Scale size of machines, soil compaction, economy

Case study: sugar beet harvesting

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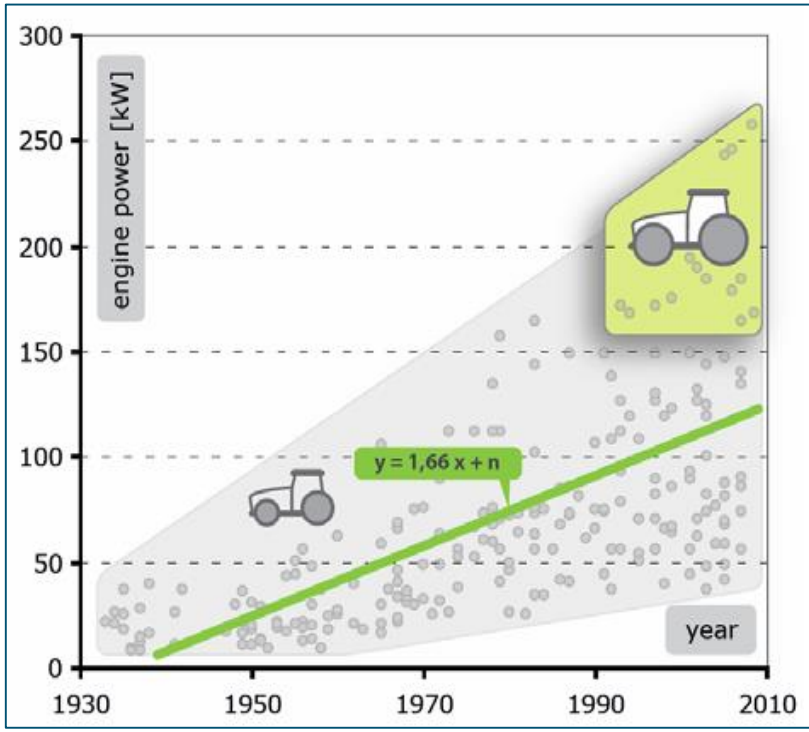
Current situation

Trend in agricultural machinery: Big, bigger, biggest

- Advantages:
  - High capacity
  - Labour efficiency

- Disadvantages:
  - Not very manoeuvrable
  - Only suitable on large fields
  - Sizes are at maximum
  - Soil compaction

