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Energy consumption in plant cropping with special consideration on soil tillage

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CO_2-enrichment in the atmosphere

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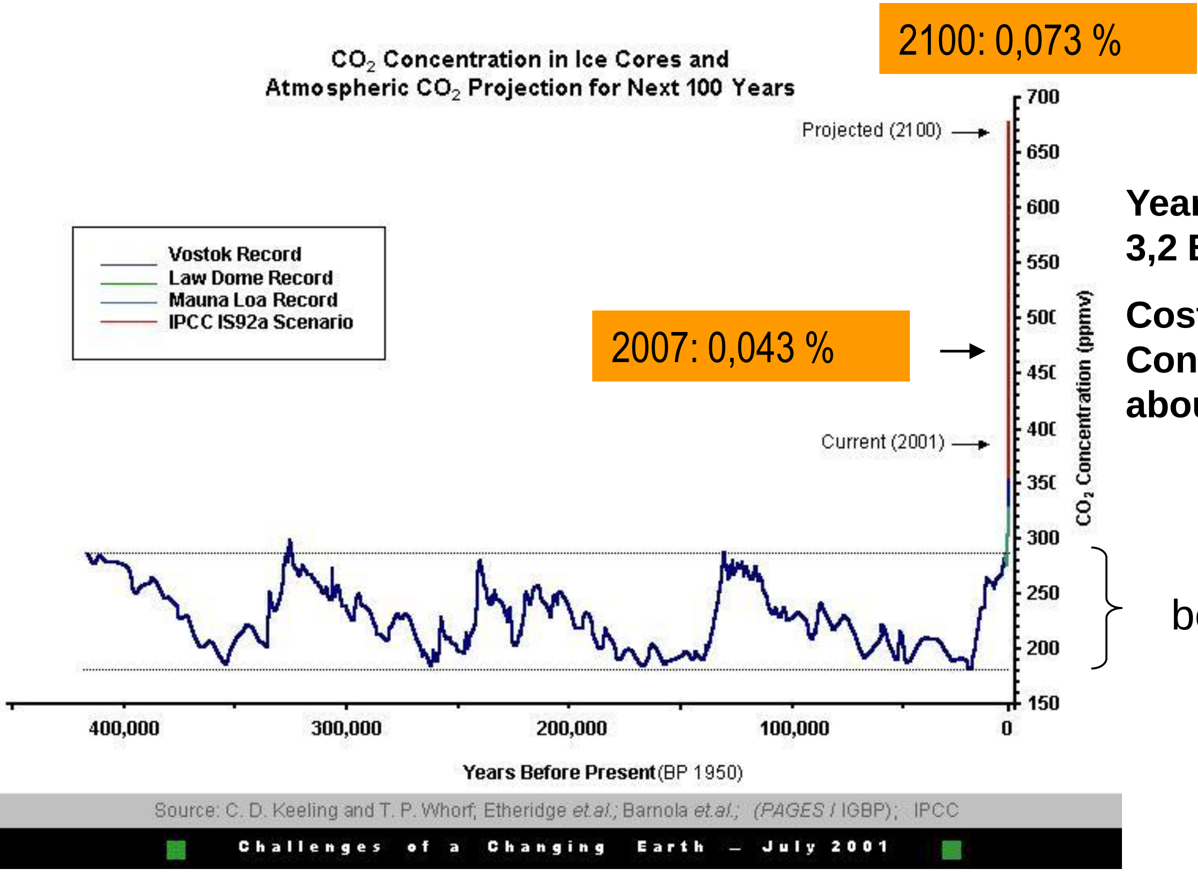
⇒ Greenhouse Gases GHG (**CO_2, CH_4, N_2O**)

⇒ 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 %

CO_2-mitigation strategie

„energy efficiency“

renewable energy

biomass utilization

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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

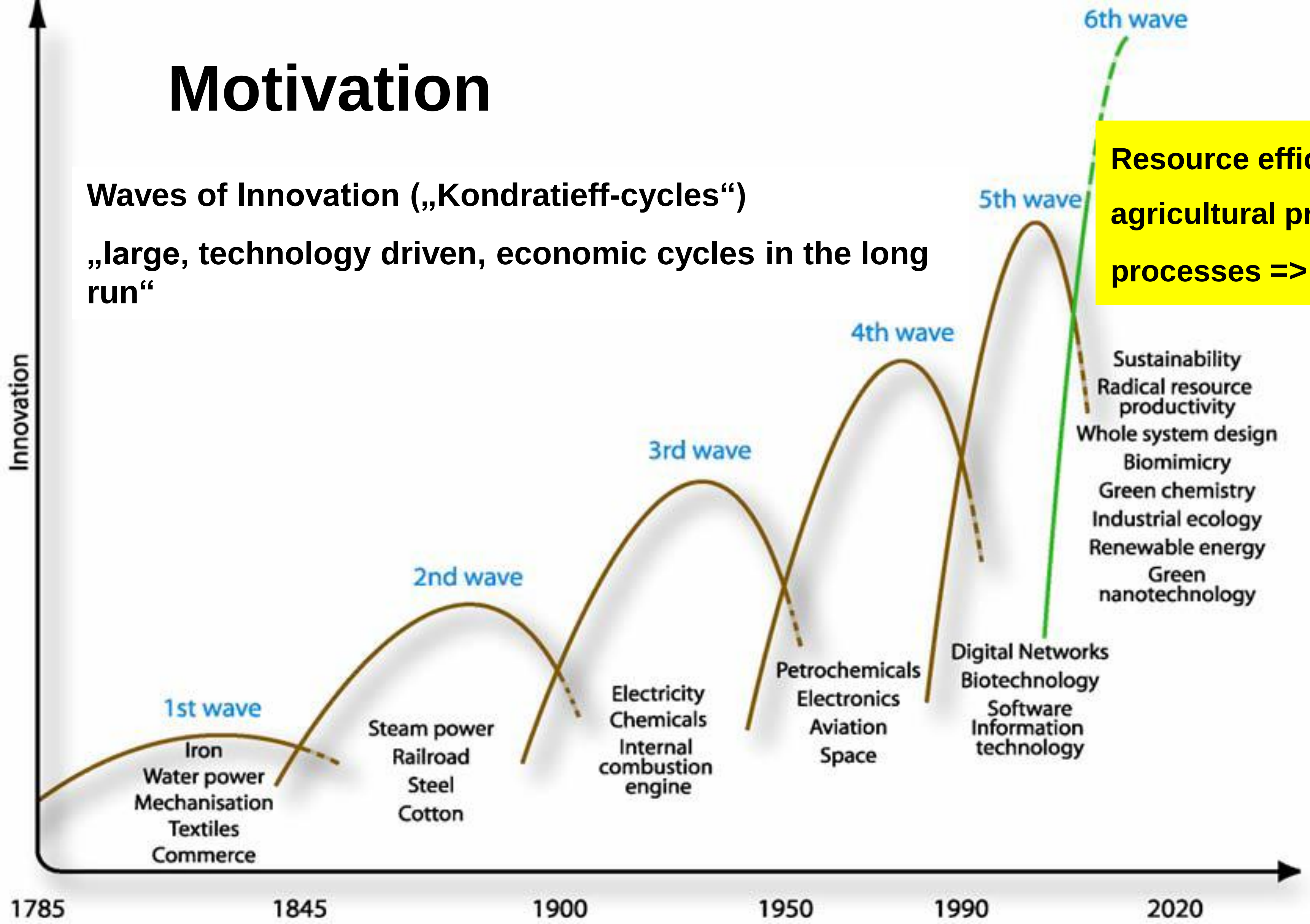
Till 2010: 5,75 % biofuel share
Till 2020: min. 10 % biofuel share

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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$$6\ CO_2 + 12\ H_2O + PAR \xrightarrow{\text{Cholorophyll}} C_6H_{12}O_6 + 6\ O_2 + 6H_2O$$

+ 2782 kJ/mol

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

Energy saving through targeted or reduced application of farm facilities

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

ural



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

- „**Precision farming**“

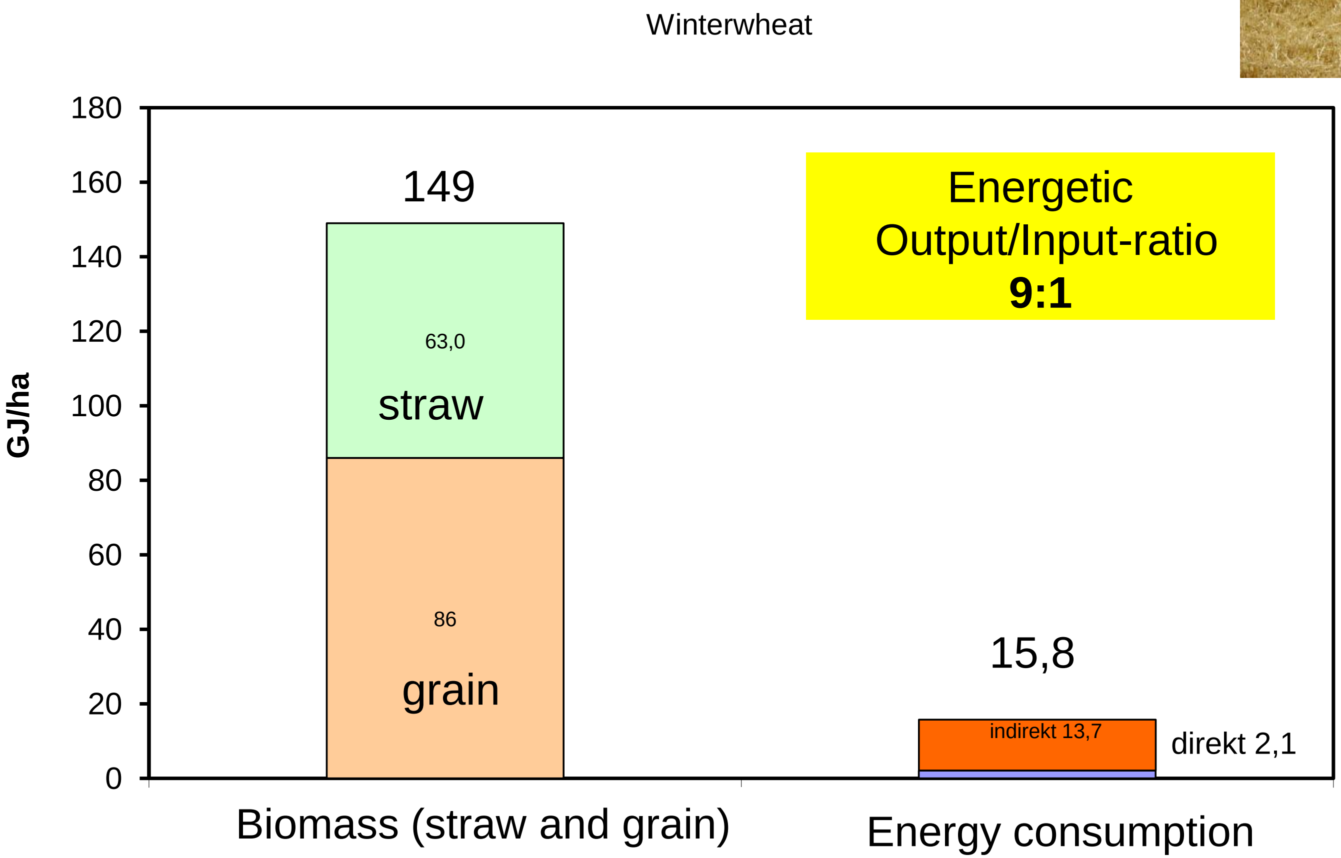
  Steering Assistance Systems, Automatic Guidance Systems

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



Agriculture as solar energy harvester

Expertimental site: Gross Enzersdorf in Lower Austria



Grain - yield: 5500kg

Straw - yield: 4000 kg

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Site-related factors (climate, soil)

Energy efficiency in plant production

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

Mechanization (e.g. soil tillage)

