of the investigations

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The experiments were conducted on the arable fields at the research station Gross Enzersdorf (Lower Austria) of the University of Natural Resources and Life Sciences (BOKU) Vienna.

The experimental site is situated in the semi-arid region with an average rainfall of 546 mm and average temperature of 9.8 °C. The silty loam soil belongs to the soil type Chernozem

	Ploughing	**Stubble field skimming**	**Sub soiling**
Soil tillage device (working width)	2x4 mouldboard plough (170 cm)	Short disc harrow (300 cm)	Subsoiler (300 cm)
Time of investigation	3th November 2005	31st July 2008	21st October 2008
Previous crop	corn	winter rapeseed	corn
Mean water content in the soil (gravimetric)	14.3 % (0-30 cm)	18.3 % (0-20 cm)	16.9 % (0-40 cm)
Mean bulk density	1.35 g/cm^3	1.40 g/cm^3	1.39 g/cm^3

Results – Mouldboard plough

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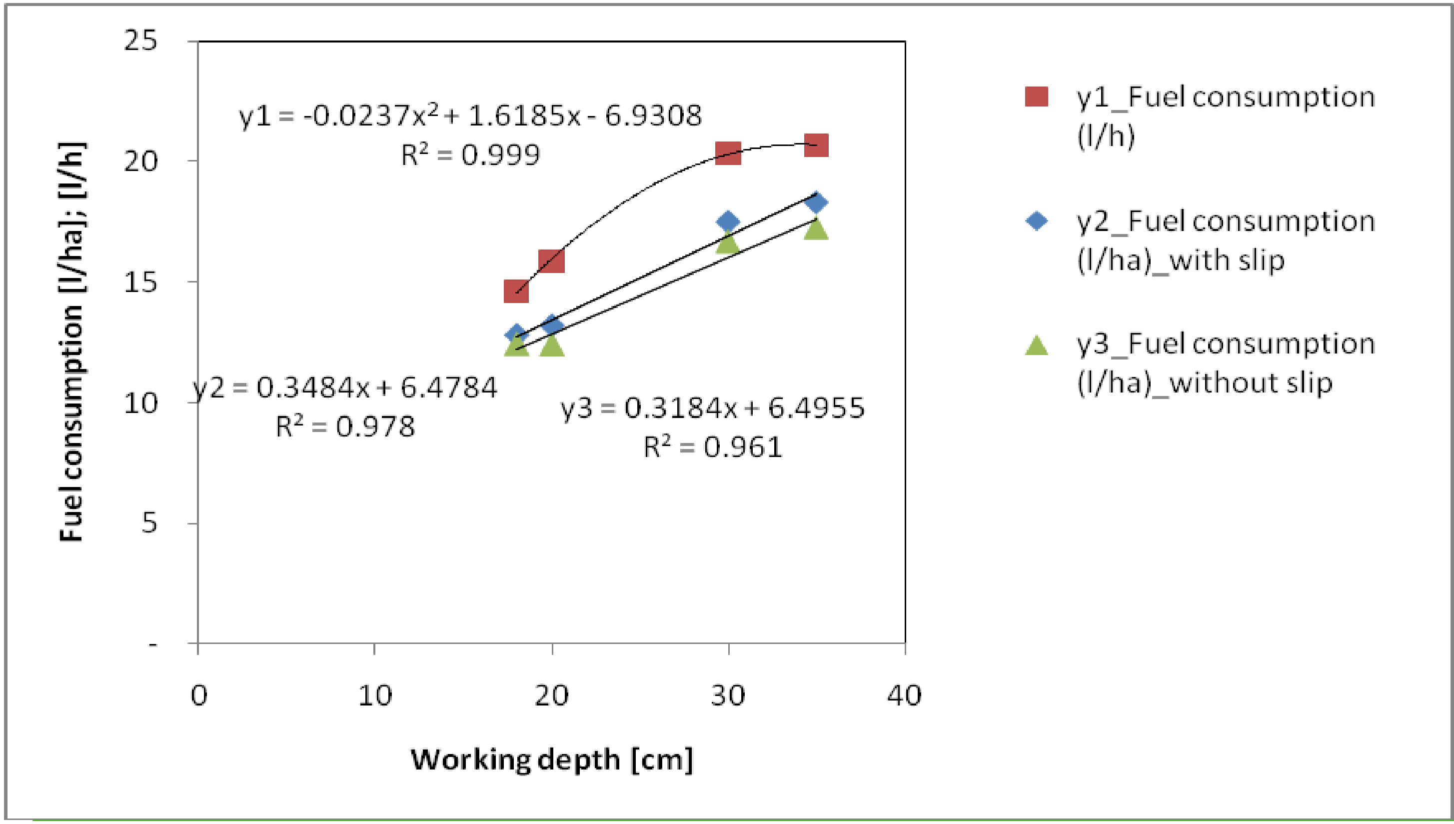
Working depths: 18 cm, 20 cm, 30 cm, 35 cm