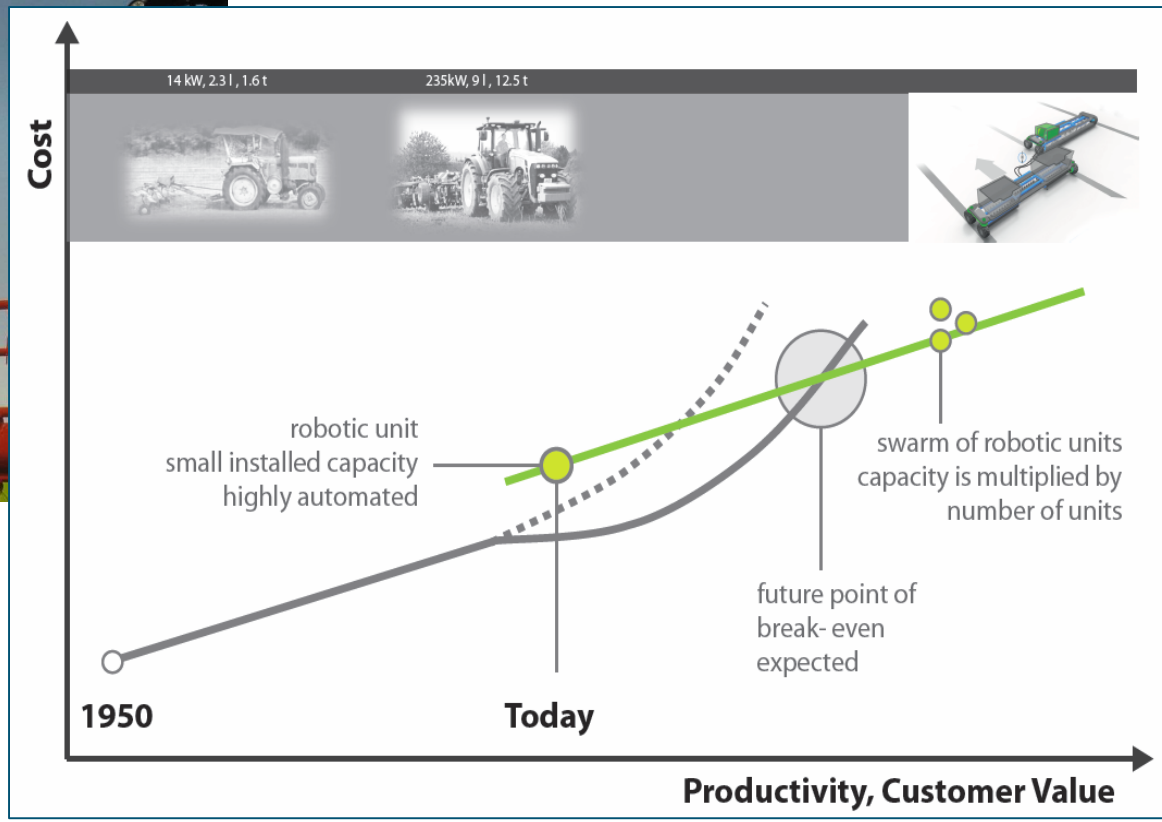


(Herlitzius, 2013)

Current situation

- Further up-scaling very hard
- Development of autonomous control
  - Advantages of large-scale disappear
  - Opportunity to reduce scale size

Current situation – future perspective



(Herlitzius, 2013)

Research question

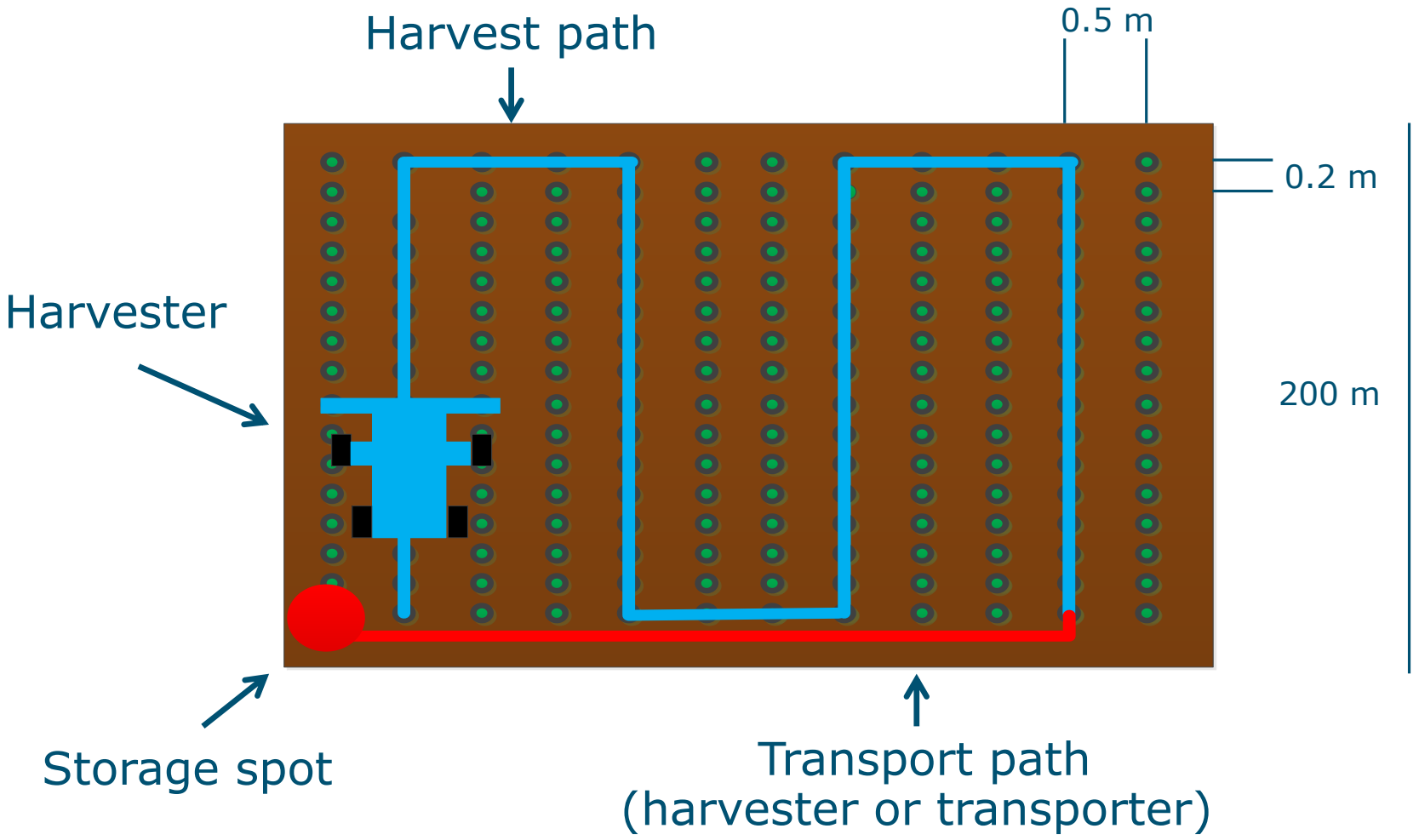
What is the most promising scale-size for sugar beet harvesters?