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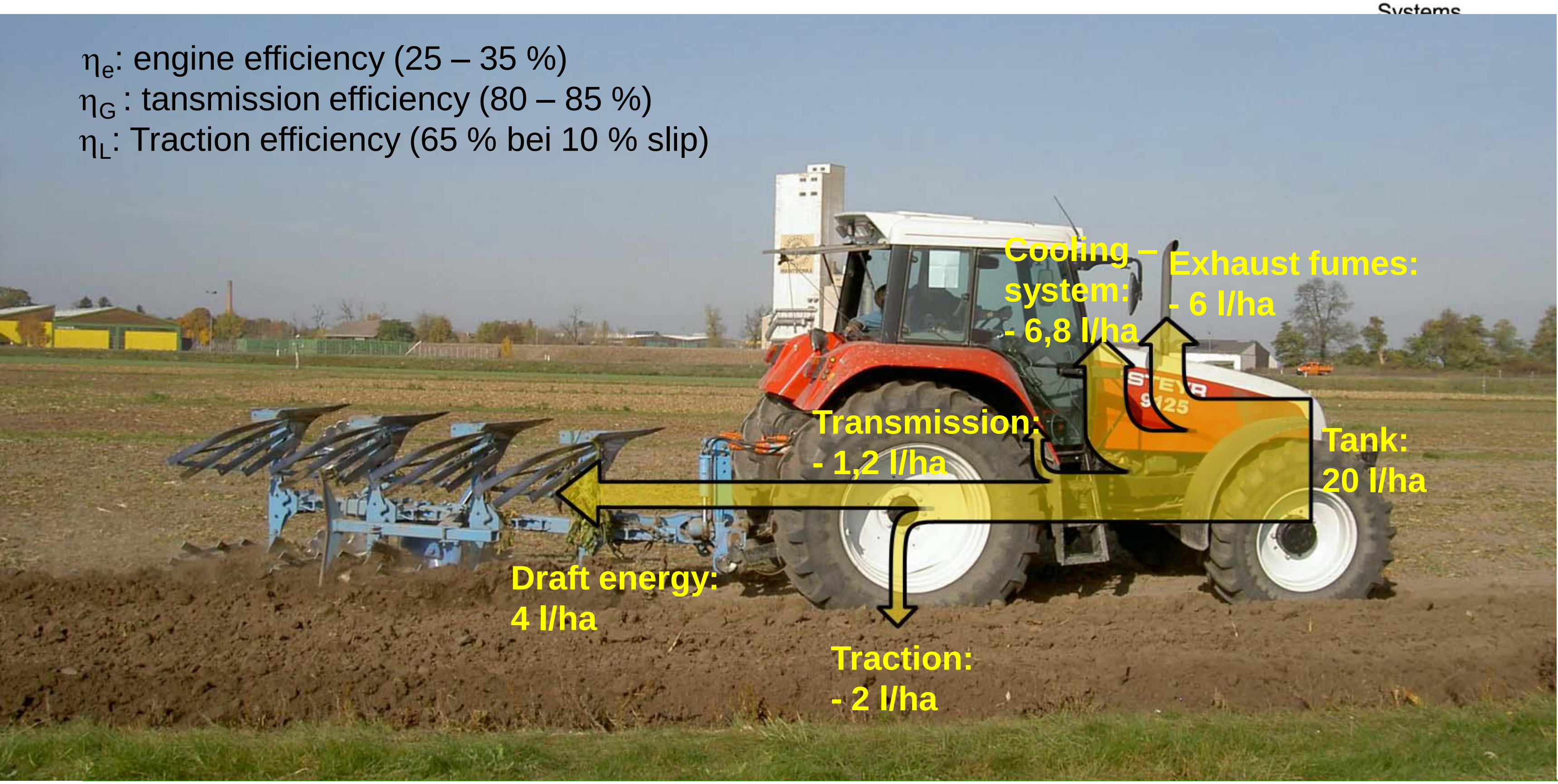
Energyflow in a tractor

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

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 m³ 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:

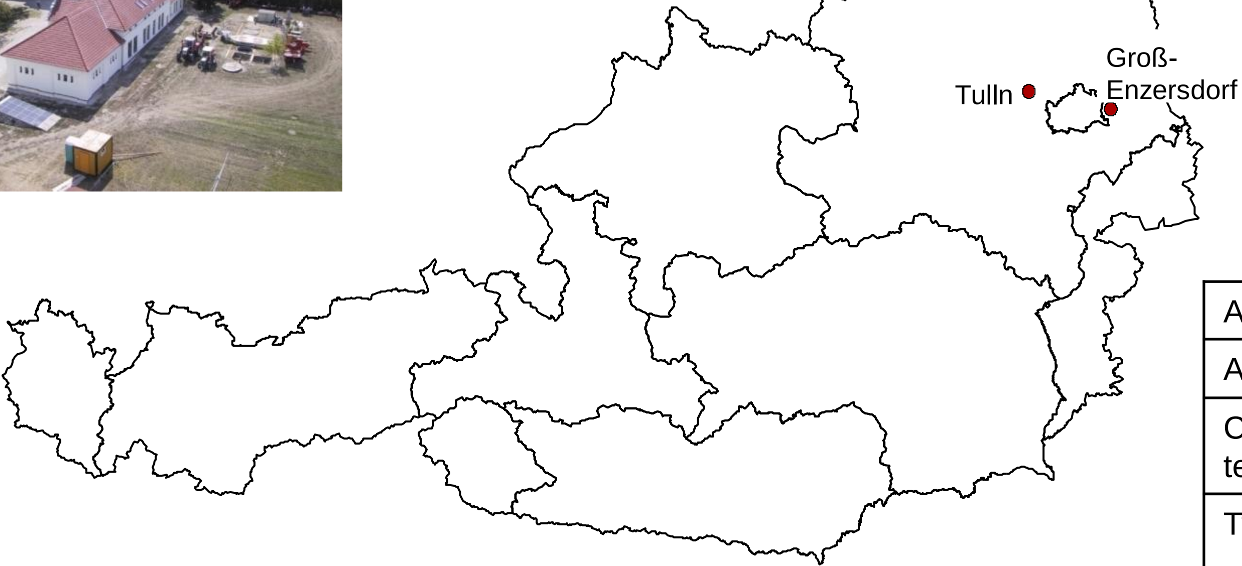
weight, number of driven axle, kind of tyre, inflation pressure etc.

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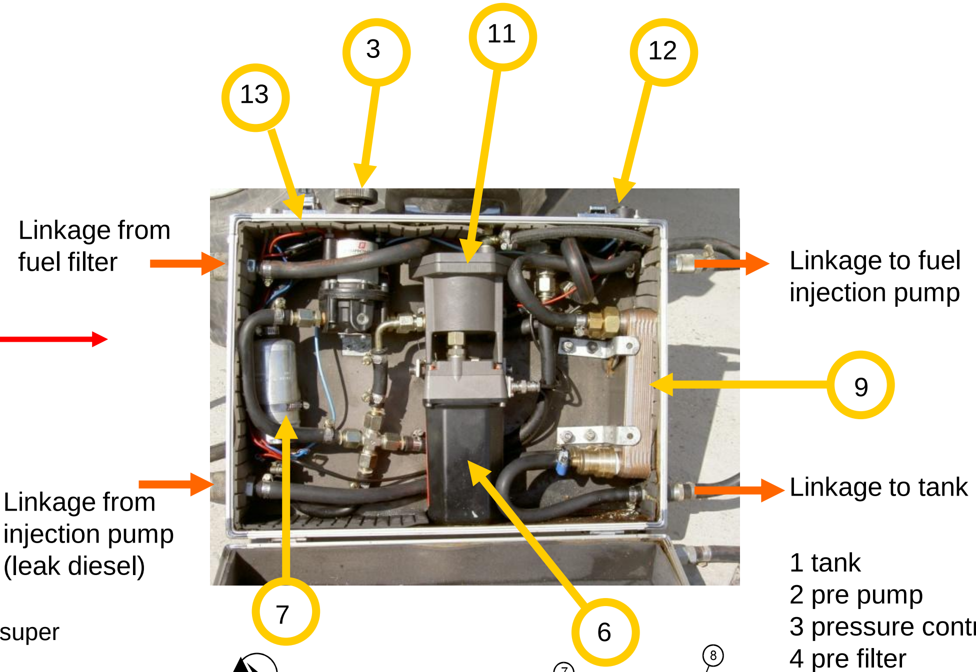
Average temperature	9.5 °C – 10 °C
Average rainfall	500 – 600 mm
Classification of soil texture	loamy clay
Type of soil	Gleyc Chernozem And pure Chernozem

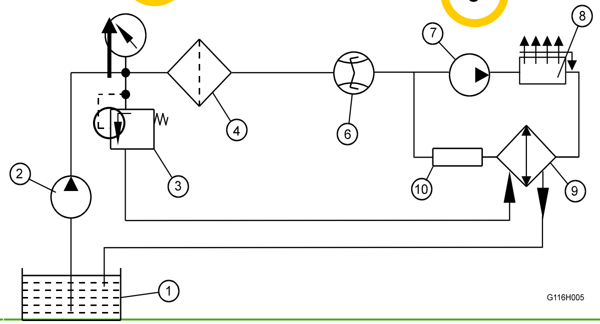
Tractor with measurement equipment

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)	Inductive sensor: generates a rectangular signal: 0-12 V
Position lifting system	> 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)



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)


Mean measured technical process parameter for different field operations

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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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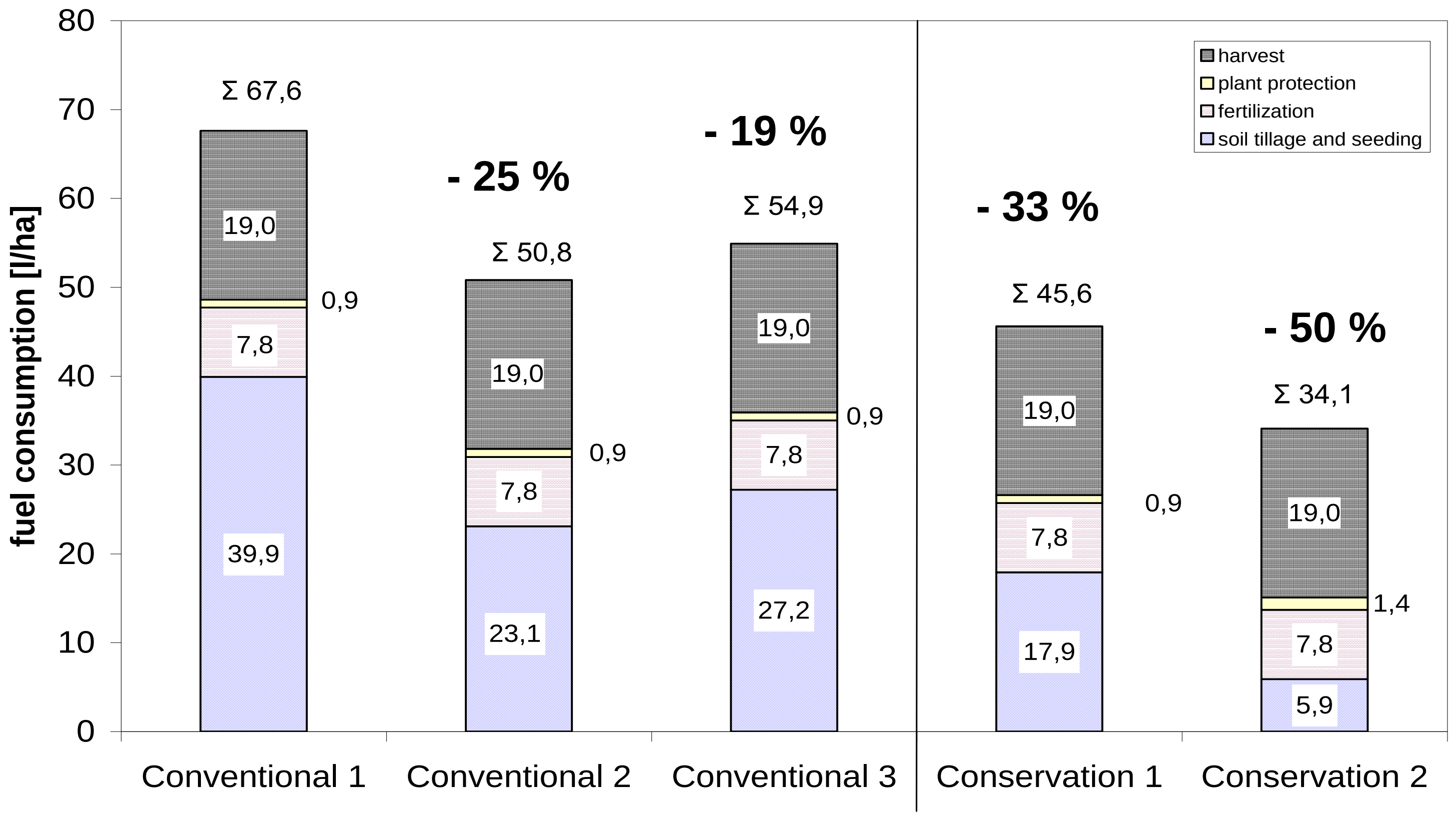