Results – Short Disc Harrow

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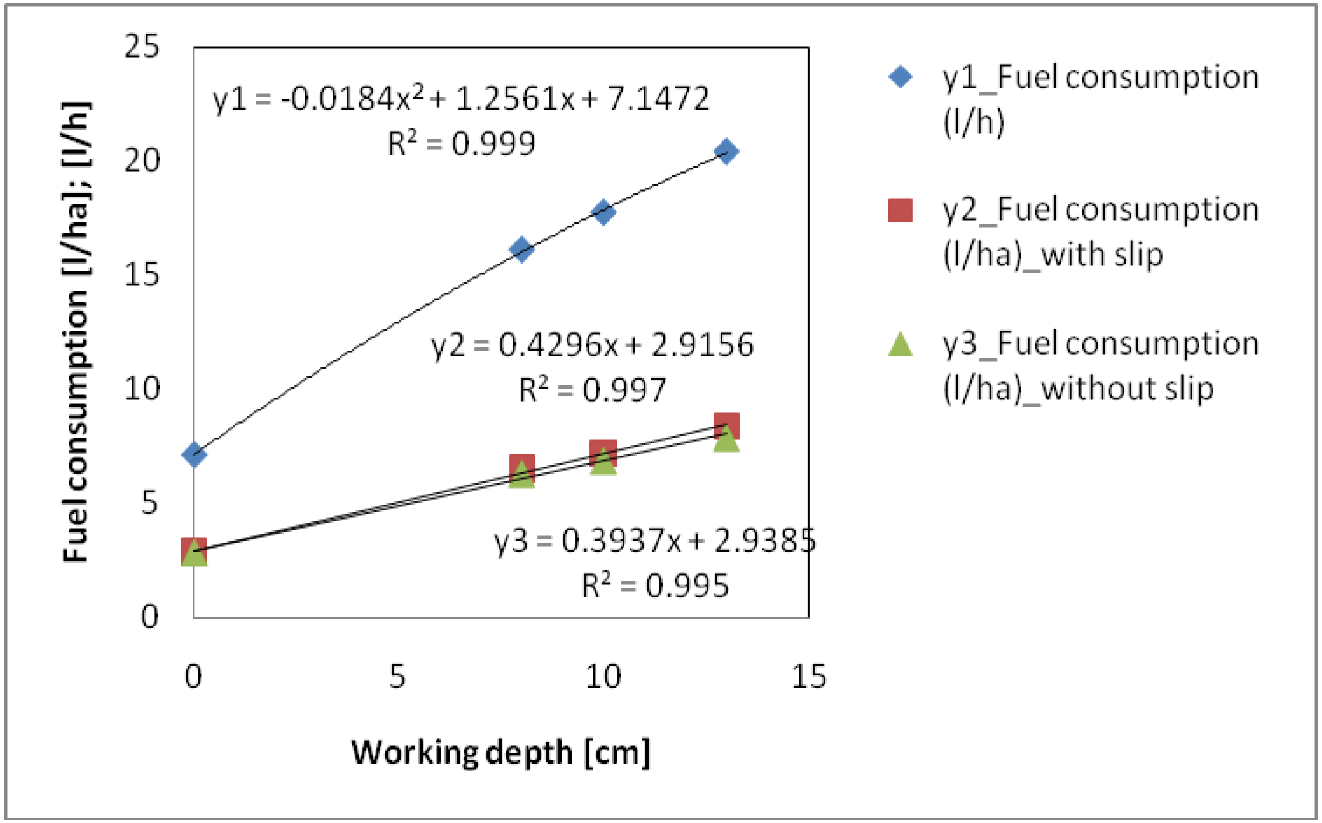
Working depths: 0 cm, 8 cm, 13 cm



Results – Subsoiler

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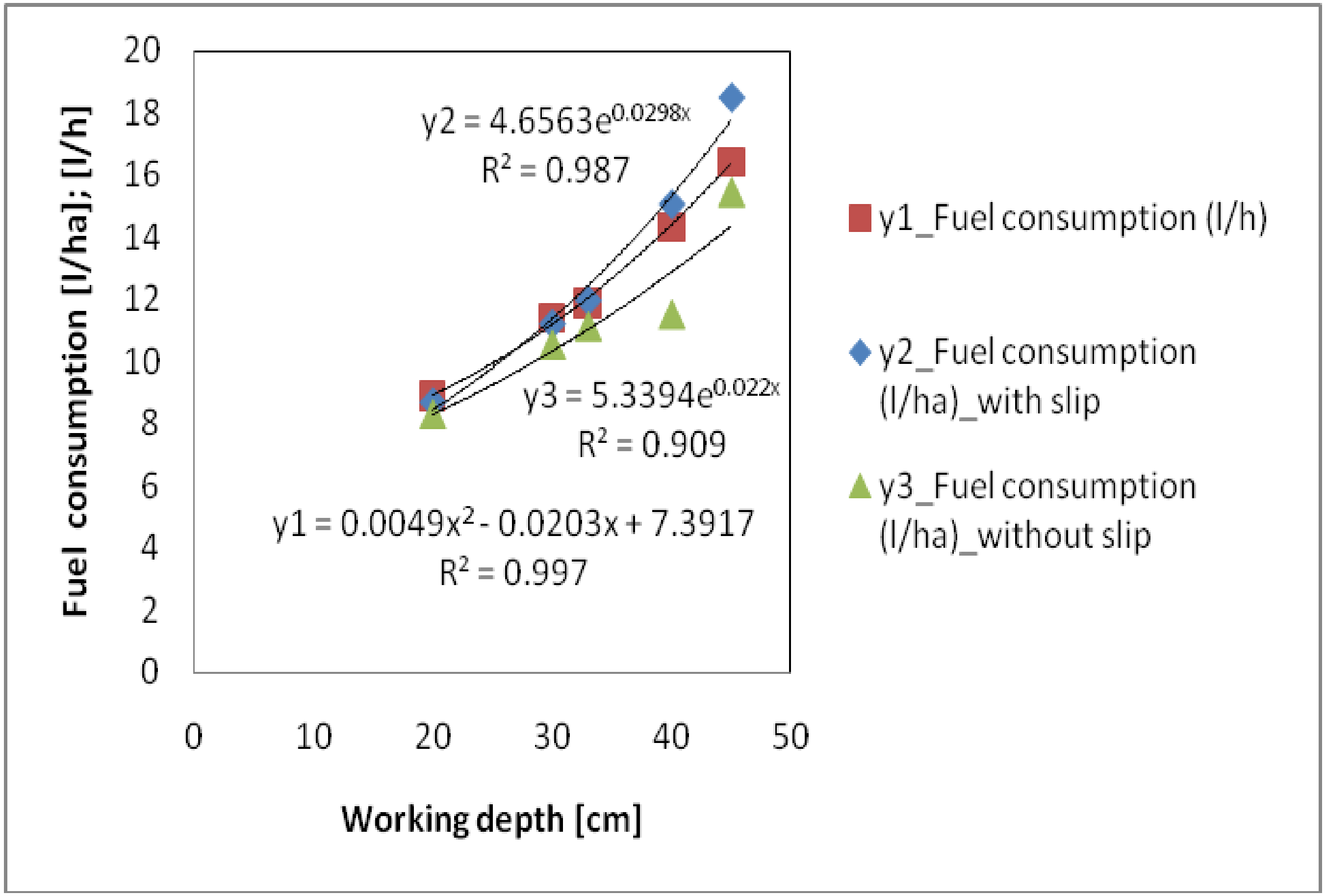
Working depths: 20 cm, 30 cm, 33 cm, 40 cm, 45 cm



