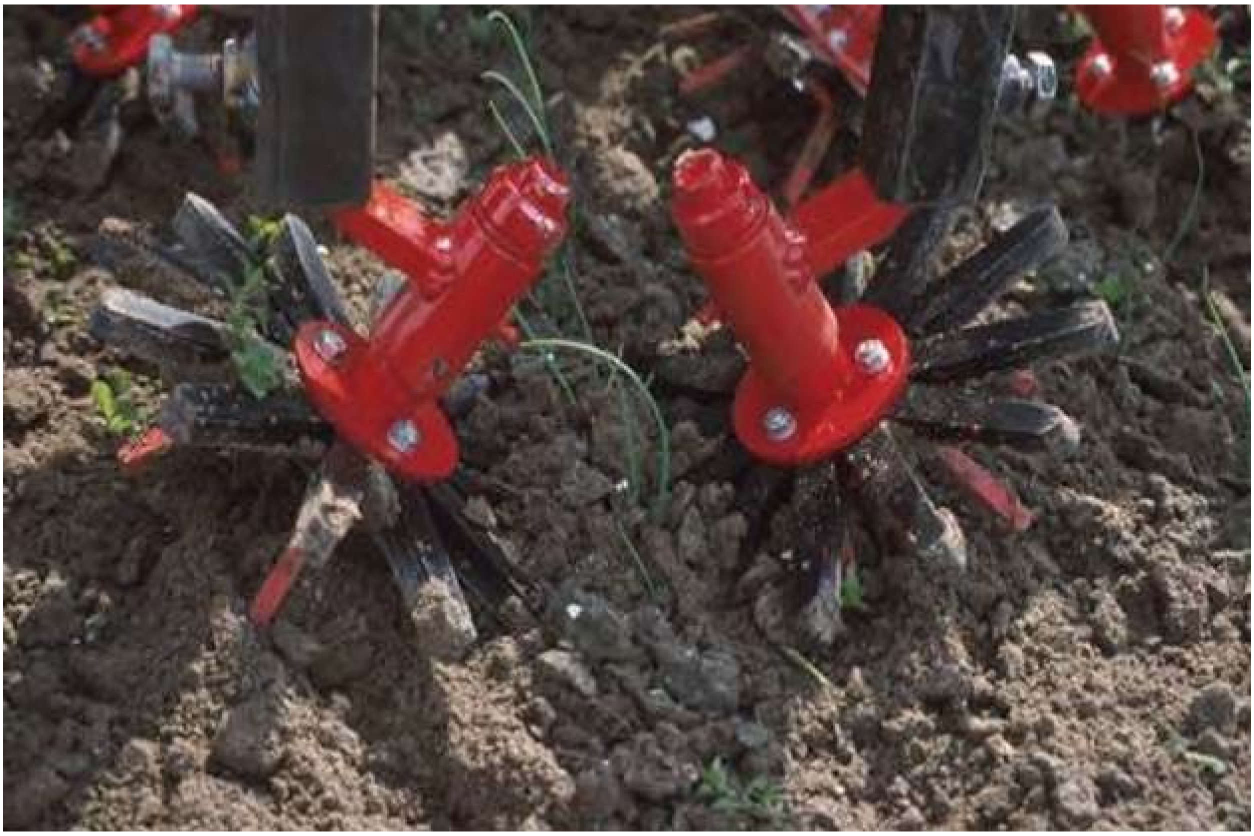
EUROPEAN WEED RESEARCH SOCIETY

Joint workshop of the EWRS working groups:
Physical and cultural weed control
and
Crop-weed interactions

Physical and cultural weed control tools as moderators of crop weed interactions

Nyon, Switzerland

2 – 5 April 2017



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Proceedings

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and
CROP-WEED INTERACTIONS

Physical and cultural weed control tools as moderators of crop weed interactions

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The combined effect of primary tillage and cultivation in soybean on the control of *Sonchus arvensis* and *Cirsium arvense*

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Sonchus arvensis L. (perennial sow-thistle) and *Cirsium arvense* (L.) Scop. (Canada thistle) represent an increasing problem in organic field crops in Canada. The effect of primary tillage implements on the root fragmentation of both weeds was studied in a field experiment on a clay loam soil under organic production. The soil was tilled three times using various types of primary tillage implements: cultivator, chisel plow at 10 cm or 25 cm depth, disk harrow, rotary harrow, offset disk and rototiller. Soybean was subsequently seeded in 76-cm rows in the treatments including cultivator or a combination of disk harrow and cultivator. It was cultivated using duo parallelogram or finger weeder on row in combination with goosefoot sweep between rows. Results of the fragmentation study show that rototiller and rotary harrow produced many small root fragments while the chisel plow at 25 cm depth teared off the root system and brought it to the soil surface. Primary tillage implements were more effective in controlling perennial sow-thistle than Canada thistle. After crop seeding, five cultivations were necessary to reduce both weed pressure. The seeding of the soybean crop was delayed because of some of the soil preparation treatments. However soybean yield was acceptable and varied from 2,7 to 3 t ha^{-1}. At harvest, there were less than 1 shoot m^{-2} of perennial sow-thistle and less than 3 shoots m^{-2} of Canada thistle. The combination of primary tillage and mechanical weeding used with a competitive crop such as soybean did succeed in controlling both perennial weeds.