- Most promising in terms of:
  - Soil compaction
  - Economy

Methodology

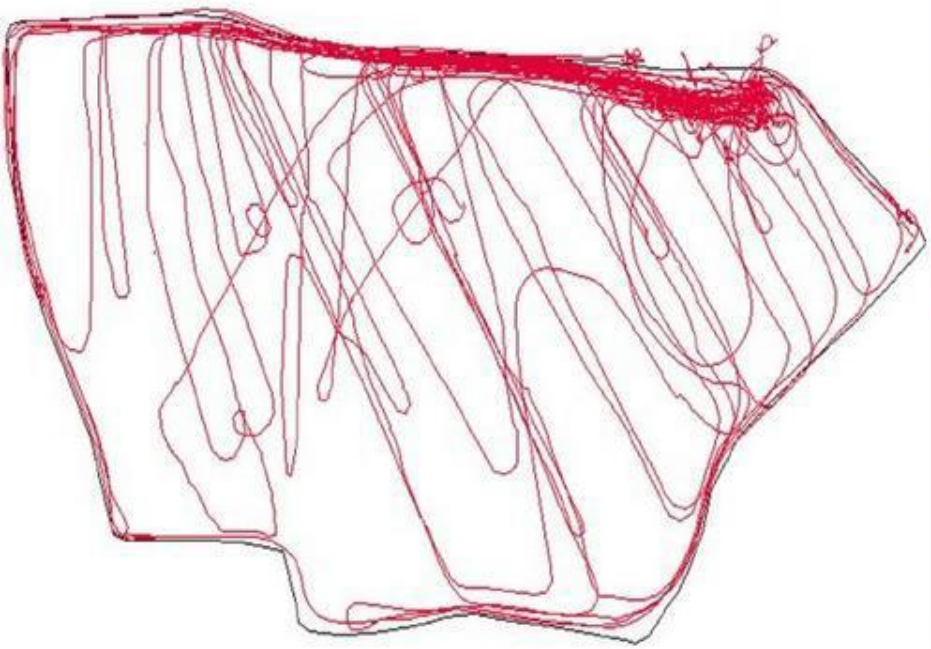
- Development of model
- Formulation of hypotheses
- Evaluation of hypotheses with scenario studies

The model


Harvest path
0.5 m
0.2 m
Harvester
200 m
Storage spot
Transport path
(harvester or transporter)
250 m