Results – Specific energy consumption

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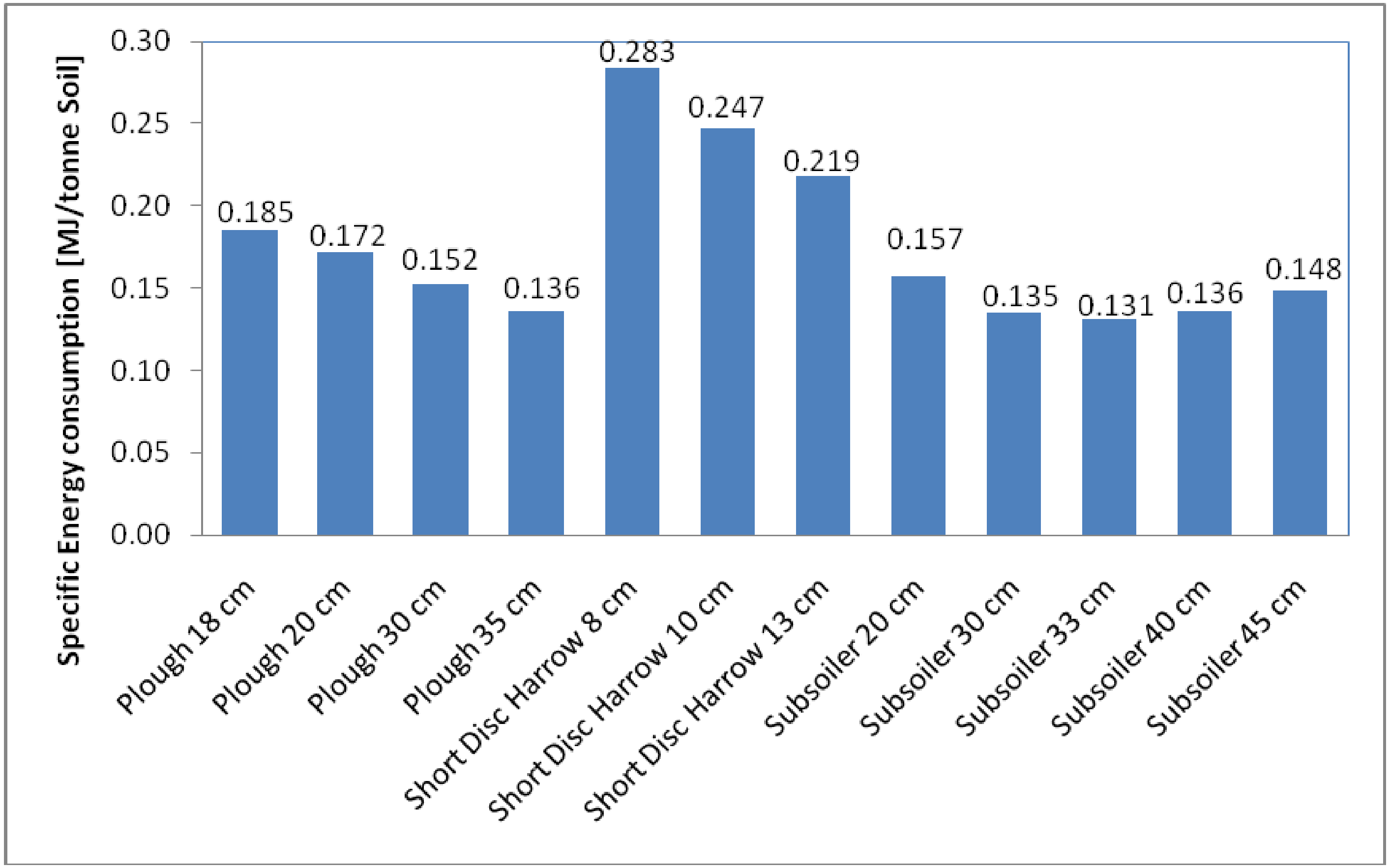

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Conclusions

- The slip in soil tillage is an important factor for analysis of fuel consumption.
- With increasing working depth, the slip rises.
- The fuel consumption [l/ha] increases linearly with working depth for mouldboard plough and short disc harrow.
- For subsoiling the fuel consumption [l/ha] increases disproportionately.

Investigated arable farms with crops share

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	Farm 1	Farm 2	Farm 3	Farm 4	Farm 5
Arable land [ha]	**59.9**	**71.7**	**62.4**	**93.4**	**150.0**
Soft Wheat [%]	22.8	33.1	30.3	34.0	38.0
Durum Wheat [%]	26.9	12.5	20.5	22.5	
Barely [%]	5.3	13.8	3.5	7.8	18.7
Rye [%]	14.8				5.3
Rape seed [%]	13.5		4.7	7.0	
Sun flower [%]			13.5		15.3
Maize (Corn) [%]		12.8			6.0
Sugar beet [%]	4.8	19.3	17.3	12.5	6.0
Potato [%]				9.0	
Green pea [%]		5.3	6.7	4.1	
Meadow [%]					6.7
Vineyard [%]					1.3
Fallow [%]	11.8	3.0	3.4	3.0	2.7

Energy analysis
five conventional arable farms (Lower Austria)

