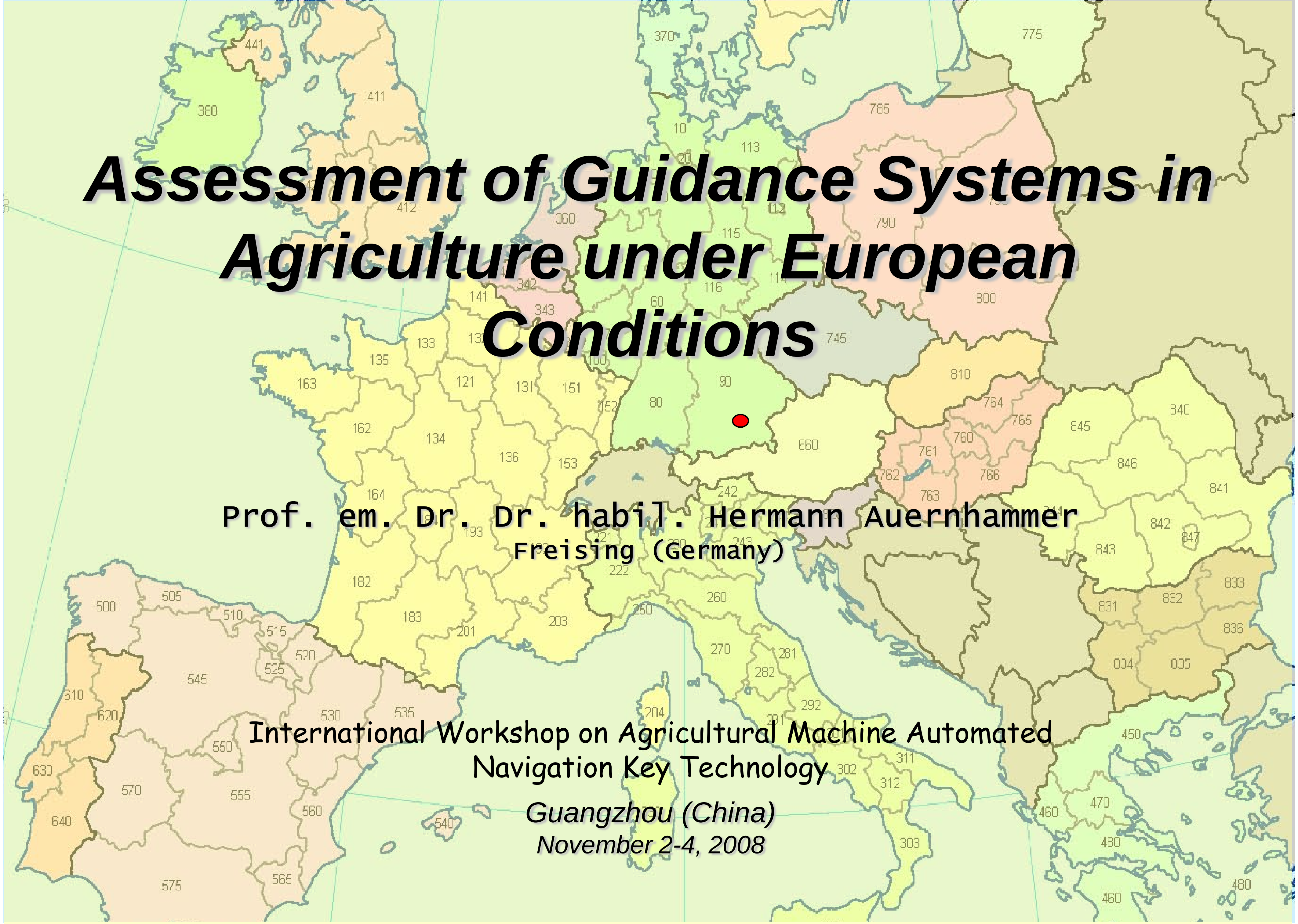

Assessment of Guidance Systems in Agriculture under European Conditions

Prof. em. Dr. Dr. habil. Hermann Auernhammer
Freising (Germany)

International Workshop on Agricultural Machine Automated
Navigation Key Technology

Guangzhou (China)
November 2-4, 2008

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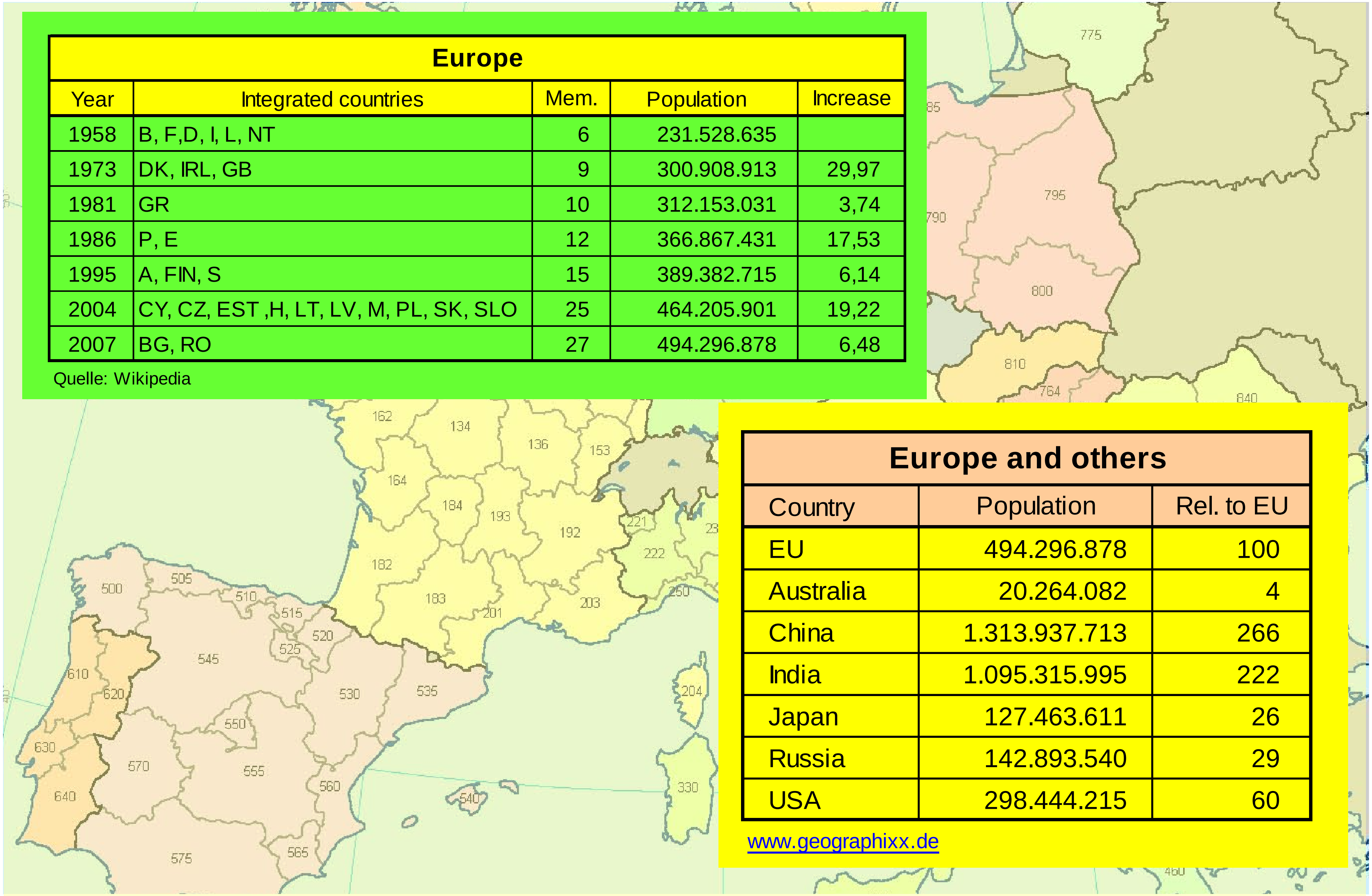
Europe and the Enlargement



Europe

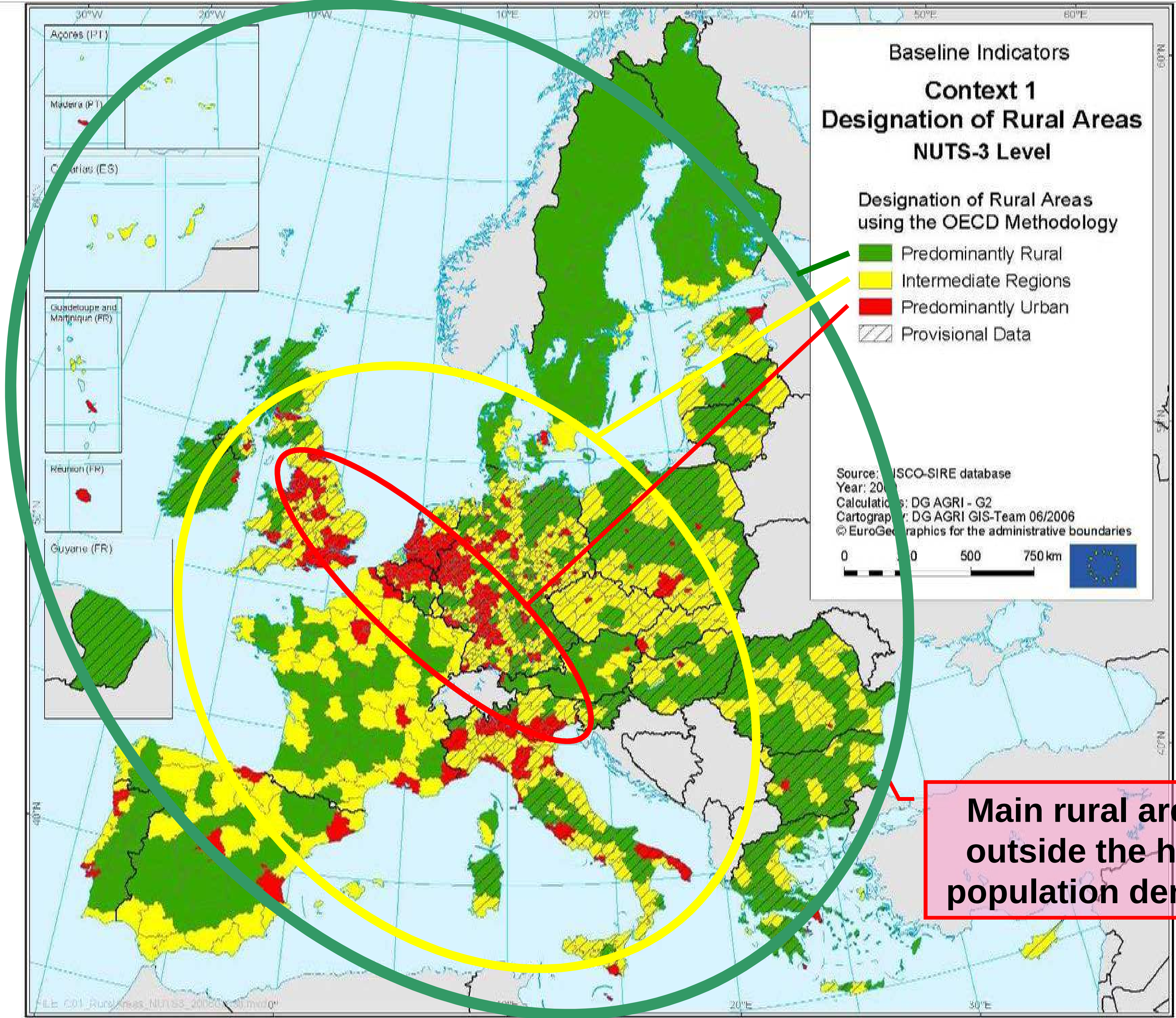
Year	Integrated countries	Mem.	Population	Increase
1958	B, F,D, I, L, NT	6	231.528.635	
1973	DK, IRL, GB	9	300.908.913	29,97
1981	GR	10	312.153.031	3,74
1986	P, E	12	366.867.431	17,53
1995	A, FIN, S	15	389.382.715	6,14
2004	CY, CZ, EST ,H, LT, LV, M, PL, SK, SLO	25	464.205.901	19,22
2007	BG, RO	27	494.296.878	6,48