Fuel consumption for fertilization, plant protection and harvest is calculated by means of data from The Association for Technology and Structures in Agriculture (KTBL)

Energy analysis for wheat production in different soil tillage systems

	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**

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*) 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.**

Thank you for your attention

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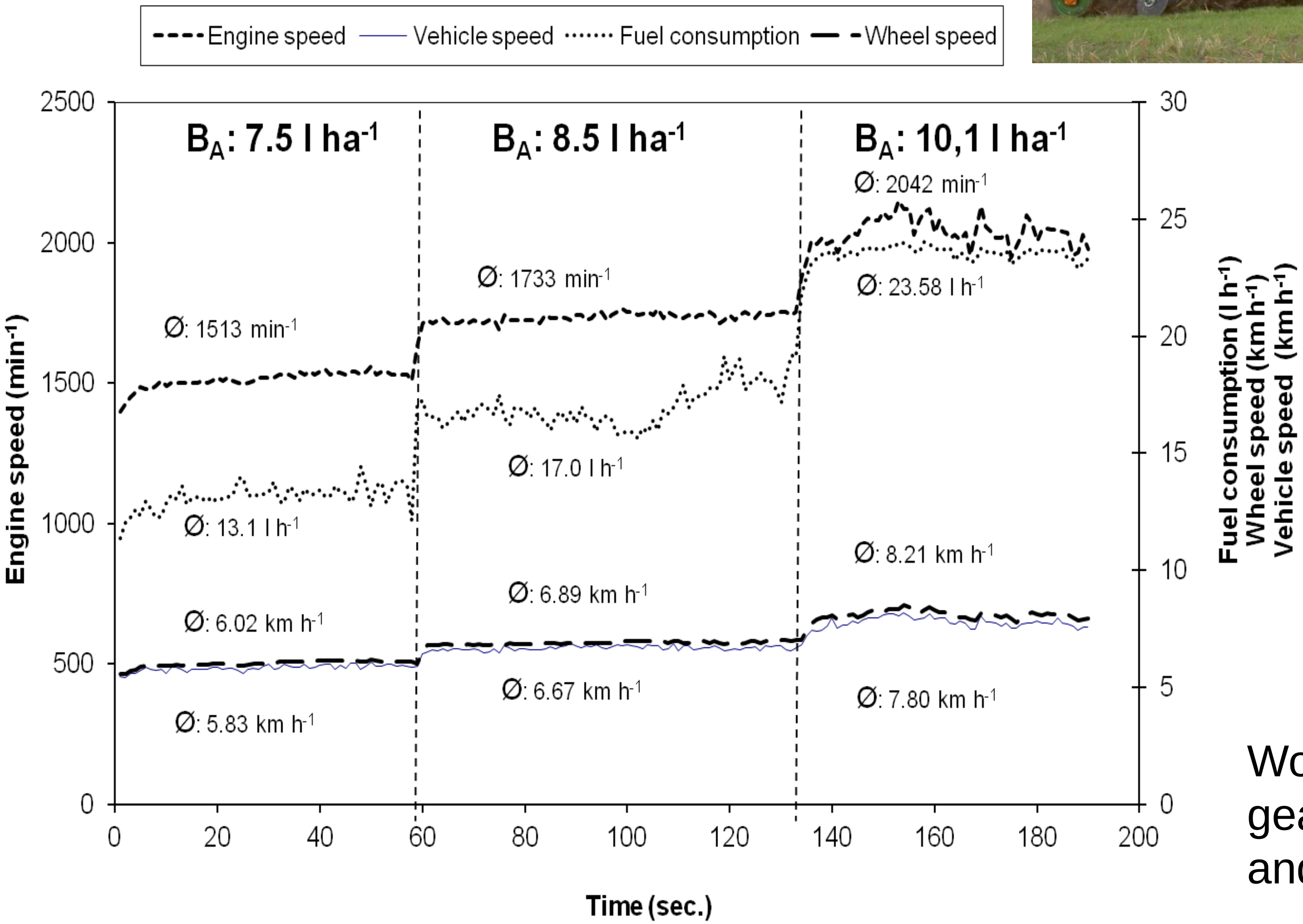
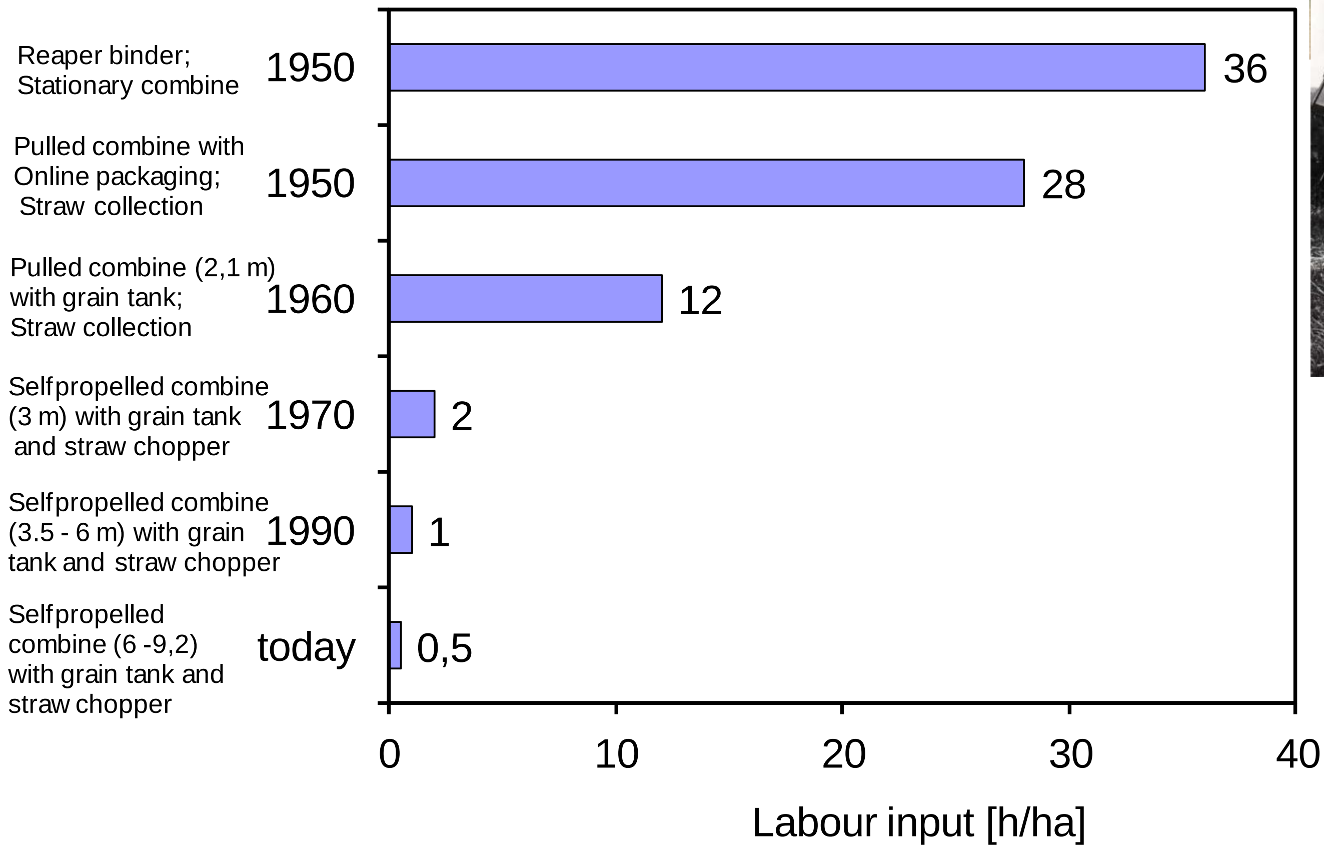
Die Ernte: Vicent van Gogh; 1888; Van Gogh Ausstellung in der Albertina; Wien

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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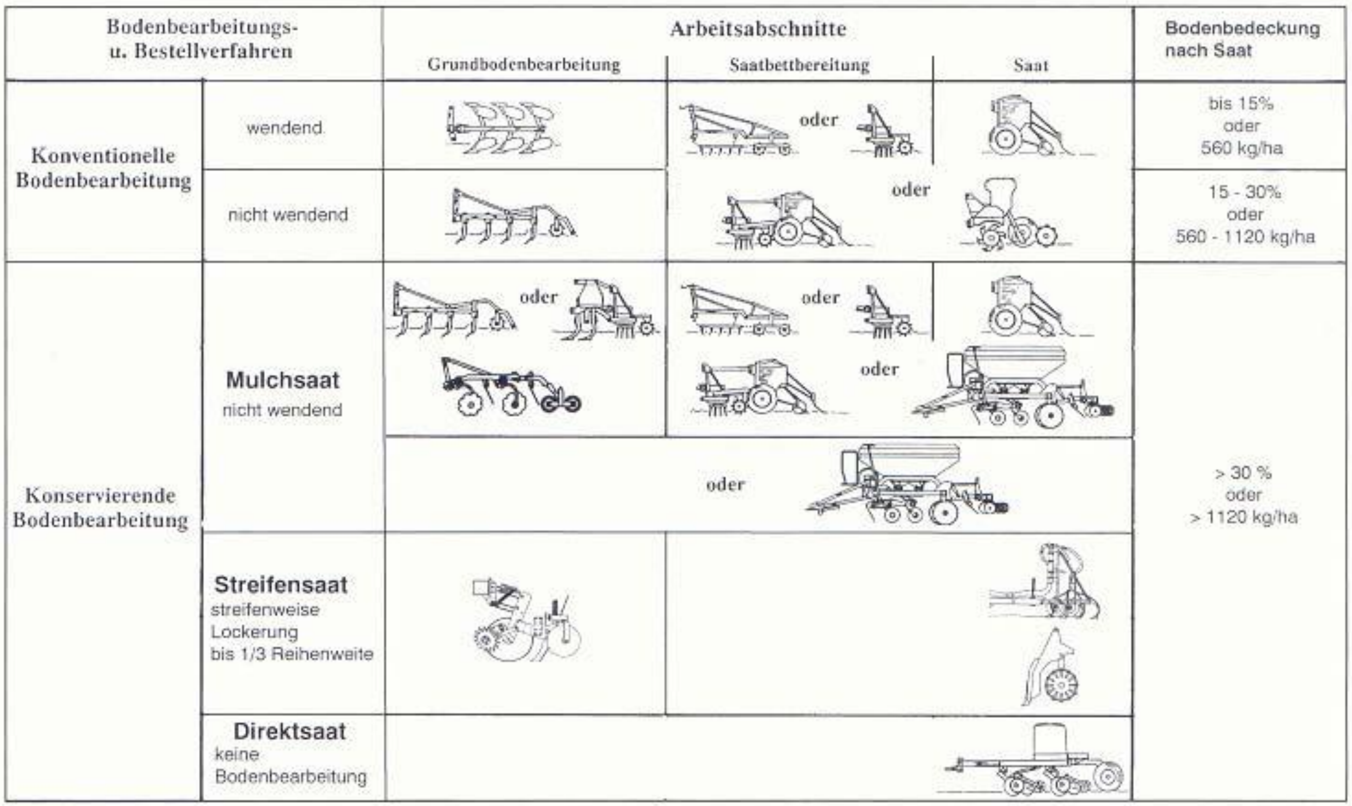