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Using vertical discs to fragment *Elymus repens* rhizomes shifts the competitive balance towards Italian ryegrass – white clover companion crops

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Despite competitive companion crops and mowing, perennial weeds, such as *Elymus repens*, can sometimes propagate in grass-clover crops. In this study, we attempted to increase the competitive advantage of the companion crops by using a prototype with vertical discs to fragment *E. repens* rhizomes, with minimal soil and crop disturbance. The aim was to develop a method for controlling *E. repens* in a grass-clover crop, with a combination of rhizome fragmentation and mowing. Experiments were performed in 2014 and 2015 in Uppsala, Sweden. Fragmentation was done pre-sowing (ERF), in the growing crops (LRF), or both (ERF+LRF). In addition to fragmentation, the treatments consisted of repeated mowing and four companion crop treatments (no sown crop, white clover, Italian ryegrass and the mixture of both). In the grass-clover crop, there was less *E. repens* rhizome biomass following rhizome fragmentation, but more Italian ryegrass shoot biomass and tendency towards more white clover shoot biomass. ERF and LRF reduced *E. repens* rhizome biomass to a similar degree, but there was significantly more Italian ryegrass following LRF than following ERF. ERF+LRF resulted in less *E. repens* rhizome biomass than single fragmentation, while the Italian ryegrass shoot biomass was tripled compared to the control. Rhizome biomass was strongly reduced by repeated mowing. When mowing was combined with two rhizome fragmentations the effect tended to be even greater. We conclude that rhizome fragmentation through vertical discs can be used both pre-sowing and in the growing crop to strengthen the competitive advantage of grass-clover crops over *E. repens*.

Effect of biodegradable mulches on pepper production and purple nutsedge control (*Cyperus rotundus* L.)

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The use of polyethylene (PE) used as a mulch in horticultural crops entails a series of disadvantatges for the producers, such as the removal costs from the field, the difficult management of waste and the bad weed control of some species as purple nutsedge (*Cyperus rotundus* L.) which is capable to pierce the plastic film. Thus, there is a need to look for alternative materials to PE to use in horticultural crops that decrease the above-mentioned drawbacks. Trials were carried out in different Spanish locations for over 10 years with biodegradable materials in order to find economically-viable alternatives to PE. The ones described here were established in Zaragoza (Aragón) during years 2014 and 2015, in pepper for fresh consumption. The design was in random blocks, four replicates and 10 treatments (5 biodegradable plastics, 3 paper films, PE and the unweeded control). Weed density was evaluated at 12, 24, 36 days after transplantation (DAT), degradation was evaluated at 15, 30 and 45 DAT and the total production was collected as many times as necessary. Biodegradable plastics and PE were not a good option for the purple nutsedge control; on the other hand, papers controlled this species effectively because the plants were not able to perforate these materials. The degradation at 45 DAT showed us that in 2014 the buried part of the paper materials suffered a higher degradation than biodegradable plastics. No differences were found in 2014 in yield between materials. In 2015, and because of the early breaks of the materials and environmental conditions, yields were very variable. Thus, paper is a very good option for nutsedge control and any of the biodegradable materials are a viable option to replace

Practical experiences from physical and cultural weed control in maize

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In the Netherlands (silage) maize is the largest arable crop, predominantly grown by dairy farmers and contractors. In general, Dutch dairy farmers mainly focus on optimizing factors directly affecting the cow. They "focus on what happens in the stable", rather than focus on aspects important for sustainable arable cropping systems such as soil quality and crop protection. The reason lies in their belief (and in the past they could improve economics of their farm in that way) that most profit can be made by optimizing factors directly affecting the cows. Nowadays, maize is often grown in monoculture bringing along challenges: increasing pest and weed pressure, pesticide runoff and leaching to the subsoil and surface water. In recent years there is an increased awareness and focus on the importance of sustainable maize production systems. Important drivers for the change in mindset are the increasing legal restrictions on maximum fertilization input and fluctuating income of dairy farmers. The need to produce more in maize production systems with less input is increasing.

Although physical weed control is well applicable in conventional maize growing systems, the Dutch maize production systems rely heavily on herbicide inputs. The main reason is the additional costs of these alternatives when applied in the current systems. In alternative production systems, often based on non-inversion tillage, the dependency on herbicides may be even bigger, creating additional challenges for alternative weed control strategies.

The current research on the application of mechanical weed control in maize cultivation focuses on 1) incorporating mechanical weed control in practical weed control – emphasizing on reduction of herbicide input and possible crop development benefits – and 2) on exploring physical weed control possibilities in non-inversion tillage systems.

The first aspect is addressed by demonstrating negative side effects of (late) applications of high rates of herbicides, in comparison with reduced split applications and combinations of chemical and mechanical weed control. Results show both that herbicide applications impact crop growth directly and cost maize yield, and demonstrate the potential of chemical-mechanical combinations, e.g. harrowing followed by reduced herbicide input.