Quelle: Wikipedia

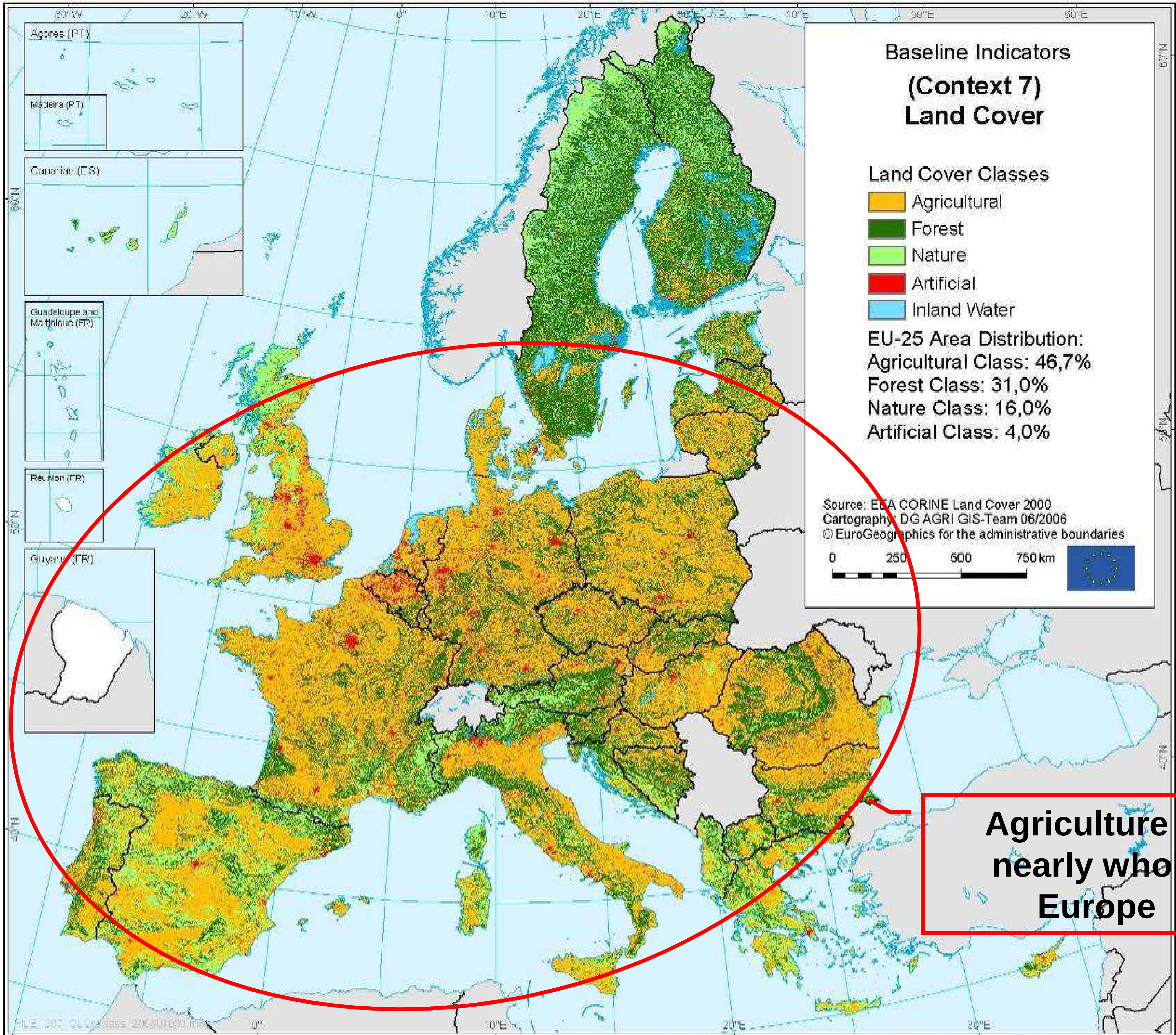
Europe and others

Country	Population	Rel. to EU
EU	494.296.878	100
Australia	20.264.082	4
China	1.313.937.713	266
India	1.095.315.995	222
Japan	127.463.611	26
Russia	142.893.540	29
USA	298.444.215	60

www.geographixx.de



Main rural areas outside the high population density



Source: EEA CORINE Land Cover 2000
Cartography: DG AGRI GIS-Team 06/2006
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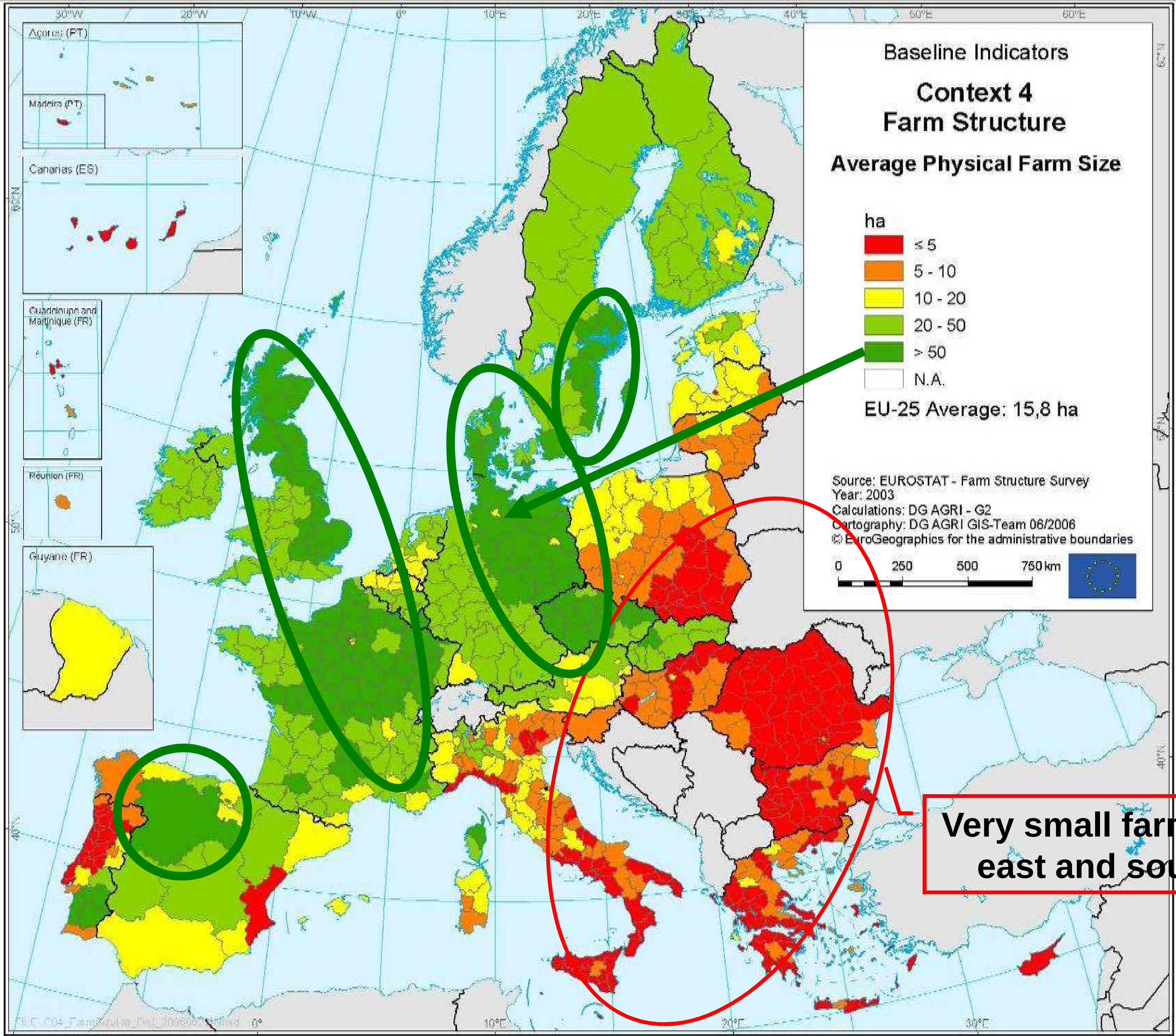
Agriculture in nearly whole Europe

Labor Structure in the EU$_{15}$ 2003

	Share of civil laborers in agriculture, forestry and fishery [%]	Laborers per 100 ha [n]	Share of farm owners <35 years [%]	Share of farm owners >65 years [%]
Belgium (B)	2.0	5.2	8.6	20.4
Denmark (DK)	3.2	2.3	8.4	16.3
Germany (D)	2.3	4.1	12.1	5.9
Greece (GR)	24.2	15.5	7.3	35.5
Spain (E)	5.9	4.0	6.2	33.6
France (F)	3.7	3.3	10.3	16.1
Ireland (IR)	6.6	3.7	11.1	20.3
Italy (I)	4.2	11.3	3.9	40.4
Luxembourg (L)	1.4	3.1	8.3	17.4
Netherlands (NL)	3.3	9.3	7.0	16.5
Austria (A)	7.9	5.4	12.8	8.6
Portugal (P)	2.0	12.2	2.7	46.4
Finland (FIN)	5.3	4.3	9.9	6.5
Sweden (S)	2.3	2.3	6.1	18.4
United Kingdom (UK)	0.9	2.2	3.4	28.6
EU-15	**3.9**	**5.0**	**6.4**	**31.2**

Farm Sizes and Share of cultivated Land EU_{15}

	average Farm size [ha]	Share of farms <5 ha [%]	Share of cultivated land by farms <5 ha [%]	Share of farms >100 ha [%]	Share of cultivated land by farms >100 ha [%]
Belgium (B)	25.4	28.0	2.2	3.1	17.6
Denmark (DK)	54.7	3.7	0.1	15.8	51.7
Germany (D)	41.2	23.6	1.8	6.9	48.3
Greece (GR)	4.8	76.1	26.8	0.2	7.2
Spain (E)	33.1	55.0	4.9	4.4	55.6
France (F)	45.3	27.6	1.2	13.7	48.8
Ireland (IR)	32.3	7.7	0.7	3.6	17.3
Italy (I)	6.7	76.8	17.0	0.7	25.4
Luxembourg (L)	52.3	19.9	0.7	13.8	38.9
Netherlands (NL)	23.5	29.6	2.7	2.1	15.3
Austria (A)	18.7	32.3	4.4	1.7	42.1
Portugal (P)	6.6	76.6	12.9	1.6	53.5
Finland (FIN)	29.9	8.0	0.9	3.0	14.1
Sweden (S)	46.1	10.4	0.6	11.6	46.5
United Kingdom (UK)	57.4	36.9	0.9	14.2	70.2
EU-15	**20.2**	**56.6**	**4.8**	**4.1**	**46.0**



Source: EUROSTAT - Farm Structure Survey
Year: 2003
Calculations: DG AGRI - G2
Cartography: DG AGRI GIS-Team 06/2006
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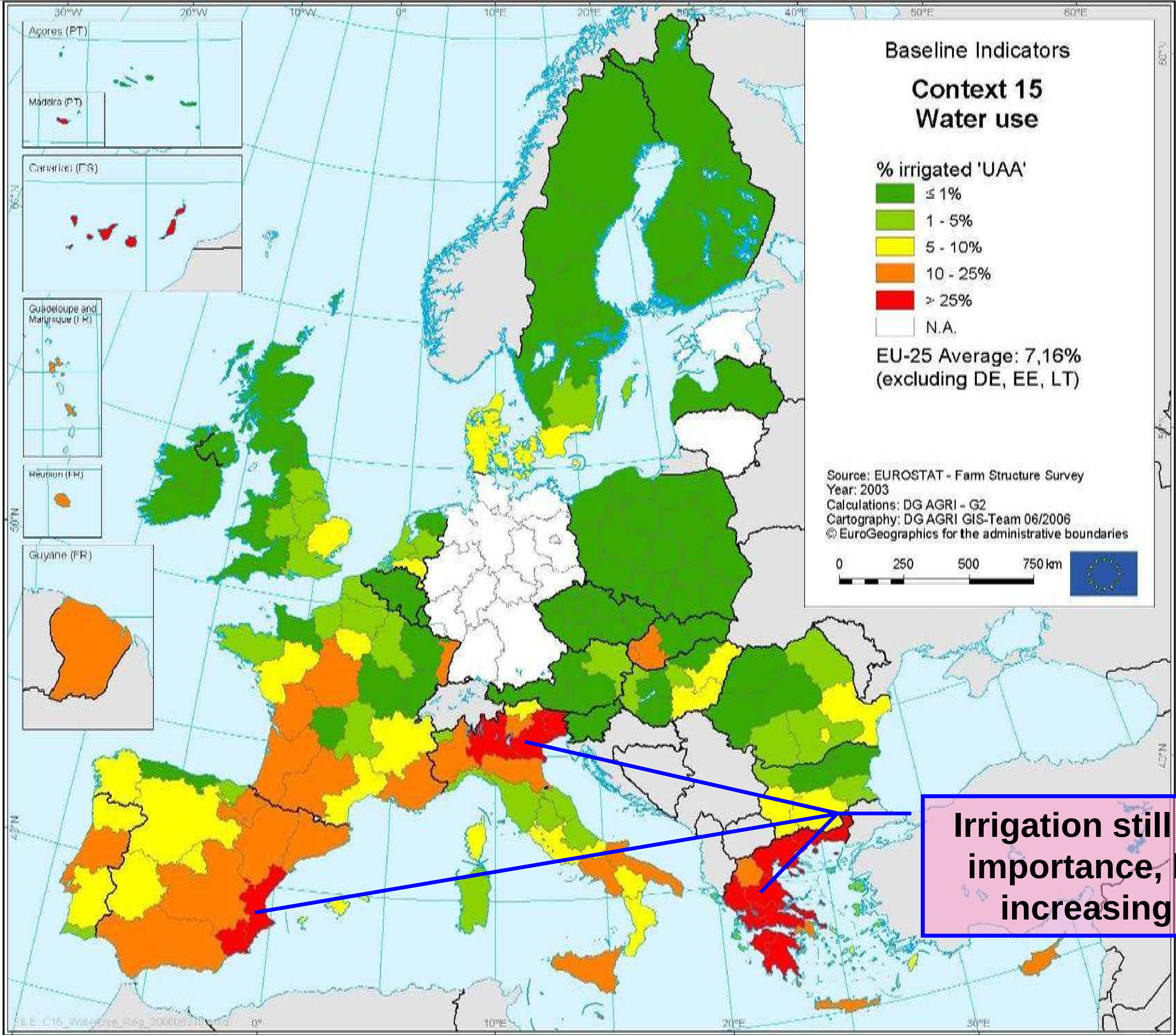
Very small farms in east and south



