AARHUS
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Tools for minimising laborious hand-weeding in row crops

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Intra-row weed control - overview of the talk

A. Low technology solutions

- Weed harrowing
- Torsion weeding
- Finger weeding
- Thermal weeding

B. The principles of selectivity

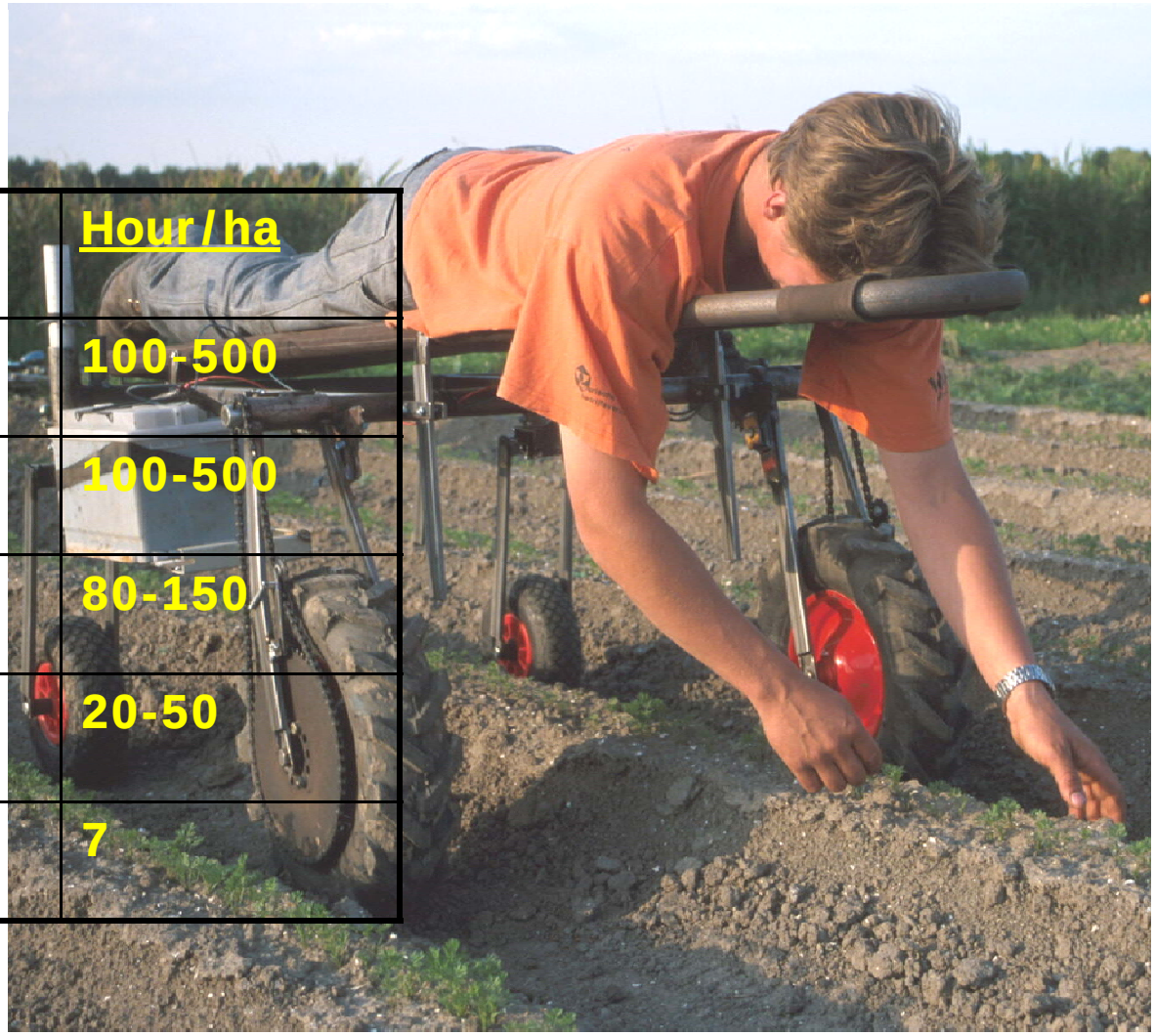
C. Advanced technologies – robotic weeders

- Robocrop (UK)
- Steketee (NL)
- Robovator (DK)

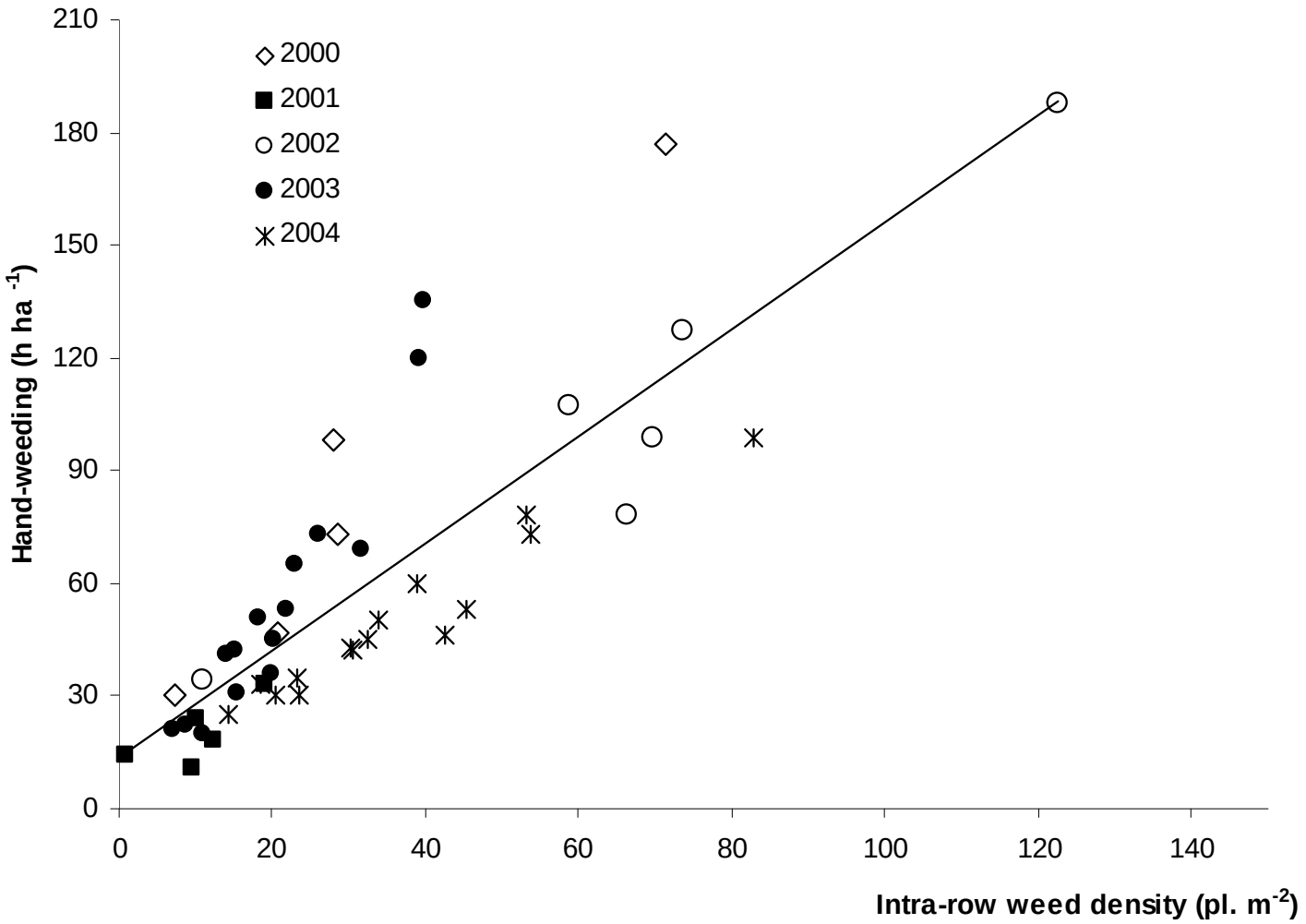
Hand weeding intra-row weeds

Time consumption for hand weeding

Crop		**Hour / ha**
Onion	**sown**	**100-500**
Carrot	**sown**	**100-500**
Sugarbeet	**sown**	**80-150**
Transplants		**20-50**
Cereals	**sown**	**7**



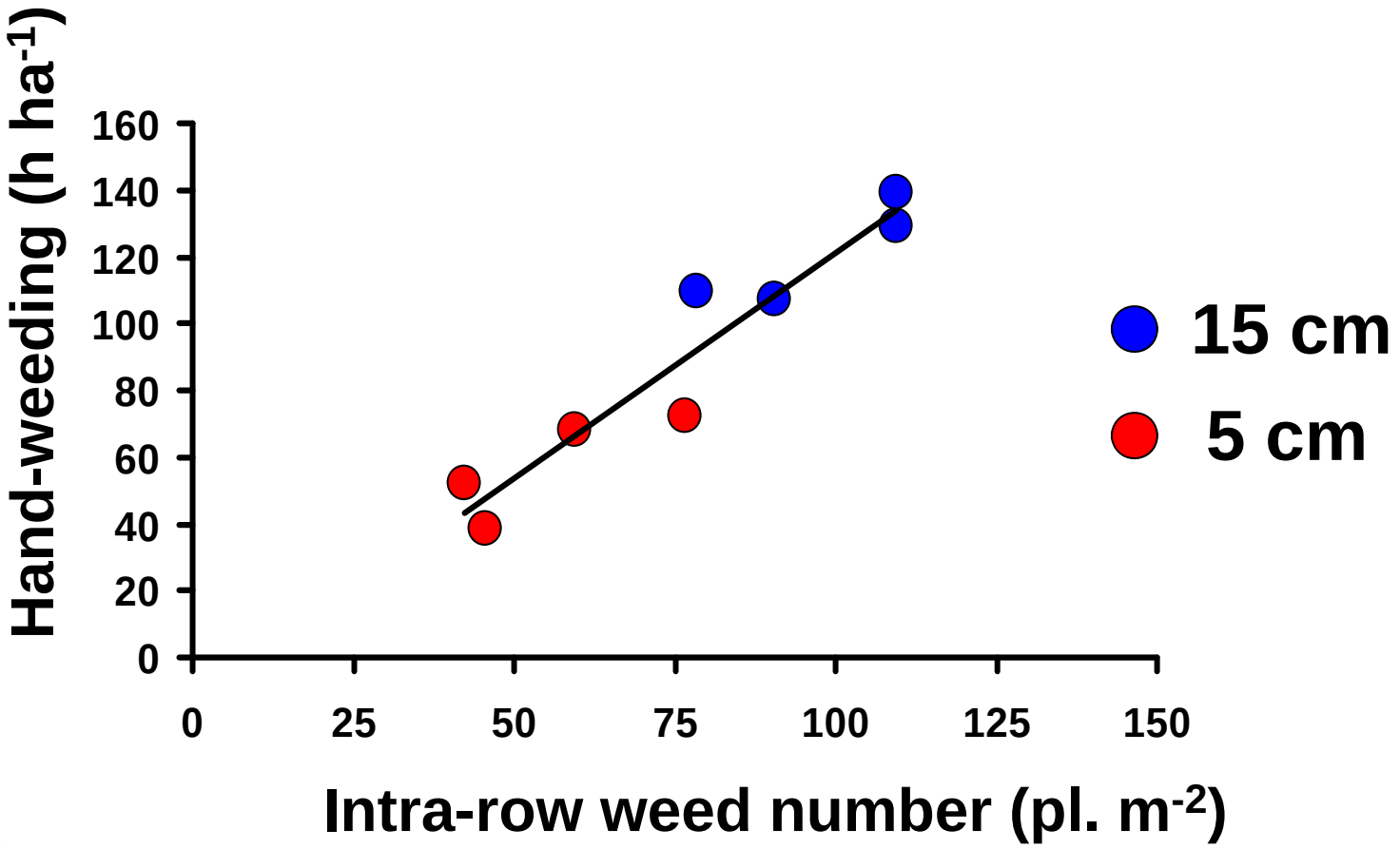
Hand-weeding in direct-sown onion



[From Van der Weide (2008). Weed Research 48, 215-224]