The second aspect is mainly investigated in a multifactor field experiment that has been running since the spring of 2009. This work is carried out on a marine loam soil (c. 25% clay) in Lelystad (the Netherlands). In the trial mainly five maize production systems are investigated based on different levels of soil cultivation

- Reference cultivation: mouldboard ploughing (c. 25 cm) followed by power harrow for seedbed preparation;
- Non-inversion tillage: deep tine cultivation and rotary hoe for seedbed preparation;
- Ridge tillage: sowing in permanent ridges, built up after sowing and top removal in following spring prior to sowing;
- Strip tillage: rotary harrow cultivation on 15 cm wide strip in existing grassland;
- No tillage: deep tine cultivation and direct seeding.

Several cover crops were used where possible, primarily to address nutrient efficiency questions, but also to contribute to weed control through competition This trial setup already creates a variety of challenges for mechanical weed control, including timing of application, type of machine and machine settings, further widened by some exploratory work included in the systems each year. Results so far both confirm comparable efficacy of mechanical weed control in more conventional growing systems and possibilities, but also more challenges for an adequate mechanical weed control with higher weed densities and crop residues in non-inversion tillage. Apart from technical results – e.g. concerning weed control and crop yield – other aspects are considered, to ultimately reach sustainable solutions: economics of the systems, energy requirements, and soil quality aspects.

The work described will be incorporated in the Horizon 2020 research in IWMPRAISE, starting in 2017.

Intra-row weeds surviving inter-row cultivation in organic spring cereals - do they harm the crop and how can they be suppressed?

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New camera technology capable of detecting crop rows makes it possible to employ selective weed control in cereals. Normally cereals are grown at 12.5 cm row spacing in Northern Europe but even a moderate extension of the row spacing can make enough room for implementing automatically steered inter-row hoeing. Experiences from practice have shown that camera-based steering systems can guide a hoe blade accurately in a 20-25 cm wide inter-row space. The steering systems have also improved work rates by increasing implement width and forward speeds and the technology is gradually being employed on an increasing number of organic farms in Denmark. Growers claim that crop injuries are negligible and weeding effectiveness against problematic weed species has improved compared with weed harrowing. However, the cereal cropping system has not been optimized to the usage of inter-row cultivation. Inter-row weeds are mostly effectively controlled whereas intra-row weeds, i.e. those growing in the crop lines, are only partly controlled by soil coverage if the hoe blade causes some sideward soil movement into the crop rows.

The aim of this study was to investigate the interaction between surviving intra-row weeds and crop growth under the influence of crop species, inter-row spacing and nitrogen rate. Results are reported from three year's field experimentation with spring barley and spring wheat grown according to organic standards. It was aimed to maintain a constant seed rate for five row spacing studied (12.5, 15, 20, 25 and 30 cm), which resulted in a higher crop density in the rows with increasing row spacing. Denser intra-row crop stands also resulted in more crop biomass per crop row meter which lead to more intra-row weed suppression, especially at the high nitrogen rate (100 kg NH_4-N versus 50 kg NH_4-N).

Other cropping factors can also play a significant role in the suppression of intra-row weeds in cropping systems for cereals where inter-row cultivation is applied. Further increasing the cereal seed rate can increase crop density and thus weed suppression, fertilizer placement can benefit the crop more than the weeds and pertinent choice of crop varieties with specific attributes for intra-row weed suppression may also become a useful tactic.

Impact of wetting agents, time of day and periodic energy dosing strategy on the efficacy of hot water for weed control

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To further increase the cost-effectiveness and sustainability of hot water weed control, the further optimisation of hot water efficacy is needed. Therefore, three dose-response experiments were carried out to evaluate the impact of wetting agents (an ethoxylated triglyceride, an esterified rapeseed oil and a liquid linseed oil-based soap), time of day (2, 4, 6, 8, 10 and 12 hours after sunrise) and treatment frequency (1 to 6 treatments in a 12-week period) on the hot water sensitivity of prevalent weed species (*Lolium perenne*, *Festuca rubra, Taraxacum officinale* and *Plantago major*) on public pavements.

Generally, wetting agents did not improve hot water sensitivity. *Taraxacum officinale* with large planophile leaves showed a higher sensitivity than grasses with an erectophile growth habit. *Festuca rubra* was more sensitive than *L. perenne* due to its high leaf dry matter content. The plant species were most sensitive to hot water in the afternoon. This variation in sensitivity during the day was related to the variation in leaf thickness and dry matter content. In general, hot water weed control was highly efficient when conducted 4 times in a 12-week period at an energy dose of 589 kJ m^{-2}.

Does curative control level influence the effectiveness of cultural weed control?

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Ever since the introduction of herbicides, weed management has heavily relied on chemical control. Weed control based on herbicides is usually highly effective, both in terms of percentage weed seedlings killed as in time investment needed per unit area. This high effectiveness creates a situation, where farmers have the luxury to rely on a single method for their weed control and to focus on avoidance of yield reduction in the current growing season. The sustainability of herbicidal control is however at stake, as herbicide resistance and stricter regulations have reduced the number of available compounds. Consequently, farmers depend on a smaller number of compounds and this further increases the likelihood of herbicide resistance to develop, undermining the actual effectiveness and sustainability of weed control.