Source: EUROSTAT - Farm Structure Survey
Year: 2003
Calculations: DG AGRI - G2
Cartography: DG AGRI GIS-Team 06/2006
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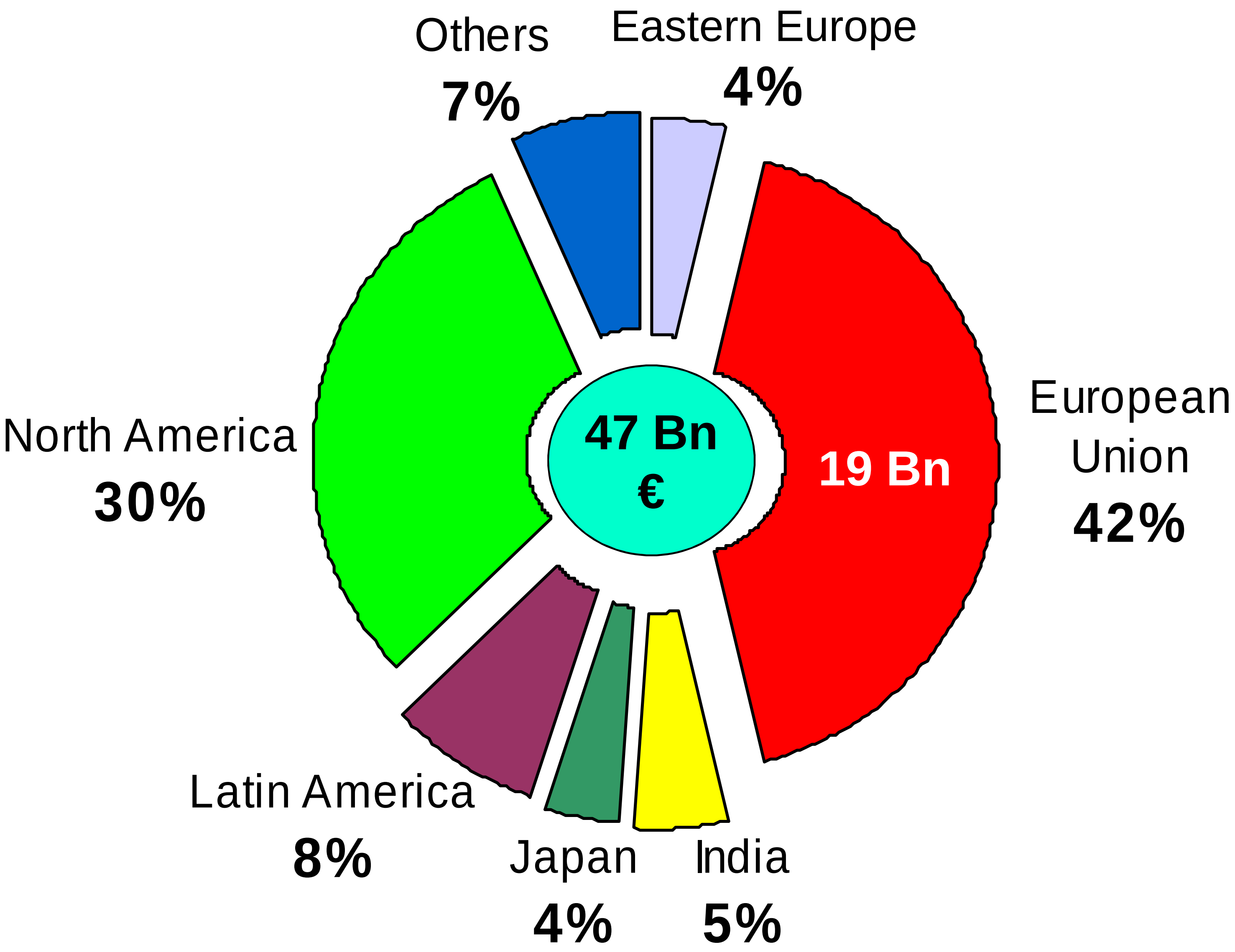
Irrigation still low importance, but increasing !

Global Production of Agricultural Machinery 2005



World leading position of Europe (and the USA) can only be maintained when products are

- *of high quality,*
- *high tech,*
- *possible to integrate in any tractor-implement combination*

→ ***Standards are essential !***

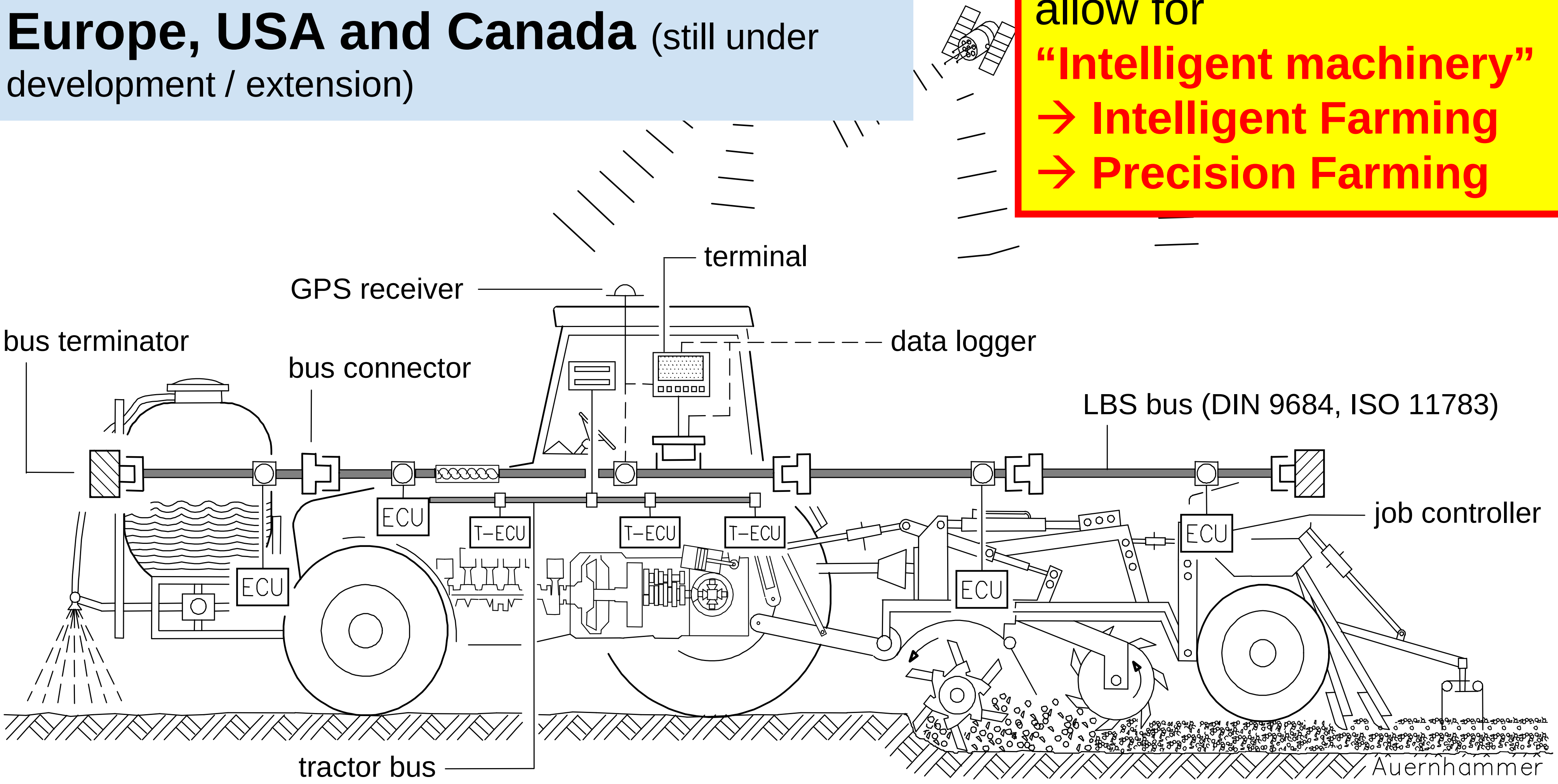
Source: Estimations VDMA Agricultural Machinery, Frankfurt

Agricultural BUS Systems by DIN 9684 and ISO 11783

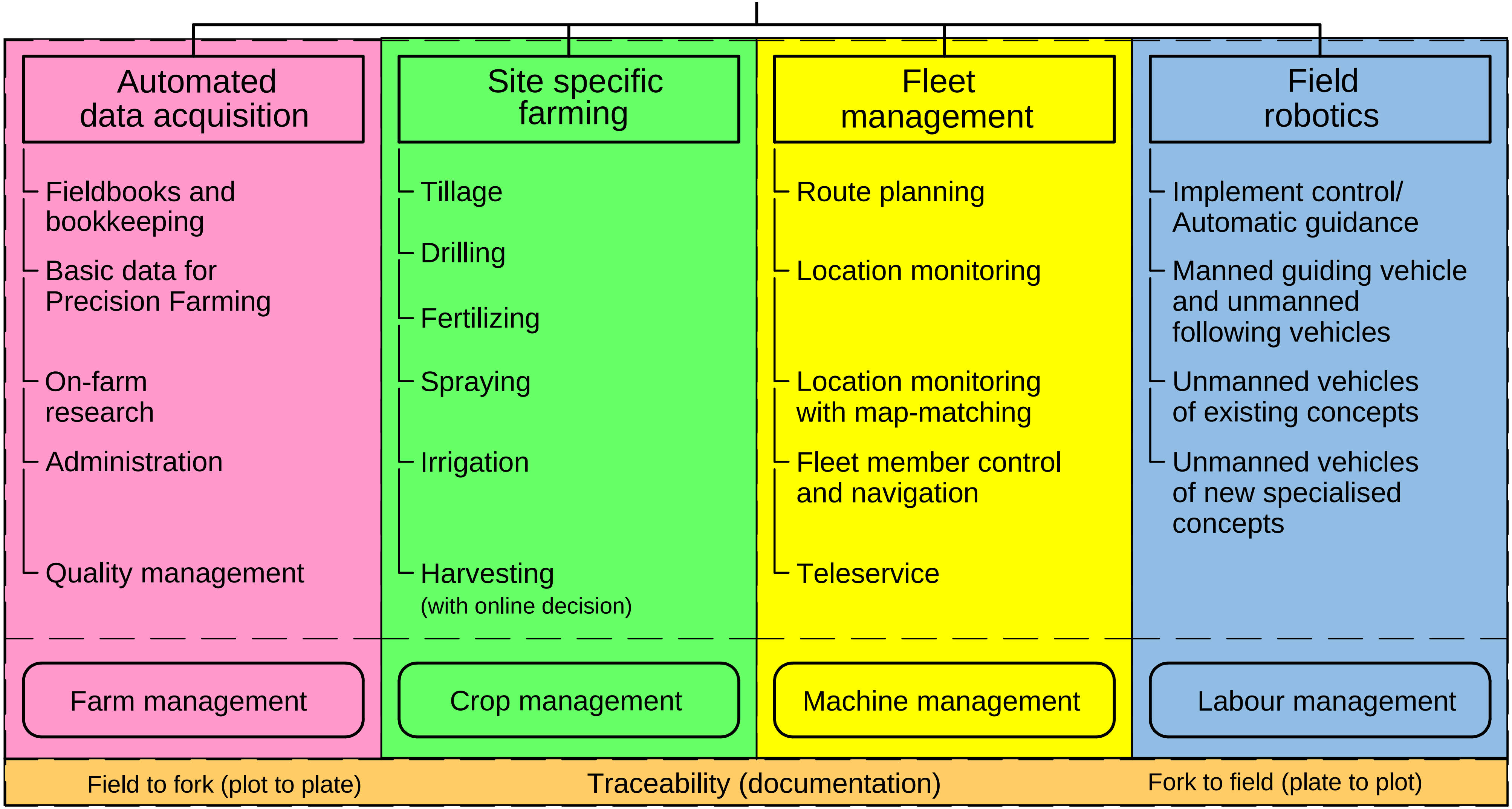
LBS established 1987 – 1997 in Europe
(predecessor and initiator of the ISOBUS)

ISOBUS established from 1994 by Europe, USA and Canada (still under development / extension)

Electronic communication, sensors and actuators and location systems allow for
"Intelligent machinery"
→ Intelligent Farming
→ Precision Farming



Precision (crop) farming *



Automated data acquisition
- Fieldbooks and bookkeeping
- Basic data for Precision Farming
- On-farm research
- Administration
- Quality management

Farm management

Site specific farming
- Tillage
- Drilling
- Fertilizing
- Spraying
- Irrigation
- Harvesting (with online decision)

Crop management

Fleet management
- Route planning
- Location monitoring
- Location monitoring with map-matching
- Fleet member control and navigation
- Teleservice

Machine management

Field robotics
- Implement control/ Automatic guidance
- Manned guiding vehicle and unmanned following vehicles
- Unmanned vehicles of existing concepts
- Unmanned vehicles of new specialised concepts

Labour management

Field to fork (plot to plate) Traceability (documentation) Fork to field (plate to plot)

Precision Farming is more than only
“Site-specific Farming !

---

*) First draft established 2001, Dec 4 by the author

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Precision in seeding operations 1930

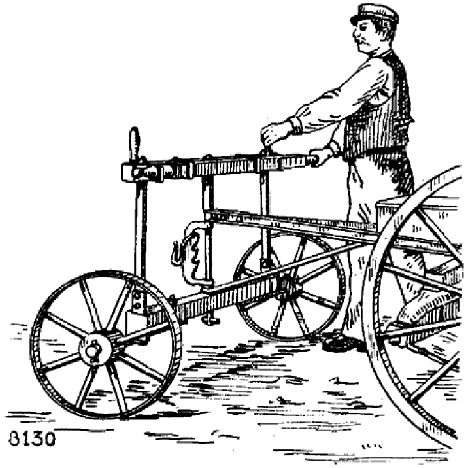


Abb. 156. Schiebe-Vorderſteuer.