Hoeing close to the row

Hoeing close to the row

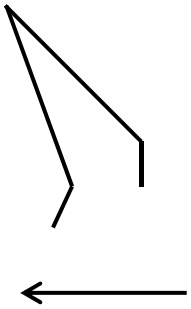


[From Melander & Rasmussen (2001). Weed Research 41, 491-508]

The flex tine harrow – pre- and post emergence control

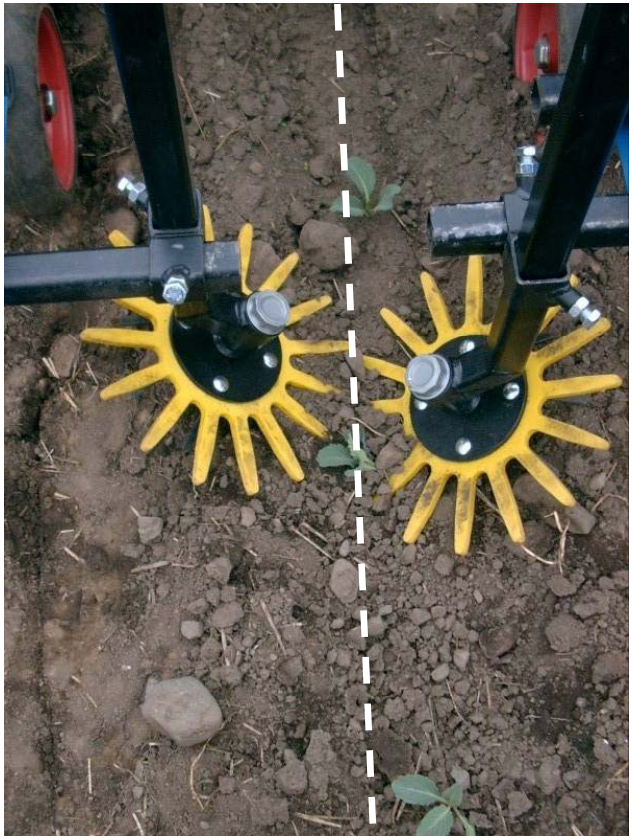
Aggressiveness

- Driving speed
- Tine angle
- Working depth



Weed harrowing

Post-emergence finger weeding

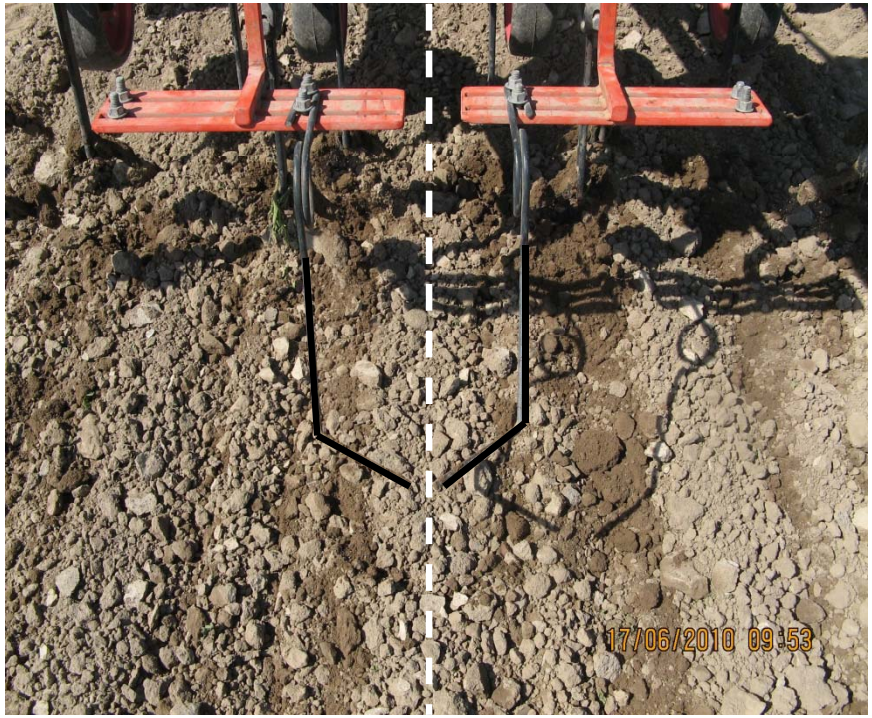


Aggressiveness

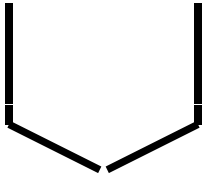
- Driving speed
- Distance between finger wheels
- Working depth

Finger-weeding

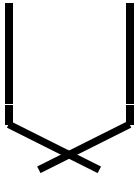
Torsion weeder



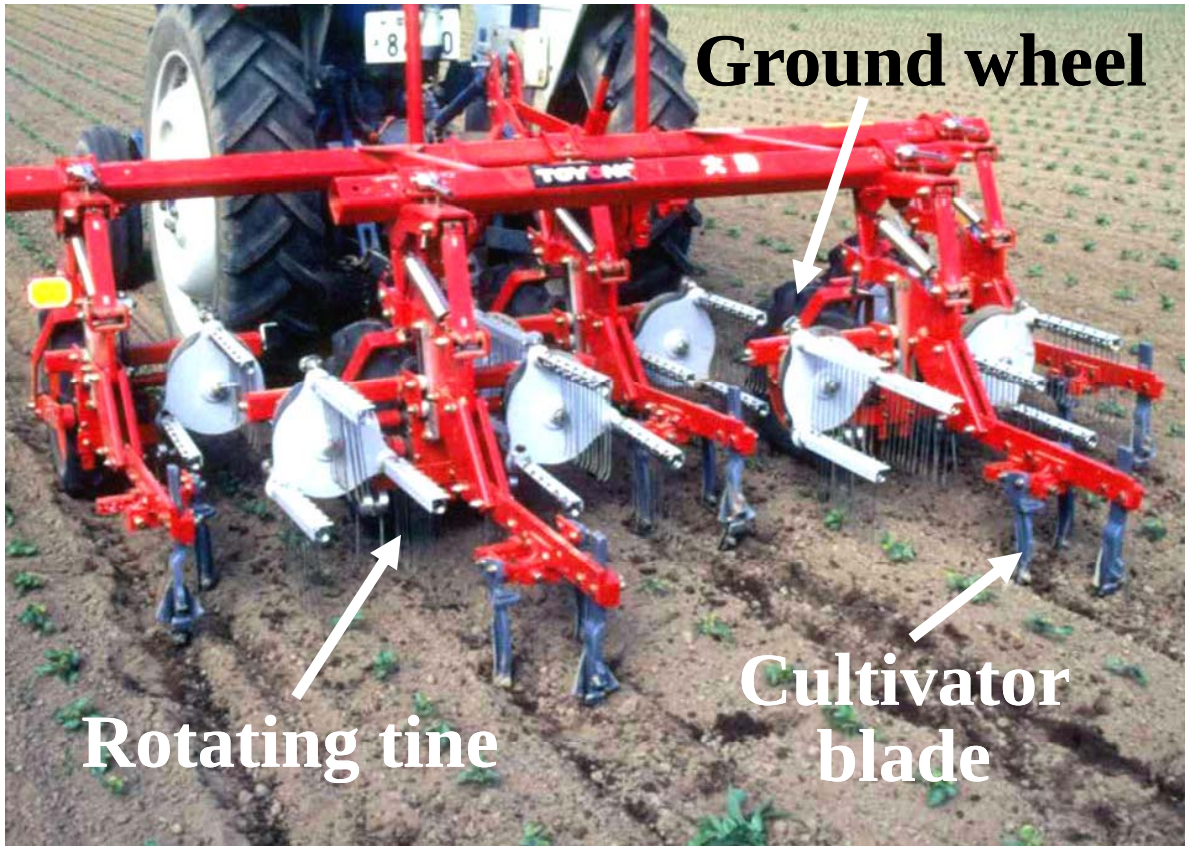
Medium aggressiveness

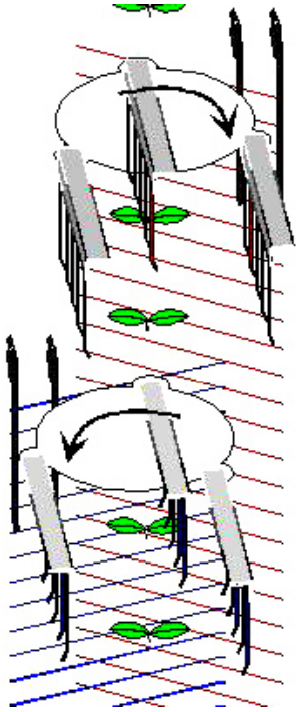


Very aggressive



Rotary tine weeder



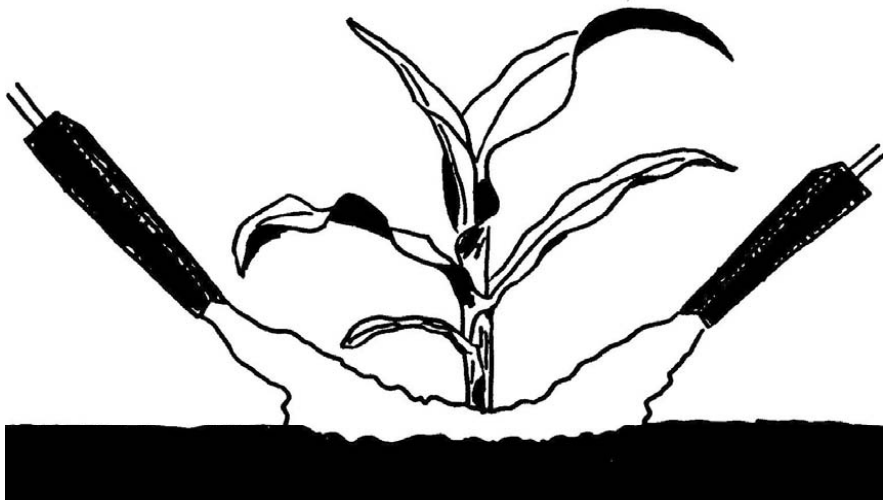


Rotating tine

Rotary tine weeder

Selective post-emergence flame weeding

Maize



Onion

Selective flaming – Canadian study in onion

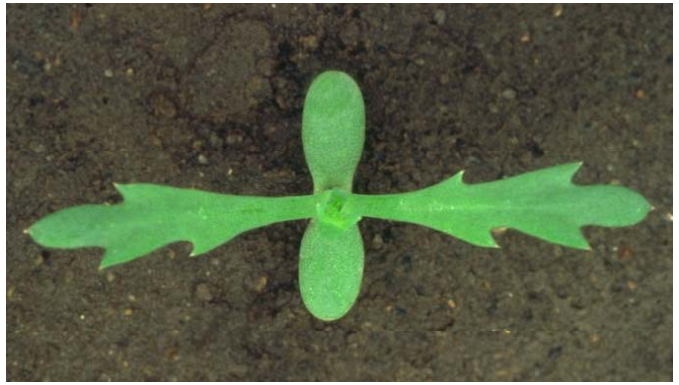
Transplanted onions

- High crop tolerance despite six treatmens 10, 24, 34, 52, 61, 74 DAT
- Cotelydon – 2-leaves stage
- High efficacy against bradleaved species
- Limited effect against grass weeds
- Supplementary hand-weeding needed