Alternative curative control measures that combine a high efficacy with a relatively low time investment are scarce. Mechanical weed control is a sound alternative, but often less effective than herbicides and not well adjusted to no-tillage systems. Hand weeding is laborious and thus expensive. The implication is that curative control will have to be supplemented with other measures, like cultural control. Cultural control measures, defined as slight adjustments in general crop management, like the use of weed suppressive cultivars, weed seed catch at harvest and mulching are often directed at lowering the weed population in the long run. Consequently, weed control transfers into weed population management, where the weed problem is envisaged in a much longer time frame. For integrated strategies that consist of curative and cultural control combined, it becomes highly relevant to study how individual measures interact: additive, synergistic or antagonistic.

In this study a weed population model was used to address this question. The model consists of different life cycle stages, with transition rates between these stages that determine the equilibrium density, depicting the potential threat of the weed. Cultural control measures target one or more of these transition rates and the reduction in equilibrium density that follows is used as a proxy for their effectiveness. Sensitivity analysis is used to identify vulnerable stages of the weed. The framework is also used to study the dependency of cultural control measures on the life cycle characteristics of the weed species and to determine how and to what extent different measures interact. Along the same lines, the modelling frame was used to examine the extent to which the level of curative weed control influences the success of cultural control measures. Such insights are instrumental for developing novel integrated weed management strategies that aim to exploit cultural control options to its full potential.

Sowing time as a measure to regulate host pant-parasite interactions in rain-fed rice production systems

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Parasitic weeds are a severe problem in rain-fed rice production ecologies in Sub-Saharan Africa. The main two parasitic weeds causing problems are the well-known *Striga asiatica* and the relatively unknown *Rhamphicarpa fistulosa*. Striga spp. are obligate, hemi-parasites growing in dry rain-fed uplands characterized by low soil fertility, while *R. fistulosa* is a facultative hemi-parasite thriving in poorly water managed rain-fed lowlands. Farmers frequently hypothesize that sowing time can be used as a strategy to minimize parasitic weed infection in rice. At the same time, farmers are afraid of postponing rice planting, as this might result in drought stress during rice grain filling. The use of short duration varieties might overcome such problems. However, little is known about sowing time and rice variety interaction effects on parasitic weed growth and rice grain yield. For that reason a 3-year-study was performed.

To evaluate sowing time effects on root parasitic weeds in rice, field experiments were conducted in both upland (*S. asiatica*) and lowland (*R. fistulosa*) rain-fed rice eco-systems during three cropping seasons (2012-2014) in Kyela district, south-west Tanzania. Five sowing times were evaluated, in which the first sowing time coincided with the start of the rainy season and two weeks intervals were used for the rest. Sowing time was combined with three rice varieties. Next to the late maturing local varieties (Supa India, Mwangulu), shorter duration improved varieties (NERICA-14, NERICA-L20 and IR64) were included.

Results showed that sowing time influenced parasite growth and rice grain yield, but the effect was very different for the two ecologies. In upland, where *S. asiatica* is the prevailing parasitic weed, parasite number and biomass reduced with a delay in sowing time. Late sowing likely resulted in Striga seeds returning to a state of dormancy, not being sensitive to the germination stimulants excreted by the rice host. Effect on rice grain yield was less clear cut. In years with mild Striga infestation, rice grain yield was significantly lower at sowing time 4 and 5, particularly with the traditional varieties. In 2013, a year with a high Striga infestation level, yield was significantly lower at the first sowing time.

In lowland, where *R. fistulosa* is the principal parasitic weed, parasite number didn’t reflect a clear pattern, but there was a very significant increase in parasite biomass with delay in sowing time. In general, with delay in sowing time, the duration of the parasite free period shortened. Early rice planting thus resulted in partial escape of parasite infection. This resulted in significantly higher rice grain yields with early sowing.

In conclusion, rice sowing time can be used as a feasible control strategy to minimize parasite infection. In *S. asiatica*-infested upland rice ecosystems, sowing at two to four weeks after the onset of the rain was found optimal. Improved short-duration varieties can help avoid risks of drought stress associated to late planting, but farmers prefer their local cultivars, due to taste, good grain quality and marketability. In *R. fistulosa*-infested lowland systems the best strategy is early sowing, as in this way parasite infection is delayed, resulting in lower parasite biomass and the highest rice grain yields.

Competitive interaction between weedy rice and rice as a function of seeding rate and cultivar

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Weedy rice (*Oryza sativa*) is a serious problem in many rice areas all over the world and it's causing high yield losses due to competitive ability. It has become more problematic since 5 years in Turkey and severe infestation caused by commercial seed which can contain weed grains. Growing highly competitive wheat cultivars with high–weed suppressing potential and increasing the crop seeding rate may improve weed control in an integrated weed management system.

Experiments were conducted at Marmara and Black Sea region of Turkey between 2015 and 2016 to measure the competitiveness of rice cultivars against weedy rice. Three rice cultivars (Osmancık, Koral and Gonen), four weedy rice densities (0, 5, 10, 20, and 30 plants m^{-2}) and three seeding rate were used. At both locations, four quadrats of 0.25 m^{-2} each were placed at random in each plot 7, 14, 21, 28, 35, 42, and 49 day after emergence (DAE) to estimate rice tillers. Plant height measurements began at 7 DAE and continued biweekly until harvest using 20 plants. Leaf area of 20 plants was measured using a portable leaf area meter. Rice grain yield was determined from the 6 m^{-2} middle areas of the plots at both sites when grain was matured and yields were adjusted to 14% moisture.