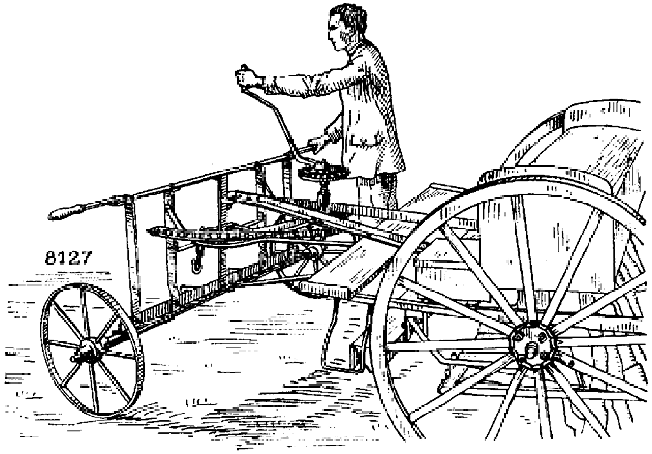


Abb. 157. Ketten-Vorderſteuer.

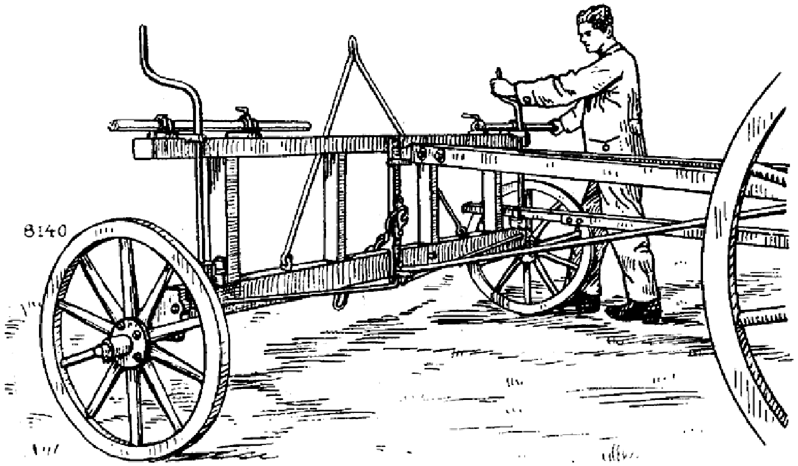


Abb. 158. Zahnſtangen-Vorderſteuer.

Source: Kühne, G. und Meyer, E.: Leitfaden der Landmaschinenkunde 1930, S. 61

Requirements:

- **New track has to be placed in the previous track**, distance error **≤½ wheel width = ≤3 cm**
- Tracks have to be **absolutely straight** (ones must be able to shoot through it)
- In sugar beets a so called **“Blind hoe”** is allowed when following the seeding track

Therefore: **Seeding was done with three people**

- One responsible for the drawing animals
- One doing highly accurate steering of the sowing machine
- A third one watching the seed distribution behind the sowing machine

Changing to tractor operated seeding in the 50th

Tractor instead of animal drawing,

- **Still accurate steering by humans on low mechanized small farms**

Roller markers at tractor and
adopted seeding technology

- **Technical assistance for parallel tracking in tractor mounted seeding units**

Tram lines in grain production since the 70th

Appearance at early state

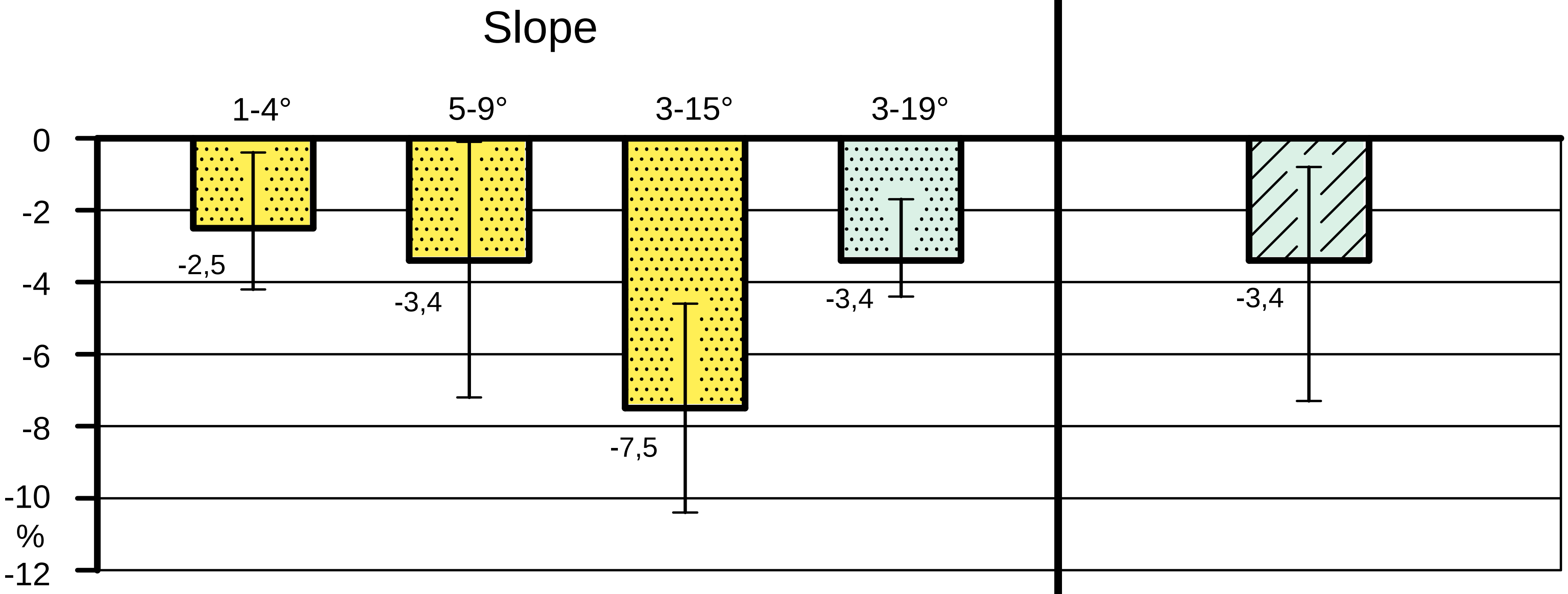
Appearance before harvesting

- **Used for fertilization (2 to 3 passes) and spraying (1 to 2 passes) operations mainly, sometimes also for harvesting in “skipped passes” (when tram line distances correlates with multiple harvester working widths)**
- **Less overall soil compaction**
- **No significant reduction in yield**

Investigated Tram Line Interspaces on Farms

Own investigations 1991
Set-distance 12 m
Region Freising (Germany), 61 fields

Investigation by SCHICK 1990
Set-distance 20 m
Region Schleswig-Holstein (Germany)



Mean tram-line error [m]	-0,30	-0,41	-0,90	-0,41	-0,68

- **All tram line distances are to narrow → Overlapping !**
- **Slope has a significant influence → Human reaction is limited !**

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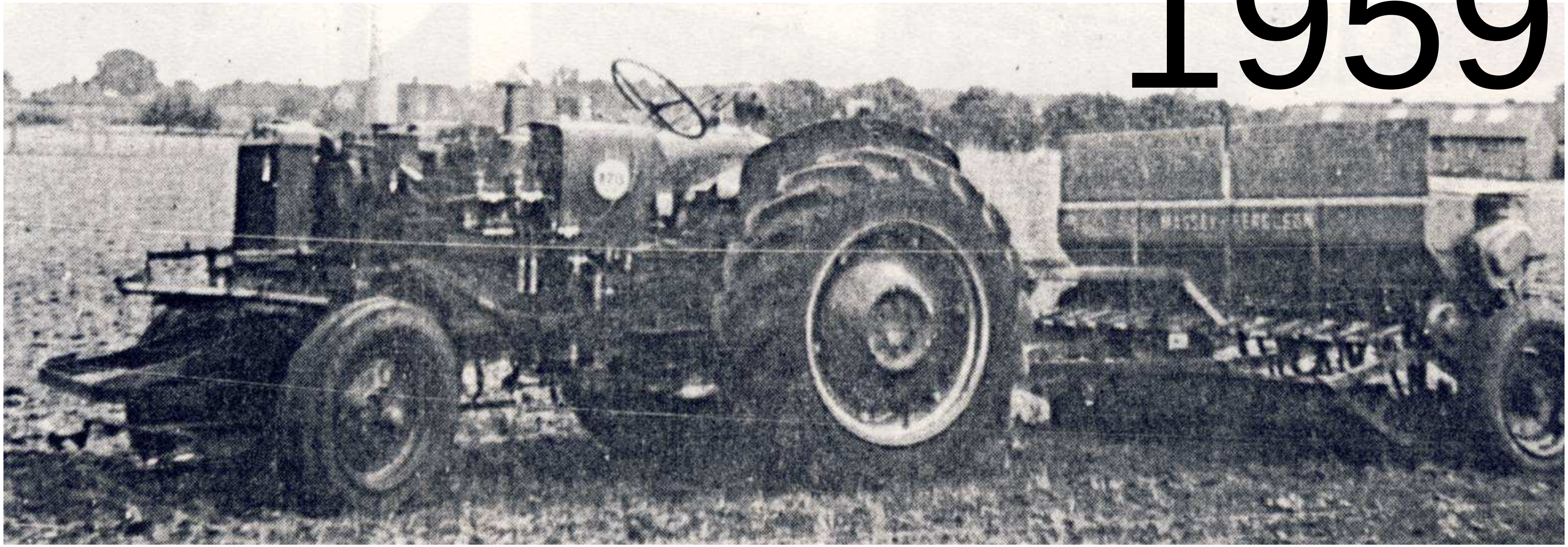
First autonomous tractor in Europe (GB) 1959

This driverless tractor was evolved at Reading University 1959, and it follows a cable buried under the Soil below cultivation depth. Picture by kind permission of Keith Morgan, Reading University.

1959



Source: GROWER 1982, Dec. 16, p 23

- **Shown for seeding purposes too**
- **Usable only after establishment of infrastructure**
- **Developed in a time when enough labourer were available**

EICHER autonomous Plough (D) in 1964

Agrirobot, a one body autonomous plough with mechanical control. Driving direction was changed at field end after passing with the “switch wheel” across a previously established lateral furrow.

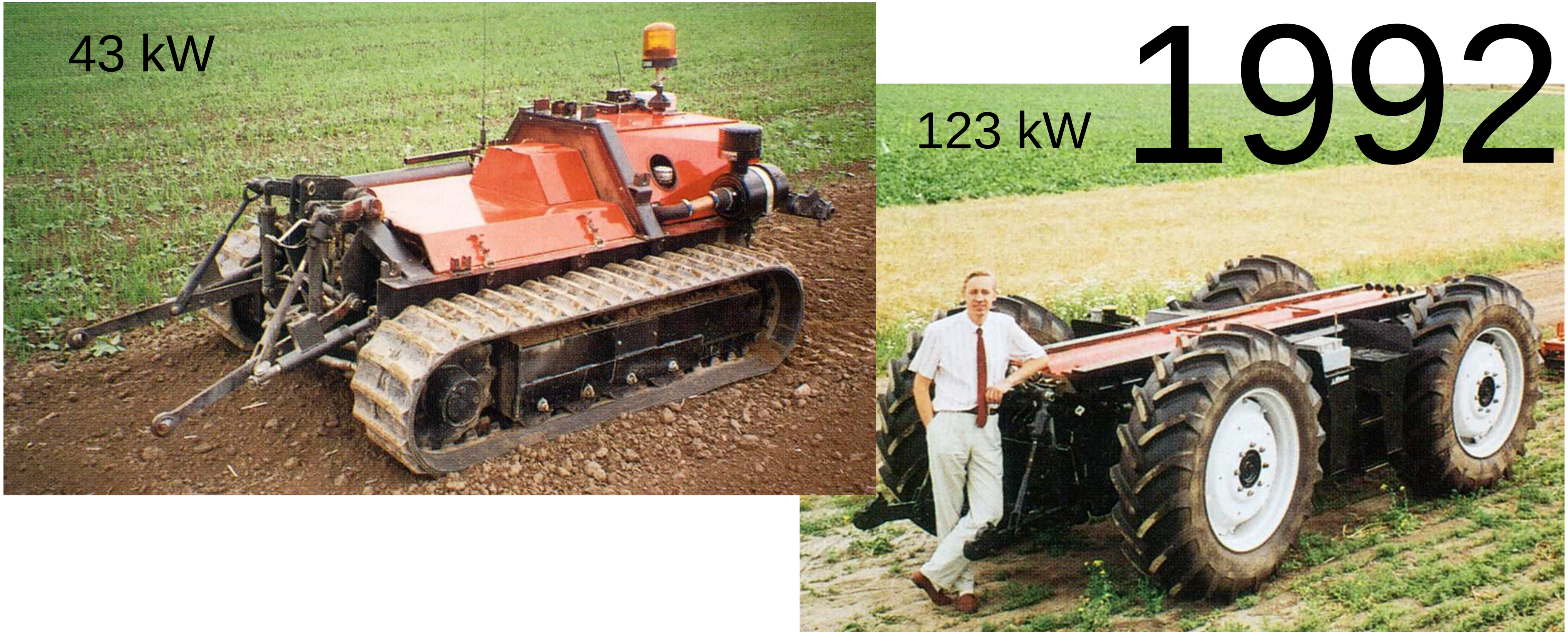
Source: Archive Landtechnik Weihenstephan (992ab058)

1964

- **Use of available tractor parts (engine, power transmission)**
- **Created as a small unit for 24-hour-work**
- **Ploughing does not need constantly manual attention and monitoring**

Modular unmanned tractor for agricultural applications (SF)

Developed in Finland in 1992 with 2 different sizes to stop the ongoing enlargement of tractors.