[From Sivesind et al. (2012), Crop Protection 39, 45-51]

Solutions for small-hold farmers

Chrysantemum segetum



Features of low-tech intra-row weeders

Advantages

- Low investment
- Simple technology
- High work rates
- Effective against small sized weeds
- Both tractor-born and hand-born versions

Disadvantages

- Risk of crop injuries
  - Harrow, torsion weeder > finger
- Requires experience and knowledge
- Adjustments and settings can be difficult
- Extra person for steering
- No complete weed control
- Energy consumption – thermal methods
- Fire hazards – thermal methods

The principles of selectivity

Low technologies with no intelligence

A. **Conditions of high selectivity:**

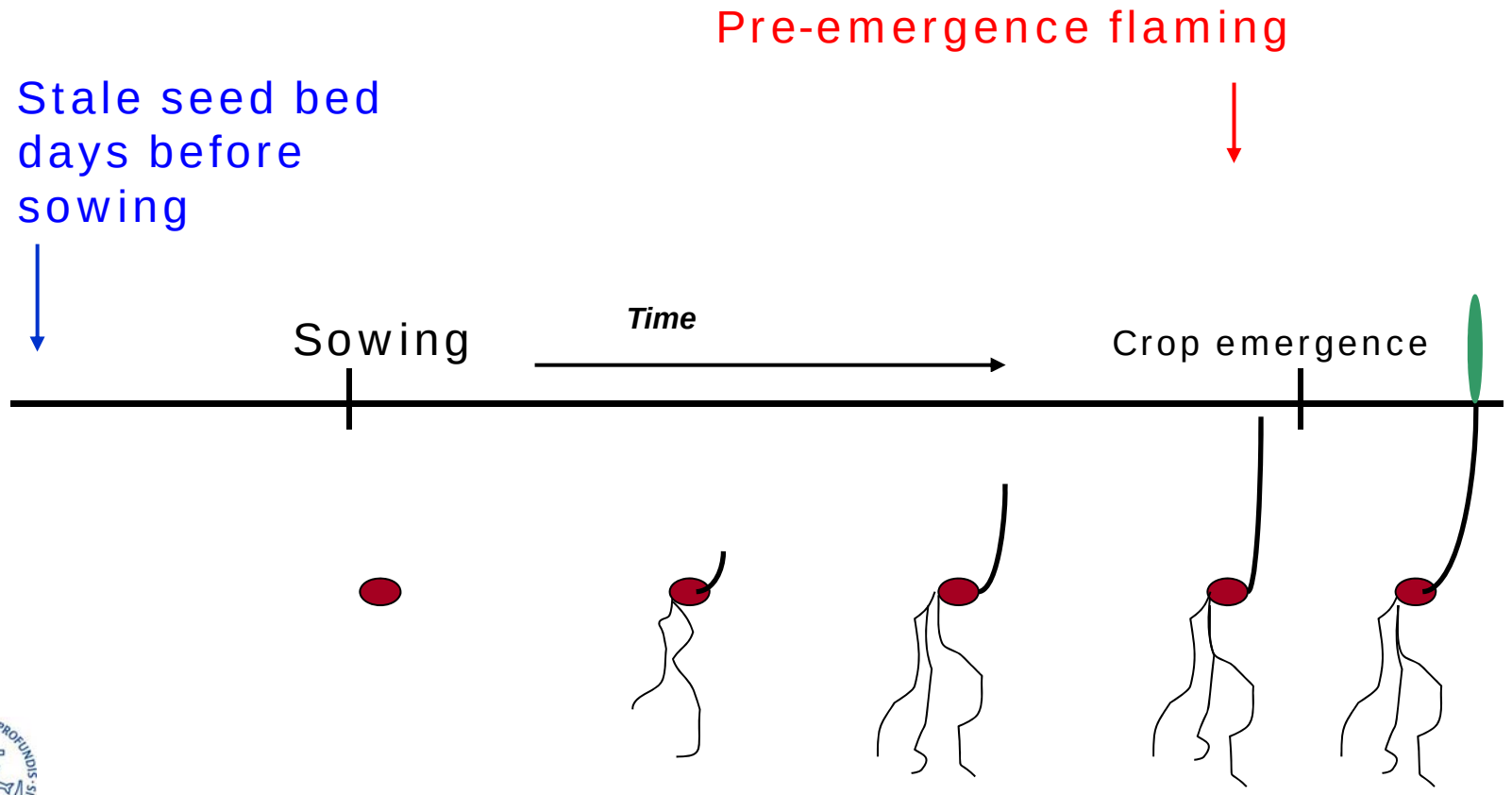
   High weed control with no or minimum crop injuries

B. **Conditions of low selectivity:**

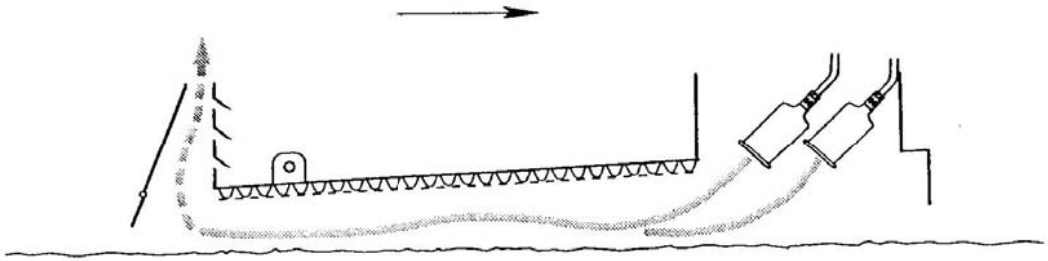
   High weed control is associated with severe crop injuries

Selectivity

Stale seed bed and pre-emergence flaming



Pre-emergence flame weeding



Flame weeding

Brush weeding in very small leek

Without pre-emergence flaming – terrible situation

With pre-emergence flaming – excellent situation

Methods for maize

Pre-emergence flaming/harrowing

Post-emergence flaming

Post-emergence harrowing / finger weeding

Ridging

Transplanting and selectivity

Selectivity for intra-row weeding with intelligence

Robotic weeding in transplant - *Robocrop*

Video clip with *Robocrop*

Growers experiences with *Robocrop*

- Erect transplants (chives, celery, salad, cabbage, bulb onion) 👍
- Prostrate or bended transplants (fennel, cabbage) 👎
- Work rate 0.23 ha t^{-1} (3 row machine, 1.5 km t^{-1}) 👎
- Only effective agianst small sized weed plants 👍👎
- Weeding effectiveness: cabbage 100%, celery 80%, onion 70% 👍👎
- Savings in hand-weeding 50-200 hours ha^{-1} 👍
- Early transplanting 👎
- Satisfaction with the investment 👍

