Oral presentation at the 2004 International Weed Science Congress, 20-25 June, Durban, South Africa. Main topic 16.

Slide 1

Good morning everybody. I am happy to be here and outline the prospects for improving the selectivity of current mechanical weeders. Coming from the Netherlands, this will have a mainly north European perspective. The machines I will talk about are mainly suited for mouldboard plough tillage systems on 20-100 hectare farms with vegetables, sugar beets, onions, maize and cereals. However, the principles probably apply to your situation as well.

I am very grateful for the support from EWRS that made it possible for me to come here. Thanks again!

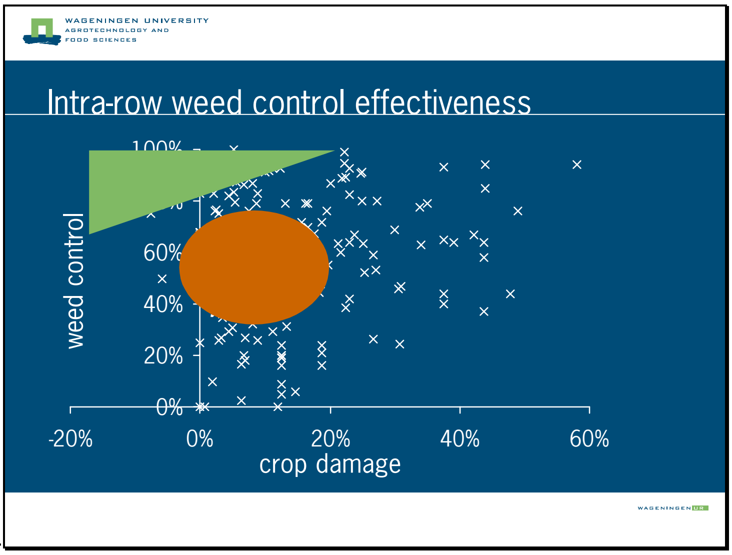
It is now about 20 years ago that mechanical weeding with spring tine harrows, inter-row cultivation and rotary hoes regained serious interest. Whereas weed control between crop rows is rarely problematic, intra-row weeds are more difficult to control (point at einböck maize row), as they require a more timely and selective action.

Slide 2

In the last decade, many different intra-row tools have been tested, such as torsion weeders, various ground driven finger weeders and brush weeders, hydraulically powered brushes, pressurised air,

Slide 3

… and various tined implements. In field experiments we learned how to adjust them, when to use them in which crops, and about their weed control potential within the crop rows.

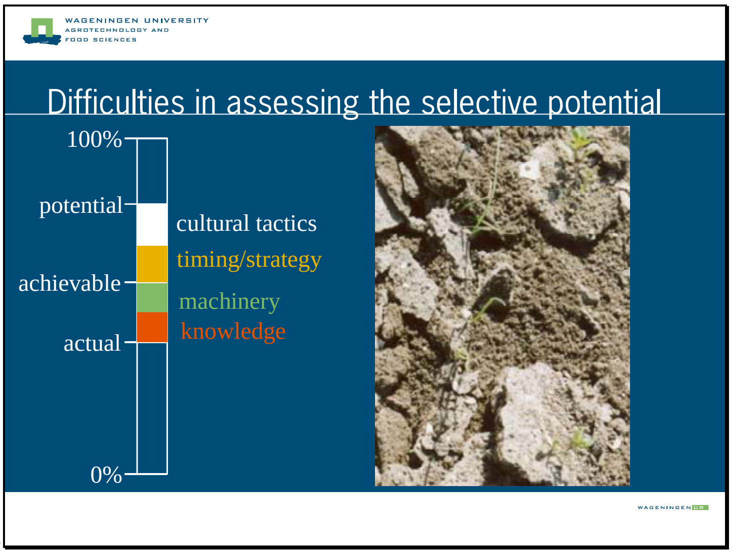


Slide 4

This graph shows the in-row weed control effect achieved in field experiments with various crops, implements and varying numbers of cultivation passes at different locations in Europe and North America. Although this graph is far from complete, it shows considerable scatter in effectiveness, with many data in a unsatisfactory range (click). The limited effectiveness may well have incited an increased emphasis on new techniques such as band steaming and robotic weeding. Also the associated crop damage is not desirable, as farmers perceive it as a risk. Although yield losses are generally small or negligible, these are important factors limiting adoption.

Selectivity is about achieving high weed control with little or no crop damage. (Click) So, we want to be in the upper left corner. Can we come there? Or should we just accept that this is just how far we can get, as the weed control potential depends on many factors. From that point of view, we could now just review these data, and examine what crops, weeds, growth stages, implements, soils, and weather conditions characterise the high and low points.