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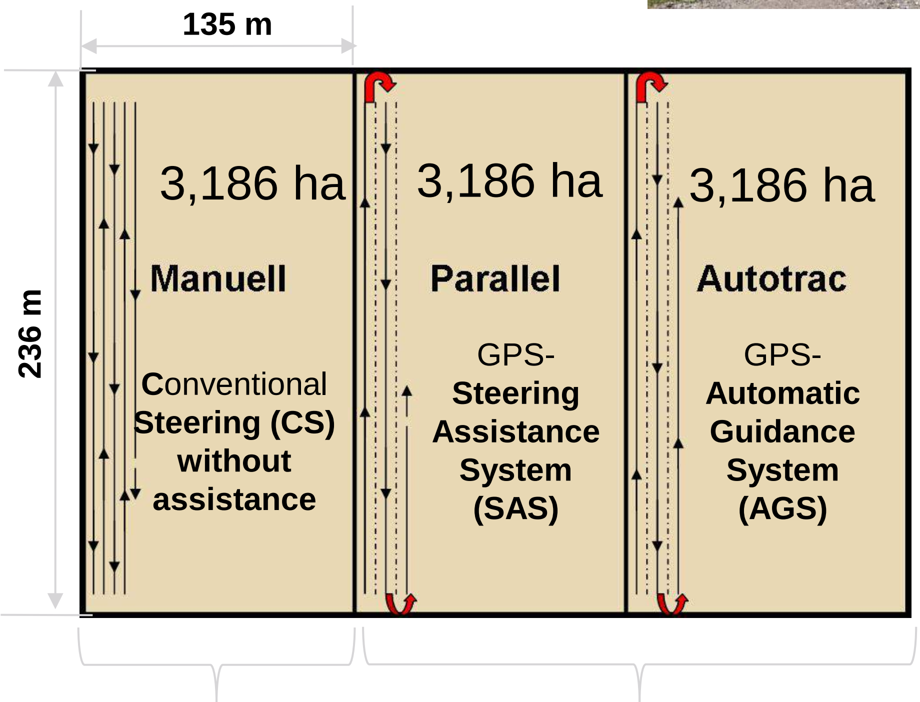
Average temperature	9.5 °C – 10 °C
Average rainfall	500 – 600 mm
Classification of soil texture	loamy clay
Type of soil	Gleyc Chernozem And pure Chernozem

	Farm 1	Farm 2	Farm 3	Farm 4	Farm 5
Energy input [GJ/ha]					
Fertilizer	5.3	4.6	4.1	5.9	4.4
Pesticides	0.7	1.1	0.7	1.0	0.7
Seed	0.6	0.5	0.7	0.9	0.6
Fuel	3.4	5.9	3.0	4.5	4.6
Total Energy input (EI)	**9.9**	**12.2**	**8.5**	**12.2**	**10.3**
Energy output (EO) [GJ/ha]	**86.0**	**133.2**	**92.7**	**119.1**	**104.9**
EO - EI	76.1	121.0	84.2	106.9	94.6
EO/EI-Ratio	8.7:1	10.9:1	10.9:1	9.8:1	10.2:1

Investigation design
Stubble field skimming



John Deere 8530 (261 kW) with SAS/AGS

Short disc harrow (Vogel &Noot; Terra Disc): 5 m

Adjusted working width for virtual guidance: 4,9 m

GPS-receiver (Starfire _SF1)

Conventional turning in a so-called „Swallowtail-turn“

„affiliation drive“

Turning event in a semicircle;

„Bed-modus“
Each second track

For each trial following parameters are measured:

- Fuel consumption (tractor terminal and volumetric measurement)
- Working time for turning and field operation
- System accuracy

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Results: Fuel consumption
for stubble skimming (field size: 3,186 ha)

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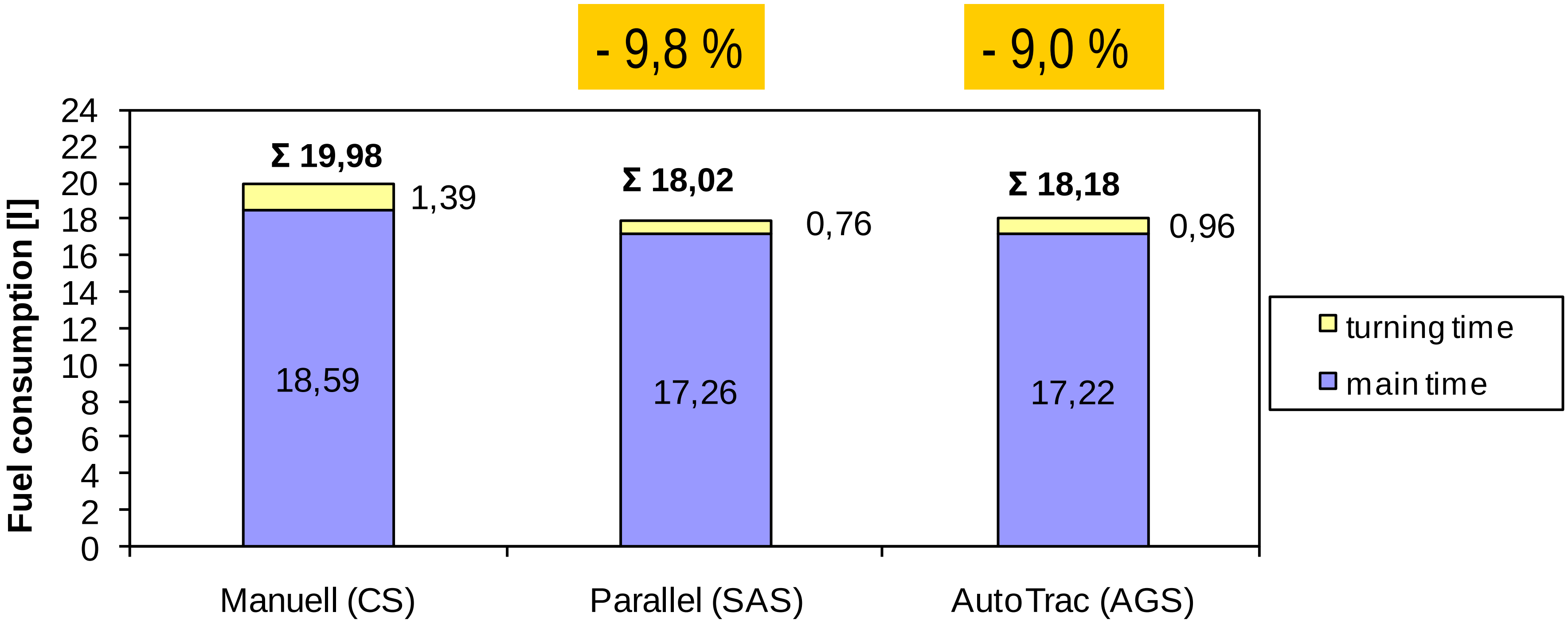