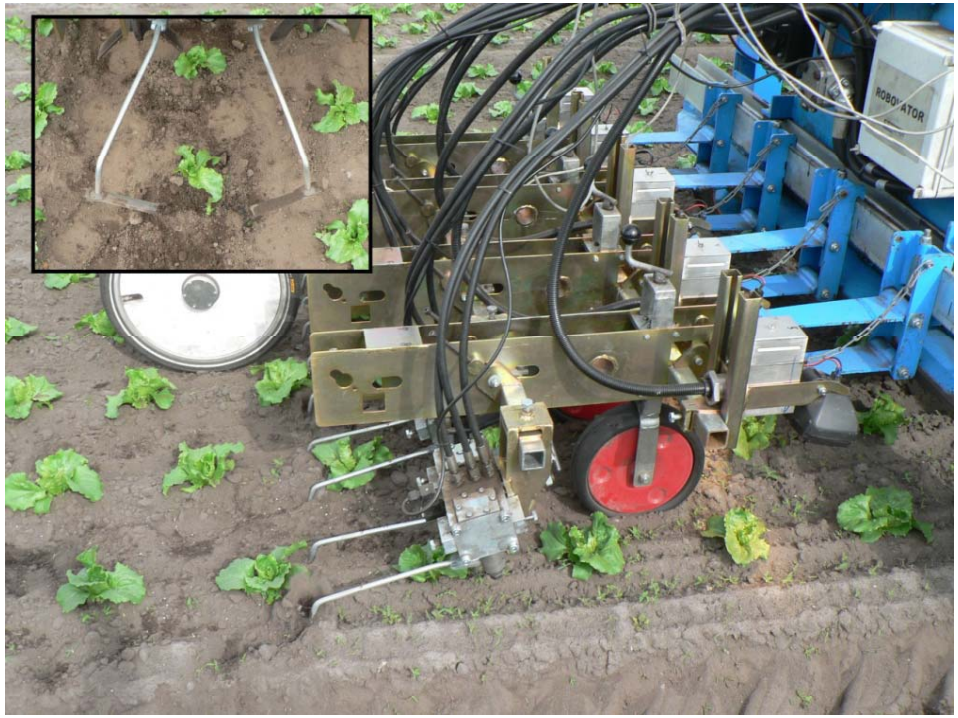
Robotic weeding with *Steketee*

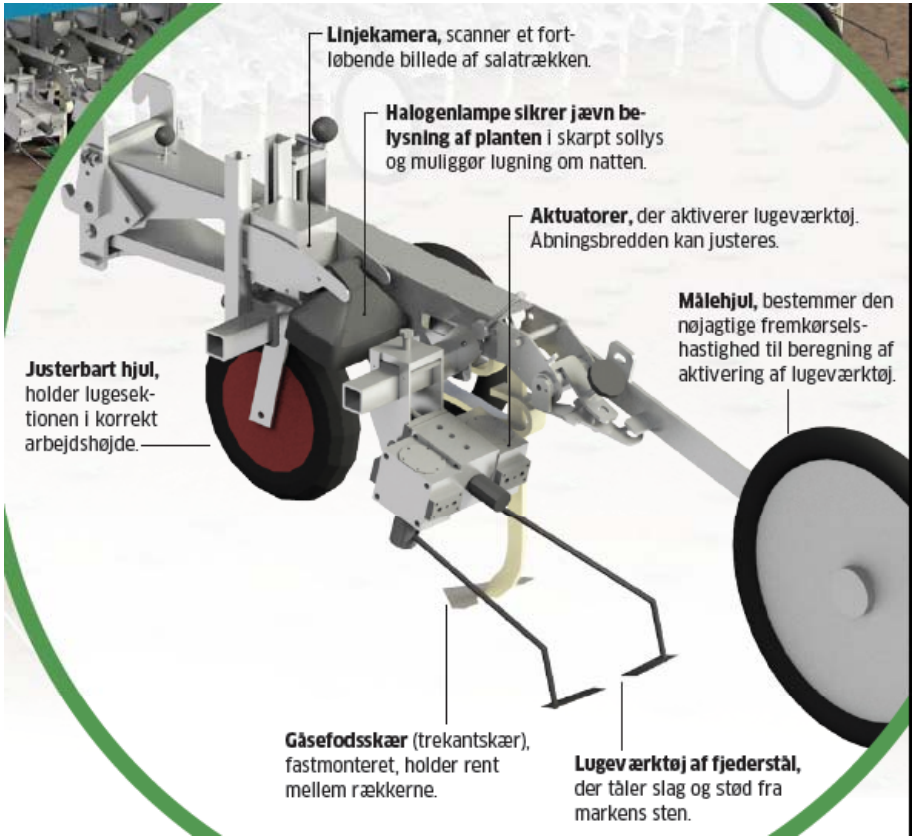
Videoclip with *Steketee*

Mechanical weed control, Westmaas (NL), 2012

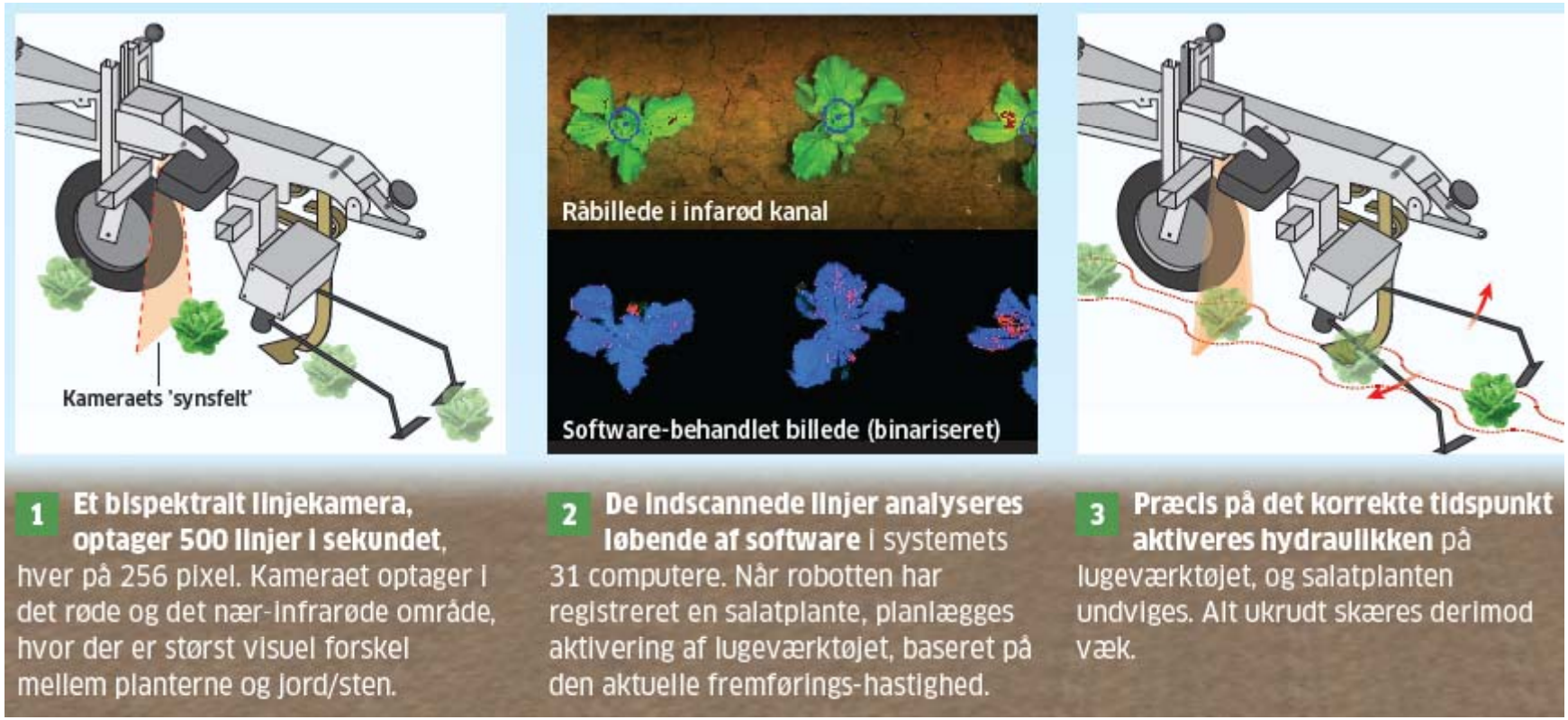
Treatments	Weed control (%)	Hand weeding (h ha^{-1})
1. Untreated	0.0	97.2
2. 1,5 Butisan + 0,2 Centium 1 June 1 Lontrel + 1 Lentagran 19 June	99.2	15.9
3. Harrowing 30 May, 14 June, 20 June	76.2	41.7
4. Finger weeding 30 May, 14 June, 20 June	92.3	19.4
5. Robotic weeding Steketee 14 June	43.1	46.3

Robotic weeding in transplants - *Robovator*





Robotic weeding in transplants - *Robovator*



1 Et bispektralt linjekamera, optager 500 linjer i sekundet, hver på 256 pixel. Kameraet optager i det røde og det nær-infrarøde område, hvor der er størst visuel forskel mellem planterne og jord/sten.

2 De indscannede linjer analyseres løbende af software i systemets 31 computere. Når robotten har registreret en salatplante, planlægges aktivering af lugeværktøjet, baseret på den aktuelle fremførings-hastighed.

3 Præcis på det korrekte tidspunkt aktiveres hydraulikken på lugeværktøjet, og salatplanten undviges. Alt ukrudt skæres derimod væk.

Videoclip with *Robovator*

Intra-row weeding in white cabbage

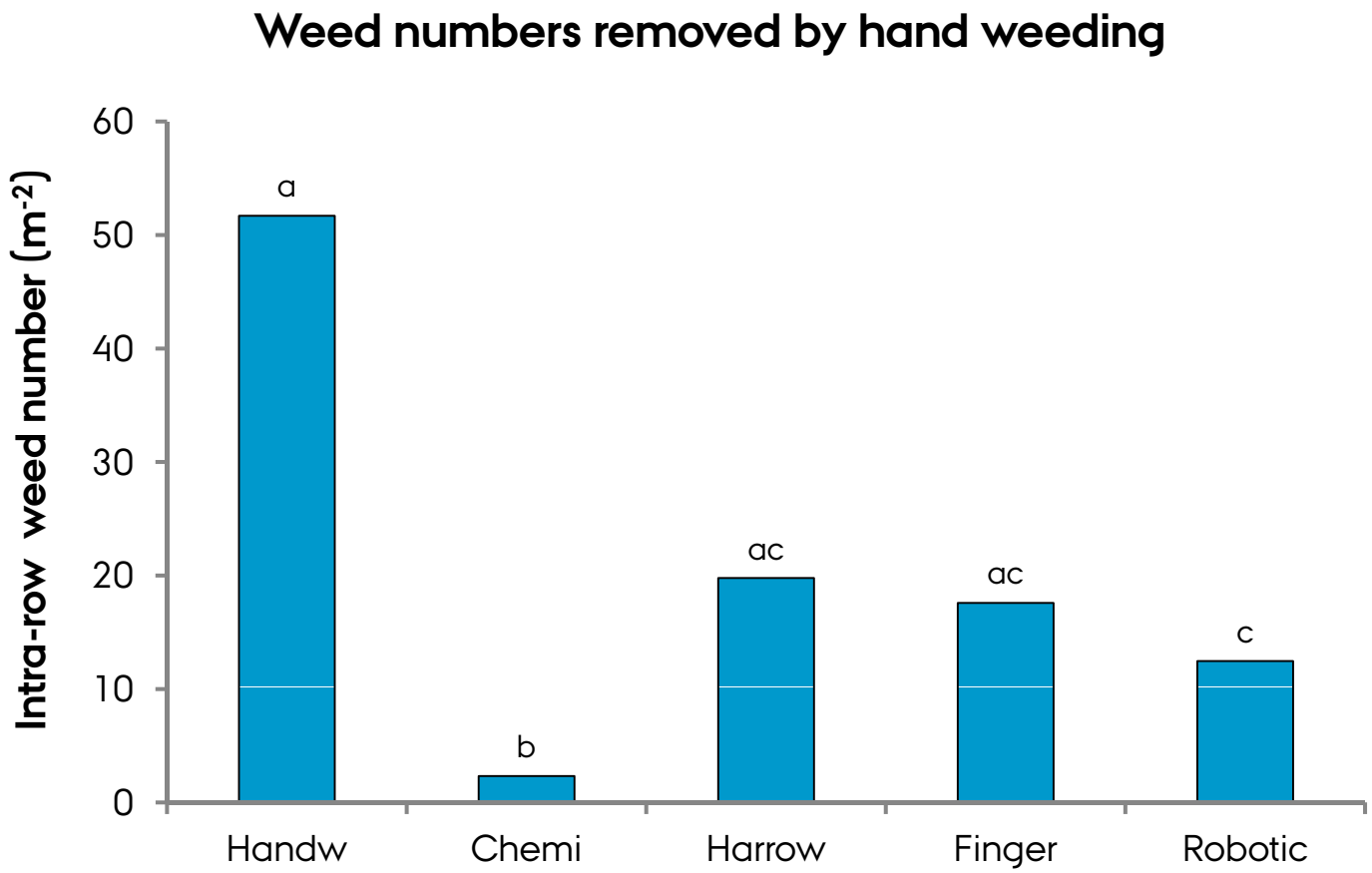
Seedbed harrowing and cabbage transplanting 14 May 2012

Treatments:

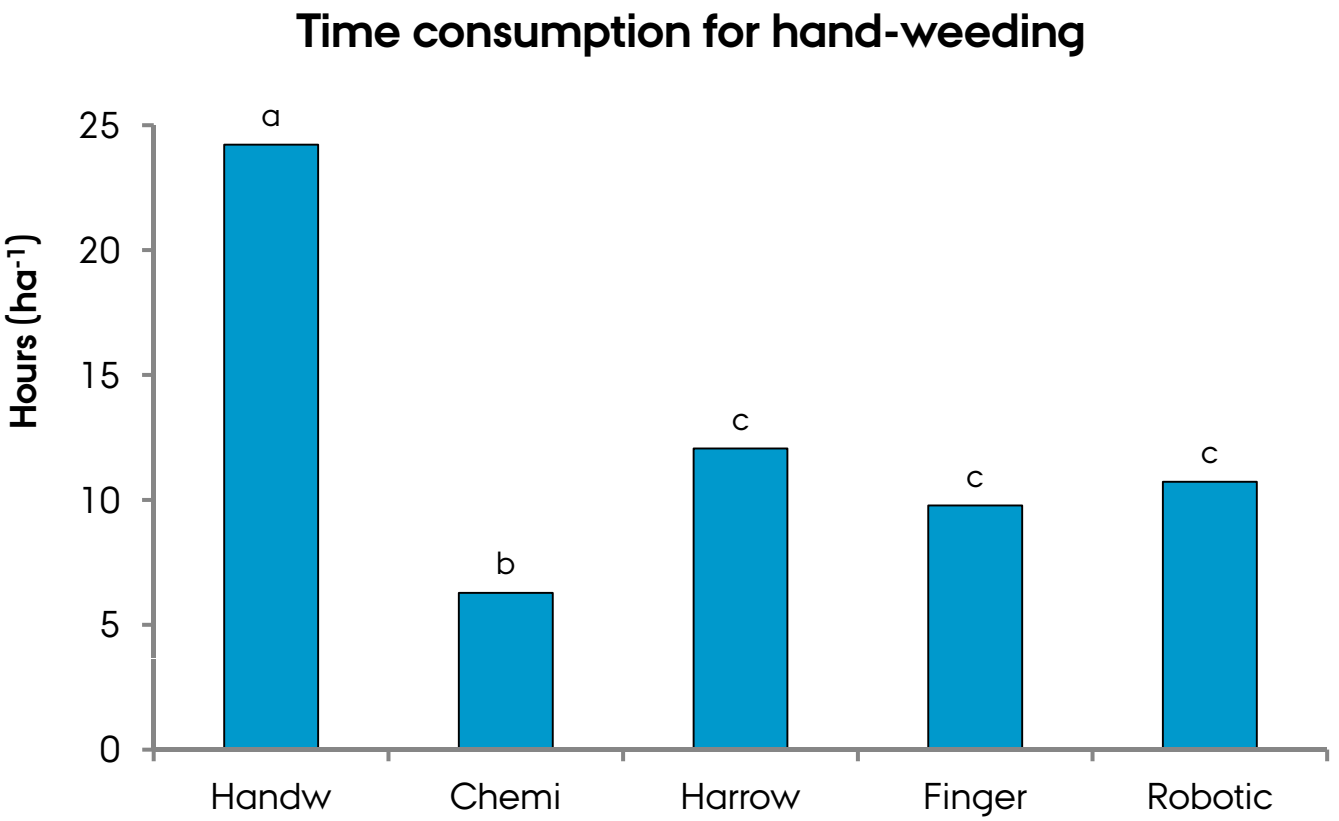
1. Hand-weeding only: 30 May and 21 June
2. Herbicide: 30 May, Butisan (1.5 l ha^{-1}) + Centium 36 (0.2 l ha^{-1}) + hand-weeding 21 June
3. Weed harrowing: stale seedbed 2 May + weed harrowing 30 May + hand-weeding 21 June
4. Finger weeding: stale seedbed 2 May + finger weeding 30 May + hand-weeding 21 June
5. Robotic weeding: 13 June + hand-weeding 21 June