- **Platforms with RTK-GPS auto guidance systems**
- **Two-way use with different implements, using the 3-point-linkage!**
- **Rubber wheels in the larger, rubber-tracked crawler in the smaller unit**

Source: Nieminen, T., Mononen, M.J., Sampo, M.: Unmanned tractors for agricultural applications. Milano 1994

GeoTec autonomous tractor guidance 1999

Overall steering and control device for use in autonomous tractors, established by GoeTec, Hallbergmoos (Germany).

- **Only a few units were sold** (around 50.000 €/unit under discount conditions for research purposes)
- **Full operational capability was demonstrated**
- **No real market under the given European conditions at that time**

Source: Ehrl, M., Stempfhuber, W., Demmel, M., Auernhammer, H.: AutoTrac - accuracy of a RTK DGPS based autonomous vehicle guidance system under field conditions. Kyoto 2004

Autonomous Christmas tree weeder 2004

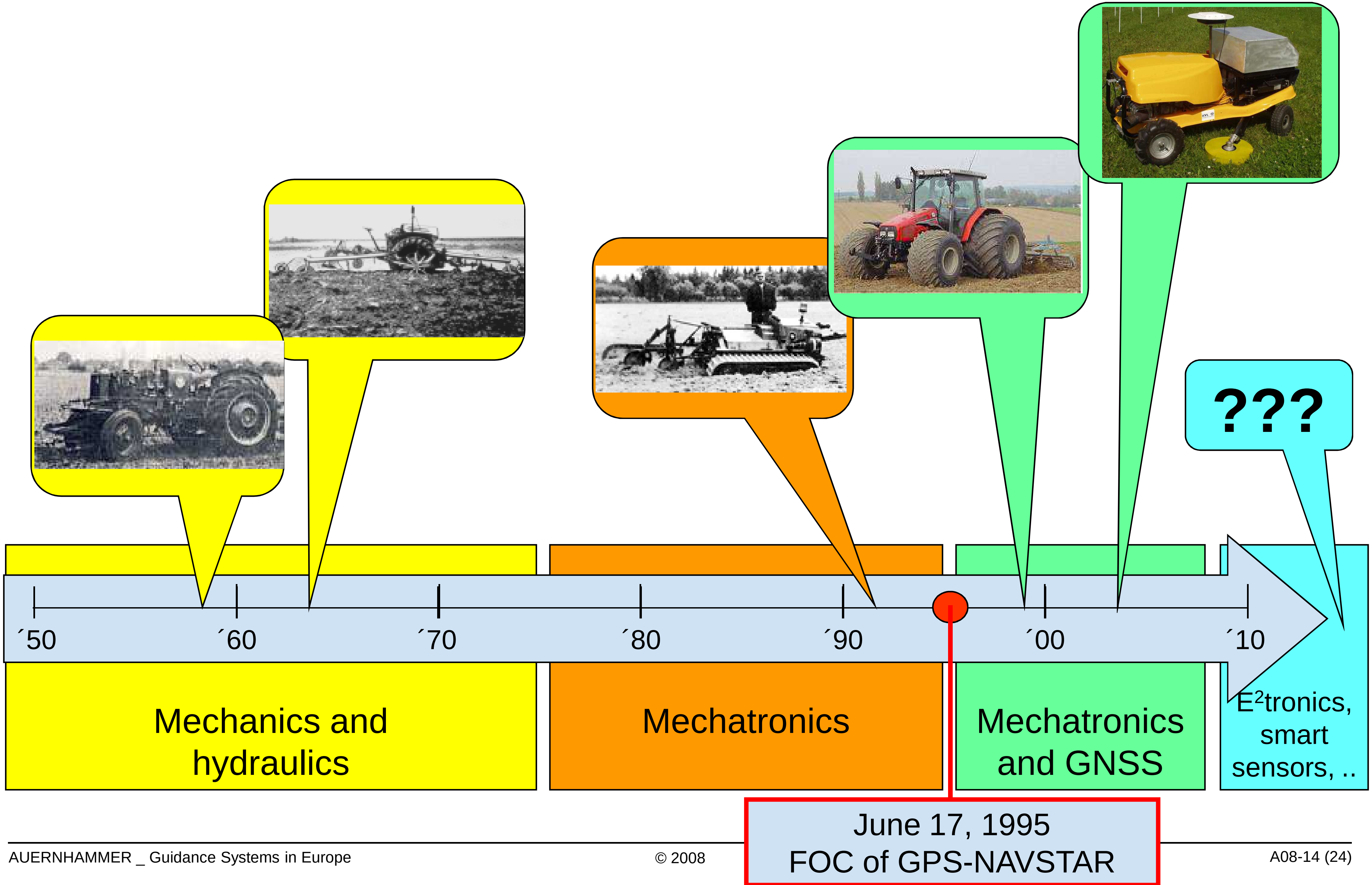
Based on a platform from a self-propelled 4-wheel grass mower, established by Simon Blackmore and others (Denmark).

2004

- **Used for weeding only**
- **Additional sensors and sensor fusion required**
- **Obstacle detection and safety requirements another challenge**

Source: *www.unibots.com/ACW.htm*

Important attempts to autonomous vehicles at a glance



Mechanics and hydraulics

Mechatronics

Mechatronics and GNSS

E²tronics, smart sensors, ..

June 17, 1995
FOC of GPS-NAVSTAR

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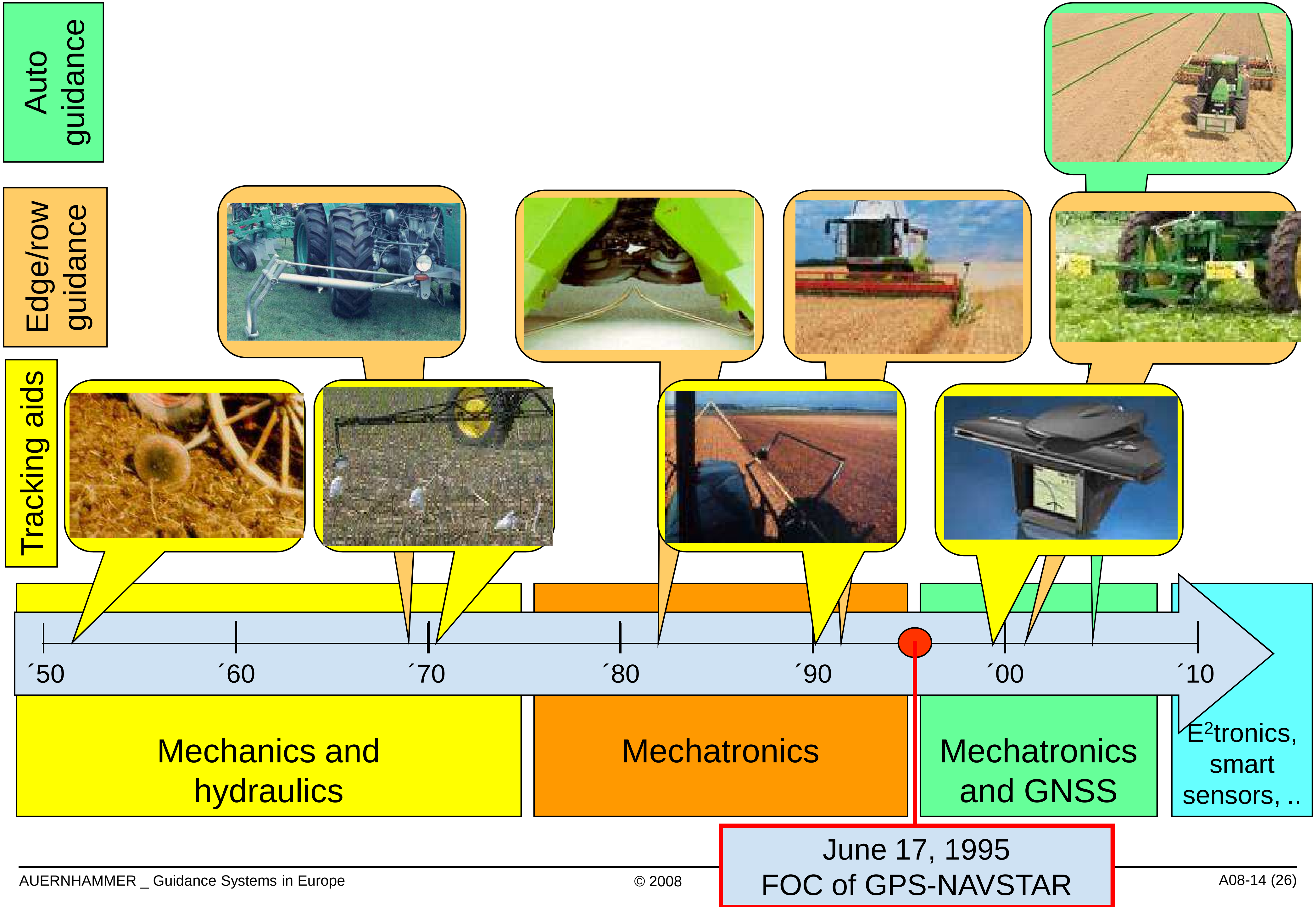
Guidance systems



Auto guidance

Edge/row guidance

Tracking aids

´50 ´60 ´70 ´80 ´90 ´00 ´10

Mechanics and hydraulics

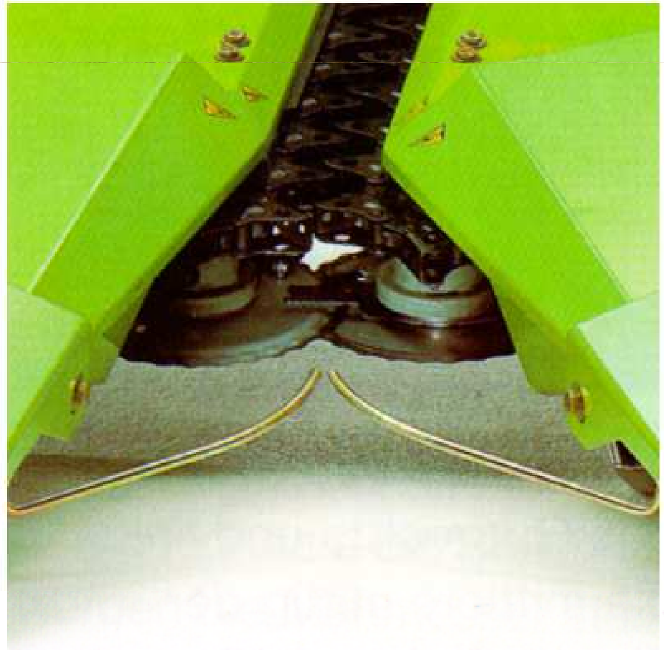
Mechatronics

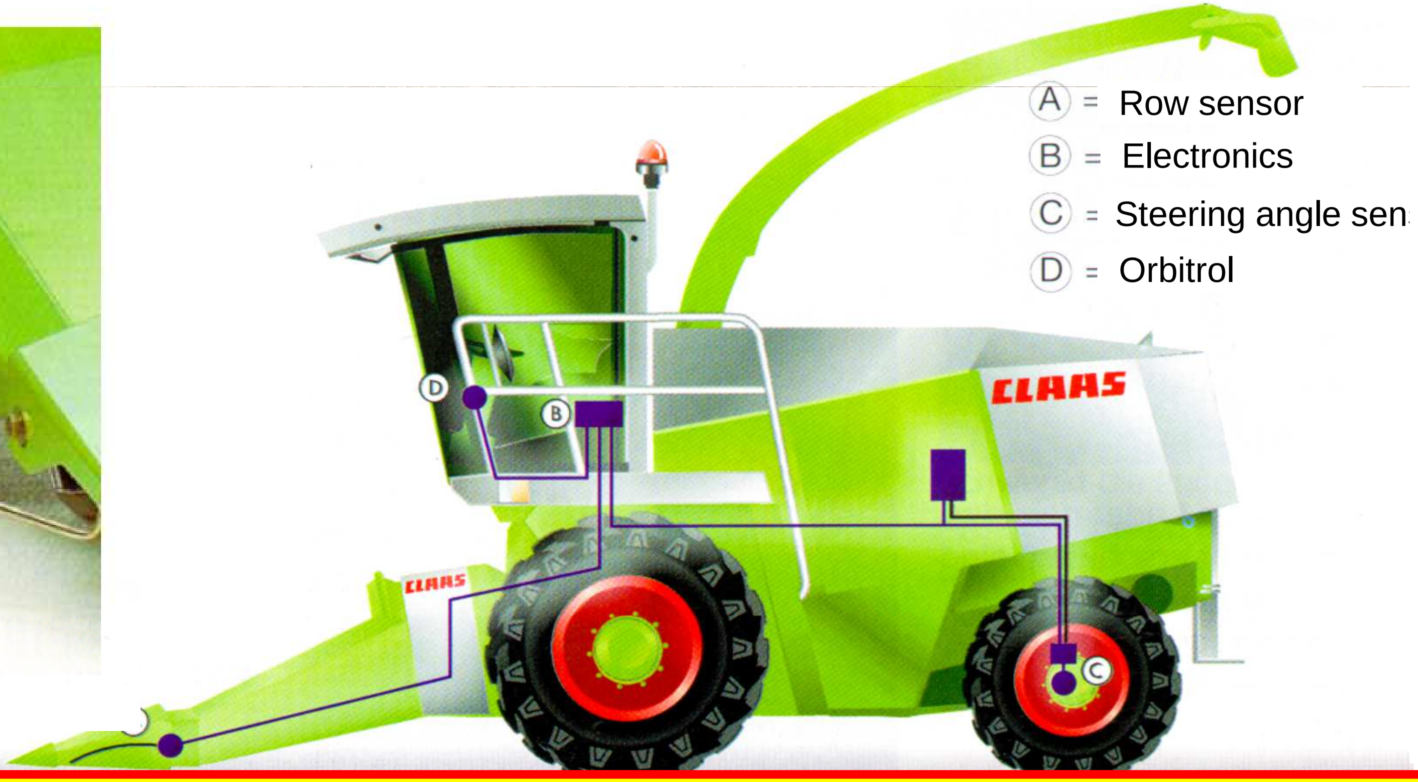
Mechatronics and GNSS

E^{2}tronics, smart sensors, ..