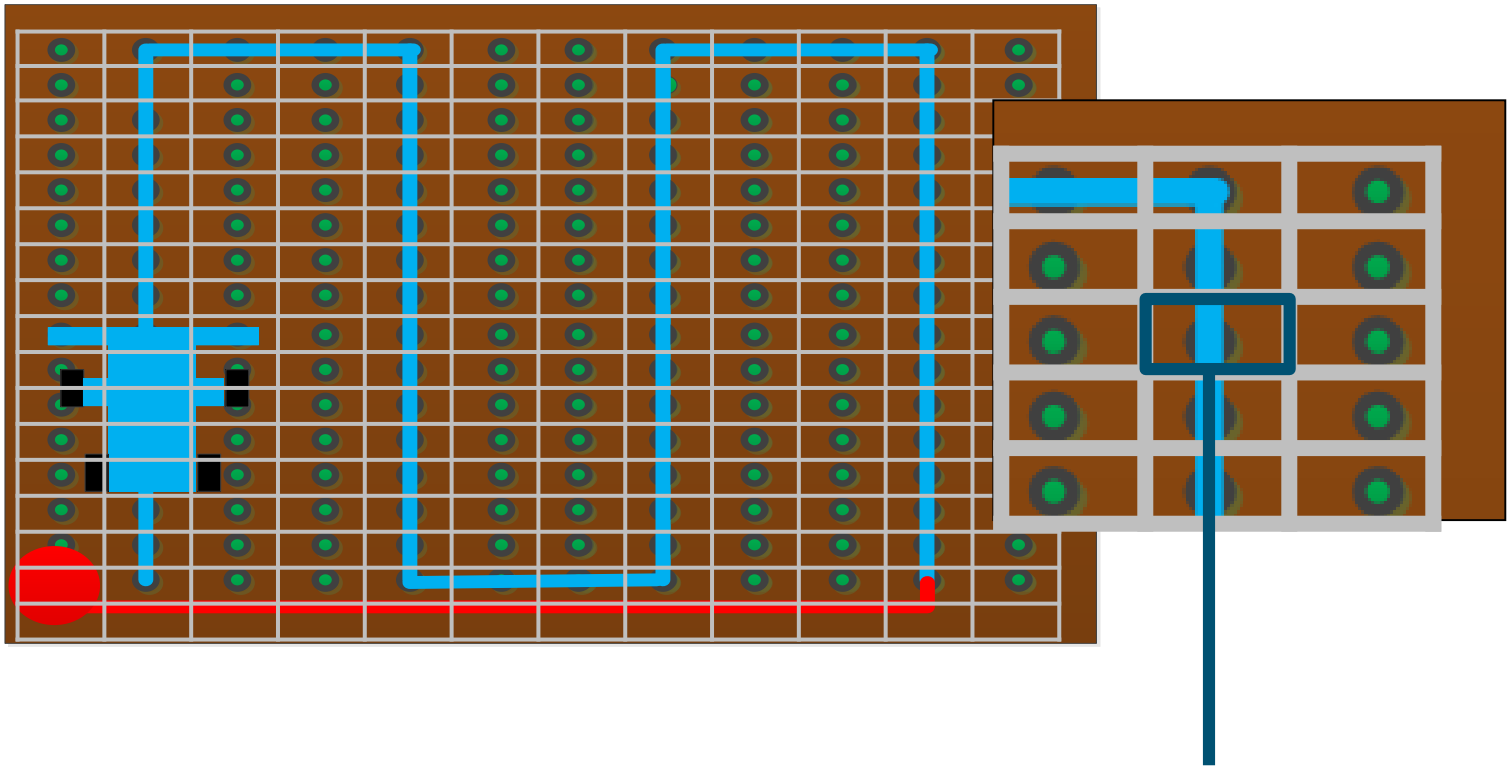
The model

- Empty bunker on headland reduces soil compaction:



(Criado, 2014)