Although this seems straightforward, I think these data may not reflect the real selective potential, as the essentially reflect our present skills, current restrictions on machinery performance, etc.

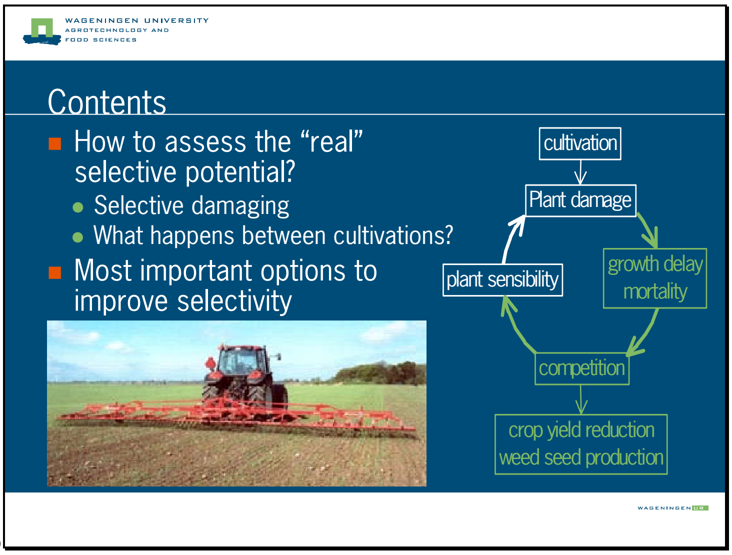


Slide 5

For example, this picture shows onions (point) and uprooted weeds (point) after torsion weeding. Can you estimate how much growth reduction and weed control will result after one week?

A different implement adjustment might have improved the actual result (click). So the question is: (click) How much weed control would be achievable in the given crop-weed situation with perfect knowledge and perfect machinery? The second question is: (click) How much could the achievable weed control have been improved by a different cultivation timing or cultural measures that increase the difference in susceptibility between the crop and weeds?

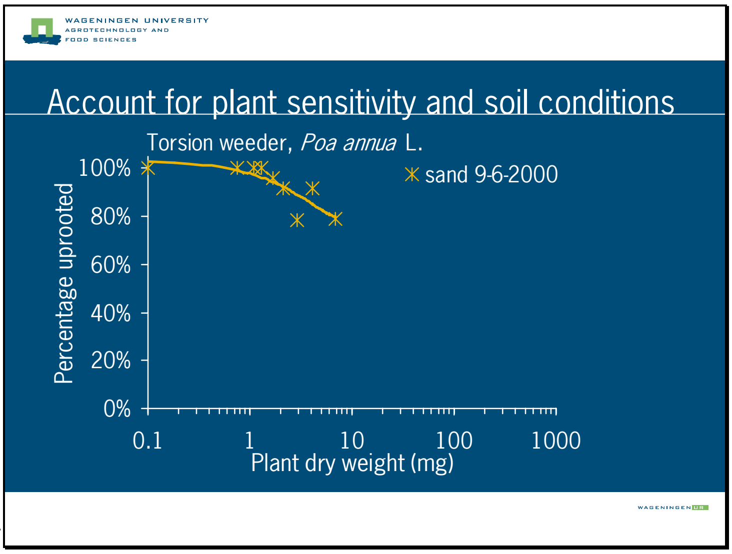
Can anybody tell how big these gaps are? How can we assess them? Would further research on mechanical intra-row weeding warrant any prospect for improvement?



Slide 6

To answer these questions, (click) I will first discuss how the "real" potential for selective mechanical weeding could be better assessed. (click) We will first look at the selective damaging of crop and weeds by cultivation, and (click) then to what happens between cultivations.