Bodenbearbeitungs- u. Bestellverfahren		Arbeitsabschnitte: Grundbodenbearbeitung	Arbeitsabschnitte: Saatbettbereitung	Arbeitsabschnitte: Saat	Bodenbedeckung nach Saat
Konventionelle Bodenbearbeitung	wendend		oder		bis 15% oder 560 kg/ha
	nicht wendend		oder		15 - 30% oder 560 - 1120 kg/ha
Konservierende 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

Real speed: 7,2 km/h

Field performance: 2,2 ha/h

Fuel consumption: 8 l/ha

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

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

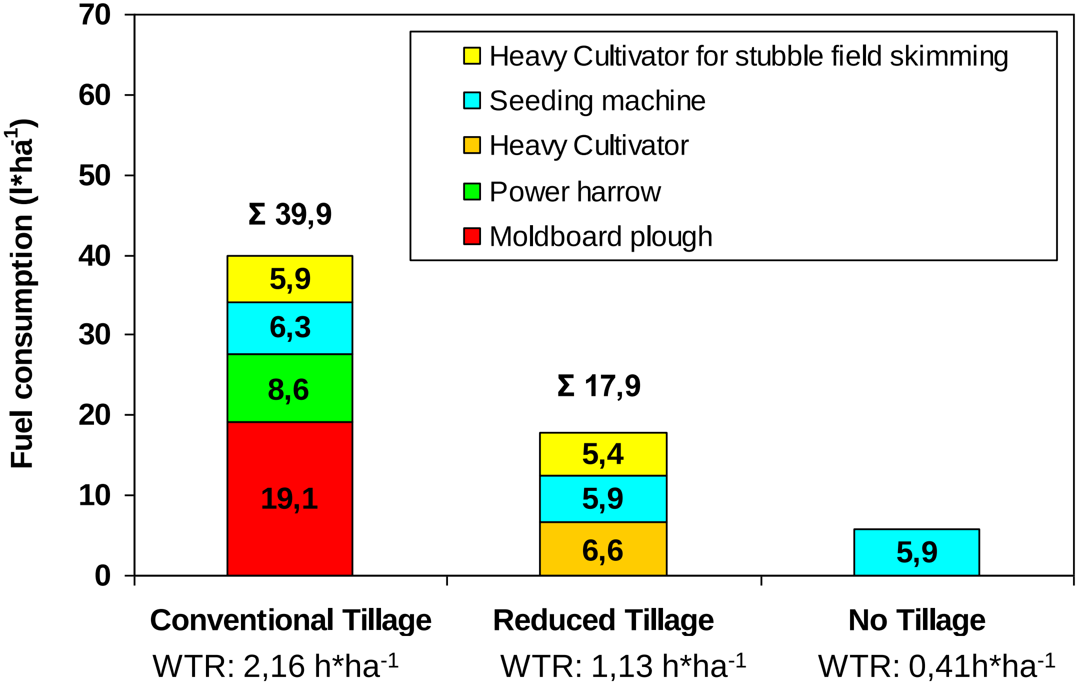
Conventional Tillage (CT)



Reduced Tillage (RT)


No Tillage (NT)

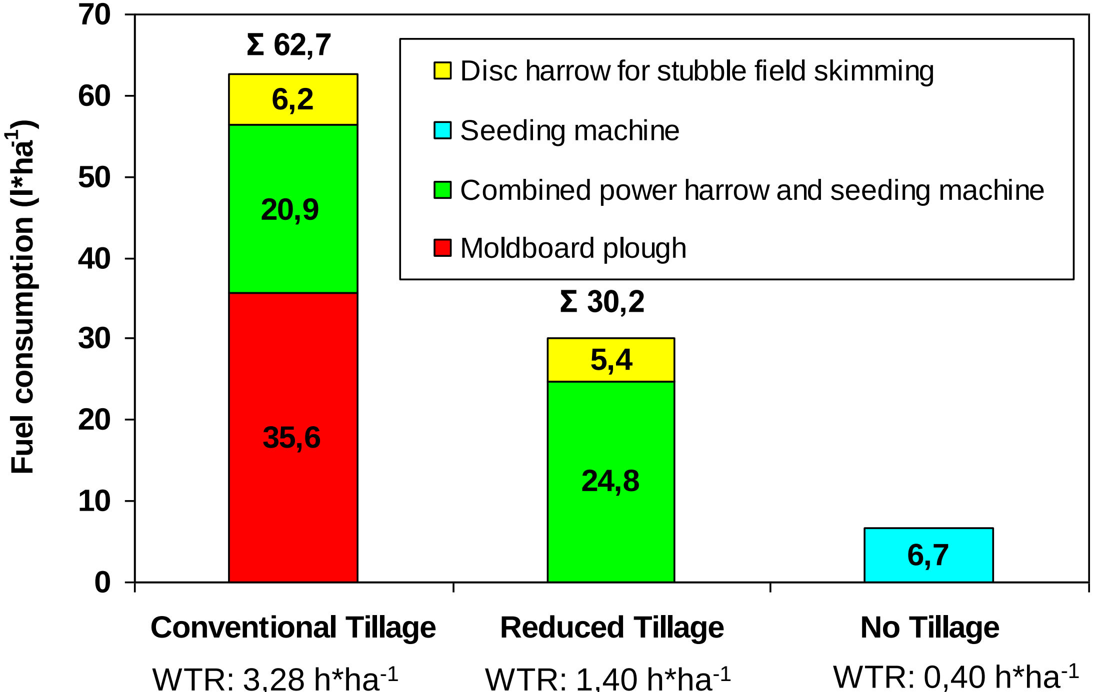
Results: fuel consumption



Location: „Gross Enzersdorf“

(soil texture: silty loam)

WTR: Working Time Requirement



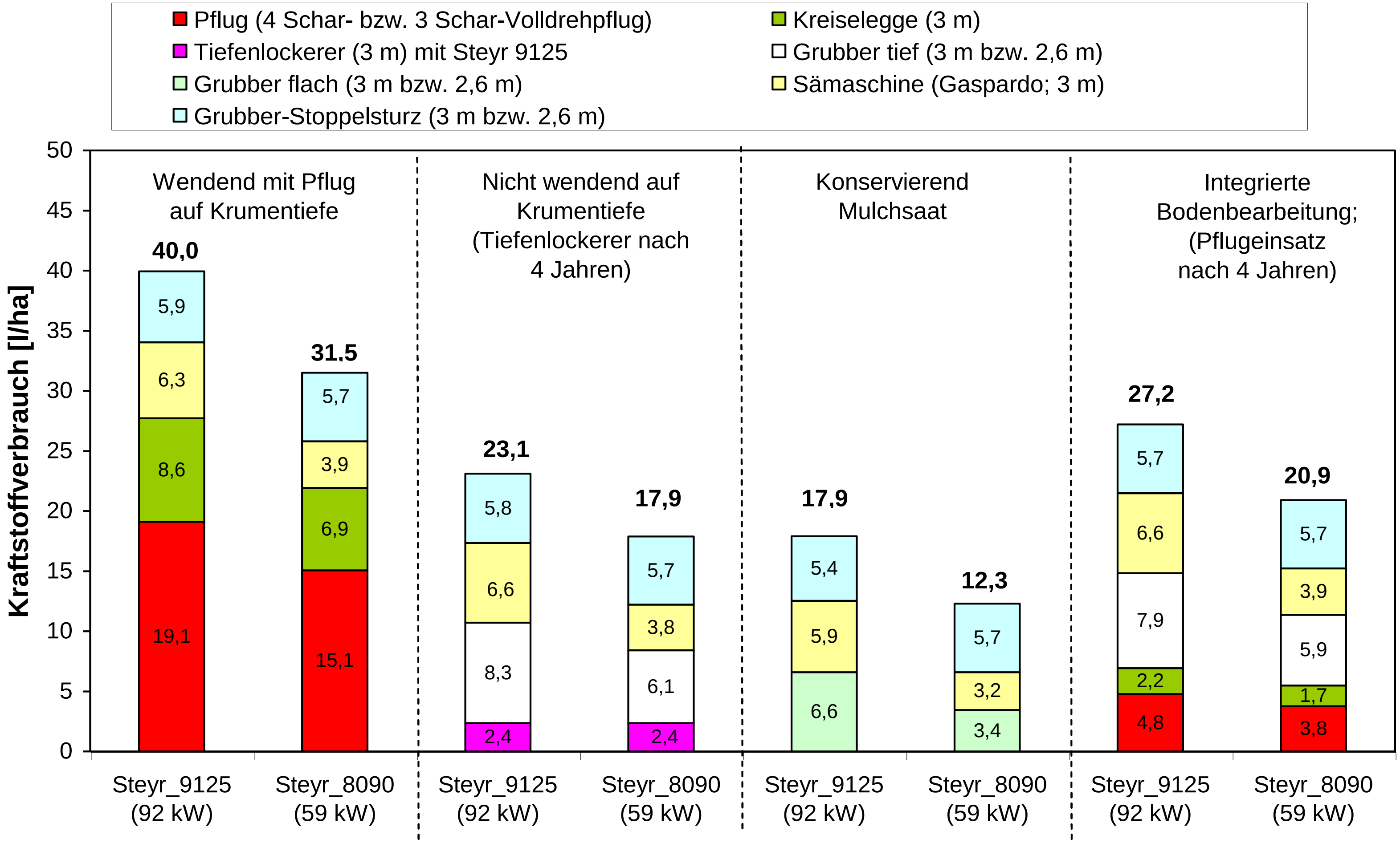
Location: „Tulln“

(soil texture: loamy clay)

WTR: Working Time Requirement

Kraftstoffverbrauch bei unterschiedlichen Bodenbearbeitungssystemen und Mechanisierung

Winterweizenanbau, Standort Groß Enzersdorf

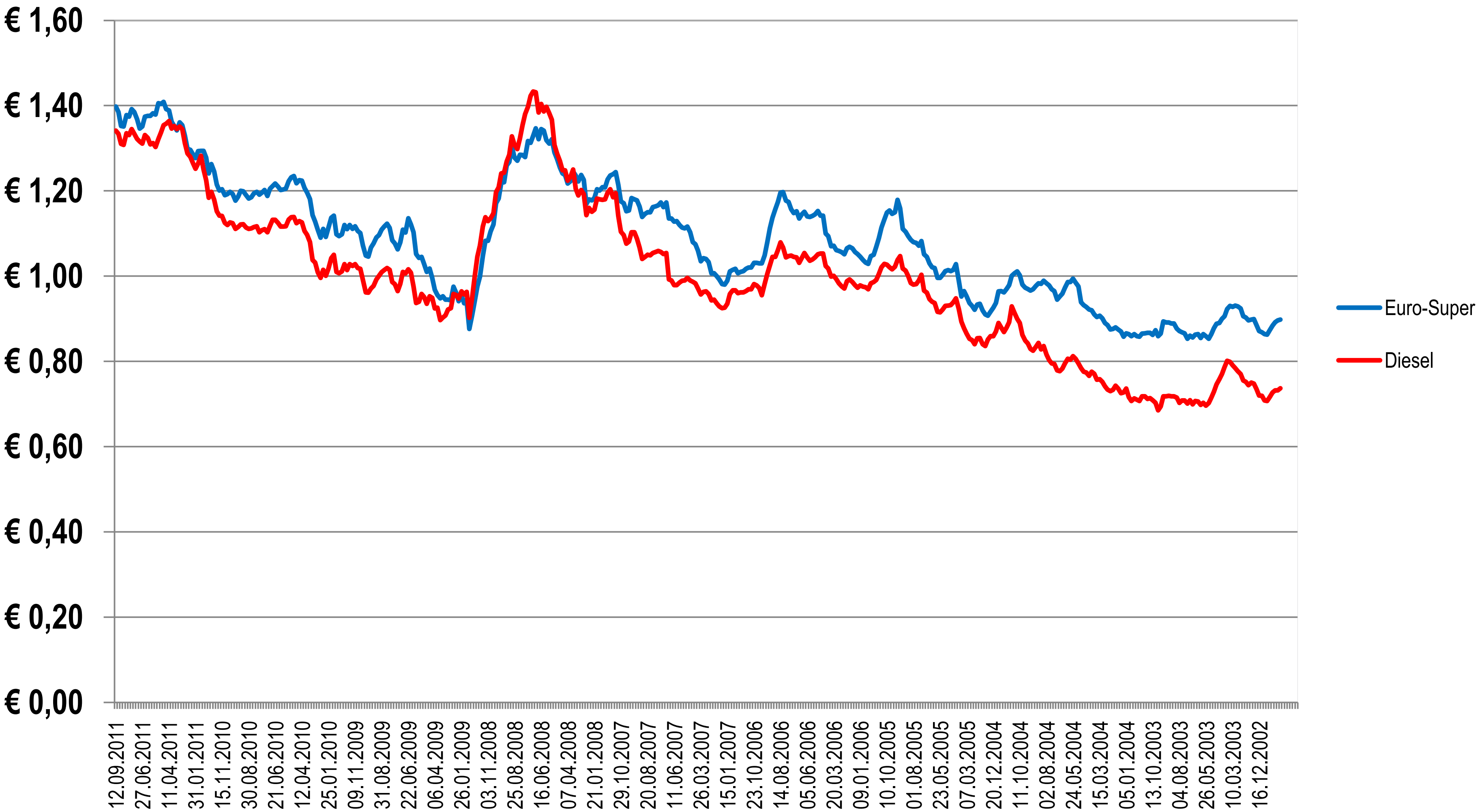


kg CO_2	***104,7***	***82,4***	***60,5***	***47,8***	***46,8***	***32,2***	***71,2***	***54,7***