June 17, 1995
FOC of GPS-NAVSTAR

Row guidance in corn and silage mais





- **First announced in 1977**
- **“One row” sensing device**
- **Meanwhile more than 10.000 systems in use, extra equipment >70 %**

Row guidance in sugar beet combine harvesters

- **Visual “backsight” to pull into the row at the headland**
- **“Three row sensing device”**
- **Secure guidance (basic accessory unit since more than 10 years)**

Guidance in grain combine harvesters

- **First announced in 1999**
- **“One edge” sensing device (often two devices installed)**
- **Meanwhile more then 15.000 systems in use, extra equipment >50 %**

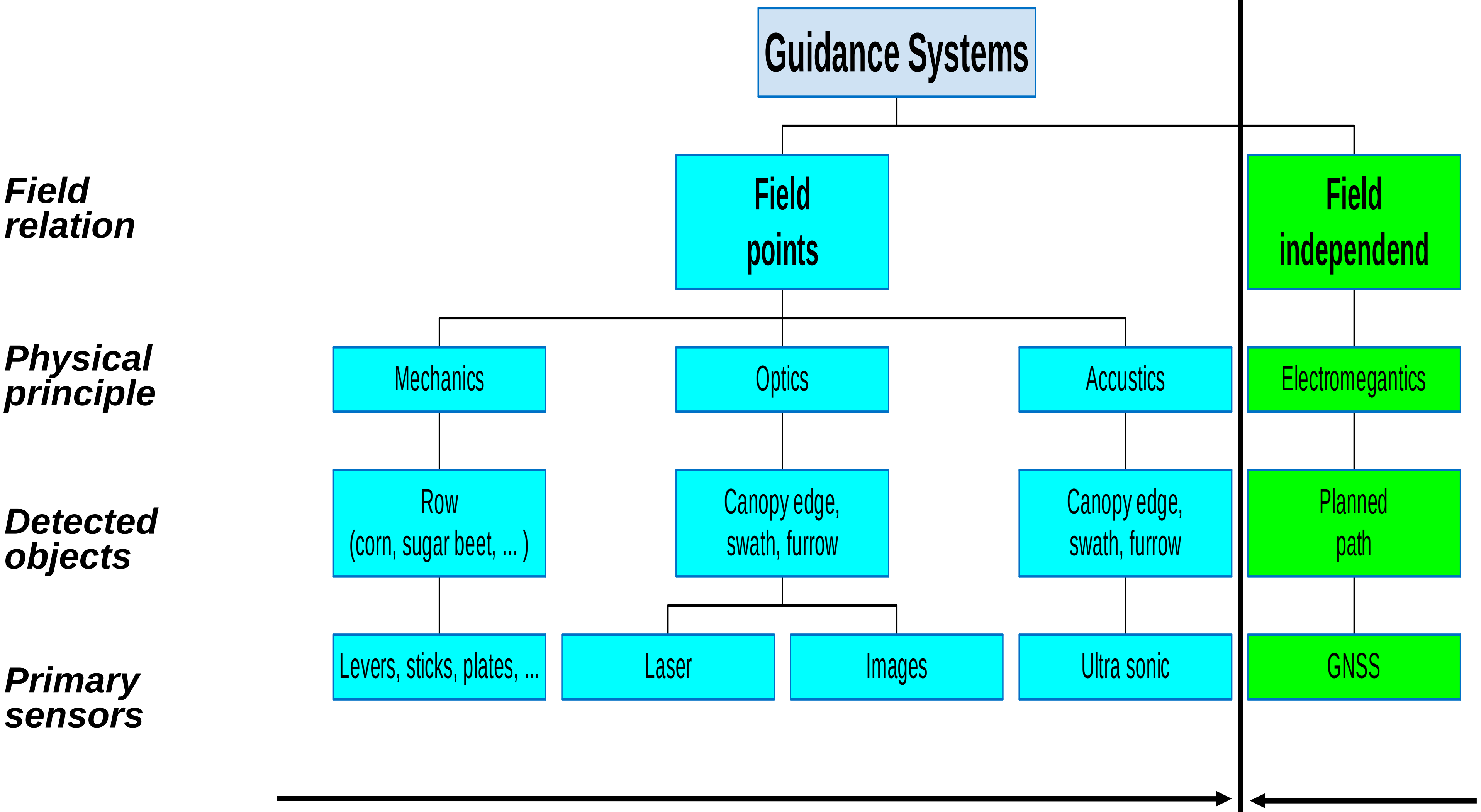
Tram line, swath and furrow guidance (ultra sonic)

- **First announced in 1998**
- **“Four sensor” adaptable device unit**
- **Mainly offered and used for swath guidance (round and square balers, …)**

Universal optical guidance system (Eye-Drive) 2008

- First announced in 2006
- “3D-Camera” sensing device
- About 100 systems in use, mainly in horticultural row crops

Guidance systems (schematic)



Guidance Systems

Field relation

Field points

Field independend

Physical principle

Mechanics

Optics

Accustics

Electromegantics

Detected objects

Row (corn, sugar beet, ...)

Canopy edge, swath, furrow

Canopy edge, swath, furrow

Planned path

Primary sensors

Levers, sticks, plates, ...

Laser

Images

Ultra sonic

GNSS

All systems are offered and used on field level
- are specialized for certain tasks
- need no infrastructure
- can simply be added to existing machinery

Systems for different use are offered and used on field level

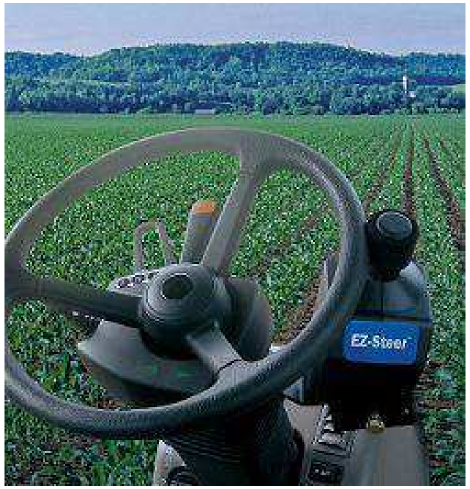
Source: Koch P., Munich-Weihenstephan 2007, modified

Today parallel-tracking gets more and more popular

Guidance aid

System signals the distance to an ideal driving lane by a visual device.

Steering assist



Assistant performs steering functionality and can be used on different machines.

Automatic Guidance

Automatically steers the tractor via hydraulic valve and becomes part of the machine.

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Accuracy requirements of guidance systems

Required accuracy	Field operations (examples)	Rough rating
± 20 to ± 30 cm	Operations on stubble fields or on grass land Soil tillage Distribution of organic matters Distribution of mineral fertilizer Plant protection measures (spraying) Liming	*Normally large working width of the implements (e.g. > 6 m)*
±5 to ±10 cm	On-land ploughing Seeding Tillage-seeding-combinations Planting Mowing Harvesting	*Working width of the implements up to ~ 6 m*
±2 cm	Seeding Mechanical weed control Seeding and husbandry of special crops Controlled traffic	*High precision field work*

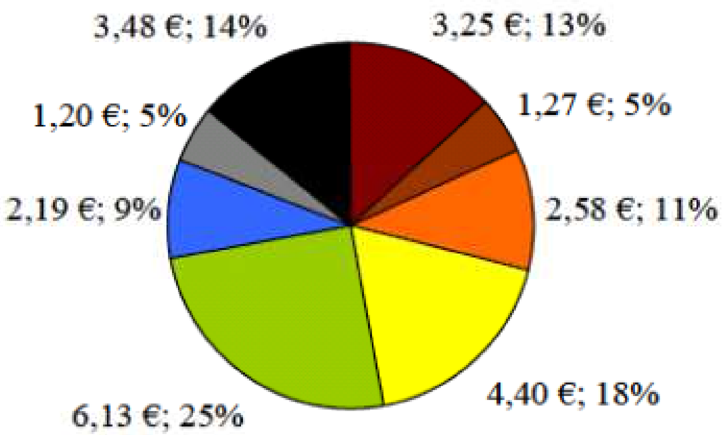
Source: Koch P., Munich-Weihenstephan 2007, modified

Expected benefits of guidance systems

Criterion		Benefit
Hard facts (measurable)	Reduction of overlapping	Savings of seed, fertilizer, plant protectants Increased working capacity Prevention of doubble applications
	Reduced labour costs and higher labour capacity	Increased working speed Reduced fuel consumption More accuracy even with larger working widths of implements Operation with less trained people Extended field working time (evening, night, fog, dust, ...) Cheaper Implements (abandonment of markers, foamers, ...) Eventually reduction of additional tractors/implements
Soft facts (not measurable)	Working conditions	More comfort More time for implement control Reduced work fatique Social effects to the family (more freedom in work termination)
	Image	Improved appearance of agriculture to the community Doing better than the neighber Avoiding of mistakes (nonattention, work overload, ...)
	Environment	Improved repeatability of working operations Improved conditions for mechanical husbandry measures in row crops Optimized management of field works Documentation of field working conditions Efficient contribution to "Precision Farming Practice"

Increased productivity of guidance systems 2007 (±5 – 10 cm)

Wheat: 24.49 €/ha

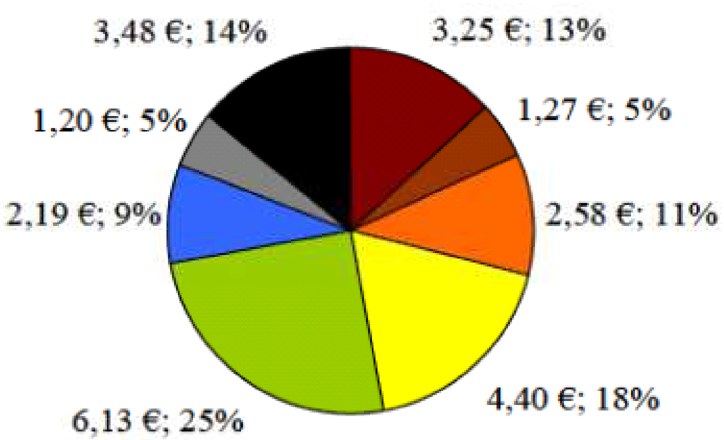


🟥 Tillage
🟫 Seed bed preparation
🟧 Seeding
🟨 Plant protection
🟩 Fertilizing
🟦 Liquid manure
▨ Liming
⬛ Round up

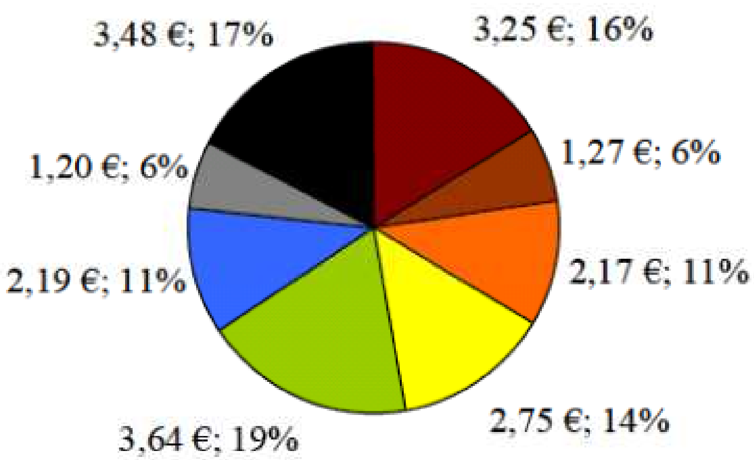
Source: Koch P.: Wirtschaftlichkeit automatischer Lenksysteme unter besonderer Berücksichtigung der John Deere-Systeme "Auto Trac", "iTecPro" und "iGuide„. Munich-Weihenstephan 2007

Increased productivity of guidance systems 2007 (±5 – 10 cm)