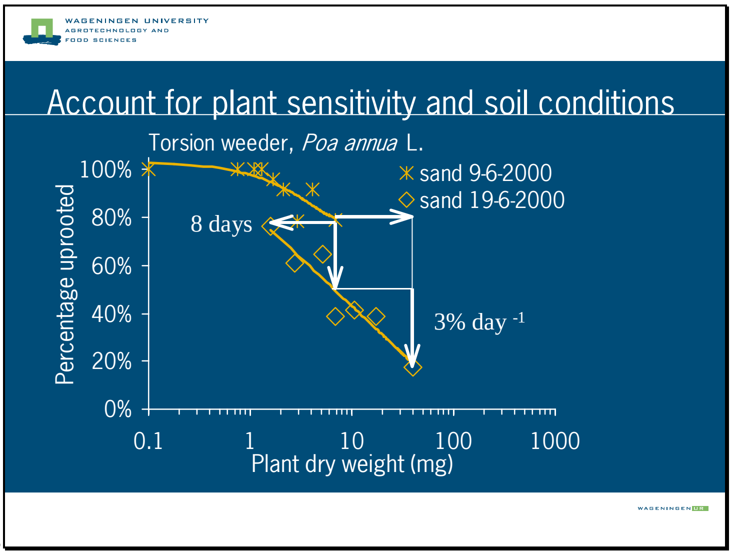
Then, (click) I will summarise the most important practical options to improve exploitation of the resources of selectivity in this diagram.



Slide 7

Assessing the selective potential of mechanical weeding is more difficult than with herbicides. Partially because plant sensitivity declines more quickly, and because cultivation effects depend on soil conditions and other factors.

This graph shows a relationship between the fraction uprooted weeds and individual plant dry weight (point), assessed by collecting plants directly after one cultivation pass with torsion weeders.

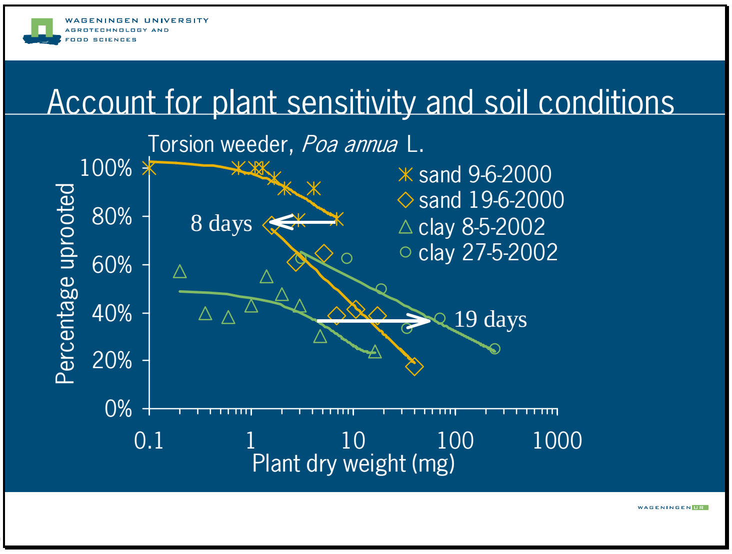


Slide 8

After repeating the treatment 10 days later, (click) the escaped weeds had grown and became less sensitive (click). The new emerged weeds and recovered damaged weeds were more sensitive (point).

This graph shows that precise assessment of weed plant size and its variability within the population is important for making sound comparisons. (click) Differences caused by soil conditions and adjustments can only be assessed at the same plant weight (point).

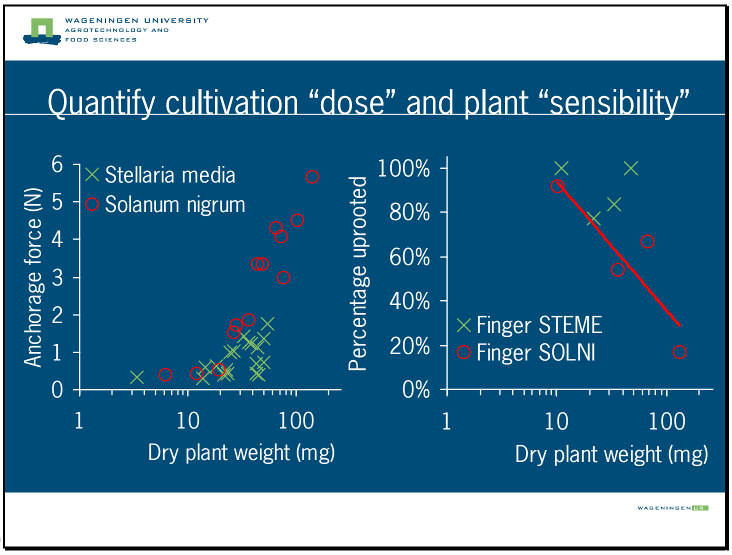
If you know more about and weed growth rates, such graphs can help estimate the consequences of delaying cultivations. However, we need to account for soil conditions and implement adjustment. (click) When expressed in time, letting the sandy soil dry out (click, point) gave a disadvantage of 8 days.