The model



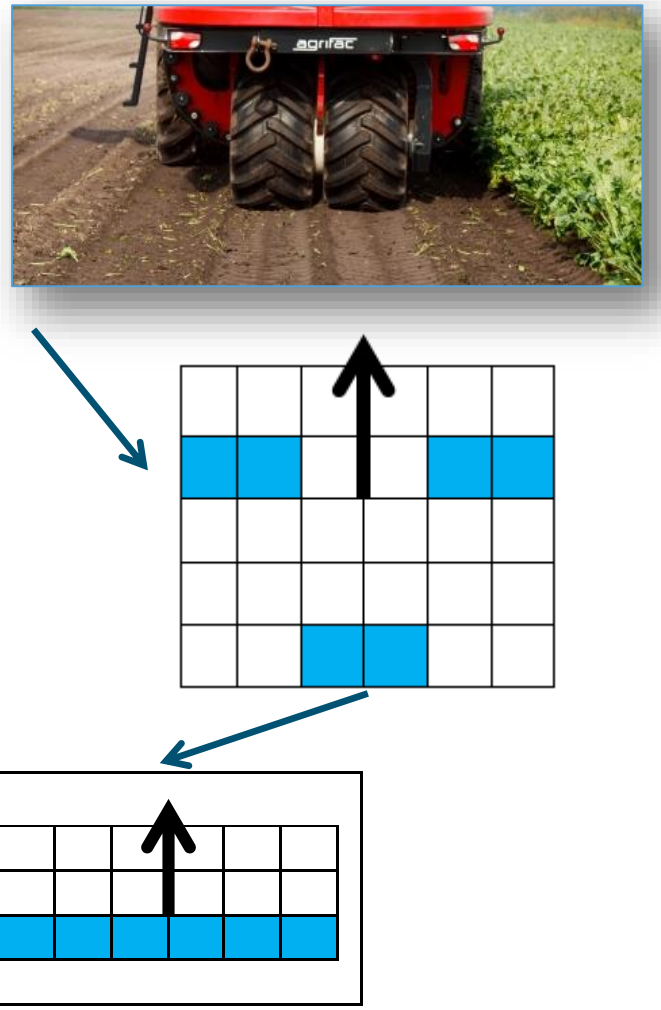
Number of passes

Weight per pass

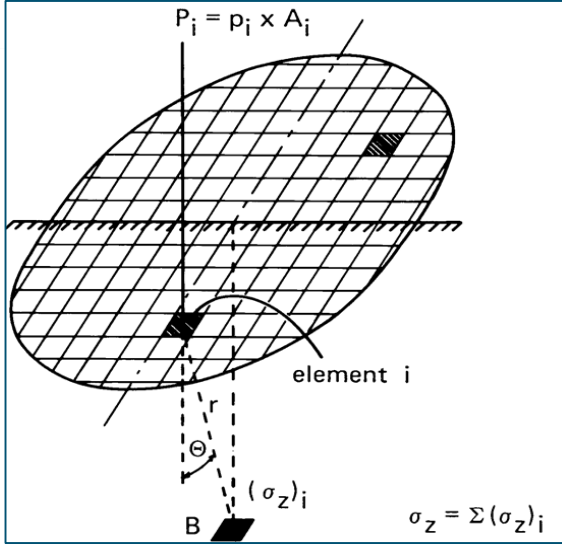
The model

Size of sugar beet harvester

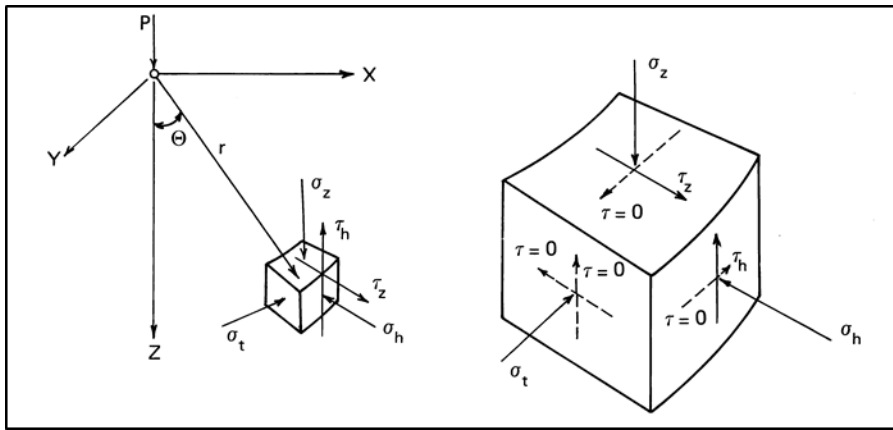
- Working width [rows]
- Empty weight [kg]
- Simulated by loaded cells:
  - Total working width used
  - Soil rolled over once



The model – soil compaction



- Socomo (Van den Akker, 2004)
- Soilflex (Keller et al., 2007)
- Soil sinkage, penetration resistence (Taghavifar and Mardani, 2014)
- Rut depth model (Kalugin and Poletaev, 1968) Compared favourably with Socomo and Soilflex and test data (Ksenevich et al., 1985)



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The model – soil compaction

- Rut depth model (Kalugin and Poletaev, 1968)

$$z_n = \left[\left(\sqrt{\frac{9}{16} * a_n^2 + \frac{1}{8} * h^3} + \frac{3}{4} * a_n \right)^{\frac{1}{3}} - \left(\sqrt{\frac{9}{16} * a_n^2 + \frac{1}{8} * h^3} - \frac{3}{4} * a_n \right)^{\frac{1}{3}} \right]^2$$