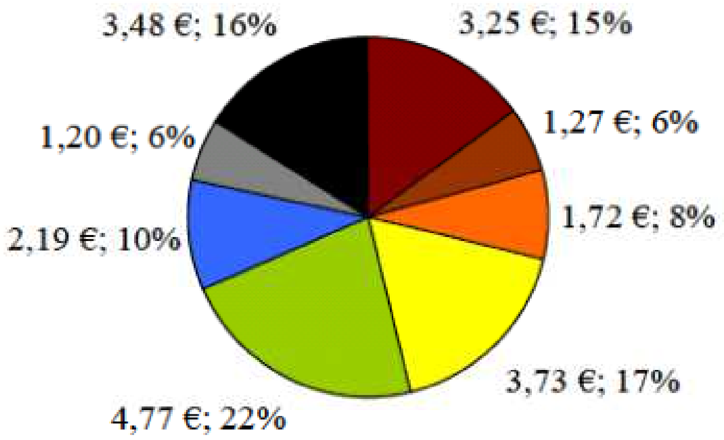
Wheat: 24.49 €/ha



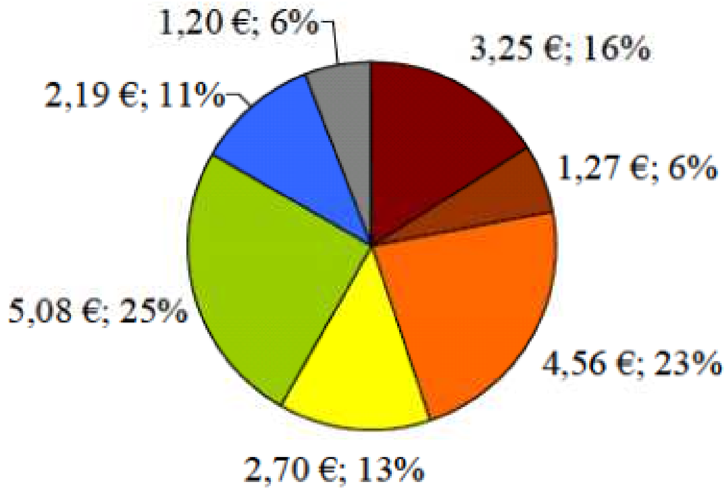
Summer barley: 24.49 €/ha



Rape: 21.61 €/ha



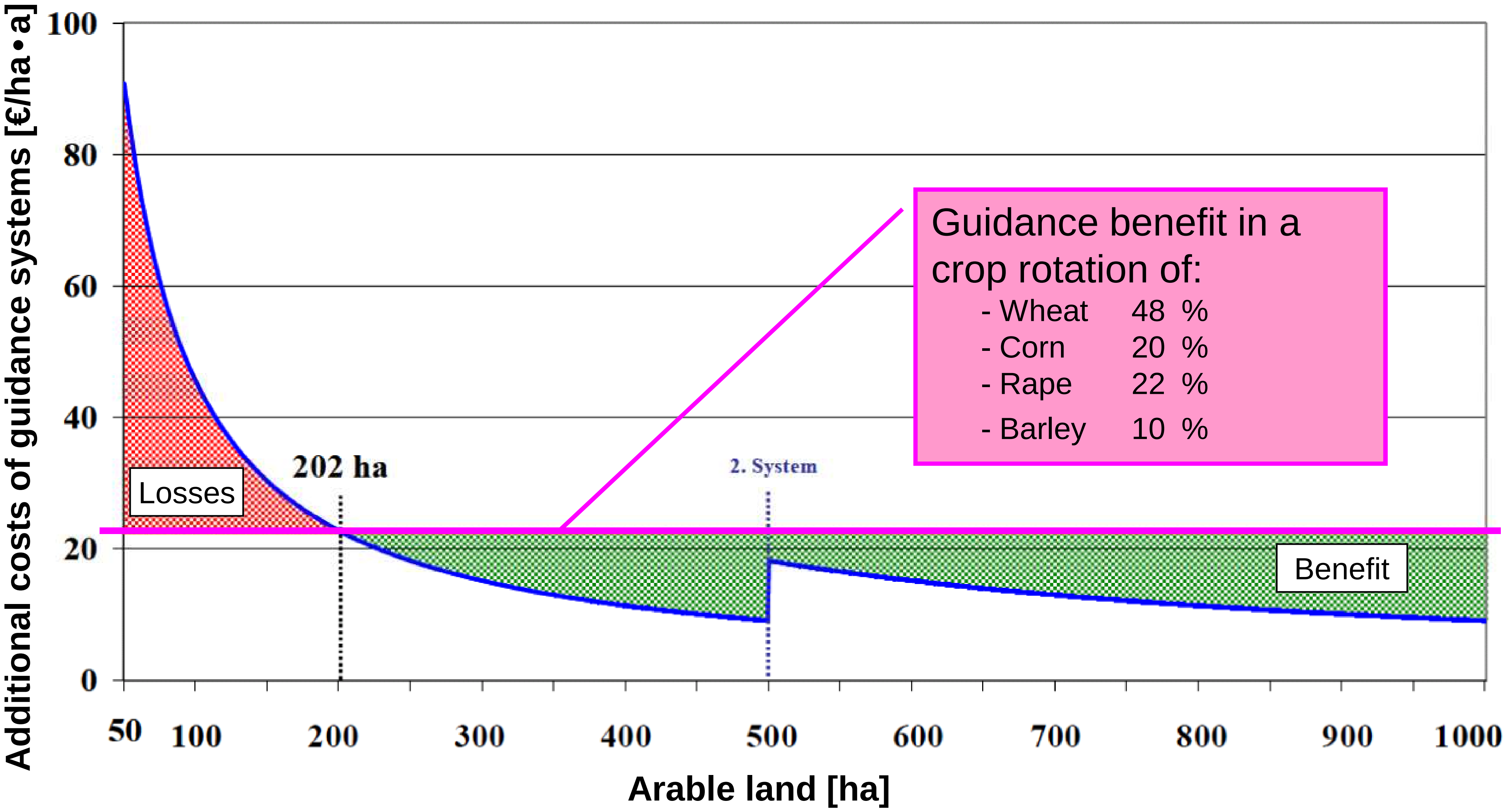
Silage mais: 20.24 €/ha



■ Tillage
■ Seed bed preparation
■ Seeding
■ Plant protection
■ Fertilizing
■ Liquid manure
■ Liming
■ Round up

Source: Koch P.: Wirtschaftlichkeit automatischer Lenksysteme unter besonderer Berücksichtigung der John Deere-Systeme "Auto Trac", "iTecPro" und "iGuide„. Munich-Weihenstephan 2007

Cost – benefit relation of guidance systems 2007 (±5 – 10 cm)

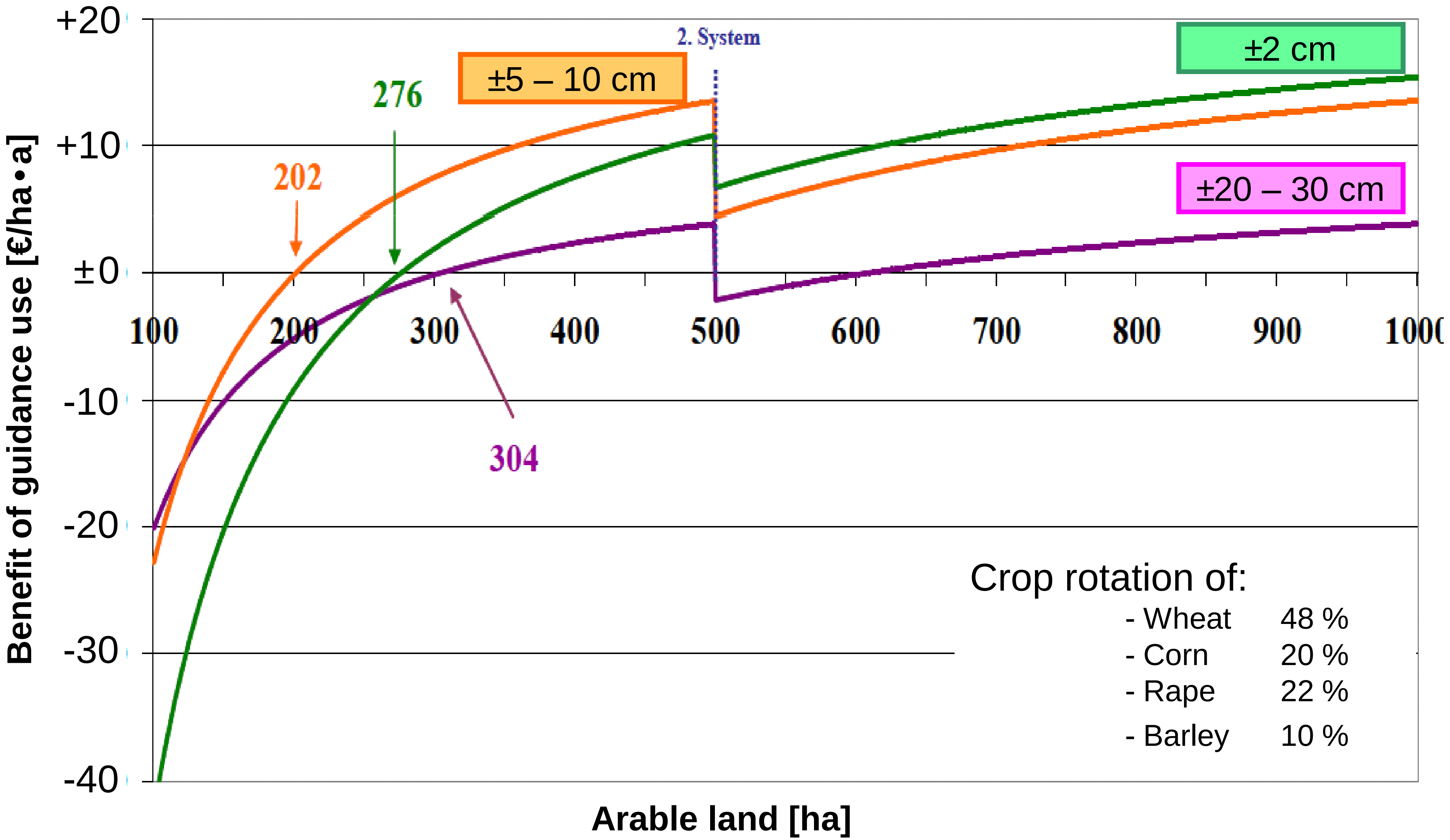


Guidance benefit in a crop rotation of:

- Wheat	48 %
- Corn	20 %
- Rape	22 %
- Barley	10 %

Source: Koch P.: Wirtschaftlichkeit automatischer Lenksysteme unter besonderer Berücksichtigung der John Deere-Systeme "Auto Trac", "iTecPro" und "iGuide„. Munich-Weihenstephan 2007

Benefit changes of guidance use 2007



Crop rotation of:

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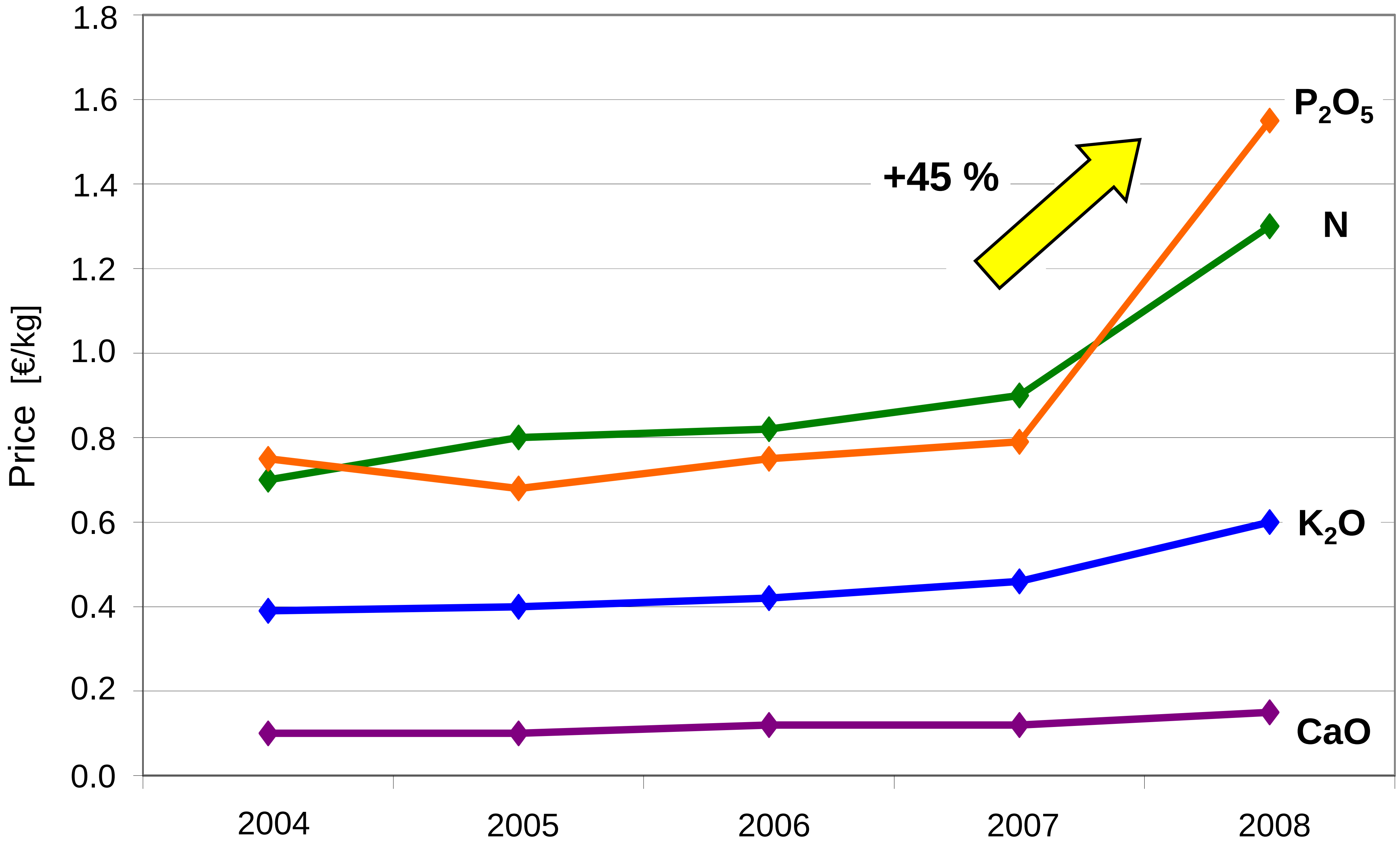
Source: Koch P.: Wirtschaftlichkeit automatischer Lenksysteme unter besonderer Berücksichtigung der John Deere-Systeme "Auto Trac", "iTecPro" und "iGuide„. Munich-Weihenstephan 2007