Rice grain yield increased with seeding rate, either in the presence or in the absence of weedy rice in both locations. Decreasing the seeding rate from 220 to 180 kg/ha or 160 kg ha^{-1} decreased rice yield in the presence of weedy rice in all cultivars. Koral and Osmancık produced significantly more tillers than the other cultivar irrespective of weedy rice densities and reduced weedy rice tiller production by around 16% at both locations at the highest weed density. The cultivars growing under weed-free condition had larger leaf area than those under weedy treatment in both locations. Rice heights at both sites in all years showed significant differences among the cultivars. Weedy rice density had significant effects on rice heights, but year did not affect rice height. Data pooled over the 2 years and sites show Gonen was 5-10% cm taller at maturity than the other cultivars. Osmancık and Koral were smaller than Gonen but grew faster than Gonen at 36 DAE at both sites, offering a competitive advantage. Results of this study indicate that differences exist in competitive ability among rice cultivars, against weedy rice, underwater-seeding production protocol. Our findings, confirm that both tiller number and rapid early growth are important determinants of potential yields and those characters can be useful selection criteria in anaerobic rice in breeding programs.

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Combining cultural and mechanical weed control in reduced tillage vegetables

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Reduced tillage (RT) vegetable production systems have the potential to improve soils and protect crops from extreme weather events. However, weed management represents a major constraint to adoption. Weed management in RT systems may benefit from integration of cultural and mechanical strategies including banding of fertility sources, and use of various mechanical tools.

"Strip-intercropping" of functionally diverse cover crop mixtures including cereal rye and hairy vetch (RV), is one mechanism by which N may be selectively targeted to the crop root zone to promote crop competitiveness. We hypothesized that by planting hairy vetch, a low C:N legume, in the zone corresponding to future crop establishment, and rye, a high C:N grass, to the zone directly between future crop rows, that N would be preferentially available to the crop at the expense of weeds. In field studies in the North Central United States, we examined the effects of tillage (strip tillage [ST] vs full-width tillage [FWT]) and RV spatial arrangement (strip-intercropping vs full width mixture) on 1) soil inorganic N (IN) and moisture; 2) weed emergence and growth; and 3) sweet corn N uptake and yield. In sweet corn production systems, segregating rye and vetch into strips increased soil N availability in the in-row zone, but did not affect sweet corn yields or N uptake, nor did it have any detectable benefits for weed suppression. In one of two years, ST increased sweet corn yields by suppressing weed emergence and growth. However, in a second year, ST decreased sweet corn yields and resulted in significantly greater weed biomass compared to FWT.

In a separate studies, we evaluated the potential for in-row cultivation tools including finger weeders and torsion weeders to manage weeds in the in-row zone of strip tilled snap beans, while relying on rye cover crop residue to suppress weeds in the between-row zone. In this system, finger weeders were more effective at managing in-row weeds than torsion weeders. However, effective finger-weeding depended on use of row-cleaners to ensure minimal residue in the in-row zone. In the between-row zone, rye residue delayed emergence of weeds, but cultivation with a rolling cultivator (Lilliston) was necessary to avoid weed interference.

"Harrowing interpreter" – a learning tool to facilitate a deeper understanding of post-emergence mechanical weed control

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Studying and understanding post-emergence mechanical weed control in growing crops is a discipline of trade-offs. As a general rule, crop damage and weed control are linked together. The higher the weed control, the higher the crop damage. Mechanical weed control may occasionally stimulate crop growth, but the general picture is that crop damage overshadows crop stimulation. This applies to flex-tines harrows (weed harrows) but also to rotary hoes, inter-row hoes and intra-row cultivators.

Experiments designed to test null hypotheses (ANOVA) contribute little to the understanding of the trade-offs. ANOVA tests differences among specific treatments, whereas regression analysis may give biologically interpretable parameter estimates that facilitate understanding of relationships. Hence, the estimation of regression parameters plays – or should play – a crucial role in mechanical weed control research. Interpreting and understanding regression parameters, however, are difficult tasks for many students, and it is equally challenging for lecturers to teach these competences. It becomes even more difficult, when predictive analytics and simulation modeling are combined. Predictive analytics attempts to make sense of data by fitting statistical models and simulation modeling attempts to mimic reality.

This presentation explains key parameters and models used in post-emergence weed harrowing research as described by Rasmussen *et al*. (2008, 2009), and an Excel spreadsheet called "Harrowing interpreter" used in teaching is presented. The spreadsheet includes procedures for predictive analytics and simulation modeling. Key parameters derived from regression analysis are crop resistance, weed control and crop tolerance. From these parameters, selectivity and crop recovery are estimated. The simulation part of "Harrowing Interpreter" calculates crop yield as response to mechanical weed control influenced by a number of decision variables.

"Harrowing interpreter" indicates that the spreadsheet is manly relevant for post-emergence harrowing but new research shows that parameters, estimation procedures and simulations are equally relevant for in-row cultivation (hoeing) in cereals.

Teaching students at the university by combining field experiments, estimation of regression parameters, predictions and model simulations has solved many former learning challenges, and the "Harrowing interpreter" has become a valuable tool for students' understanding of trade-offs in mechanical weed control.