Where:

z_n	=	Rut depth after nth pass	[m]
a_n	$= \frac{W}{B * k_\varphi * \sqrt{D}}$		[-]
h	$= z_1 + z_2 + \cdots + z_{N-1}$	Total rut depth before pass	[m]
z_1	$= \left(\frac{3 * W}{2 * B * k_\varphi * \sqrt{D}} \right)^{\frac{2}{3}}$	Rut depth after fist pass	[m]
W	=	Normal load on wheel or track	[kN]
B	=	Wheel width	[m]
kφ	=	Bekker's frictional modulus of soil deformation	[kN/m^{n+2}]
D	=	Wheel overall diameter	[m]

The model – economics

- Assumption: no increase in harvesting costs!
  - Calculate maximum purchase price:

$$\text{Purchase price} = \left(\frac{Costs_{current} - Costs_{transport\ units}}{Number\ of\ needed\ harvesters} - Costs_{variable}\right) * ha_{year} * TL$$

Where:

$Costs_{current}$	=	Total current harvester costs	[€*ha^{-1}]
$Costs_{transport\ units}$	=	Total costs of transport units	[[€*ha^{-1}]
$Costs_{variable}$	=	Variable costs	[€*harvester^{-1}*ha^{-1}]
ha_{year}	=	Harvested hectares per year	[ha*year^{-1}* harvester^{-1}]
TL	=	Technical life	[years]

The model – inputs & outputs

Inputs/parameters/ assumptions:

- Labour costs = 0
- Field size and shape
- Harvest capacity
- Fuel cost
- Sugar beet weight
- Empty weight harvester
- …

Outputs:

- # harvesters needed
- # transport unit needed
- Price per harvester
- Minimum rut depth
- Maximum rut depth
- Average rut depth

Hypotheses

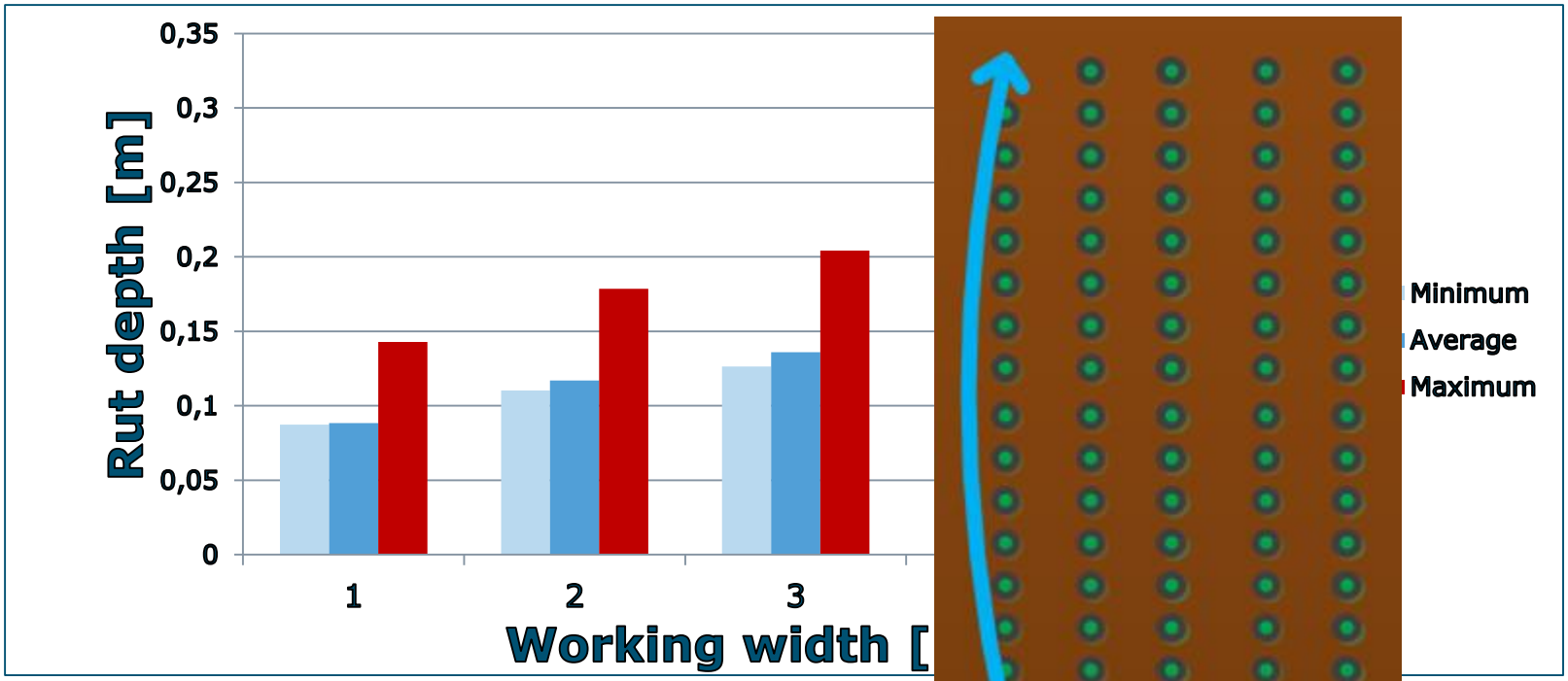
Hypotheses:

1. Smaller working width leads to less soil compaction
2. Smaller bunker capacity leads to less soil compaction
3. Transport units are needed to increase the maximum purchase price per harvester

Hypothesis 1: working width

Smaller working width leads to less soil compaction

- Working widths: 1,2,3,6 and 12 rows
- Minimum bunker capacity (unloading on headland)



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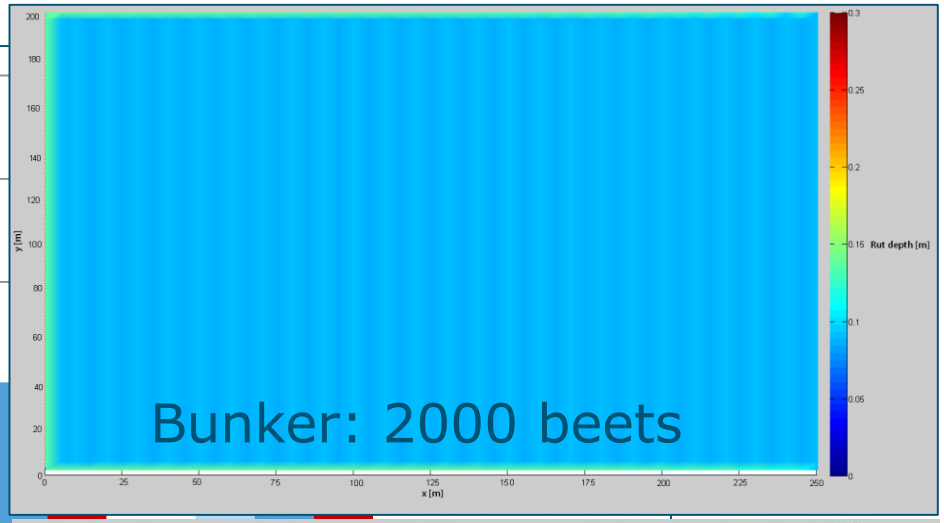
Hypothesis 2: bunker capacity

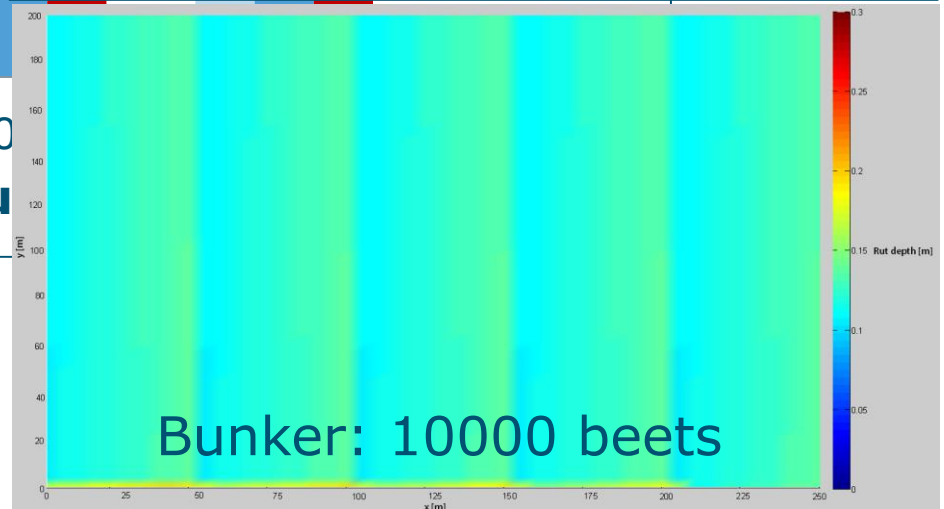
Smaller bunker capacity leads to less soil compaction?