Kraftstoffverbrauchsmessungen an der Versuchswirtschaft der BOKU in Groß Enzersdorf

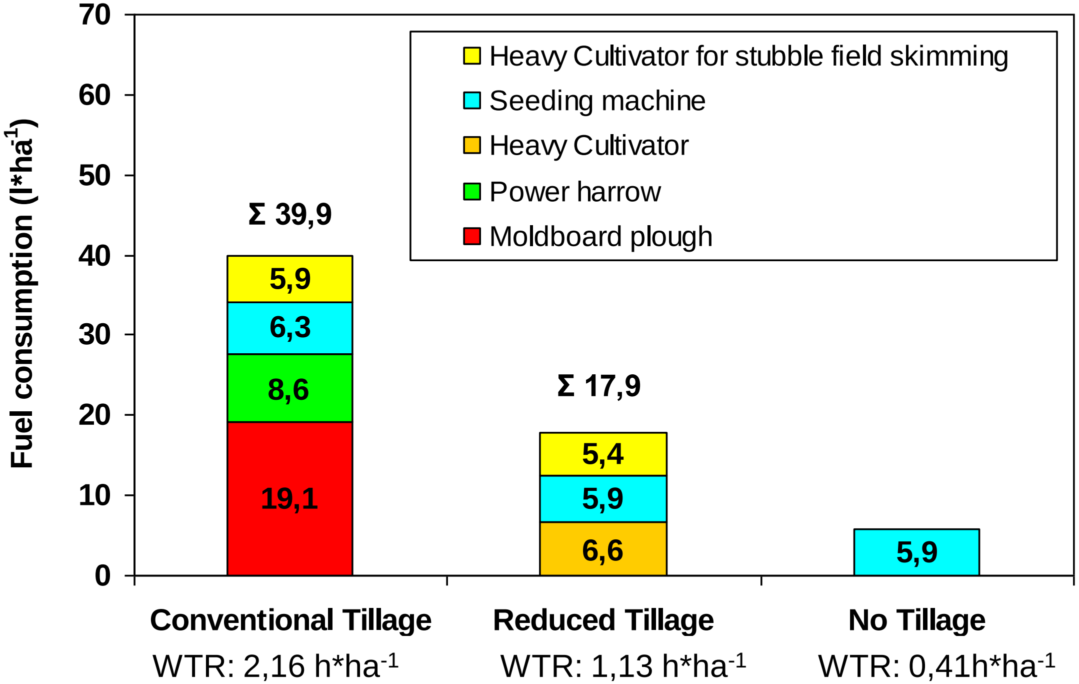
Fuel prices since 2002

Datasource: Austrian Ministry of Economy



1 € = 1.40 CAD

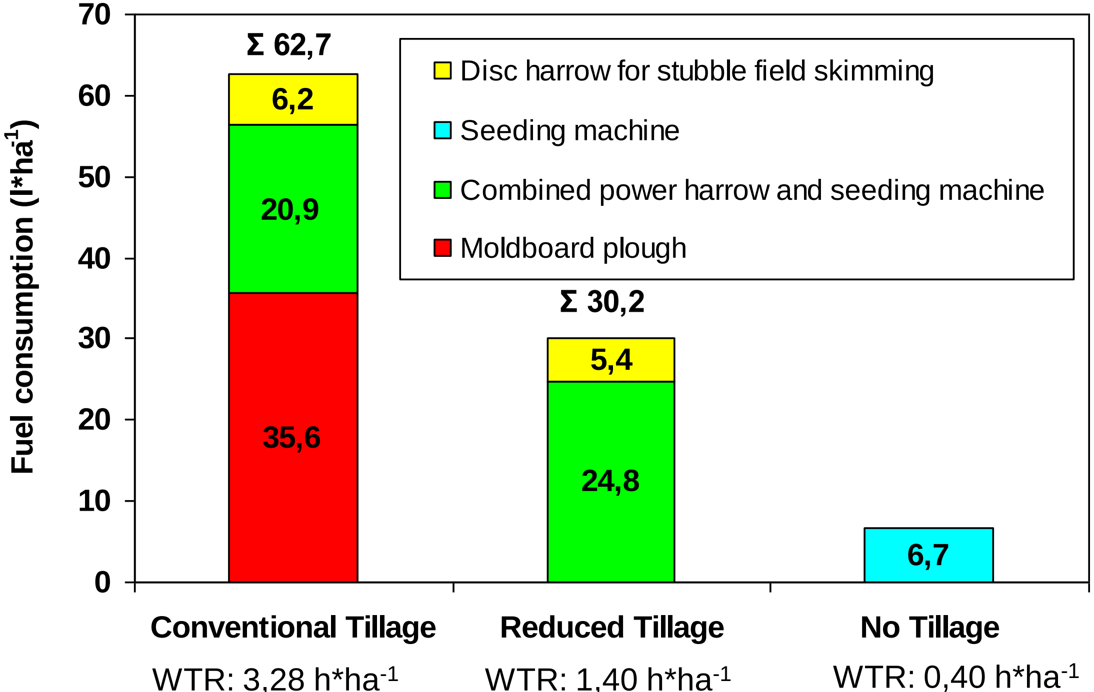
Results: fuel consumption



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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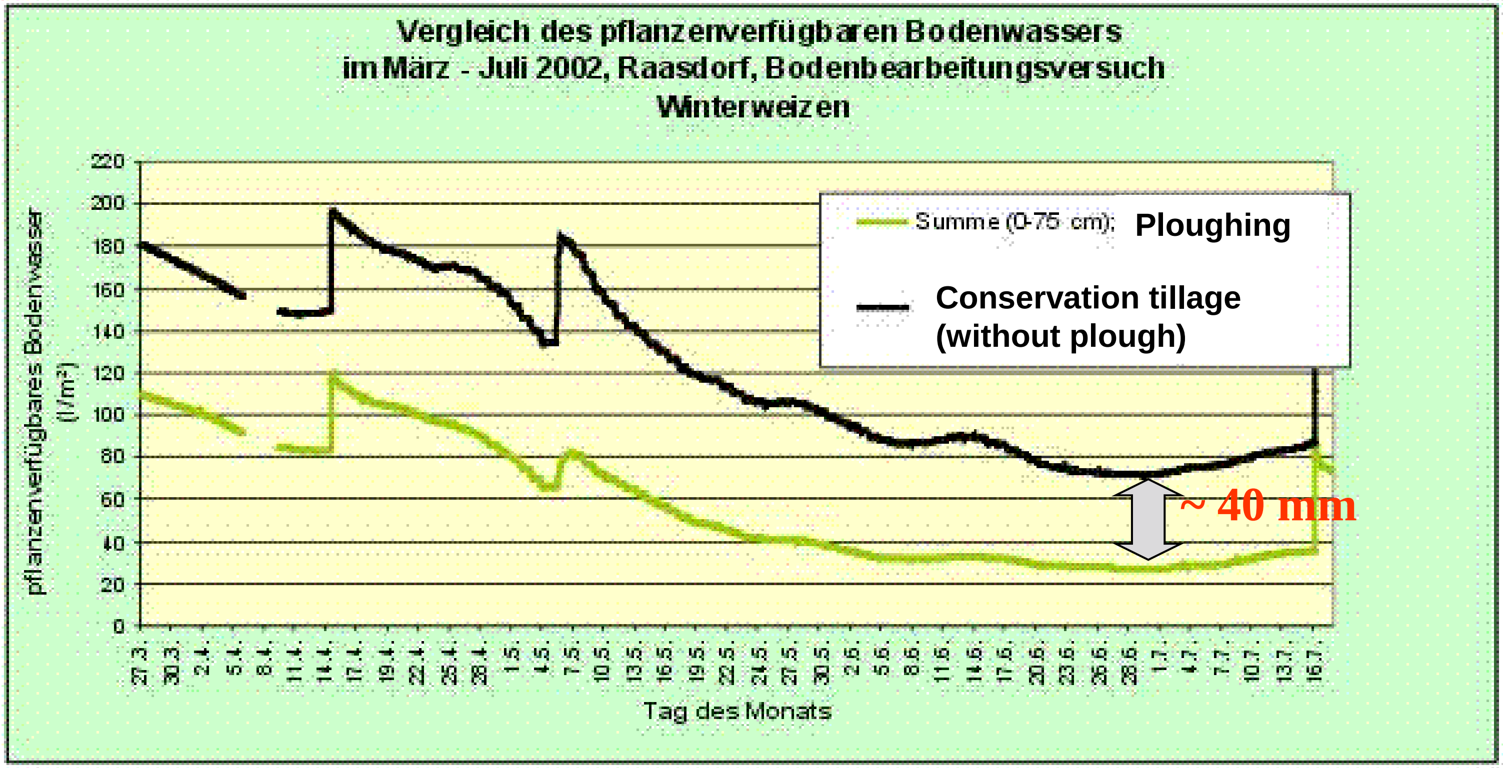

Mittlere Transpiration über die Pflanze:

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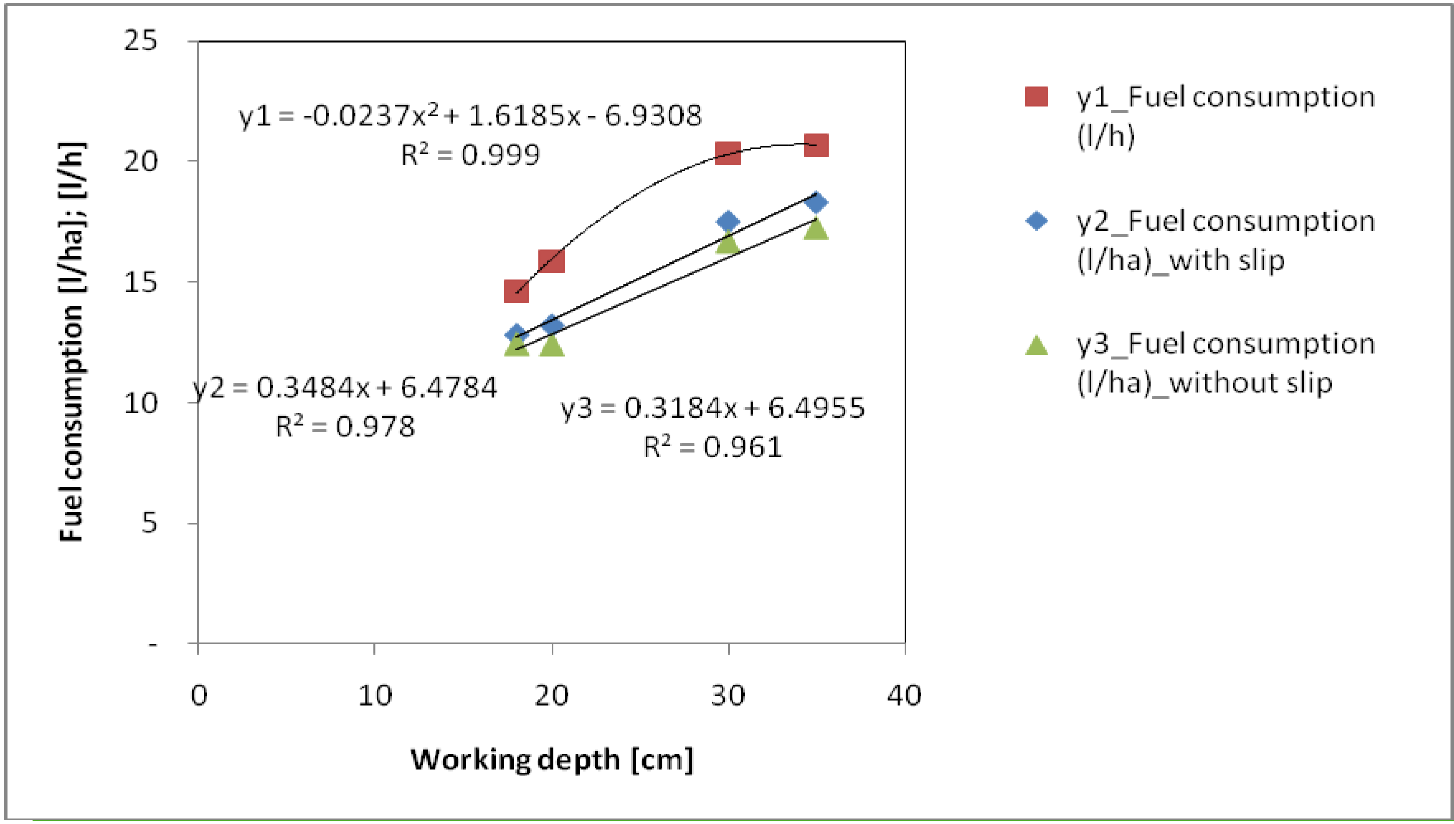
Working depths: 18 cm, 20 cm, 30 cm, 35 cm