Slide 9

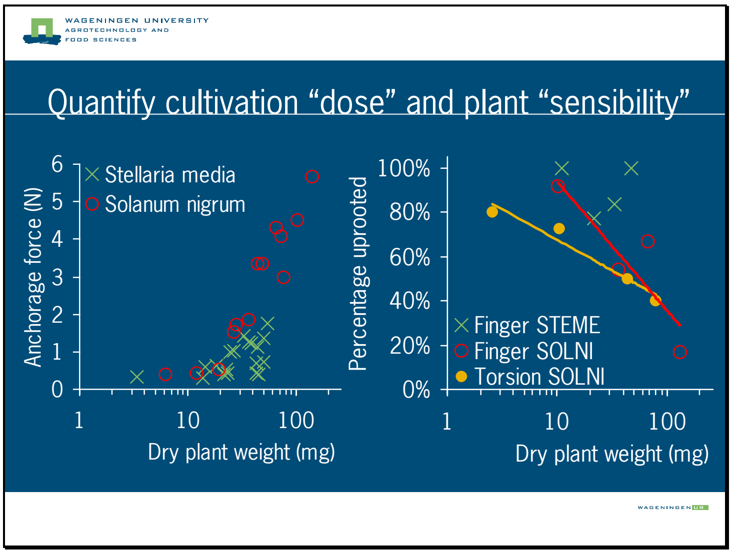
However, using a more aggressive adjustment on clay corresponded to an advantage of 19 days. Although plants had multiplied their weight by 10, the uprooting performance on clay was quite similar.

The comparability of experiments would greatly improve if plant sensitivity and cultivation aggressiveness could be quantified. Later on, we will see this has many more advantages.



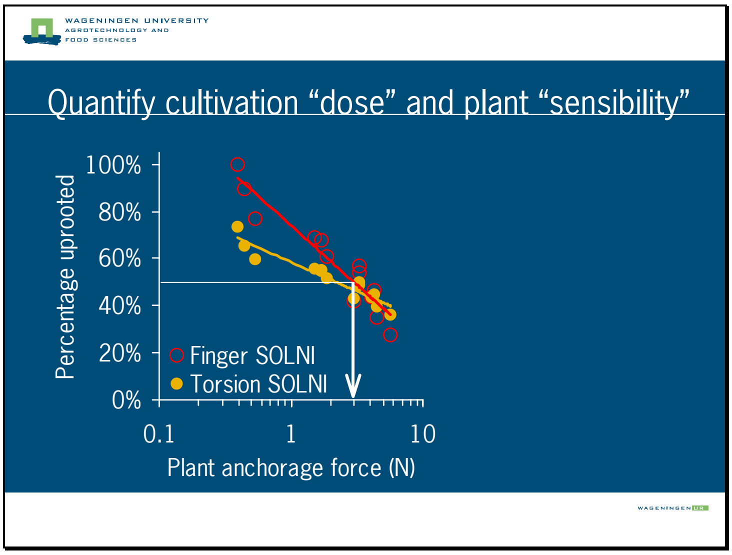
Slide 10

In-row cultivation selectively covers and uproots crop and weed plants. We might quantify uprooting aggressiveness by measuring how strong individual plants are rooted in the soil as related to their dry weight. We see that the more weakly rooted chickweed (click) was also more uprooted by the finger weeder than black nightshade.



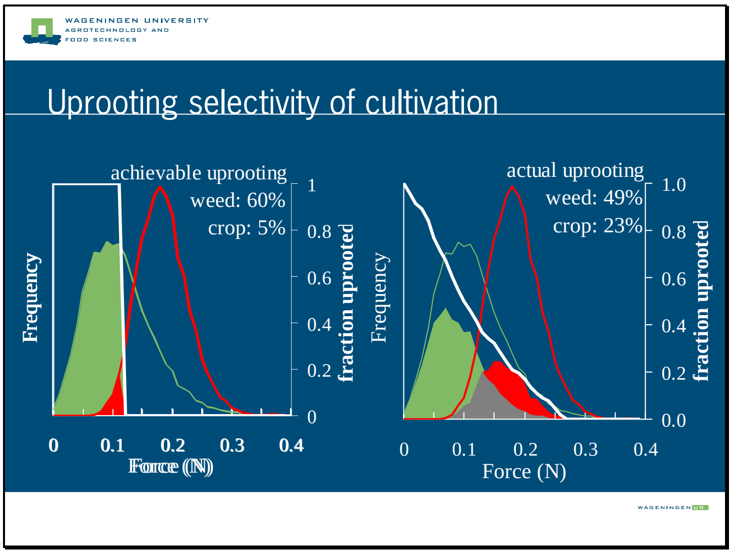
Slide 11

However, (point) the torsion weeder gave less uprooting than the finger weeder.
If we would link these graphs together, we would arrive at…