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Improving selective potential of mechanical weeders through cultivar choice

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By what methods can we improve the selectivity of mechanical weeders? Generally selectivity can be improved through either adjustments to tool or adjustments to crop. For tools that act primarily by uprooting plants, Kurstjens et al (2004) suggest two ways of improving selectivity – either by reducing the variability of uprooting force applied by the tool so that it more precisely exploits difference in plant anchorage forces between crop and weed (increasing "selective ability" of the tool), or through increasing the mean difference between the anchorage forces of the crop and weeds at the time of cultivation (increasing "selective potential").

Previous work has demonstrated intra-specific variation in tolerance to uprooting and burial due to plant growth stage (e.g. Fogelburg & Gustavsson, 1998) and inter-specific variation in tolerance to various forces due to both size and plant traits that are independent of size (e.g. Toukura et al. 2006). However, few studies have explored the potential for improving selective potential through identification and exploitation of crop cultivars with tolerance to physical weed control (PWC) tools.

The primary objective of our research was to explore the possibility for improving selective potential of PWC in vegetable crops through identification of cultivars that are most tolerant to uprooting and burial. We hypothesized that 1) commercially available carrot cultivars would vary in their tolerance to PWC tools, and that 2) this tolerance would be positively correlated with seed size, root:shoot ratio (RSR) or height at the time of weeding.

In field studies, we evaluated the impact of finger weeder, torsion weeder, flex-tine harrow and partial burial on the mortality of six commercial carrot cultivars. We also scanned carrot plants to determine size of root and shoot and their ratio (RSR) at the time of weeding. Carrot cultivars varied in their tolerance to flex-tine harrowing and burial. Tolerance to burial appeared to be positively correlated to shoot size at the time of mechanical weeding (20 days). Cultivar differences in tolerance to finger or torsion weeders were less distinct. Seed size varied considerably across cultivars, and appeared to be correlated with seedling size at the time weeding. However, seedling size was not a good predictor of tolerance to flex-tine harrowing. These preliminary results suggest that cultivar choice can increase tool selectivity, and that understanding more about the relationship between crop morphology and tolerance to PWC methods may provide a useful crop characteristic to consider in selecting a cultivar for production.

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Automated weed/crop differentiation and weed control in vegetable crops

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Intra-row weeds compete with vegetable crops and increase the cost of production because herbicides used in vegetables do not adequately control weeds and normally require hand weeding. However, the pool of laborers available to perform hand weeding is shrinking and increasingly more expensive. Our project objective is to develop and integrate various novel engineering and automation technologies to develop cost-effective weed control systems for intra-row weed control in vegetable crops. This system will reduce the need for both hand labor and high-rate herbicides while increasing productivity and long-term sustainability of vegetable production.

A major problem with weed automation is the differentiation of weeds from the crop. Differentiation, in theory would allow for very precise weed detection and removal while leaving the crop untouched. We seek to differentiate weeds from the crop by placing a distinctive marker on the crop that can be detected by a camera. We are using three approaches to mark the crop: 1. Physical markers that are highly visible, but do not contact the crop plant; 2. Topical markers on the plant; 3. Root absorbed markers that are translocated from the roots to the foliage. Lettuce and tomato are the crops of focus for the project.

Physical markers under evaluation include biodegradable plastic straws that are readily detected, indicating close-proximity to the crop. The advantage to the straws is that they do not contact the crop and could be used in organic fields. The disadvantage is that the straws stunt the crop when placed in seedling trays with the germinating crop, and growers do not like the clutter of additional plastic in the fields even when it is biodegradable.

Topical markers that we have tested are dilute fluorescent paint applied to the crop plants just before or during transplanting. Bright fluorescent paint markers are simple for cameras to detect. Additional advantages are that the paint does not contact harvestable portions of the crop. Disadvantage of topical markers are that the markers are quickly diluted by growth of the crop – especially lettuce, and that they can be washed off by sprinkler irrigation.

Root absorbed markers have been difficult to implement. The ideal material could be applied as a seed treatment that is absorbed by the growing crop plant and then translocated to foliage where it can be rapidly detected during the first 4 to 5 weeks of growth. The product also must be food safe if it is to be used on crops like lettuce and tomato. Products that we have tested thus far do not translocate readily and are hard to detect unless high doses are applied.

The weed control actuator used in the project is an intra-row cultivator under control of the crop detection system. The detection system controls pneumatic cylinders that push cultivator knives in to cultivate intra-row space between crop plants and pulls the knives out to protect the crop.

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Suppressing *Ambrosia artemisiifolia* by undersown crops

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Ambrosia artemisiifolia can be a strong competitor to open row crops like sunflowers, maize, potatoes, pumpkins and legumes and can lead to high yield losses. But it also reacts very sensitively to competition.

Between 2011 and 2016 six field trials were conducted with sunflower, maize and horse bean respectively (2 trials per crop). The treatments were the same for sunflower and maize: two row spacing with 35 and 70 cm widths (8 plants/m² in each case) in combination with or without undersown white clover (*Trifolium repens*). Horse bean was sown in 25 and 50 cm row widths with 40 plants*m-2 in each case and with or without perennial ryegrass (*Lolium perenne*). Seeds of *A. artemisiifolia* were sown along one metre between two rows in the middle of each plot and were thinned out at the four-leaf stage to five plants per metre (one plant every 20 cm). *A. artemisiifolia* was harvested at growth stage was in the range of beginning of budding until beginning of flowering in each year.