Inter-row hoeing in all plots except for treatment 2: 21 June

Intra-row weeding in white cabbage

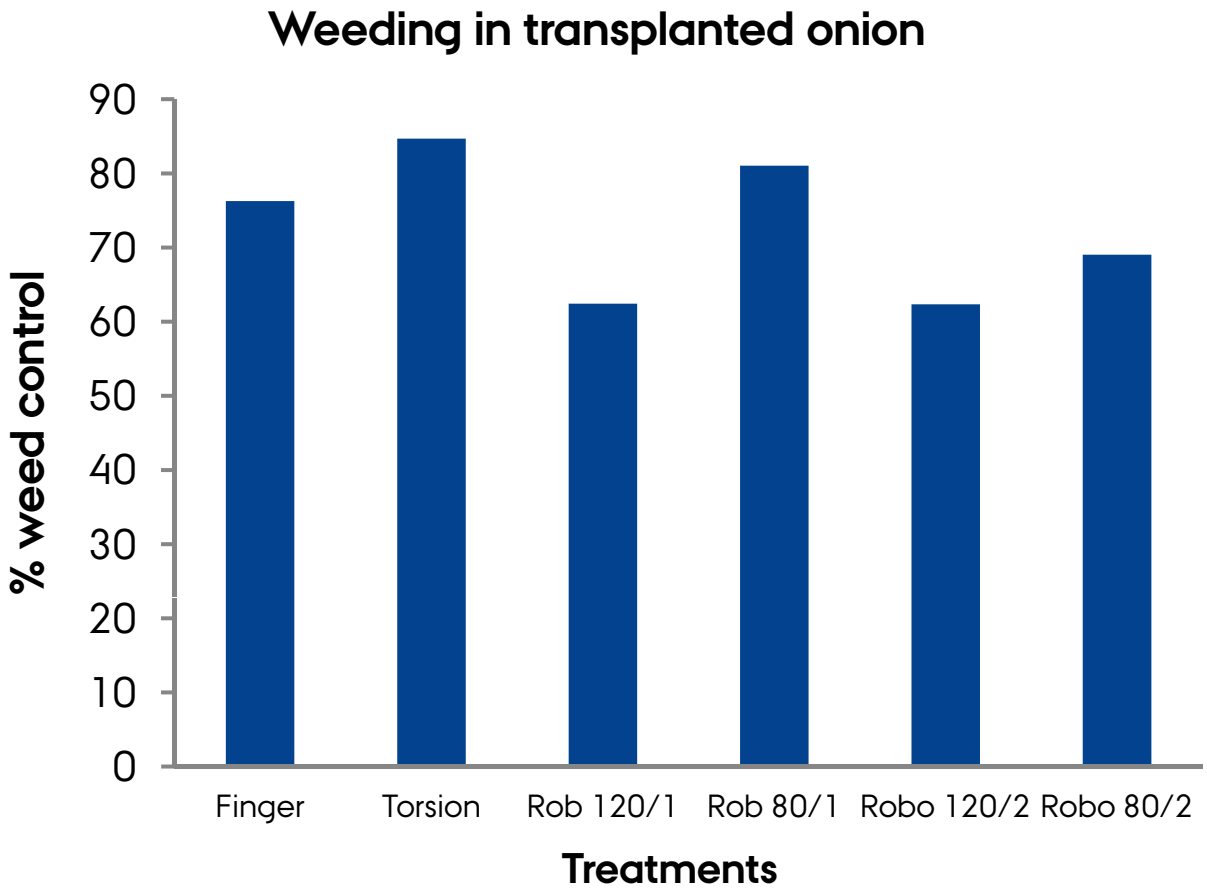


Intra-row weeding in white cabbage



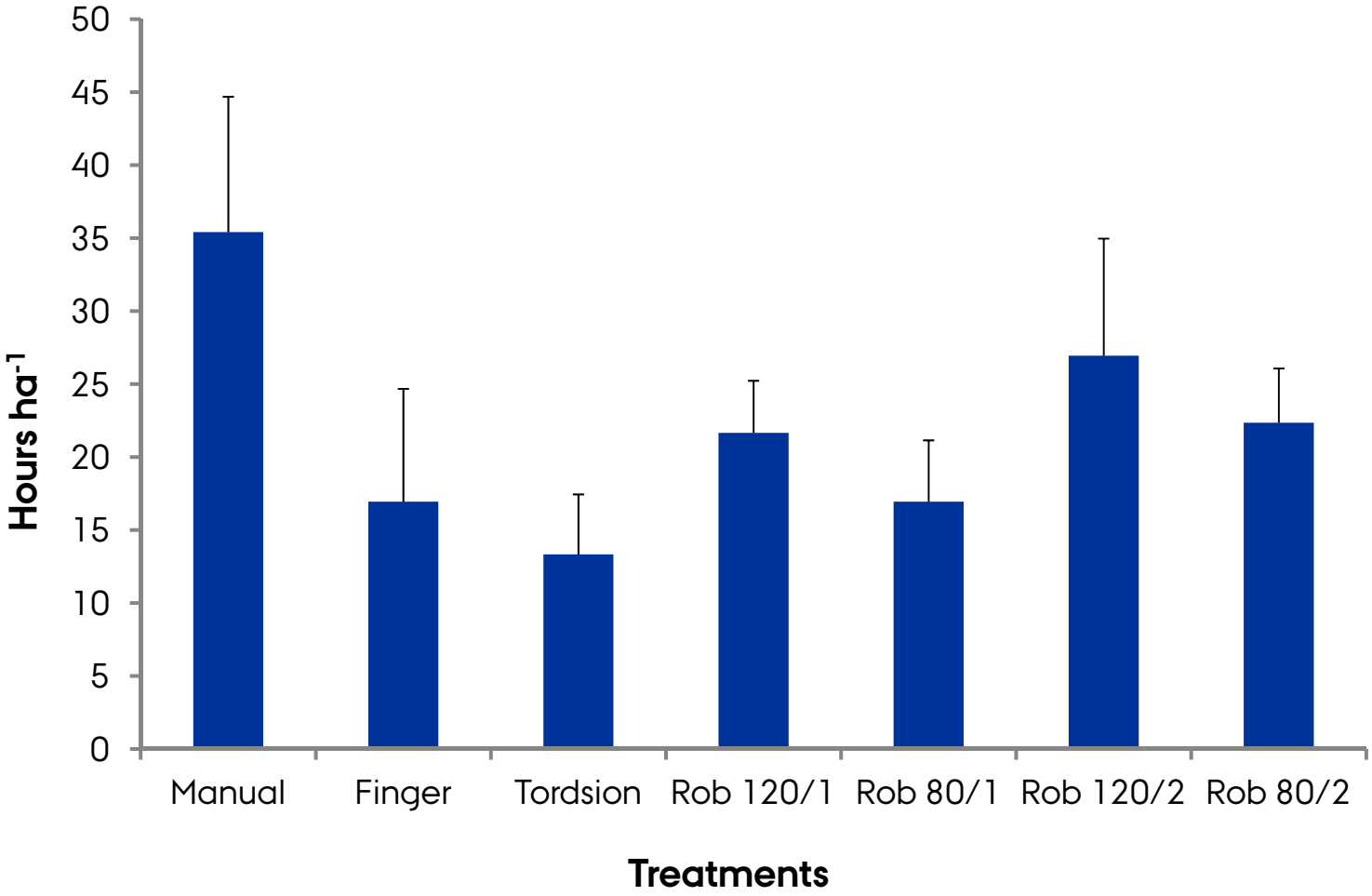
Intra-row weeding in white cabbage

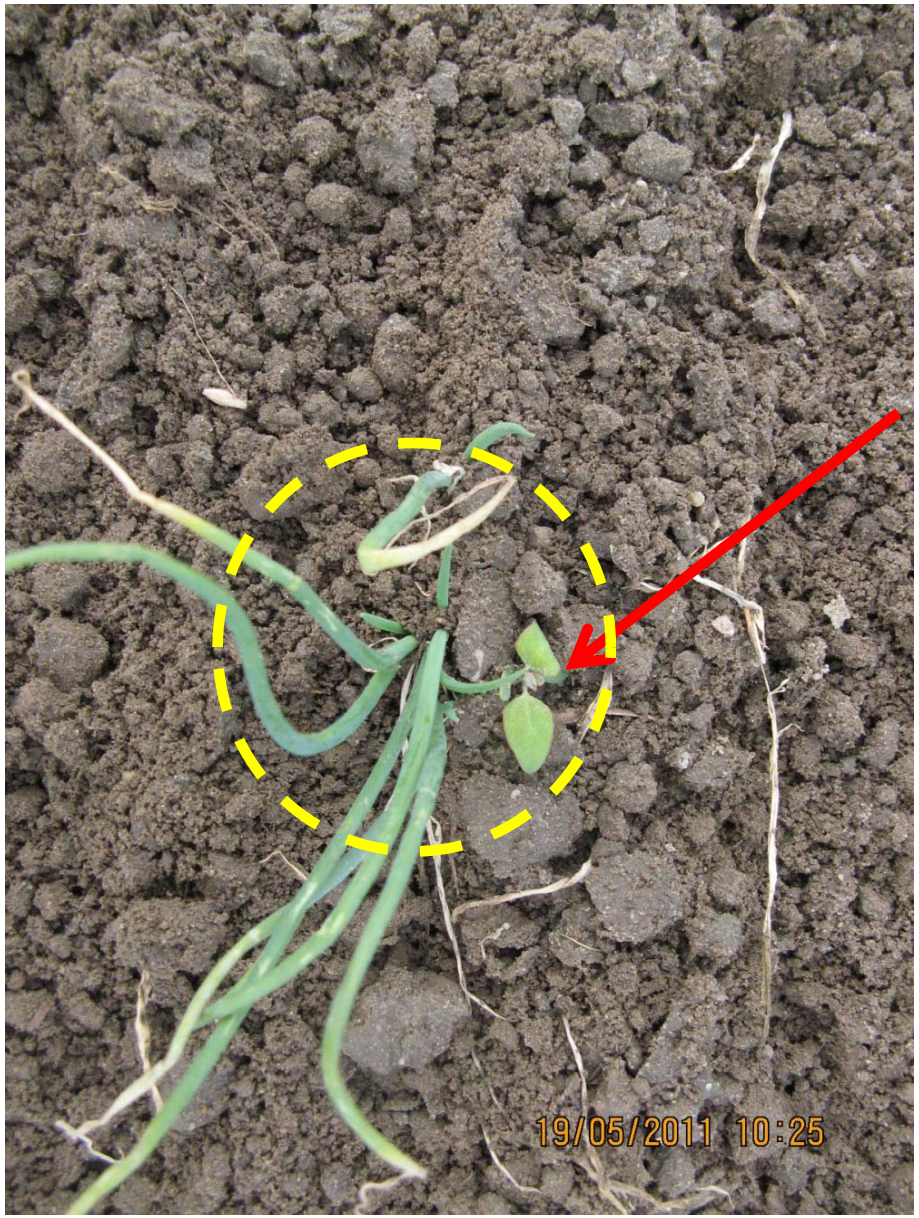
Treatments	Weed control (%)	Hand-weeding (hours ha^{-1})	Cabbage head no (rel.)	Head weight (rel.)	Tot. yield by weight (rel.)
1. Only handw	-	24.2	100	100	100
2. Herbicide	95	6.3	103	96	99
3. Harrowing	62	12.1	94	121	113
4. Finger	66	9.8	92	104	97
5. Robotic	76	10.7	90	113	102