Results – Short Disc Harrow

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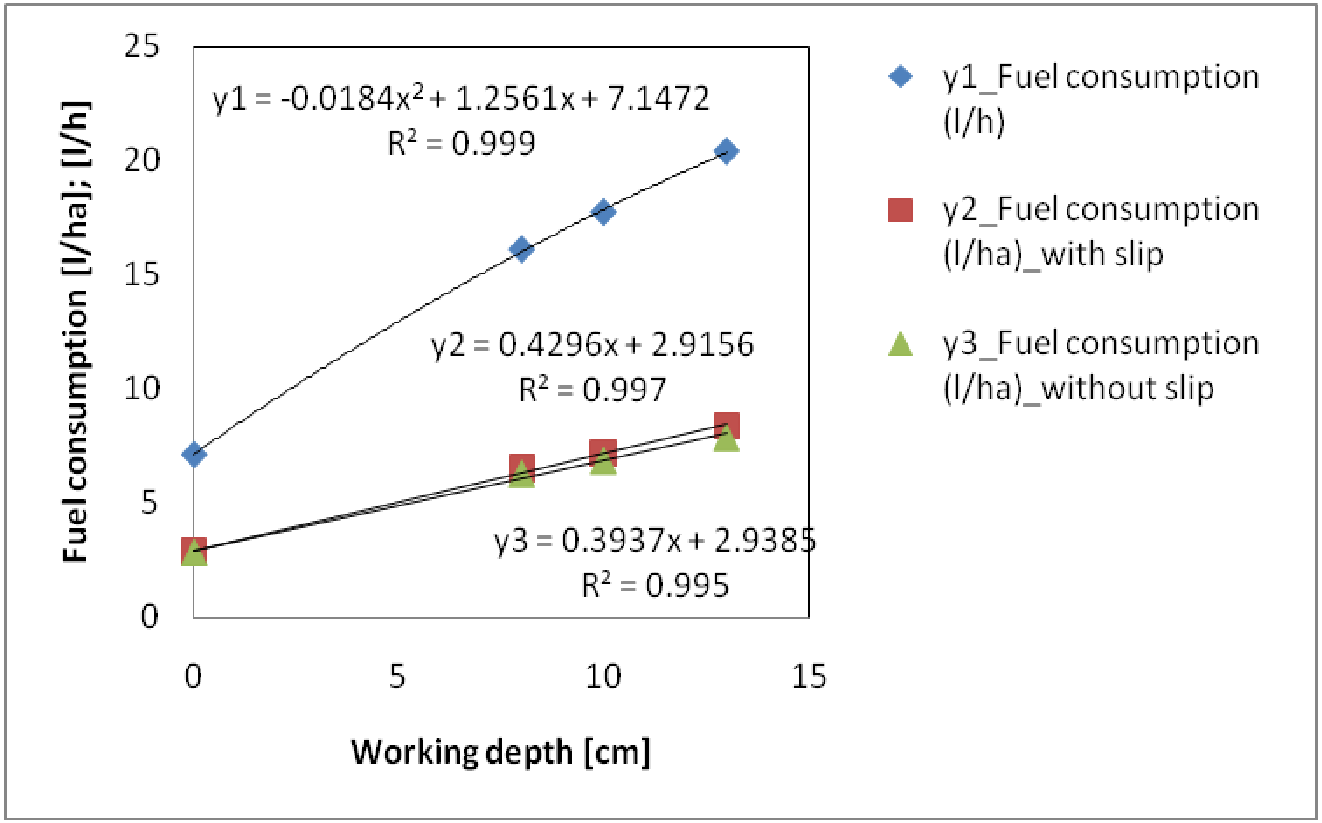
Working depths: 0 cm, 8 cm, 13 cm



Results – Subsoiler

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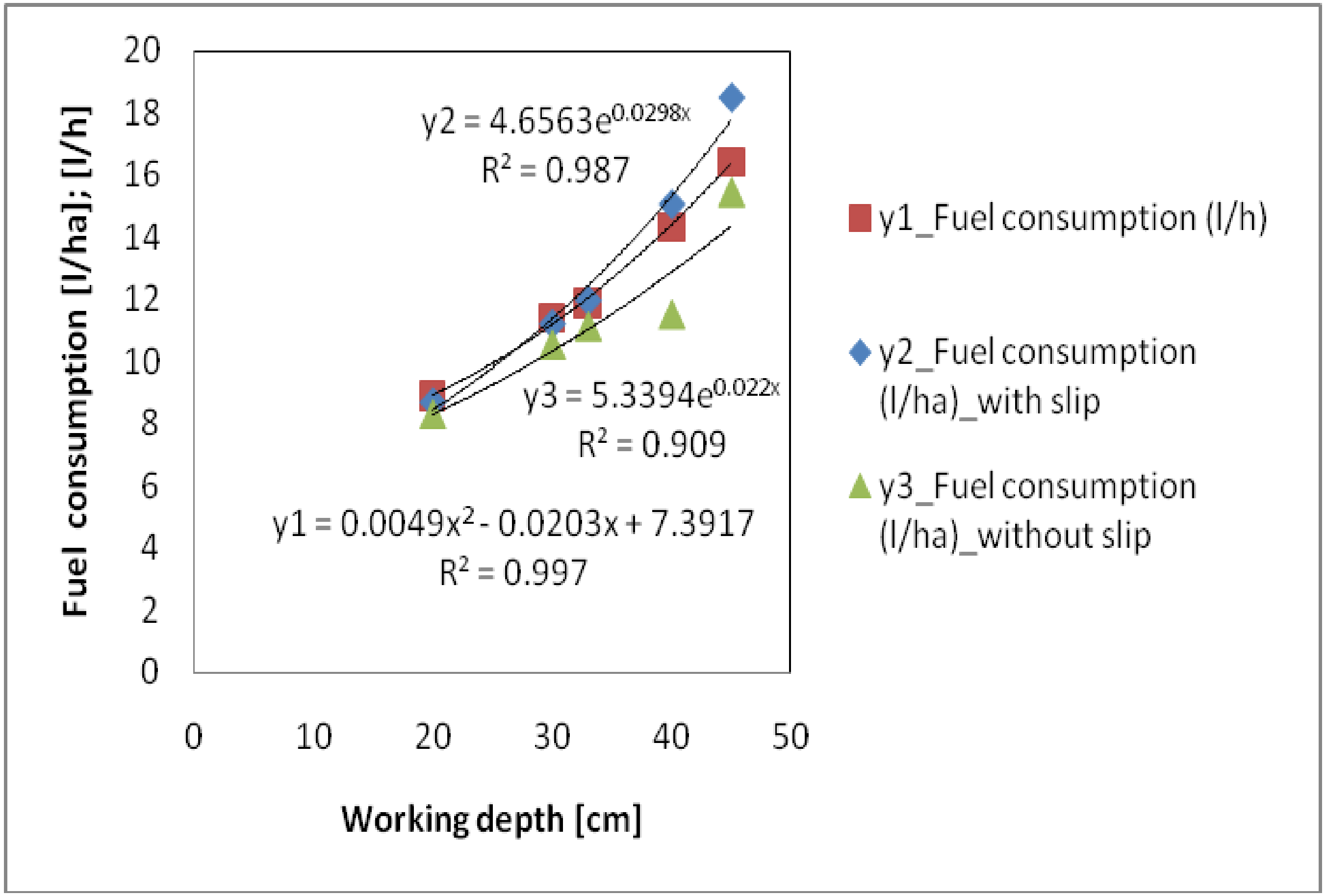
Working depths: 20 cm, 30 cm, 33 cm, 40 cm, 45 cm



Results – Specific energy consumption

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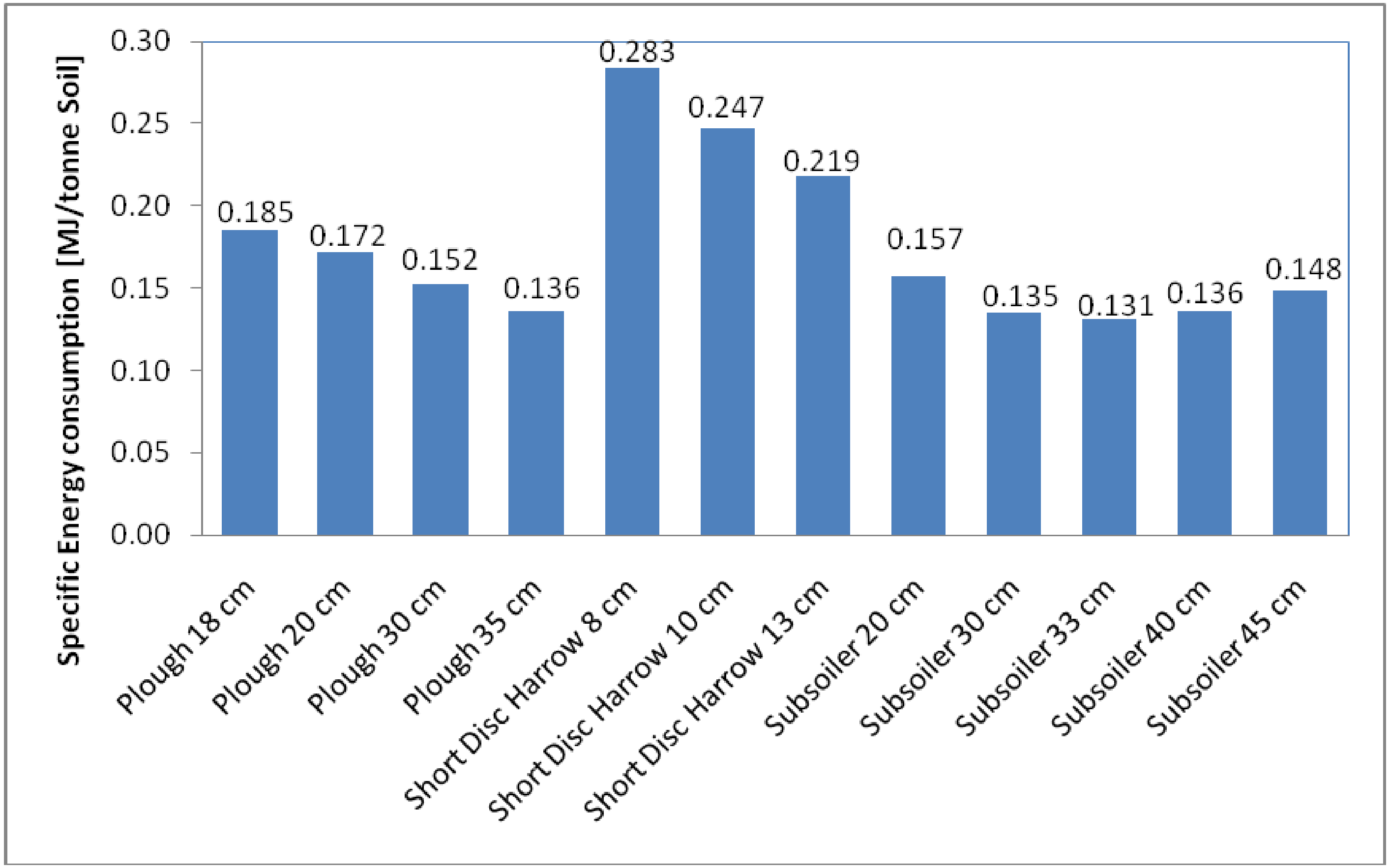