At the same time the sunflower, maize and horse bean plants directly neighbouring on the left and right side of the 1 m common ragweed row were harvested too. Fresh matter of sunflower, maize and horse bean and dry matter of common ragweed was determined in order to detect the impact of row spacing and the undersown crop on common ragweed, sunflower, maize and horse bean biomass. The plots were irrigated if necessary.

Significantly lower (*P<0.05) dry matter of *A. artemisiifolia* was found in narrowly spaced sunflower and maize plots with undersown white clover compared to the other treatments. Fresh matter of sunflower and maize therefore was not affected by wide or narrow spacing or by undersown clover.

The horse bean plots showed different results: significantly lower (*P<0.05) dry matter of common ragweed was found in the plots with the undersown crop and in the narrow spacing plots. In the wide spaced plots common ragweed had the highest dry matter yield. The same was determined for the horse bean fresh matter: plots with the undersown crop and the narrow spaced rows affected the fresh matter of horse bean negatively. The results show that there is an impact of competition on dry matter of *A. artemisiifolia* and it can be assumed that seed production would be reduced as well. While sunflower and maize dry matter was not affected by narrow spacing and the undersown crop, horse bean reacted with lower fresh matter yield.

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Crop-weed interactions in short rotation coppice willow

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Biomass produced in short rotation coppice (SRC) willow (*Salix* spp.) is used as a source of renewable energy. SRC willow has an economically productive life-span of 20 to 25 years and is commonly harvested in winter every 3 to 4 years. The average biomass production in well-established commercial SRC willow is estimated to approximately 10 t biomass ha^{-1} yr^{-1} but it decreases significantly under weed pressure. During the establishment phase, willows are susceptible to weeds and consequently both mechanical and chemical weed control are strongly recommended.

To study the effects of weed competition on willow establishment, a randomised block experiment was performed in buckets outdoors in 2013 in Uppsala, Sweden (59°48'N, 17°39'E). In the experiment, two types of willows cuttings [dormant (cold-stored) and non-dormant (freshly harvested)] from three different willow clones (Tora, Jorr, and Olof) were grown with and without a model weed, *Hordeum vulgare* L. Willow cuttings were planted at three occasions during May to June. Five days after willow planting, weeds were sown in half of the buckets. Weeds were also sown in monoculture at each planting occasion to assess weed performance without willow competition. Destructive harvests were performed after 8 weeks. Willow total (shoots + leaves) aboveground dry weight (DW, g $bucket^{-1}$) and mean shoot height (H, cm $bucket^{-1}$) were recorded for willows and weed in all treatments. The ability to compete (AC) and the ability to withstand competition (AWC) were calculated for both willow and weed.

The results showed that willow DW was significantly affected by weed competition, willow cutting type, willow clone, and their interactions ($P < 0.0001$). On average for all planting occasions, weed competition reduced willow DW with 34.97% to 70.30%, and 61.47% to 83.08% for dormant and non-dormant willow cuttings, respectively. Similarly, when competing with weeds, willow H was reduced 16.28% to 35.31%, and 28.25% to 49.33% for dormant and non-dormant willow cuttings, respectively. Neither weed DW nor weed H differed significantly between treatments, but statistically significant correlations were found between total DW of willow and weed ($P = 0.0154$, $R^2 = 0.049$), and willow and weed H ($P < 0.006$, $R^2 = 0.097$). On average, willow AC and AWC was 3.79% and 41.13%, respectively. Weed AC and AWC was 96.21% and 76.82%, respectively.

Under the experimental conditions of this study, weed was good competition-tolerator (AC) (high ability to tolerate suppression from willow) and good competitor (AWC) (high ability to suppress willows). In contrast, willow presented very low competitive ability in comparison with the model weed. Although willow seemed to be a slightly better competition-tolerator (AWC) (low ability to tolerate suppression from weeds) than competitor (AC) (very low ability to suppress weeds), recorded willow AWC still led to large losses in biomass production. Therefore, weed control during the willow establishment phase is crucial and should be performed in order to maximize production of biomass in SRC willow.

Buckwheat root exudation in presence of redroot pigweed

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The growth repressive effect of common buckwheat (*Fagopyrum esculentum*) on redroot pigweed (*Amaranthus retroflexus) w*as studied by separating resource competition from root interactions between the two plant species in a pot trial. In order to verify this result in situ field trials were performed. A strong repression of redroot pigweed growth by buckwheat could be observed independently of shading. However, soil both from the field and phytotron trials in which buckwheat had been growing didn't have an effect on redroot pigweed and lettuce (*Lactuca sativa*) growth. Assuming that allelopathic compounds are present in the soil solution supplementary experiments were conducted. Lettuce root length was measured after exposing seeds to different "buckwheat soil" extracts. Moreover, buckwheat and lettuce developed at the same time next to each other in petri dishes. In none of the experiments an influence on lettuce and redroot pigweed development could be observed. We conclude that there are either no allelopathic molecules in the soil solution (not soluble in water) or that they are rapidly degraded. To look for allelopathic molecules, we decided to grow buckwheat in glass sand in presence or absence of the redroot pigweed. We isolated and analyzed the roots exudates by quadrupole time-of-flight liquid chromatography mass spectrometry (Q-TOF LC MS) in order to know if buckwheat root exudates are different in presence or absence of redroot pigweed. Results are under analysis.