Slide 12

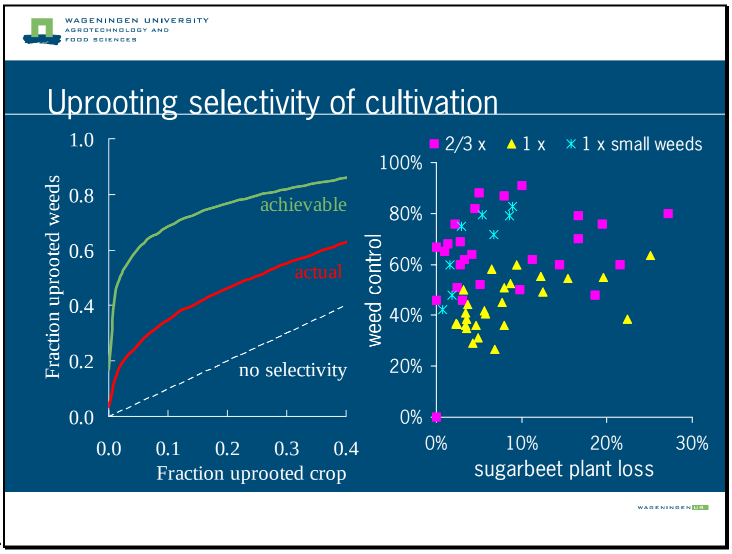
… a relationship between plant anchorage force and the fraction uprooted plants. This line is a kind of plant sensibility-response curve. Ideally, it should not depend on species, only on soil properties and implement characteristics.
(click) The force that uproots 50% of the plants may quantify the mean uprooting aggressiveness, in this case 3 Newton plant-applied force. The slope corresponds to the selectivity of the uprooting action. Please let me illustrate that with a graph.



Slide 13

(click) In these example anchorage force frequency distributions, the red crop is better rooted and less sensible to uprooting than the green weed population. An ideal weeder would apply the same force on all plants, so that (click, point) the white dose-response curve is very steep. All plants below 0.12 N are uprooted (point), resulting in 60% weed and 5% crop plant loss. With that level of aggressiveness, this is the achievable selectivity, as the frequency distributions partially overlap.

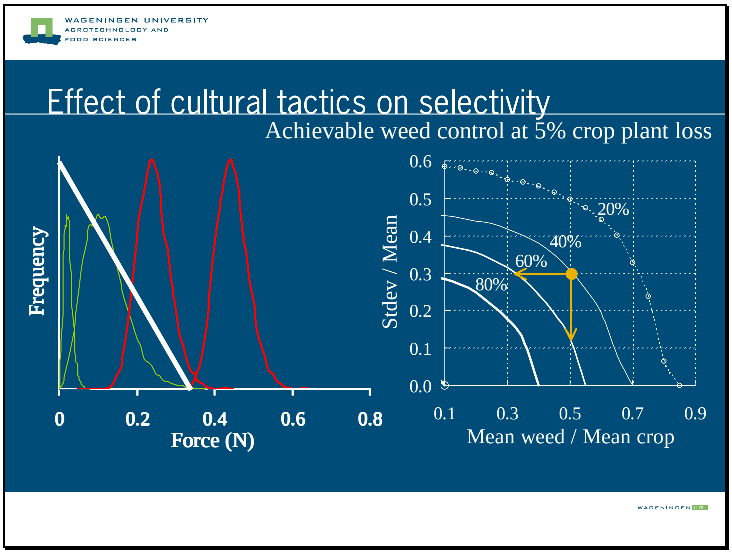
(click). A less steep slope would decrease selectivity. Larger plants (point) will be uprooted by the occasionally higher cultivation-induced forces, whereas some of the (point) smallest plants escape. Thus, selectivity is related to within-population variability of plant sensibility <u>and</u> the variability of the force applied by cultivation. The impression that good soil tilth improves weeder performance may be related to the smaller force variations in well structured soils. Please note that the mean aggressiveness (point) of both graphs is the same. Increasing cultivation aggressiveness would mean shifting the white lines to the right. If we calculate crop and weed uprooting for a range of aggressiveness, …



Slide 14

… a graph like this will result. Such graphs help to find a compromise between crop damage and weed control. Most field experiments only include one level of aggressiveness of a machine, based on “expert judgement”. How many experts know or assess such (point) relationships when adjusting the machine? How sure do we know that the pursued or achieved crop damage levels are optimal? For example, if there is no crop damage (point) we don’t know whether a more aggressive adjustment would have controlled more weeds, with still no crop damage. If this background knowledge is lacking, how could we train farmers to become experts in using the machines in the best possible way?