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Conclusions

- 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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Agricultural

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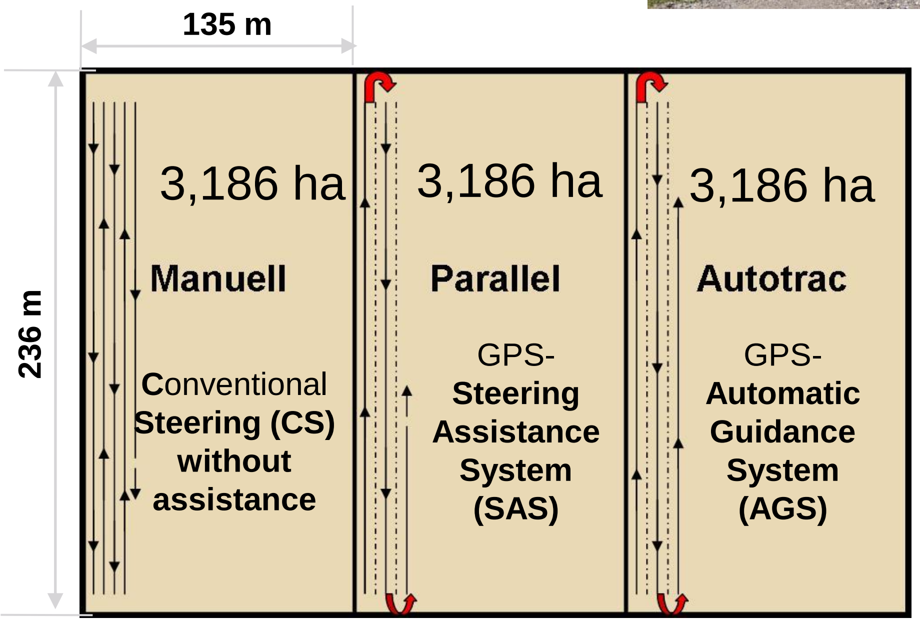
Average temperature	9.5 °C – 10 °C
Average rainfall	500 – 600 mm
Classification of soil texture	loamy clay
Type of soil	Gleyc Chernozem And pure Chernozem

	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



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

„affiliation drive“

Turning event in a semicircle;

„Bed-modus“
Each second track

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)

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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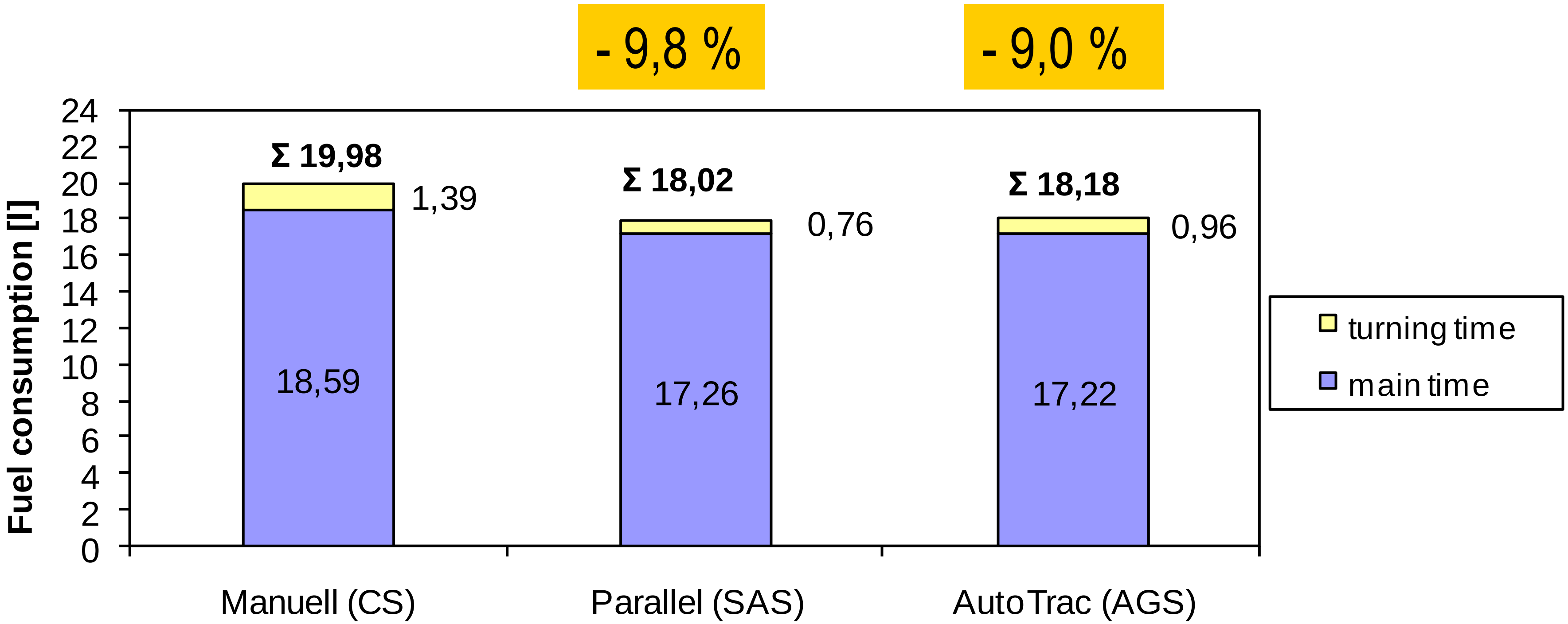
Results: Fuel consumption

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



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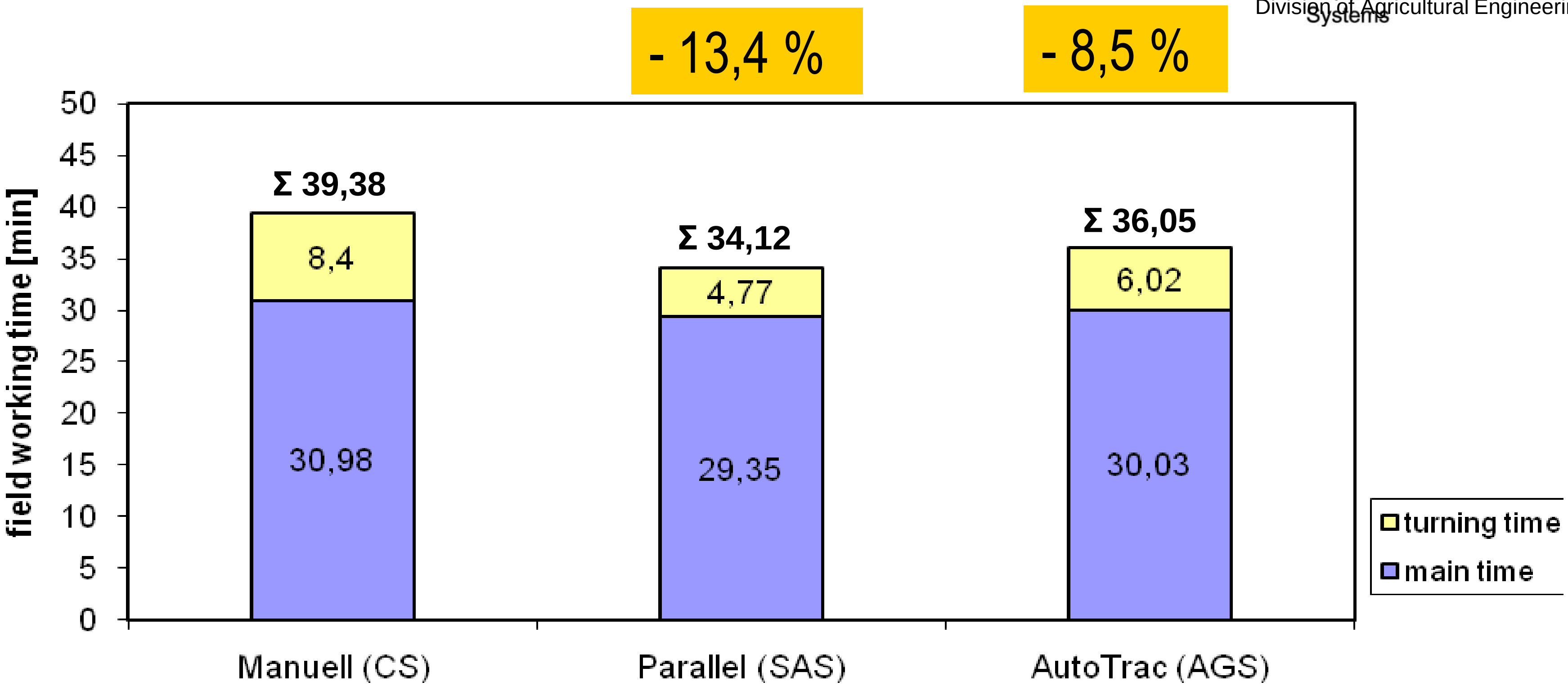
Results: Field working time

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



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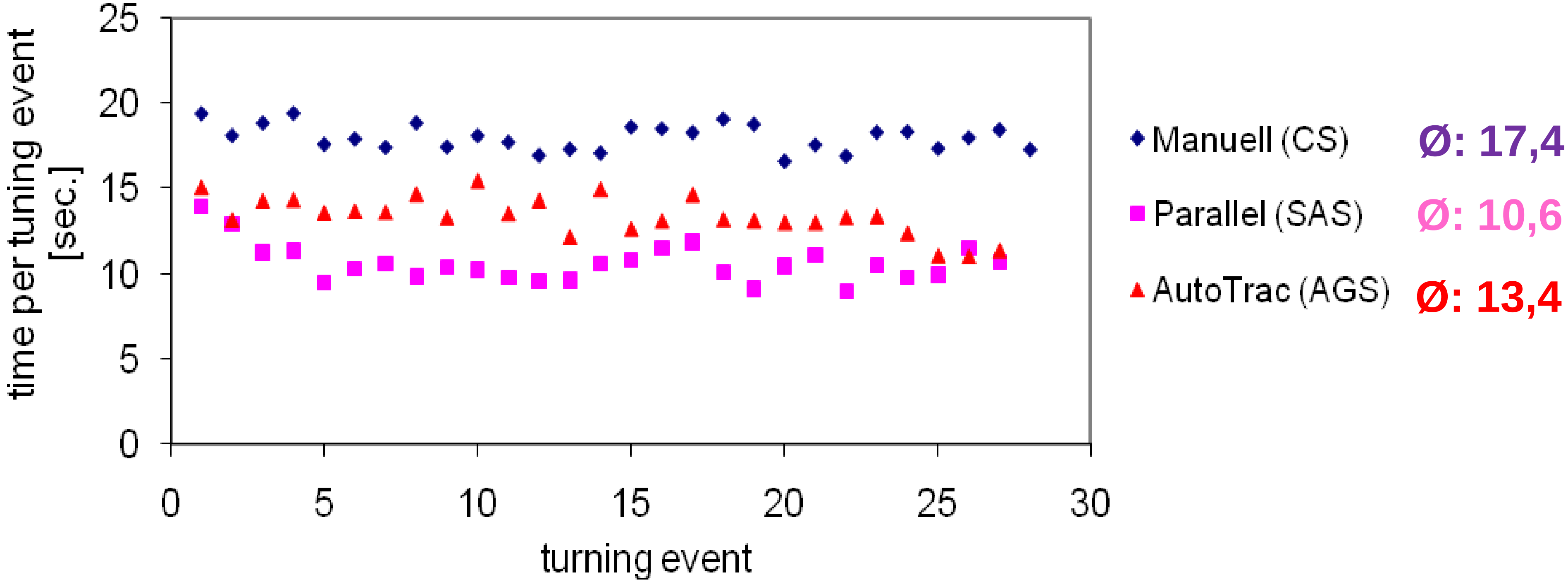
Results: Measured time per turning event