- Bunker capacity was varied:
  - Minimum bunker capacity
  - Two times minimum
  - Four times minimum
  - Ten times minimum
- Different working widths (1 row, 6 rows)

Bunker capacity

Smaller bunker capacity leads to less soil compaction?

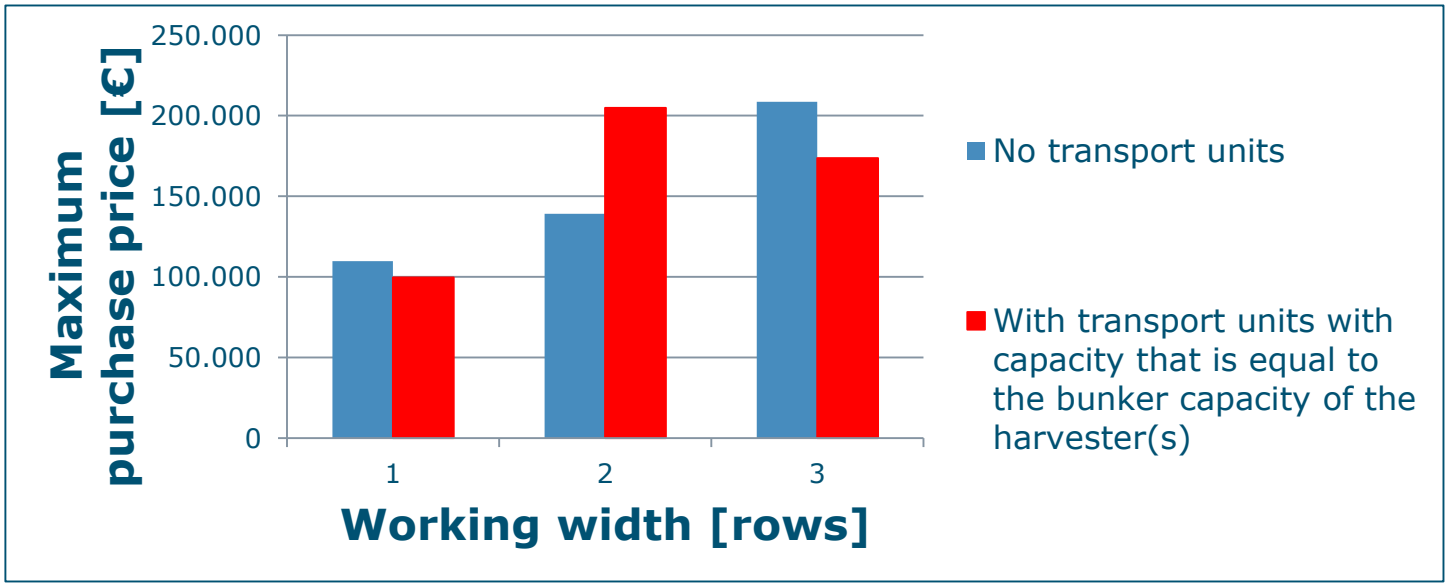




Hypothesis 3: transport units

Transport units are needed to increase the maximum purchase price per harvester?

- Splitting function of transport
- 15 most promising scenarios



Most promising scenario

Most promising in agronomical view:

Working width [rows]	Bunker capacity [beets]	Capacity transport units [beets]	Number of transport units [-]	Number of harvesters [-]	Average rut depth [m]	Maximum purchase price [€]
1	1000	1000	8	4	0.0876	99,700
1	1000	-		4	0.0883	109,700
1	2000	-		4	0.0938	107,900
1	**2000**	**2000**	**6**	**3**	**0.0938**	**131,133**
1	4000	-		4	0.1014	104,300

Rut depth in current situation: ± 0.20 m

Conclusion/indication...

- Methodology is in place
- With autonomous technology small scale size machinery might become an interesting option:
  - soil compaction
  - economy
- Disclaimer: model study based on a large number of assumptions! ☹
- So: further research is needed! ☺

Thank you for your attention!

Harvesting wise…

… is using small-size!

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