(Click) The right graph shows a similar relationship from field experiments in sugarbeet. However, those data alone cannot quantify the selective ability of the weeder, as the selective potential of the crop-weed situations may differ. Look at the difference between the blue dots for small weeds and the yellow ones. Measuring crop and weed anchorage force distributions could give us a reference for the maximum selectivity in the given crop-weed situation, so we can compare the weeder’s selective ability between experiments.

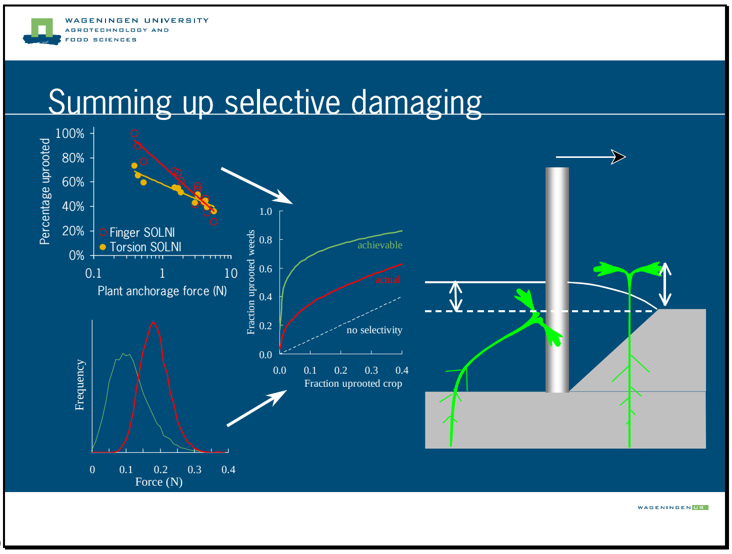


Slide 15

These reference measurements may also quantify the effects of cultural tactics on the achievable selectivity. For example, the overlap between crop and weed sensibility may be reduced by (click) delaying weed emergence is relatively to the crop, or (click) reducing within-population variability. There are many tactics that may achieve this, which I will not review here.

If we know (click) from the slope of this line how selective our weeders are, we may calculate how far these frequency distributions should be apart to achieve a certain effect. (click) This graph shows the estimated weed control at 5% crop plant loss, as a function of the ratio of mean crop and mean weed anchorage force, and the within-population variability of crop anchorage force. With a certain variation coefficient, say 0.3 (click) we can achieve 40% weed control if the crop is rooted twice as strong as the weeds. To achieve 60% control, the crop needs to be anchored (click) three times stronger than weeds, or its within-population (click) variability should be decreased threefold.

Another interesting opportunity arises when models to predict emergence patterns and plant dry weight distributions could be used to predict these anchorage force distributions over time.



Slide 16

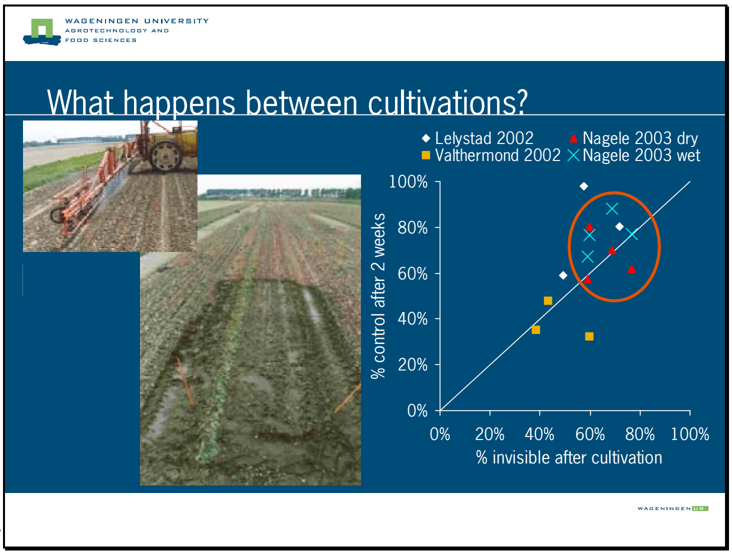
Summing up, assessing and maximising the selective damaging potential comes down to three things.

First, (click) these kind of relationships should be assessed for various soil conditions, machines, and adjustments. Both to assess selectivity and the achievable range of aggressiveness.