Price Development of Input Costs

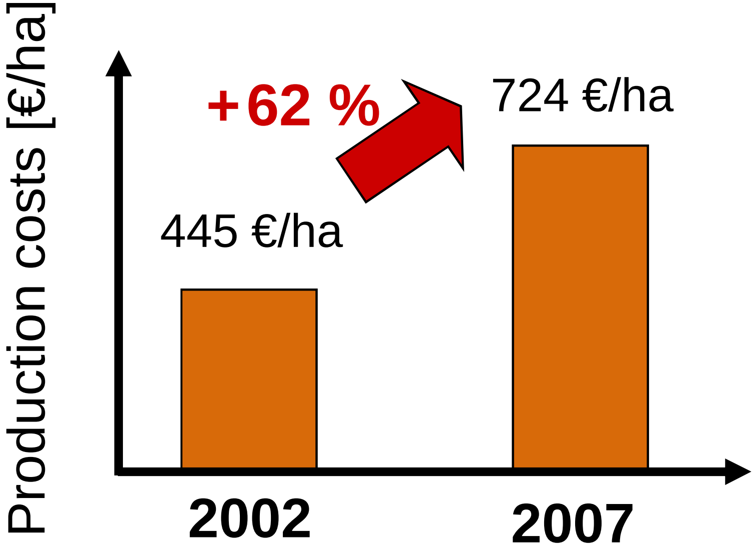


Source: Koch, P., Mannheim 2008

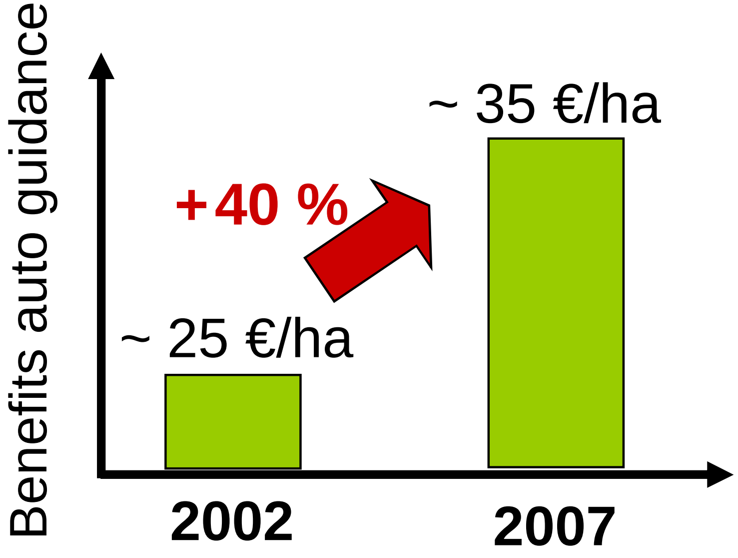
Increasing prices and competition in land use

- More and more cultivated crops are used for energy production
- Price levels for production factors are increasing
  (labour, fuel, fertilizer, crop protection, rents….)

To produce 1 ha (~ 2.4 acre) of wheat
Took from …. to ….

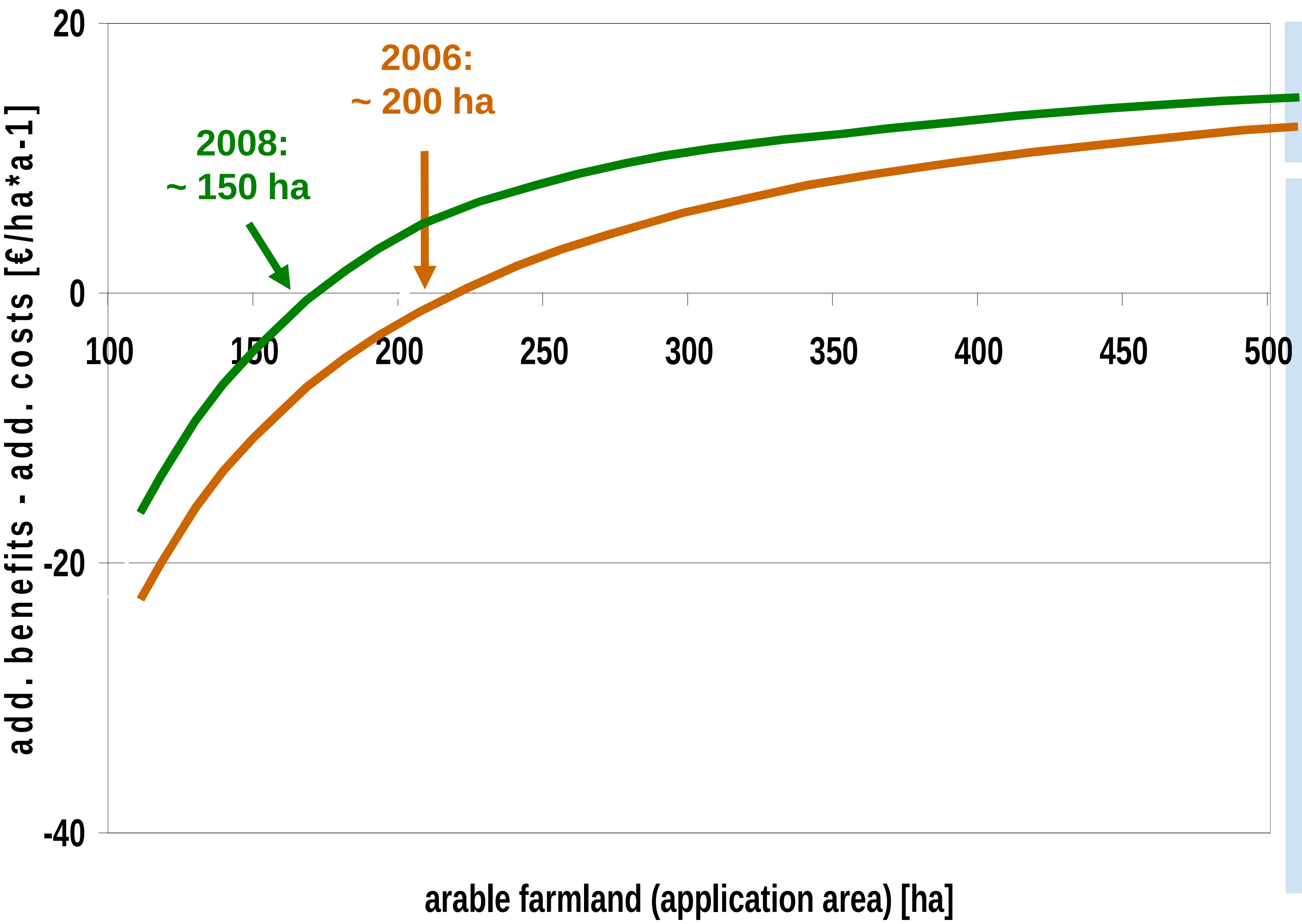


In the same way benefits by auto
guidance per ha increased ….



Source: Koch, P., Mannheim 2008

Influence of direct costing to the „Break Even Point“



2006:
~ 200 ha

2008:
~ 150 ha

Economic Assumptions:

- Depreciation: 5 a
- Interest rate; 6 %
- Field size: 20 ha
- Accuracy ±5 cm
- Terminal: GS 2600
- Overlapping: 8 %
- Crop rotation:
  - Wheat 48 %
  - Corn 20 %
  - Rape 22 %
  - Barley 10 %

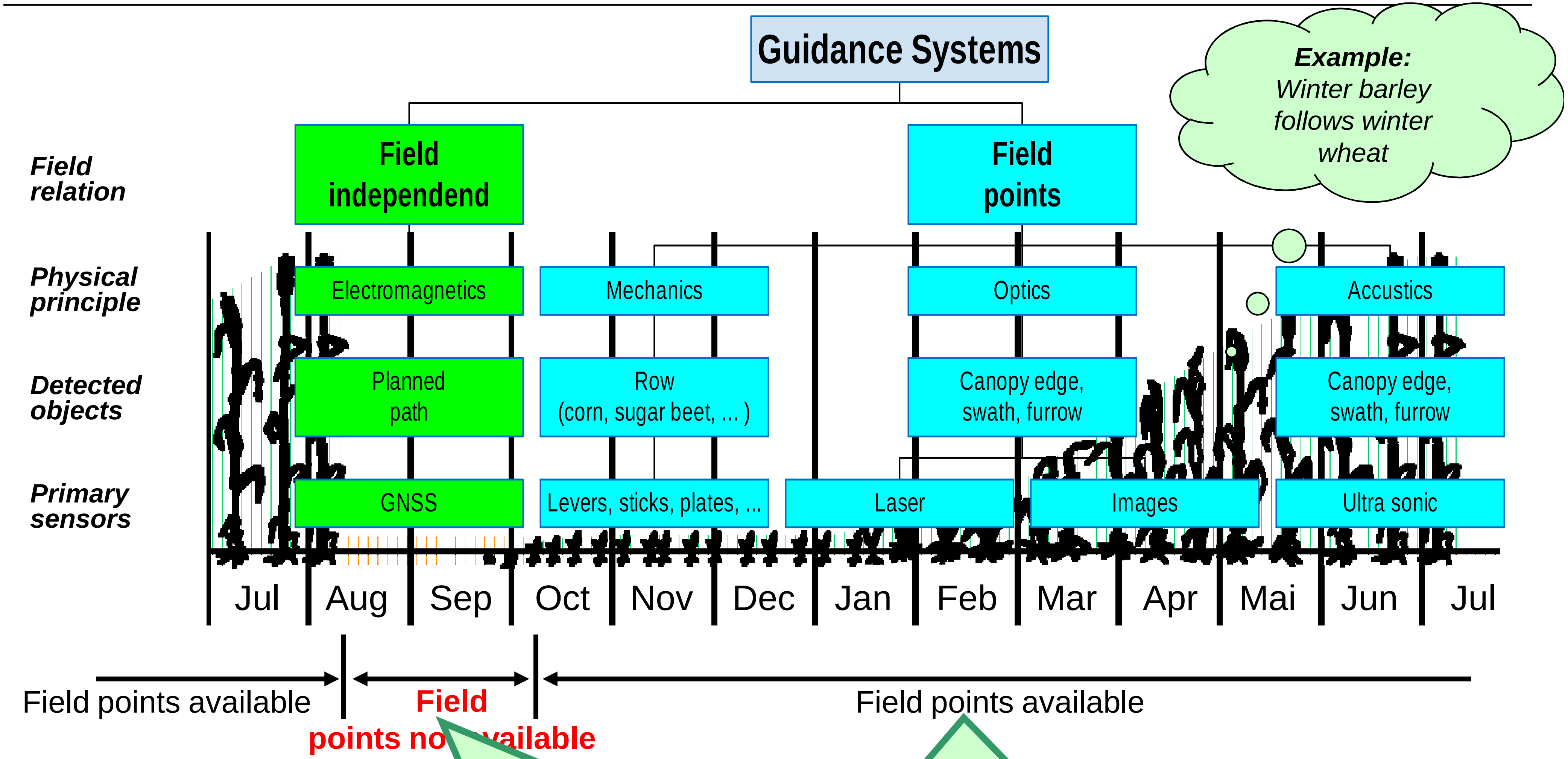
- **Higher direct costs reduces the “Break Even Point”**
- **Higher direct cost increase the benefit of guidance systems**

Source: Koch P.: Wirtschaftlichkeit automatischer Lenksysteme unter besonderer Berücksichtigung der John Deere-Systeme "Auto Trac", "iTecPro" und "iGuide„. Munich-Weihenstephan 2007

1. Agriculture in Europe
2. Precision in the past and today
3. Guidance systems in autonomous vehicles
4. Guidance systems in driver operated vehicles
5. Assessment of driver operated guidance systems

6. Conclusions

Guidance systems in a farm based conclusion



Guidance Systems

Field relation	**Field independend**		**Field points**		
Physical principle	Electromagnetics	Mechanics	Optics		Accustics
Detected objects	Planned path	Row (corn, sugar beet, ...)	Canopy edge, swath, furrow		Canopy edge, swath, furrow
Primary sensors	GNSS	Levers, sticks, plates, ...	Laser	Images	Ultra sonic

Example:
Winter barley follows winter wheat

Field points available

Field points no vailable

Field points available

Only GNNS-based guidance systems fulfill all requirements (and allow the use of other systems during the growing period!)

All guidance systems fulfill the requirements under regular conditions!

Sensor fusion allows highest benefits !!!

Conclusions

- Guidance in Europe (and in other continents too) have experienced highest attention during animal drafted field operations.
- The move to tractor drawn implements induced a loss in precision.
- First improvements produced fully automated tractor or field robot guidance systems (unreliable, expensive, unsophisticated,) and were niche products only.
- Automatic row guidance of self propelled choppers took a wide acceptation for the first time and is standard in newly sold machines for more than 15 years.
- Also row guidance systems in sugar beet harvesters came early and are standard in all today used machines.
- Laser-based guidance systems in combine harvesters were established, when header widths increased to more than 5 meters and are standard now in 7.5 and 9 m cutting width .
- Ultra-sonic and optical guidance systems are on the market available too, but have not earned great importance so far.
- GNNS-based guidance systems have an increased importance to farmers. The fast acceptance is mainly driven by cost:benefits and by comfort reasons.