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Results: Field working time
for stubble skimming (field size: 3,186 ha)

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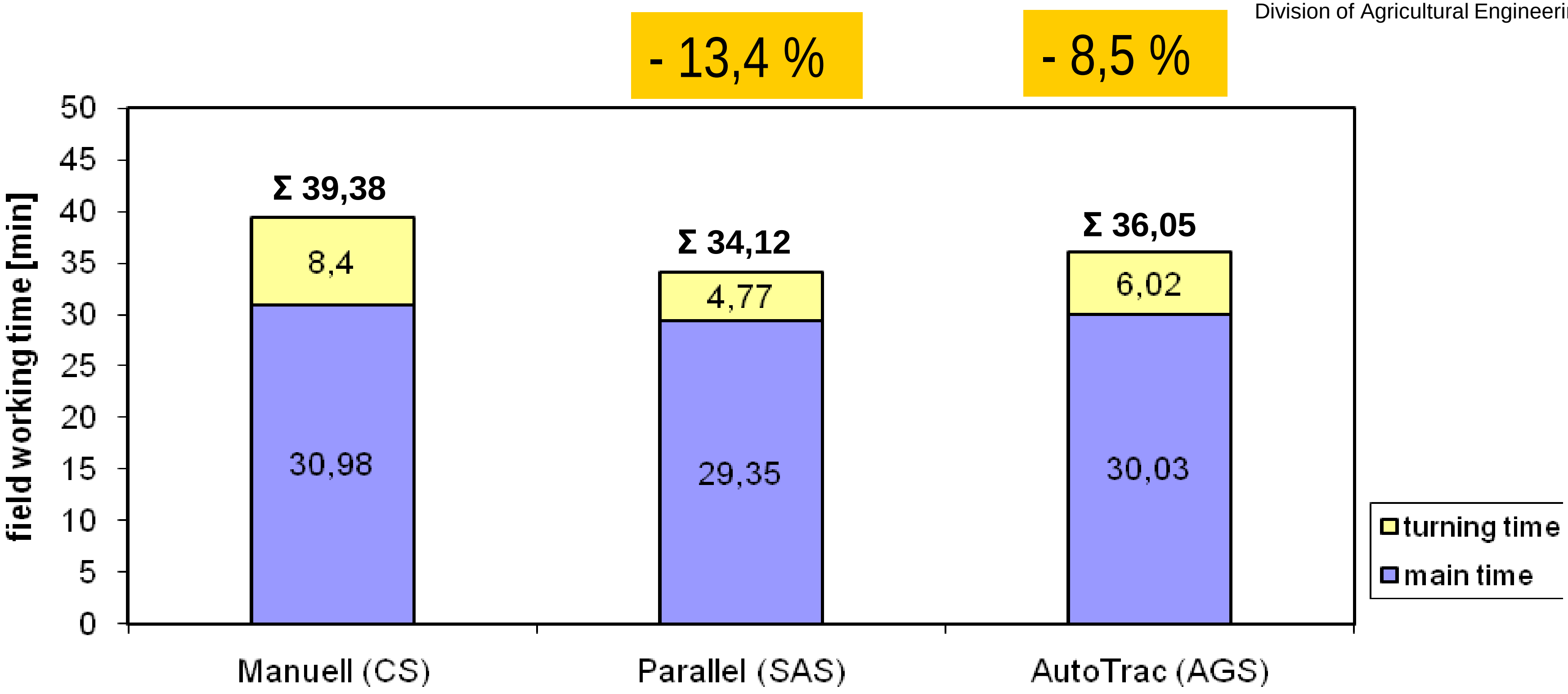

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Results: Measured time per turning event

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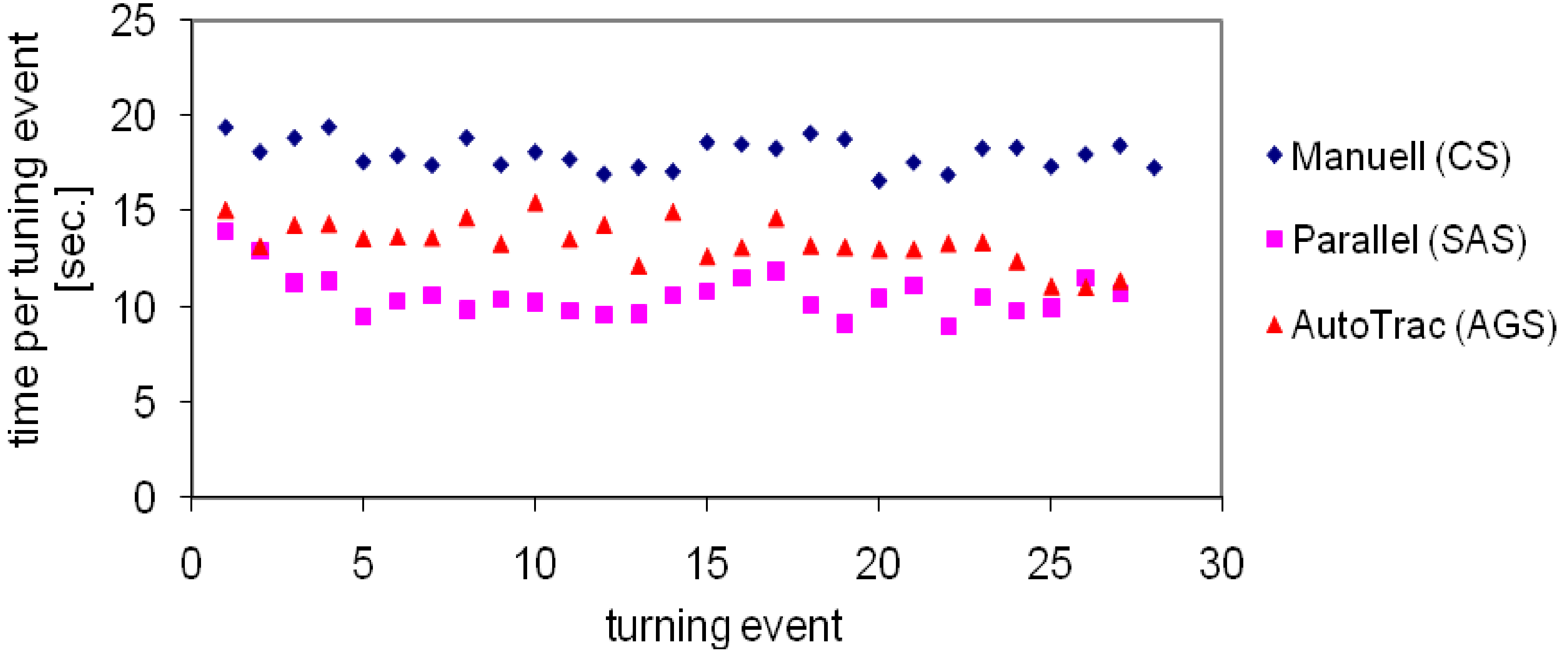