Second, (click) assessing crop and weed sensibility, including within-population variability, and

Third (click), combine these relationships to optimise cultivation aggressiveness and assess the selective potential.

(click) A similar approach could also be applied to the soil covering action. The plant height (point) minus the soil level upheaval (point) could be the covering dose on the horizontal axis (point) on this graph. However, as a harrow (point) pushes plants down as well, plant rigidity and forward soil impulse should be considered as well. The spatial patterns involved in the upheaval and forward pushing may complicate things further.

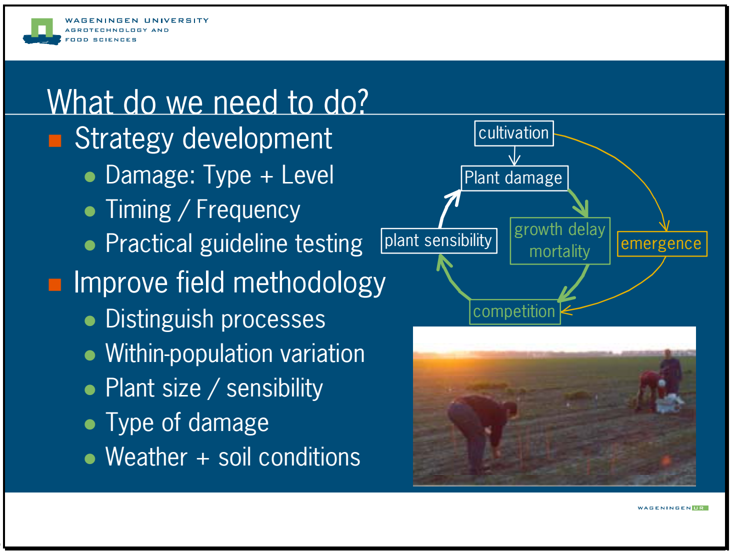


Slide 17

Until now, we focussed on the selective damaging of crop and weed plants. However, the optimisation of cultivation aggressiveness and timing requires insight in (click) what happens to damaged plants after cultivation, and how that affects subsequent cultivations.

Do these processes work synergetically or do they level out the selective damage created initially? (point) Which proportion of the weeds regrows? How much weed damage is sufficient to improve the competition balance? What determines the time of the next cultivation: new weed emergence or insufficient damage to existing weeds? How does a cultivation operation affect weed and crop sensibility at the next cultivation? How and to what extent can the outcome of all these processes be manipulated by cultivation timing and aggressiveness?

Research that can answer these questions is yet very scarce, as we often assess the joint outcome of processes on crop yield and weed infestation. That would not be a problem if cultivation effects would be well predictable. (click) The shatter in this graph shows that this is often not the case, even is new weed emergence is excluded. If we compare (click) the red triangles (point) with the blue crosses, we see that simulated rain shortly after cultivation <u>improved</u> weed control. So, the idea that mechanical weeding requires dry weather may not always be true. (click) As uprooted weeds were probably desiccated before we could get there with the sprayer, irrigation made recovery from burial more difficult.



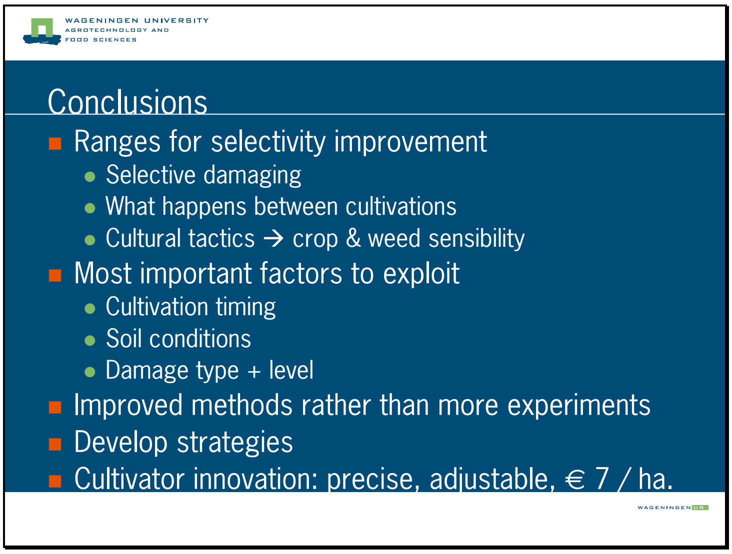
Slide 18

As uprooted and buried weeds may react quite differently to dry or moist conditions, (2 x click) it might be possible to develop cultivation strategies that adapt the type and level of damage to weather conditions. (2 x click) Optimising cultivation timing involves many issues such as crop and weed sensibility decline, weed emergence flushes, soil conditions, and weed recovery. These factors determine how quick we move through the cycle. For example, if weeds break through the soil cover within a few days, the required cultivation frequency may be higher than if all weeds are killed and new emergence is impeded by dry weather.