Weeding in transplanted onion
% weed control
90
80
70
60
50
40
30
20
10
0
Finger
Torsion
Rob 120/1
Rob 80/1
Robo 120/2
Robo 80/2
Treatments


19/05/2011 10:25

Time for hand-weeding

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Comparison of the 3 robotic weeders – my judgement!

Attributes	Robocrop	Robovator	Steketee
Product maturity	+++	++	+
Crop range	+++	++	++
Weight	+	++	+++
Weeding device	++	+++	+++
Precision	++	+++	+++
In-row distance	++	+++	+++
Transplants	+++	+++	+++
Direct-sown crops	+	+	(++)

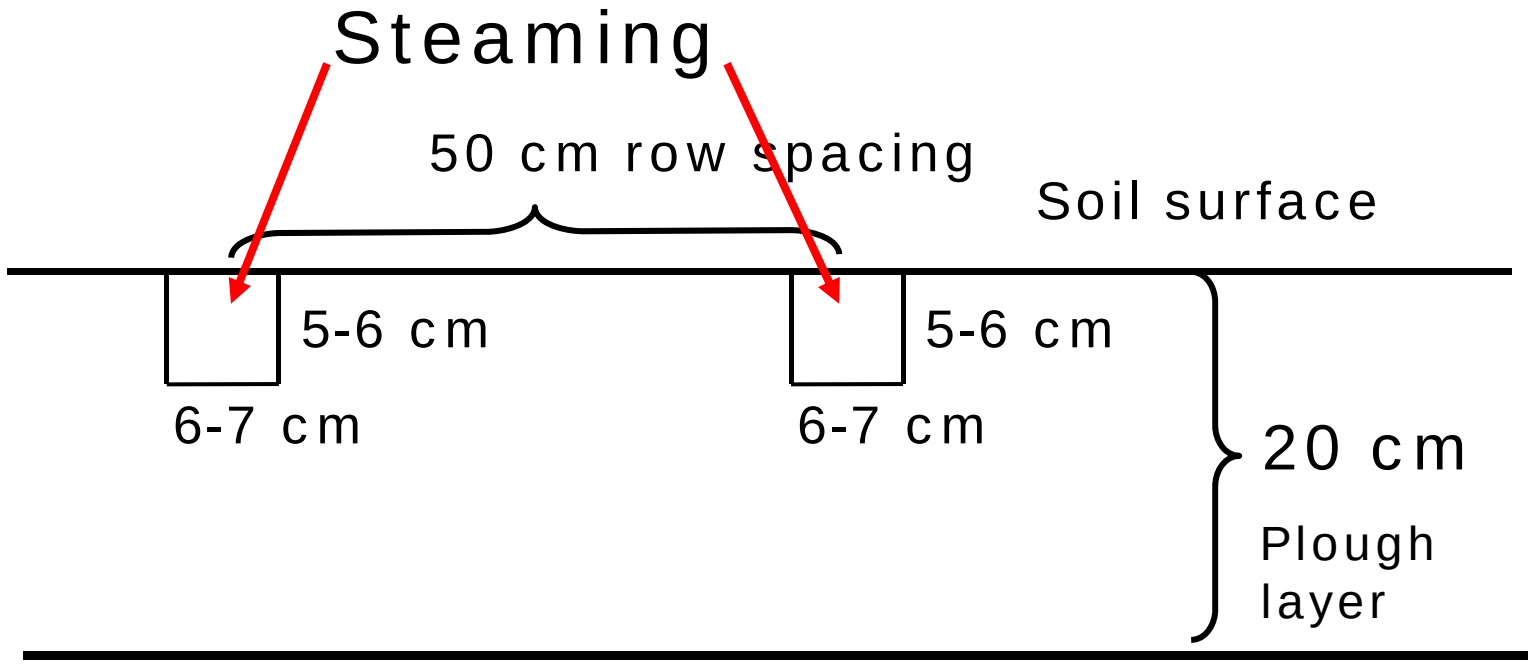
Machinery investment

Implement	€ per row
Robocrop	17,830
Robovator	16,000
Steketee	10,800
Weed harrow	530
Finger weeder	1,230
Torsion weeder	200
Flame weeder	3,900

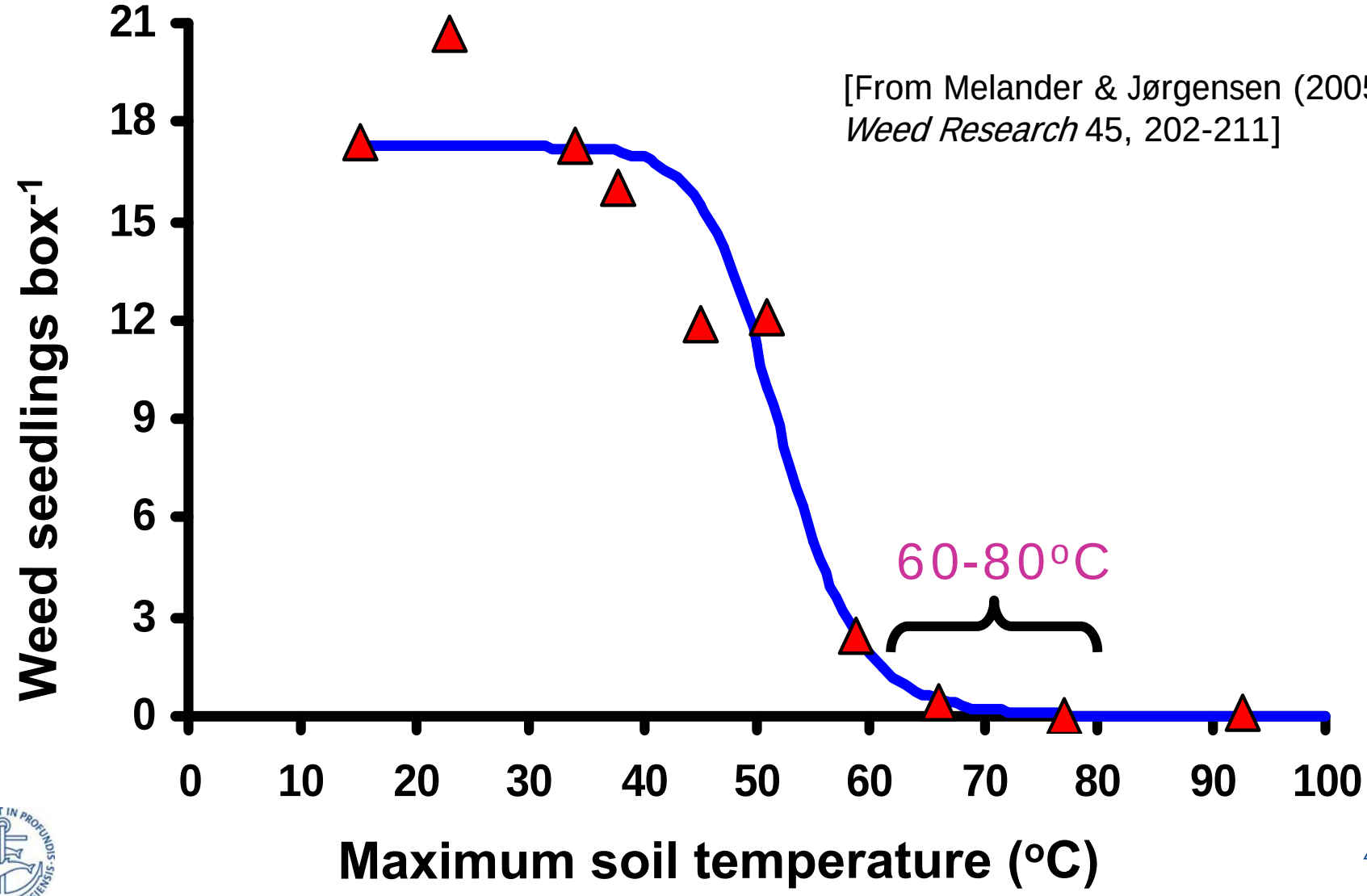
Advantages of robotic weeding versus low-tech solutions

- Less risk of crop injuries
- No extra person needed for steering
- Soil staining can be minimised
- More hours of operation per day
- Easier to change operator

Steaming in narrow bands



[From Melander & Jørgensen (2005)
Weed Research 45, 202-211]



Band steaming before carrot sowing

- 9 rows, 3 rows per bed
- 14 cm band width and 5 cm soil depth
- 600 litre oil and 7000 litre water ha^{-1}
- 0.2 km h^{-1}, capacity 0.112 ha h^{-1}

Temperature profiles on sand, target max. 80°C

0.5 min	0 cm	2 cm	4 cm	6 cm	8 cm	10 cm	12 cm	14 cm	16 cm
0 cm	38	55	53	58	49	52	53	52	51
1 cm	58	64	66	56	68	65	67	67	63
2 cm	64	60	71	69	63	67	70	66	63
3 cm	59	73	75	75	74	74	73	60	60
4 cm	42	69	74	76	75	73	69	61	27
5 cm	34	65	71	73	74	73	67	33	27
6 cm	17	48	62	68	67	63	45	24	16

1.5 min	0 cm	2 cm	4 cm	6 cm	8 cm	10 cm	12 cm	14 cm	16 cm
0 cm	39	38	46	51	44	46	44	46	44
1 cm	52	59	55	52	60	58	60	58	49
2 cm	57	51	66	68	67	67	67	58	45
3 cm	58	69	74	74	73	72	69	55	47
4 cm	53	67	73	75	74	71	64	57	27
5 cm	42	62	70	72	71	68	61	30	24
6 cm	33	55	62	65	65	60	43	24	15

2.5 min	0 cm	2 cm	4 cm	6 cm	8 cm	10 cm	12 cm	14 cm	16 cm
0 cm	37	42	42	48	40	42	44	43	37
1 cm	50	51	53	48	56	53	55	53	43
2 cm	55	52	65	64	62	61	62	54	46
3 cm	60	68	71	71	69	68	63	52	43
4 cm	56	67	71	72	70	67	58	52	31
5 cm	51	64	67	68	68	63	51	30	29
6 cm	41	56	62	62	59	52	40	24	16