Ø: 17,4

Ø: 10,6

Ø: 13,4

Results:
System accuracy and overlapping degree

Manuell (CS): no untreated stripes

Parallel (SAS): partial stripes (driver influence)

Autotrac (AGS): no untreated stripes

	Set width* [m] a	Treated width measured [m] b	a-b [m]	Overlapping per pass [cm]	Overlapping per pass [%]
Manuell (CS)	130	122,10	7,90	30,30	6,07
Parallel (SAS)	130	128,05	1,95	7,50	1,50
AutoTrac (AGS)	130	128,29	1,71	6,60	1,32

*** 26 passes x 5 m theoretical working width = 130 m**

Energy consumption for Transport

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Lorry

Total weight: 40 Tonne

Transported payload: 25 Tonnen

Average fuel consumption: 31 Liter/100 km

Specific fuel consumption: 12,4 ml/t*km => 0,436 MJ/t*km

Specific CO_2-emission: 812 g/km

Tractor with two trailers

Total weight: 30 Tonne

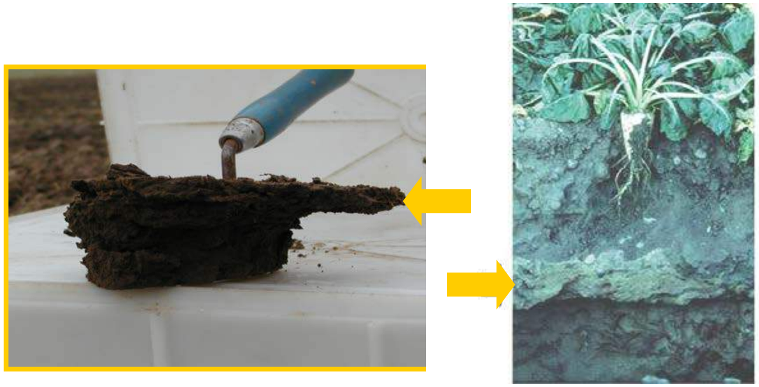
Transported payload: 16.5 Tonnen

Average fuel consumption: 45 Liter/100 km

Specific fuel consumption: 27,3 ml/t*km

Specific CO_2-emission: 1179 g/km

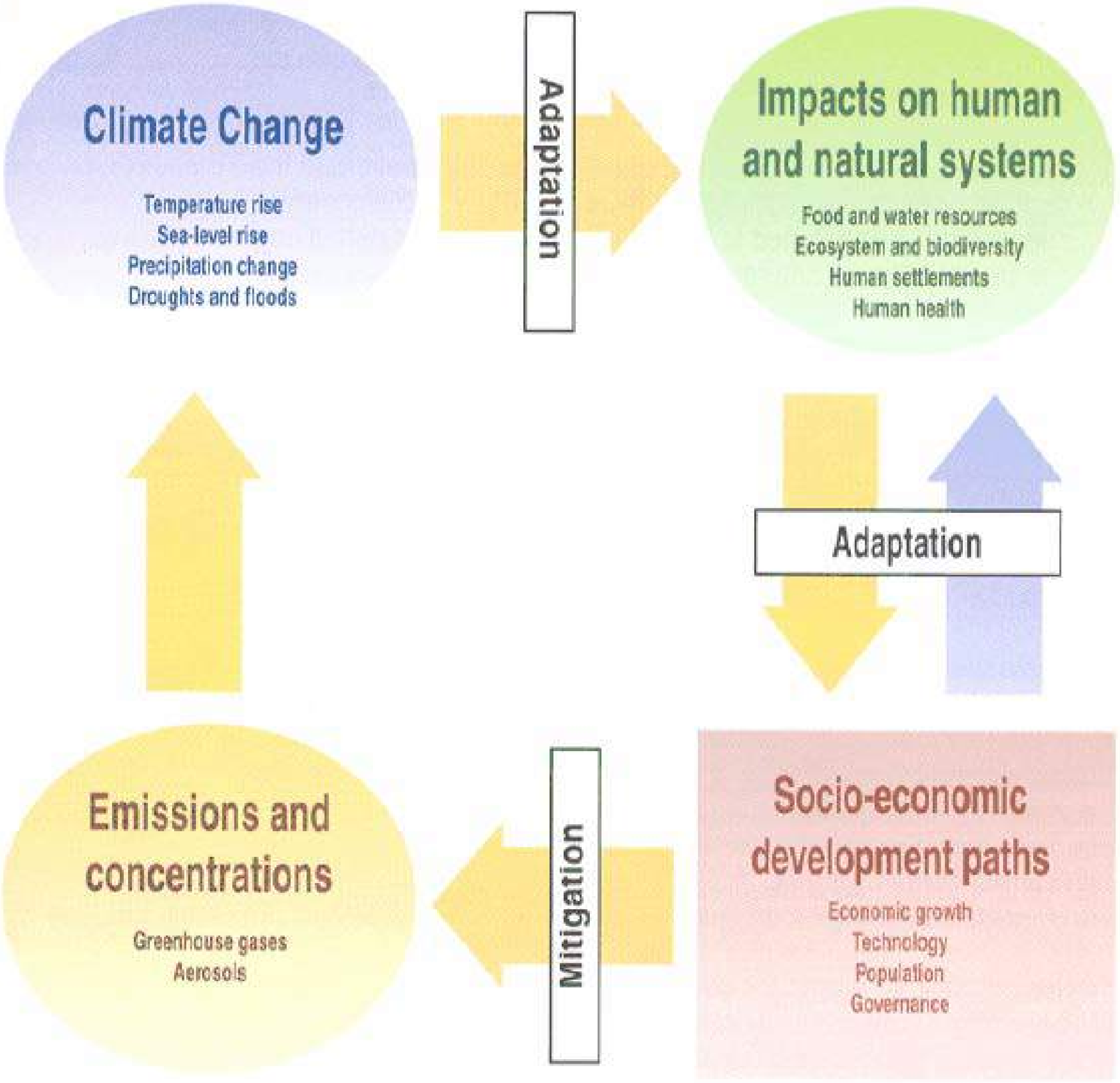
Traffic induced soil compaction



Technical repair solutions

Agraria; Cluj: 2006

USAMV;
Department for Mechanization 2006



Univ. Prof. Eitzinger (BOKU Wien, 2007)

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http://www.adagio-eu.org/

ADAptation of AGriculture in European RegIOns at Environmental Risk under Climate Change

Anpassung der Landwirtschaft in gefährdeten Europäischen Regionen an den Klimawandel

N-Düngungsvarianten und Düngungszeitpunkte

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Standort Wagna

Düngungs-variante	2007	2008	2009	2010	2011	2012
0 kg N						
90 kg N[1)]	UF: 16.4. RD: 8.6.	UF: 21.4. RD: 3.6.	UF: 17.4. RD: 26.5.	UF: 17.4. RD: 31.5.	UF: 13.4. RD: 30.5.	UF: 13.4. RD: 31.5.
115 kg N[2)]	UF: 16.4. RD: 8.6.	UF: 21.4. RD: 3.6.	UF: 17.4. RD: 26.5.	UF: 17.4. RD: 31.5.	UF: 13.4. RD: 30.5.	UF: 13.4. RD: 31.5.
Schweine-gülle[3)]	16.4., 73 kg N_{ff} 8.6., 73 kg N_{ff} *Σ 146 kg N_{ff}*	16.4., 83 kg N_{ff} 3.6., 81 kg N_{ff} *Σ 164 kg N_{ff}*	16.4., 62 kg N_{ff} 26.5., 55 kg N_{ff} *Σ 117 kg N_{ff}*	14.4., 62 kg N_{ff} 31.5., 80 kg N_{ff} *Σ 142 kg N_{ff}*	11.4., 55 kg N_{ff} 30.5., 60 kg N_{ff} *Σ 115 kg N_{ff}*	11.4., 51 kg N_{ff} 31.4., 73 kg N_{ff} *Σ 124 kg N_{ff}*