Maybe I tend to make things too complicated. However, I think that (click) simply testing practical guidelines can be a suitable way to both improve practical skills of farmers and acquire more knowledge of these processes. Simple on-farm experiments could apply a guideline and compare it with a contrast. For example: if the loosened layer is shallow enough to be completely desiccated within one day, all uprooted plants will die. Or: with dry weather, uprooting should be pursued rather than covering, and vice versa. Thus, we are comparing explicit decision rules and the consistency of the weeding results, rather fixed treatments and machines. Rather than taking year-to-year difference for granted, we should try to reduce them.

(click) Such experiments need support from improved field methodologies that account of all the things listed here. They should explain where differences in effectiveness come from. Simply including a counting area where weeds are removed before cultivation lets you evaluate whether weed recovery or new weed emergence makes another cultivation necessary. In the first case more aggressive or earlier cultivation should be considered. In the second case perhaps soil moisture conditions less conducive to germination.

The additional measurements are time consuming and require long working days (click, point). However, they may improve our understanding more efficiently than just doing more experiments. Recently, a group of people within the EWRS working group Physical and Cultural Weed Control has developed a guideline paper on experimental methods in physical weeding. If you are interested in this work or in the recently developed field methods, please talk to me afterwards.



Slide 19

Ok, time to sum up. (click) Prospects for improving weeder selectivity can be found in three ranges: Selective damaging at cultivation, managing with processes between cultivations and cultural tactics that increase the difference between crop and weed sensitivity.
(click) The most important factors we could further exploit are: cultivation timing, soil conditions and damage type and level. They all involve multiple processes.
(click) To improve our understanding of these processes and improve cultivation strategies, improved methodology is required rather than just more experiments. This should help us explain where effectiveness variations come from.
(click) Based on that knowledge, we can develop strategies for optimum cultivation timing and adjustments as related to soil and weather conditions.
(click) To realise these strategies and exploit these factors, improved machinery will be needed that is easily adjustable from the driver's seat and has precise automatic steering and working depth control. This might require the smart tools with sensors and electronics. They should achieve a high capacity with a light tractor, that can get in the field any time topsoil conditions are right. I'm thinking of 12-18 metre wide implements that only cultivate narrow crop strips and can drop costs to about € 7 per ha per pass. I think this combination can make selective mechanical weeding seriously competitive to herbicides.
Thanks for your attention.

Additional remarks / text:
Within-population variability of plant sensibility and type of damage and on weather and soil conditions: In onions and sugarbeet we found that only the smallest plants were lost. Would these plants have contributed much to the yield? And what about the largest weeds that escape and produce the bulk of seeds?
As herbicides do not significantly affect the crop, the effect on competition and yield simply follows from weed biomass reduction. With mechanical weeding the crop is often damaged as well. Therefore, Jesper Rasmussen developed a modeling approach to separate the compensating effects of crop damage and weed competition. In this respect, experiments exploring crop damage in various growth stages in weed free conditions are also very valuable.
The largest gap in our knowledge is probably on growth delay and mortality of damaged plants and the effect of previous cultivations on on plant sensibility. Yes, several studies compared the effect of various types of artificial damage under greenhouse conditions. But do they correspond to the damage created by real implements? (Click) This graph shows that the torsion weeder uprooted more weeds than the other implements. However, the final effect was lower because the soil was stirred less intensively. Soil-root detachment, root position within the loosened topsoil and drying fronts within this layer probably have an impact.
Improving the selectivity of mechanical weeding would allow us to rely less on the selectivity of herbicides or handweeding in organic farming. Handweeding is an expensive and restricted resource. High development costs, resistance and governmental restrictions make herbicide an exhaustible resource, which is however still relatively cheap. Mechanical weeders are relatively cheap, applicable in many crops (more than any single herbicide). However, mechanical weeding should not just replace herbicides, but be a part of a diversified system, to alleviate major weaknesses (e.g. with high weed densities, weather dependence, timeliness) and avoid selection. The other way around, selective control measures are needed as a backup if other cultural measures fail to sufficiently suppress weeds. The quality and costs of backups may affect farmer willingness to adopt preventive cultural practices.