3.5 min	0 cm	2 cm	4 cm	6 cm	8 cm	10 cm	12 cm	14 cm	16 cm
0 cm	35	37	38	43	38	39	40	39	35
1 cm	44	50	53	45	52	49	52	49	40
2 cm	55	49	61	60	61	58	58	52	43
3 cm	56	65	69	68	66	65	61	53	36
4 cm	51	62	69	70	68	63	59	50	33
5 cm	49	61	62	64	64	59	50	36	31
6 cm	35	51	58	63	56	50	43	29	16

4.5 min	0 cm	2 cm	4 cm	6 cm	8 cm	10 cm	12 cm	14 cm	16 cm
0 cm	29	37	35	41	39	38	36	37	34
1 cm	38	44	50	41	50	48	49	46	42
2 cm	45	43	55	58	59	54	56	52	42
3 cm	46	58	64	60	63	61	60	54	38
4 cm	39	53	63	65	64	62	59	54	37
5 cm	36	50	57	62	62	60	56	42	35
6 cm	28	43	51	58	54	52	47	38	21

5.5 min	0 cm	2 cm	4 cm	6 cm	8 cm	10 cm	12 cm	14 cm	16 cm
0 cm	30	33	35	36	37	37	34	32	30
1 cm	36	45	42	38	48	46	47	43	35
2 cm	44	37	54	55	55	54	54	49	38
3 cm	41	52	61	62	61	60	58	53	36
4 cm	37	49	60	64	63	59	57	52	38
5 cm	34	47	54	59	60	58	53	44	37
6 cm	27	40	49	56	53	50	48	38	22

6.5 min	0 cm	2 cm	4 cm	6 cm	8 cm	10 cm	12 cm	14 cm	16 cm
0 cm	29	33	34	35	36	36	33	34	30
1 cm	35	38	42	36	47	44	42	42	36
2 cm	36	36	51	51	49	50	50	47	39
3 cm	38	49	56	59	57	57	55	50	34
4 cm	35	46	56	60	59	56	55	50	35
5 cm	30	43	51	55	56	54	51	42	34
6 cm	26	38	45	51	50	48	44	37	23

7.5 min	0 cm	2 cm	4 cm	6 cm	8 cm	10 cm	12 cm	14 cm	16 cm
0 cm	29	31	31	35	33	33	31	30	25
1 cm	35	39	41	34	41	40	39	36	31
2 cm	39	36	49	51	50	47	47	42	32
3 cm	41	51	56	56	54	54	51	45	32
4 cm	40	50	55	57	56	54	50	45	33
5 cm	35	46	53	55	55	52	47	37	33
6 cm	32	42	48	51	50	47	41	33	21

Band-steaming on a sand soil in 2009 and 2010

Year	Max temp. (°C)	% effect	Stderr	Significance *P* - value
2009 Ca. 500 pl. m^{-2}	60-65°C	**71**	3.6	*P* = 0.55
	75-80°C	**78**	9.5	
2010 Ca. 280 pl. m^{-2}	60-65°C	**79**	3.7	*P* = 0.008**
	75-80°C	**89**	1.9	

Band steaming in beetroot

Band steaming in carrot

Preliminary conclusions on bandsteaming

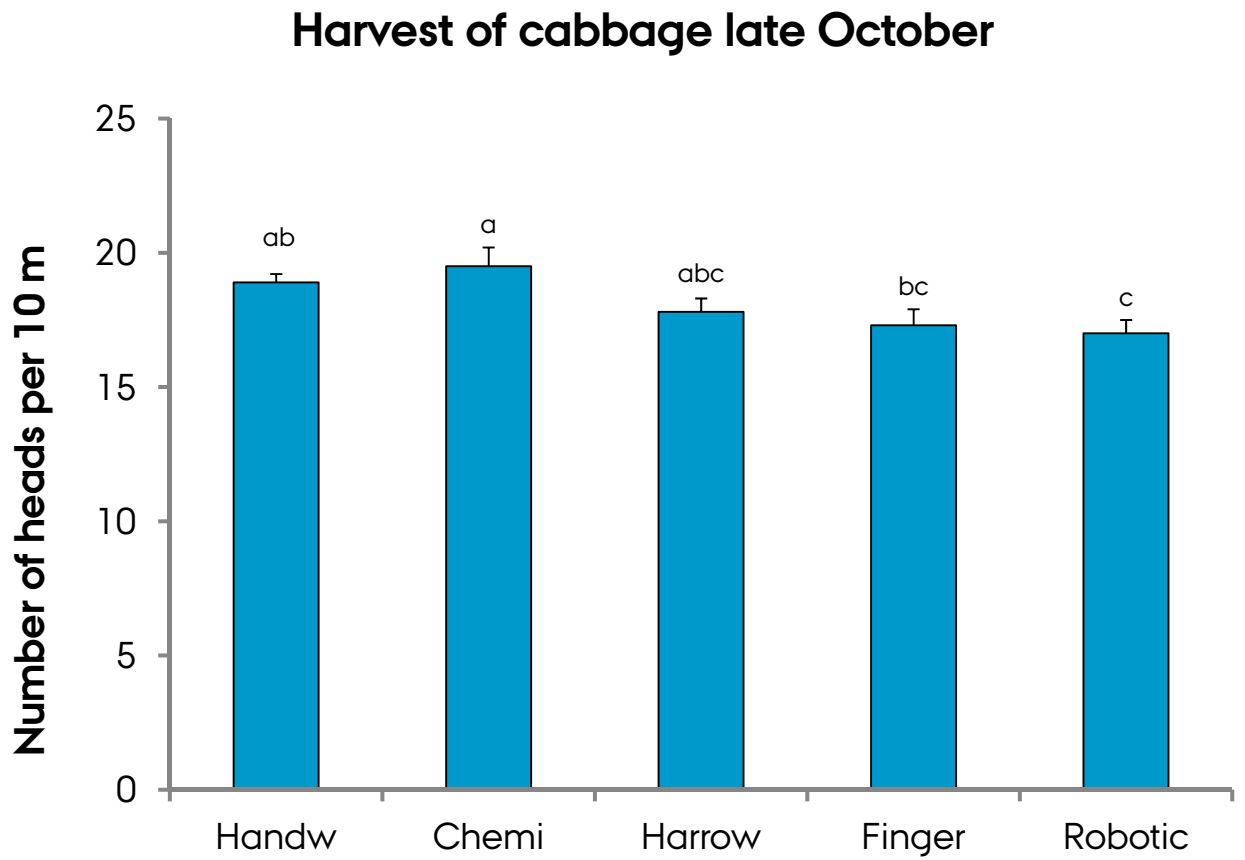
Advantages

- High weeding effects
- Tendency for higher yield in some crops
- Pest and disease control
- Substantial savings in labour for manual weeding
- Release of manpower