145 kg N[4)]	UF: 16.4. RD: 8.6.	UF: 21.4. RD: 3.6.	UF: 17.4. RD: 26.5.	UF: 17.4. RD: 31.5.	UF: 13.4. RD: 30.5.	UF: 13.4. RD: 31.5.
175 kg N[5)]	UF: 16.4. RD1: 10.5. RD2 : 8.6.	UF:21.4. RD1: 13.5. RD: 3.6.	UF:17.4. RD1: 10.5. RD: 26.5.	UF:17.4. RD1: 11.5. RD: 31.5.	UF:13.4. RD1: 10.5. RD: 30.5.	UF:13.4. RD1: 10.5. RD: 31.5.

[1)] 45 kg N in KAS (Kalkammonsalpeter, 26 % N) als Unterfußdüngung (UF), 45 kg N in KAS als Reihendüngung (RD)
[2)] 55 kg N in KAS als Unterfußdüngung (UF), 60 kg N in KAS als Reihendüngung (RD)
[3)] 1. Gabe mit Gülletankwagen + Pralltellter vor dem Anbau - anschließend eingeeggt, 2. Gabe mit Gülletankwagen + Schleppschlauchverteiler (SS), Berechnung des feldfallenden N (N_{ff}= 87 % von N_{total}), N_{total} wurde chemisch analysiert, Gesamtmengen zw. 23 und 45 m^3/ha
[4)] 55 kg N in KAS als Unterfußdüngung (UF), 90 kg N in KAS als Reihendüngung (RD)
[5)] 55 kg N in KAS als Unterfußdüngung (UF), 60 kg und 60 kg N in KAS als Reihendüngung (RD)

N-Düngungsvarianten und Düngungszeitpunkte

University of Natural Resources and Life Sciences, Vienna
Department of Sustainable Agricultural Systems

Standort Wagendorf

Düngungs-variante	2008	2009	2010	2011	2012
0 kg N					
90 kg N[1)]	UF: 11.4. RD: 2.6.	UF: 8.4. RD: 26.5.	UF: 19.4. RD: 1.6.	UF: 9.4. RD: 30.5.	UF: 11.4. RD: 4.6.
115 kg N[2)]	UF: 11.4. RD: 2.6.	UF: 8.4. RD: 26.5.	UF: 19.4. RD: 1.6.	UF: 9.4. RD: 30.5.	UF: 11.4. RD: 4.6.
Schweine-gülle[3)]	11.4., 55 kg N_{ff} 3.6., 66 kg N_{ff} *Σ 121 kg* N_{ff}	8.4., 55 kg N_{ff} 26.5., 60 kg N_{ff} *Σ 115 kg* N_{ff}	15.4., 36 kg N_{ff} 1.6., 60 kg N_{ff} *Σ 96 kg* N_{ff}	7.4., 55 kg N_{ff} 30.5., 60 kg N_{ff} *Σ 115 kg* N_{ff}	11.4., 45 kg N_{ff} 4.6., 49 kg N_{ff} *Σ 94 kg* N_{ff}
145 kg N[4)]	UF: 11.4. RD: 2.6.	UF: 8.4. RD: 26.5.	UF: 19.4. RD: 1.6.	UF: 9.4. RD: 30.5.	UF: 11.4. RD: 4.6.
175 kg N[5)]	UF: 11.4. RD1: 13.5. RD2: 2.6.	UF: 8.4. RD1: 10.5. RD2: 26.5.	UF: 19.4. RD1: 10.5. RD2: 1.6.	UF: 9.4. RD1: 11.5. RD2: 30.5.	UF: 11.4. RD1: 10.5. RD2: 4.6.
210 kg N[6)]	UF: 11.4. RD1: 13.5. RD2: 2.6.	UF: 8.4. RD1: 10.5. RD2: 26.5.	UF: 19.4. RD1: 10.5. RD2: 1.6.	UF: 9.4. RD1: 11.5. RD2: 30.5.	UF: 11.4. RD1: 10.5. RD2: 4.6.