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

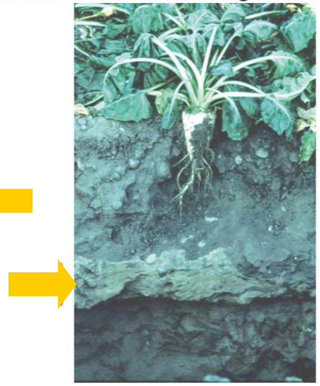
Transported payload: 16.5 Tonnen

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

Response of subsoil compaction on plant growth

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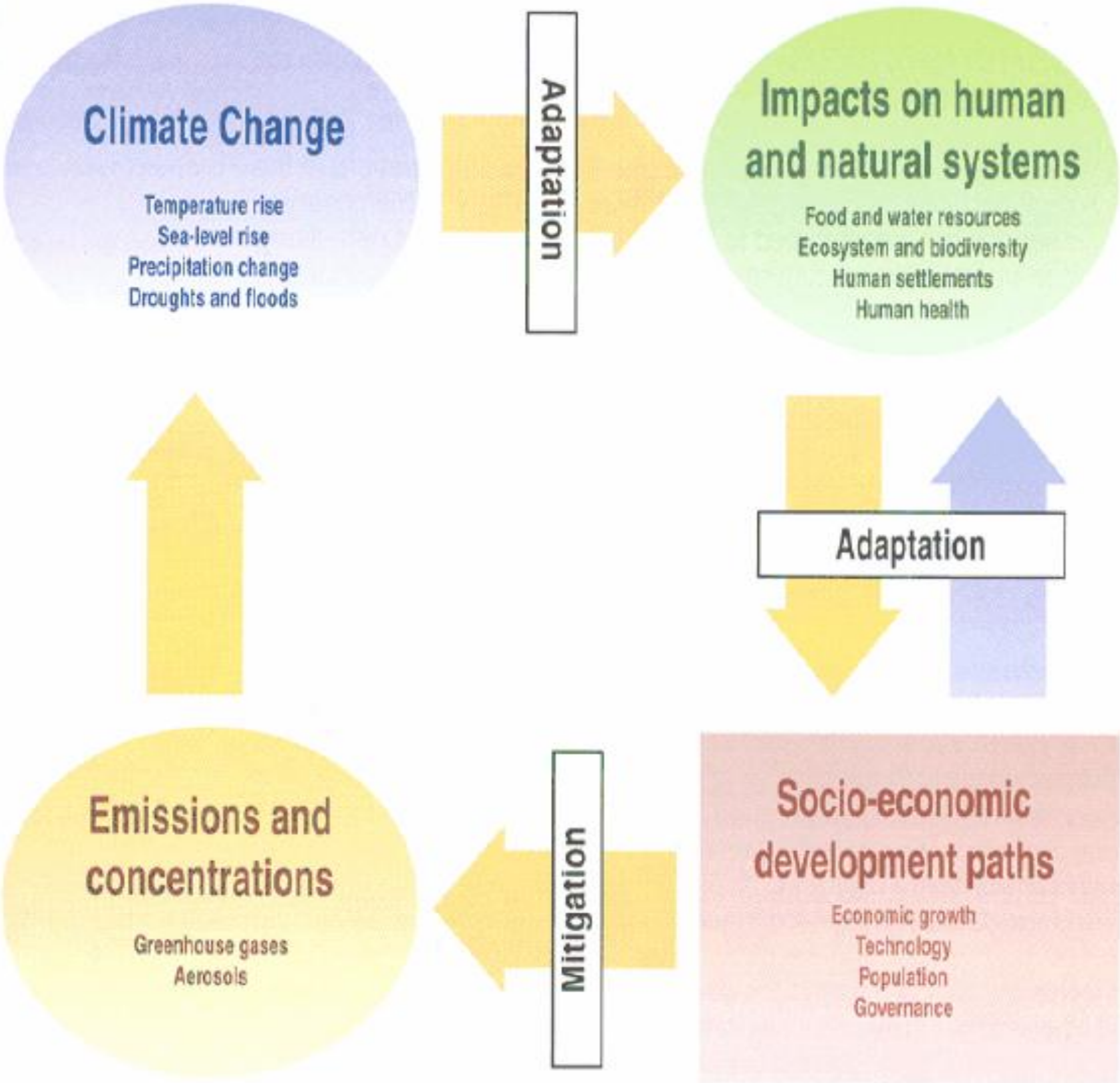
Topsoil: overlossend caused by intensive soil tillage with many passes

Subsoil: compacted

Without soil compaction

Bildquelle: Großlercher (Probstdorfer Saatzucht)

Reduced plant growth caused by subsoil compaction and drought.



Univ. Prof. Eitzinger (BOKU Wien, 2007)

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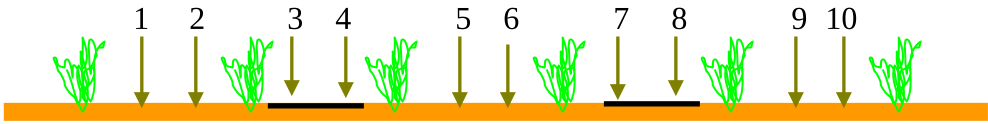
http://www.adagio-eu.org/

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

Anpassung der Landwirtschaft in gefährdeten Europäischen Regionen an den Klimawandel

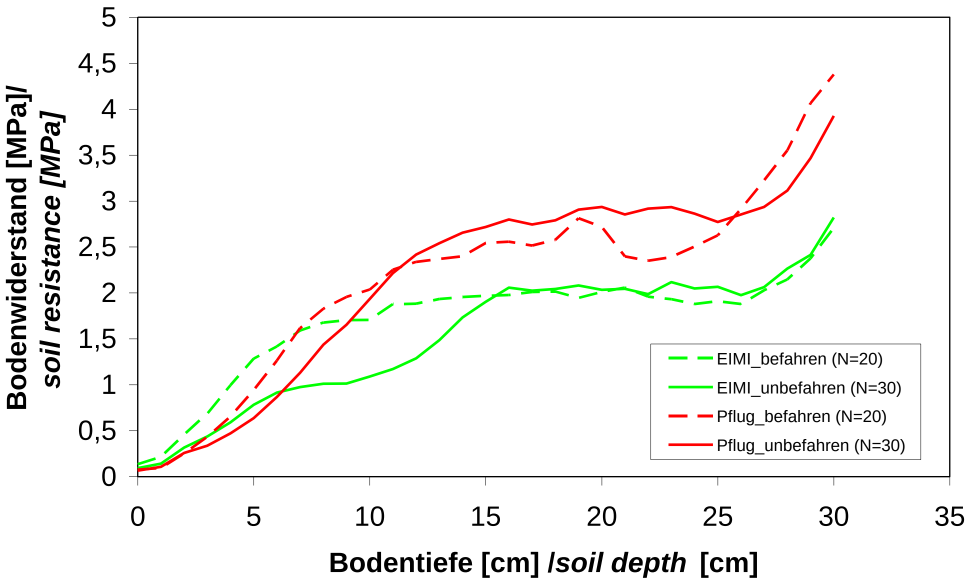
Fronttiefengrubber



Ergebnisse 2005 (VW Groß Enzersdorf)

Mittlerer Dieselaufwand: 14,5 l/ha

Mittlere Flächenleistung: 1,7 ha/h



Ergebnisse 2006 (LFS Goldbrunnhof):

- Verstärkte N-Mineralisierung (+ 100 kg N_{min})
- Juli Trockenheit wurde besser überstanden
- höhere Silomaiserträge (Ø: + 2 t TM/ha)

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Landtechnische Präventivmaßnahmen (Reduktion von GHG in der Atmosphäre)

- Änderung der Produktionstechnik in der Bodenbearbeitung

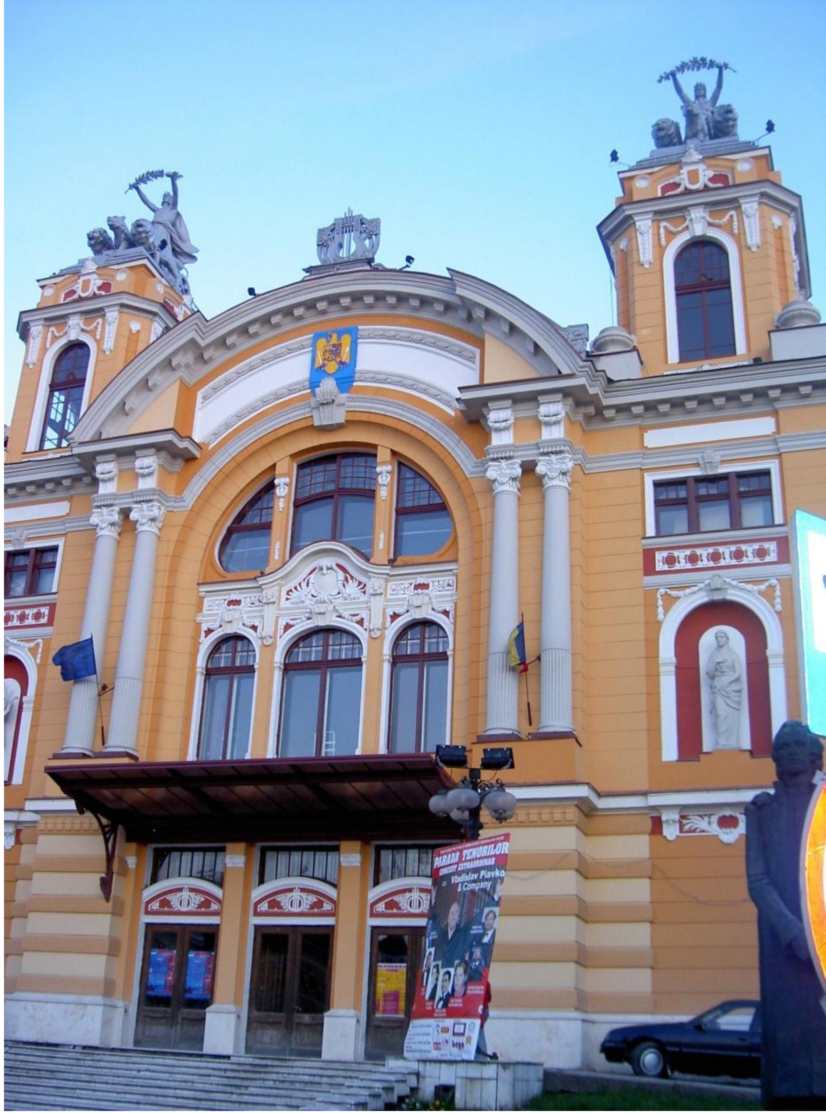
  Minderung der direkten fossilen CO_2-Emissionen (Kraftstoffeinsparung)

  Erhöhung der CO_2-Sequestrierung (Humusaufbau)

- Verminderung der fossilen CO_2-Emissionen (**Energieeinsparung** => Erhöhung der Energieeffizienz)

- Minderung der CH_4- und N_2O Spurengasemissionen (z.B. Biomethanisierung von Wirtschaftsdünger mit bodennaher Flüssigmistausbringung)

Teatrul National, Cluj Napoca, 2006



Teatrul National, Cluj Napoca, 2007

Historischer Link

Teatrul National, Cluj Napoca

Systems

Ferdinand Fellner und Hermann Helmer die bedeutendsten Erbauer von Theatern in der österreichisch-ungarischen Doppelmonarchie

Volkstheater, Wien