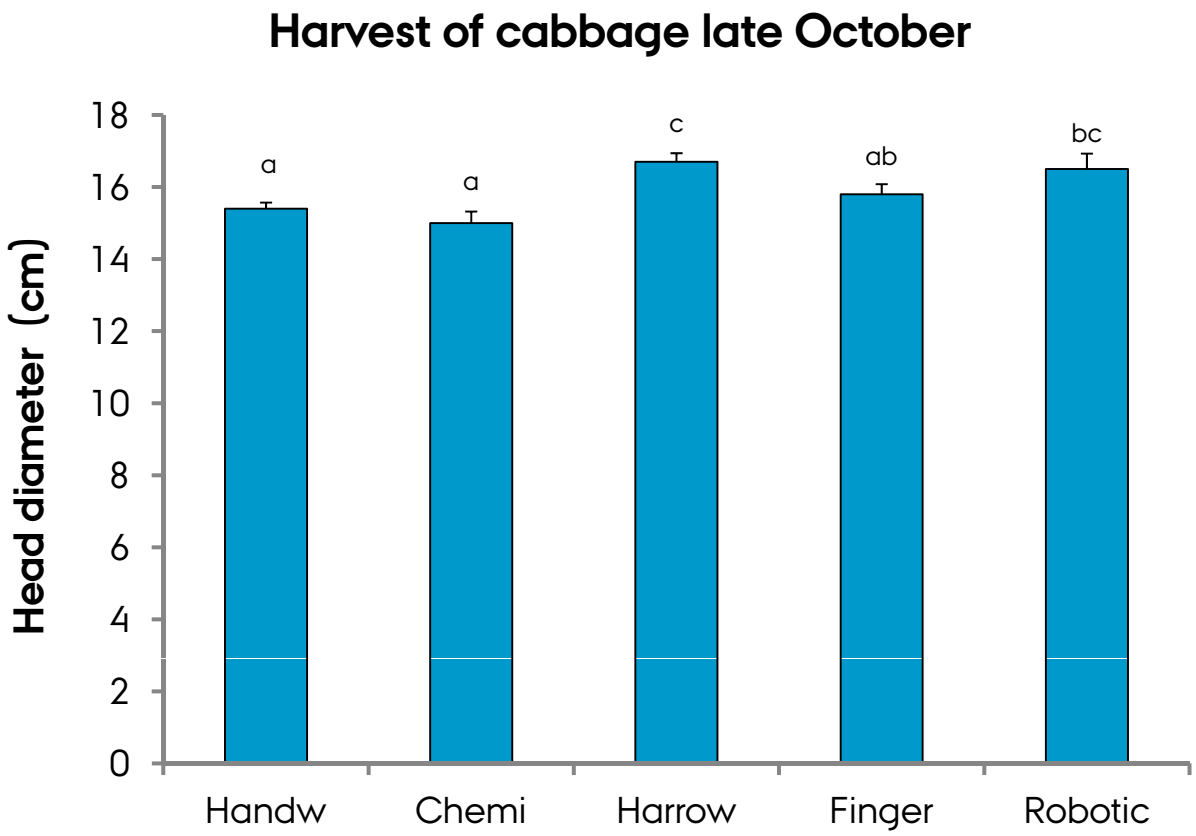
Disadvantages

- High fuel and water consumption
- Low work rates
- Sterilizes the soil

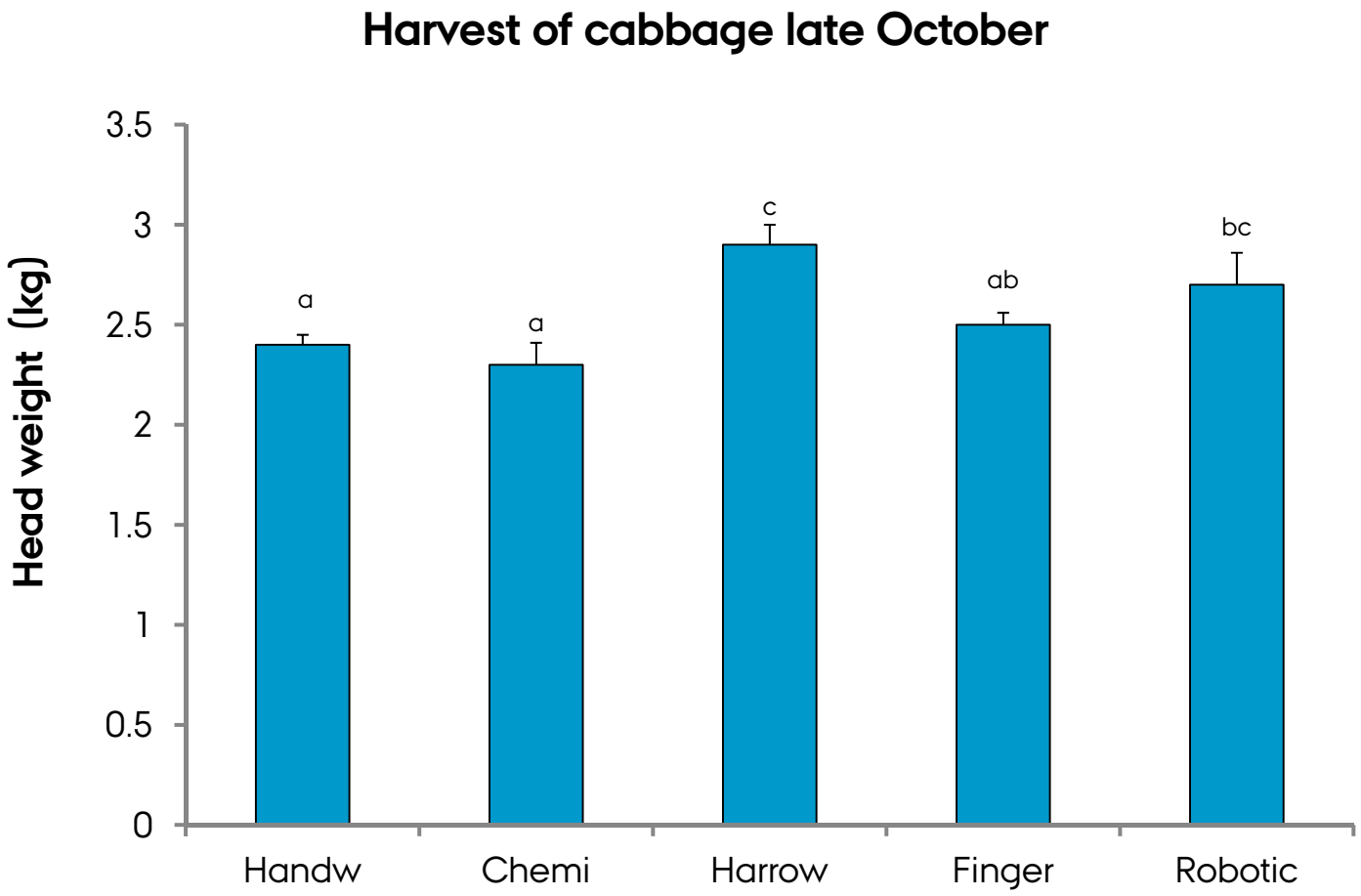
Intra-row weeding in white cabbage



Intra-row weeding in white cabbage



Intra-row weeding in white cabbage



Preliminary experiences with robotic weeding

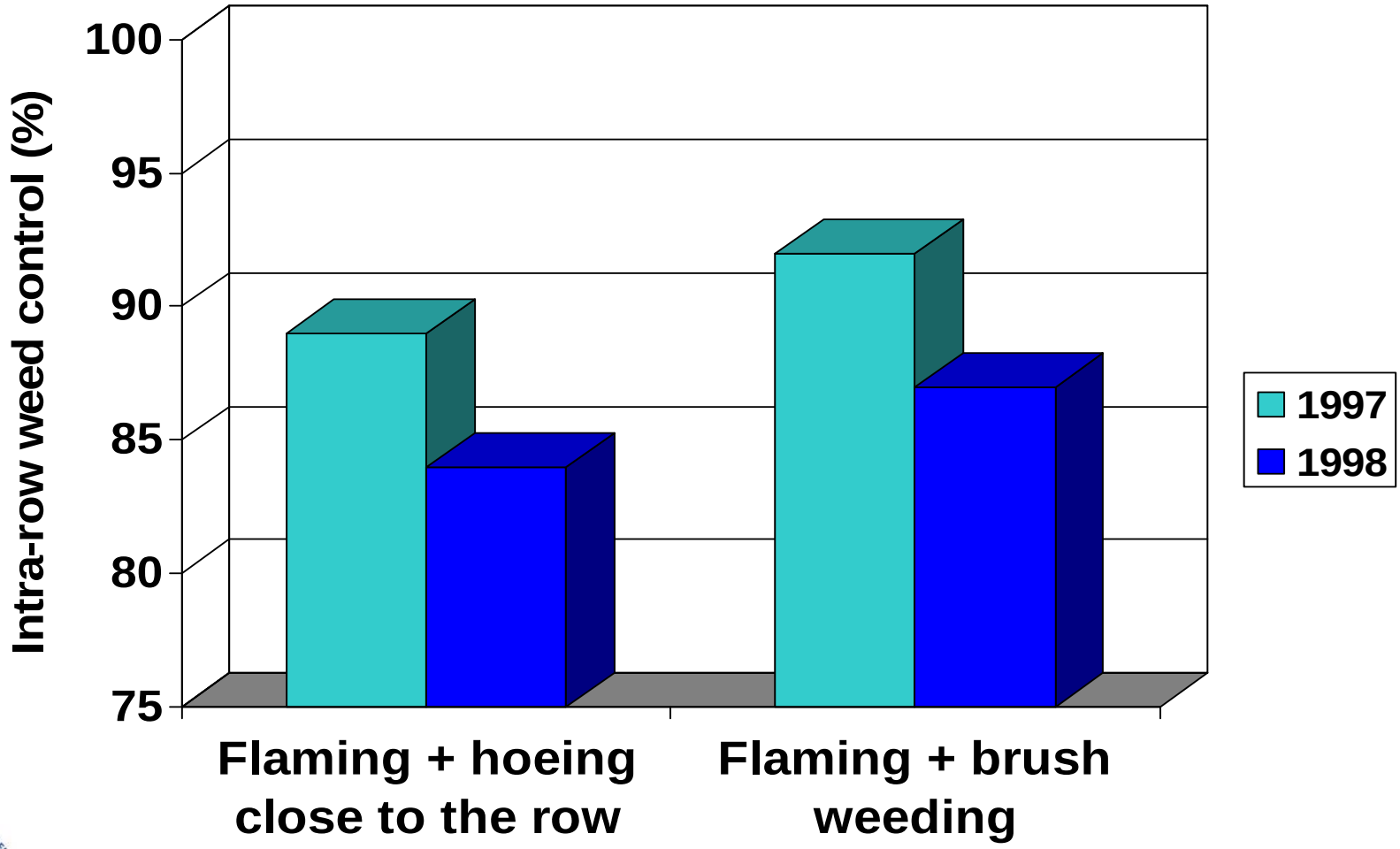
Advantages

- Selective weeding
- Less sensitive to weed growth stage
- High work rates
- Easy to operate
- Application for most transplants

Disadvantages

- High purchase costs
- No application for direct-sown crops
- Simpler tools may provide equal weeding effectiveness
- Repairs
- Closeness to the crop

Direct-sown leek



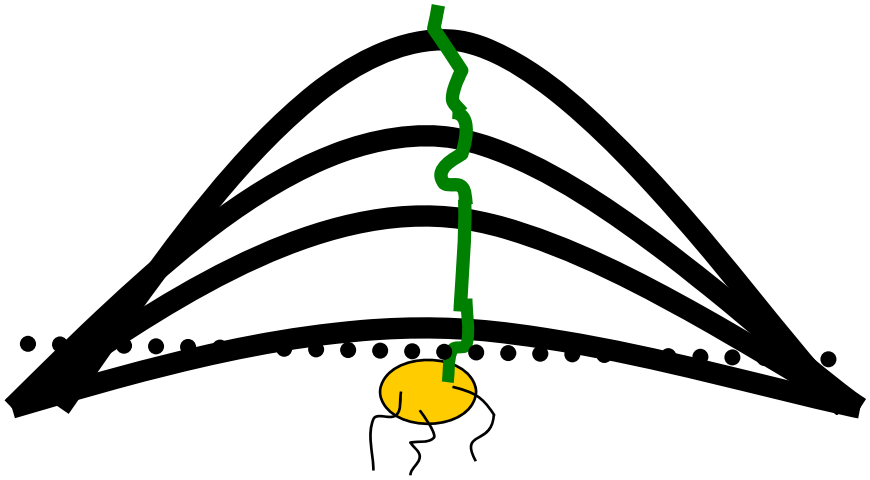
[From Melander & Rasmussen (2001), Weed Research 41, 491-508]

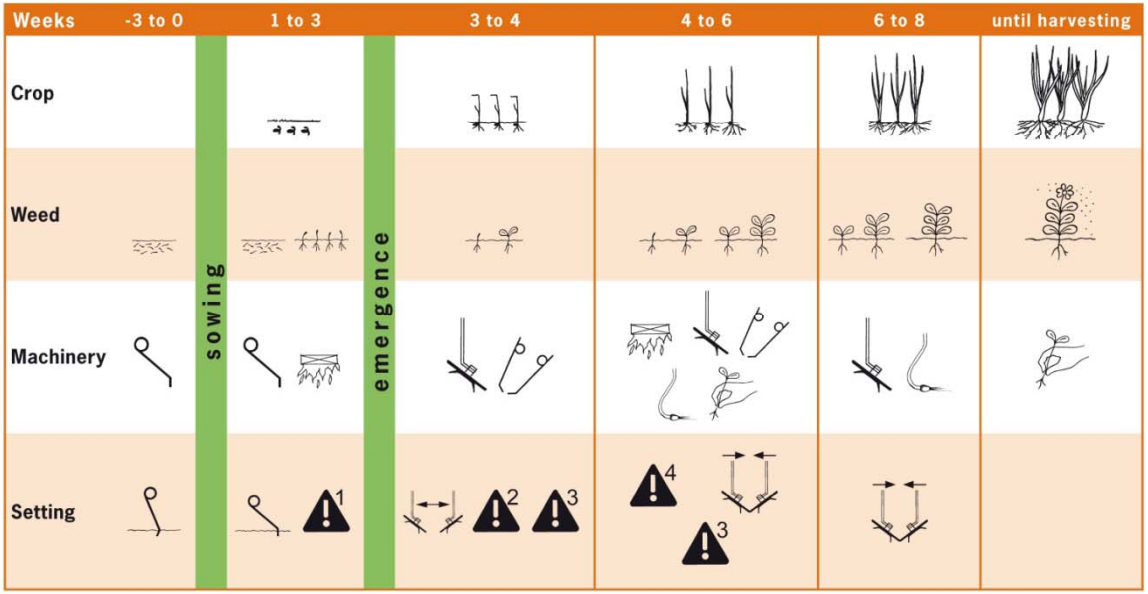
Ridging

Beans

Maize

Gradually ridging





Explantion of drawings

Crop		Weed		Machinery		Setting	
	Germination		White filaments		Harrow		Harrow tines, angle forward
	cotyledon		cotyledon		Finger weeder Torsion weeder		Harrow tines at vertical setting
	1 - 3 leaves		cotyledon to 2 - leaf		Pneumat		Weeder elements separated
	3 - 5 leaves		2 - 4 leaves		Flame weeding		Weeder elements against each other - overlap
	30-100% soil cover		6 leaves		Hand weeding	1	Harrow as shallow as possible, above sowing depth
			Flowering and seed-bearing			2	With small crops and loose soil elements approx. 1 cm apart
						3	With small crops and crust formation drive slowly and use discs
						4	Flame weeding in the crop solely for onion and chicory (onion 4 - 6 leaves and chicory

The significance of weed growth stage

Chrysanthemum segetum

White thread stage
Mechanical weeding
very easy with all implements.

Cotyledon stage – *Chrysanthemum segetum*
Mechanical and flaming weeding easy with all implements


Two true leaves - *Crysanthemum segetum*
Harrowing, finger weeding, torsion weeding, flaming: possible
Hoeing and robotic weeding: all easy


Seven true leaves - *Chrysanthemum segetum*
Harrow, finger, torsion and flame: no effect
Hoeing and robotic: possible