1) 45 kg N in KAS (Kalkammonsalpeter, 26 % N) als Unterfußdüngung (UF), 45 kg N in KAS als Reihendüngung (RD)
2) 55 kg N in KAS als Unterfußdüngung (UF), 60 kg N in KAS als Reihendüngung (RD)
3) 1. Gabe mit Gülletankwagen + Pralltellervor dem Anbau - anschließend eingeeggt, 2. Gabe mit Gülletankwagen + Schleppschlauchverteiler (SS), Berechnung des feldfallenden N (N_{ff}=87 % von N_{total}), Gesamtmengen zw. 29 und 58 m^3/ha
4) 55 kg N in KAS als Unterfußdüngung (UF), 90 kg N in KAS als Reihendüngung (RD)
5) 55 kg N in KAS als Unterfußdüngung (UF), 60 kg und 60 kg N in KAS als Reihendüngung (RD)
6) 70 kg N in KAS als Unterfußdüngung (UF), 70 kg und 70 kg N in KAS als Reihendüngung (RD)

Energieeffizienz in Abhängigkeit der mineralischen N-Düngung

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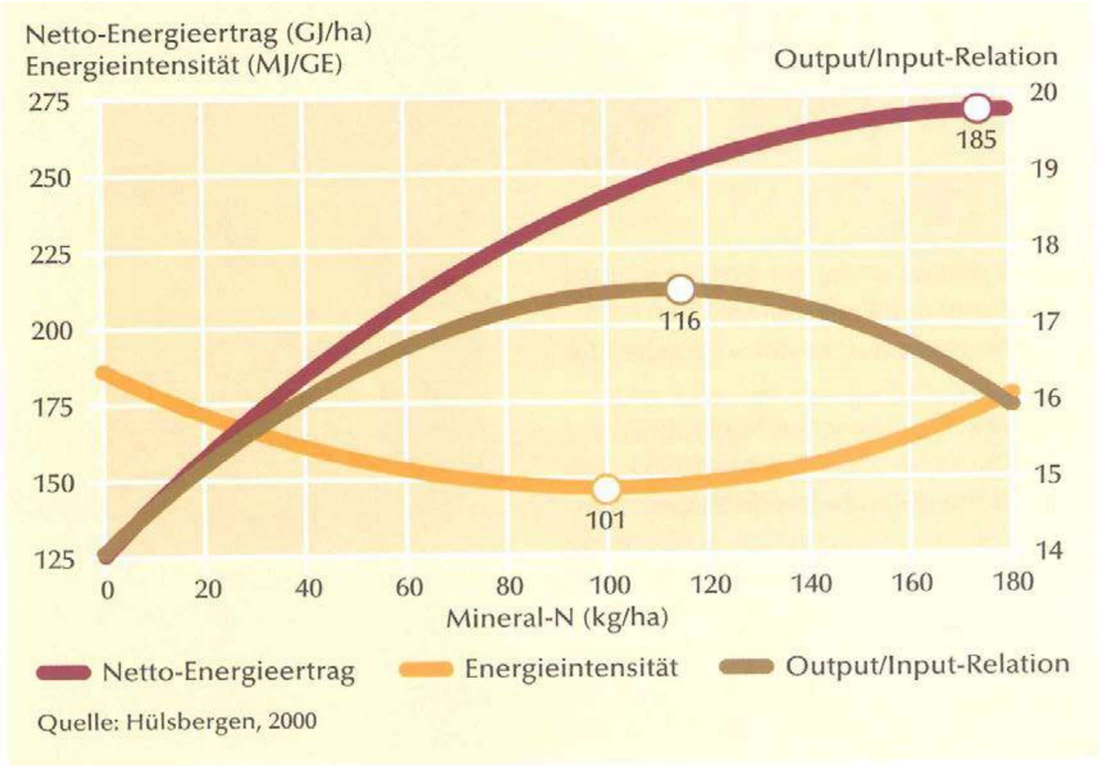

Der maximale Winterweizenertrag wird bei 185 kg N/ha erzielt. Interpretiert man dagegen die N-Steigerungskurve aus energetischer Sicht – geringe Energieintensität und optimales Aufwand/Ertrag-Verhältnis – wäre ein Düngungsniveau zwischen 100 und 120 kg Mineral-N optimal. Dies hätte jedoch einen energetischen Minderertrag von ca. 20 GJ/ha zur Folge. Winterweizen, der mit 180 kg N/ha und mehr gedüngt wird, hat zwar einen höheren Energieertrag, die N-Effizienz ist jedoch schlechter.

Energetische Kennzahlen:

=> Energieintensität (MJ/kg) =

Energieeinsatz (MJ/ha)/Kornertrag$_{Korn(14\%)}$ (kg/ha)

=> Energieoutput/Energieinput-Verhältnis =

Energieoutput$_{Korn(14\%)}$ (MJ/ha)/Energieeinsatz (MJ/ha)

=> Netto-Energieoutput =

Energieoutput$_{Korn\ (14\%)}$ (MJ/ha) - Energieeinsatz (MJ/ha)

DLG-Mitteilungen 5/2009