Influence of residue mulching on ecological weed growth and marketable yield in Indian spinach (*Basella alba* L.) in a humid tropical environment

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Basella alba L. cultivation is largely restricted to backyards and home gardens due mainly to potential weed management problems. Successful commercial production of the crop would therefore, largely depend on effective cultural weed management. Straw mulching is the main method of cultural weed control that results in reduced frequency of weeding in vegetable crops in Nigeria, but not adequately exploited.

Results of this study show that Asteraceae (36.8%) followed by Poaceae (21.8%), and annual broadleaves dominated the weed flora. Weed dominance (expressed as relative importance value, RIV) and diversity varied widely with residue mulch and cropping season. Legume (*Calopogonium mucunoides* L.) and grass (*Digitaria horizontalis* Wild.) mulches suppress weed growth considerably ($P< 0.05$). Legume mulch weed control efficiency (WCE) was appreciably acceptable only above 12-15 t ha^{-1}, due to rapid decomposition. Medium rate of grass mulch in the early season (weed control efficiency, WCE= 38.6%), and higher rate of grass mulch in the late season (WCE= 61.5%), suppressed weeds most effectively due to greater soil persistence. Mulch WCE was consistently high in the late season (49.0– 61.5%), but varied widely in the early season (-3.3-38.6%). Residue mulching was considerably more efficient (mean WCE= 19.7%) than non-mulched weed-free treatment in the early season (WCE= 6.4%) than in the late season (55.1 and 60.8%, respectively). *B. alba* growth and yield increased markedly with increased mulch WCE from 6 to 12 t ha^{-1} of grass mulch, and from 15 to 18 t ha^{-1} of legume mulch. The enhanced crop establishment in the lower-quality grass mulch was absent above 12 and 15 t ha^{-1}. Legume mulch at >15 t ha^{-1} encouraged optimum crop performance and yield. Thus, residue mulching exerts variable effect on ecological weed growth in *B.alba*, and mulch WCE depends on mulch type, quality and decomposition, and cropping season. Differential crop growth and yield responses may be due to mulch type, probable differences in soil fertility, crop water and nutrient uptake, and nutrient-use efficiency.

Residue mulching guarantees effective early management of weeds and optimum marketable yield of *B. alba*, and these are better for legume clippings than for grass clippings.

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Reducing in-row weed density in no-tillage systems through a modification of a no-till seeder

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Seed germination is a key process in the dynamics of weed populations and is affected by several factors. In conservation agriculture, keeping a thick and uniform layer of residues on the soil surface reduces weed seed germination, and it is considered a form of cultural weed control. The seeding process of annual crops, like soybean and maize however, normally opens a furrow in the soil, from which weed seeds are stimulated to germinate. For this reason, in no-till systems, weed density in the crop rows is normally higher than in between the crop rows. We developed a tool in format of a snow ski, to be coupled on the coulter-disks of no-tillage seeders, which reduces the size of furrow opening and keeps the mulch in the top of the seeding row at seeding. The technical aim of this tool was to allow to seed in no-tillage fields on which a thick layer of mulch (6 to 10 t ha^{-1} dry mass) is present on the soil surface. However, an interesting additional effect on the weed population was obtained from the reduced soil disturbance and mulching preservation provided by this equipment. To test the magnitude of this effect, five distinct experiments were conducted in no-tillage fields in south Brazil using soybean and maize as indicator crops. In all experiments, the performance (soil exposure and weed density) of a standard and a modified seeder were compared. Using the adapted seeder reduced soil exposure in the crop rows up to 78% if compared to the standard seeder. Density of annual weed species were reduced with 55% (*Bidens* sp.), 37% (*Urochloa plantaginea*), 50% (*Ipomoea* sp.) and 26% (*Raphanus raphanistrum*) in no-tillage fields cultivated with maize. In experiments conducted with soybean, an overall reduction of 56% of within-row weed density was observed. The reduced weed density that followed from a reduced soil exposure resulted in a 17% increase in chemical weed control efficacy in maize. The promotion of a minor soil disturbance combined with a maintained soil cover at seeding provided by the modified seeder proofed to be an effective way to reduce weed establishment in no-tillage systems. It clearly demonstrates that relatively small adjustments to standard devices can already provide important contributions to a more environmentally-friend Integrated Weed Management strategy.

Tillage and cover crop effects on weed management and community changes in organic tomato cropping system

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The adoption of no-till practices in organic vegetable production has been challenged by an ineffective cover crop management and absence of season-long weed control. The objectives of our research were to determine the effects of tillage (no-till vs conventional tillage), winter soil cover (bare soil vs cover crop) and weed control approaches on weed abundance, season-long suppression, diversity and community composition in organic tomato cropping system. The trial, implemented as a split-split plot design, was conducted during 2015-2016 season under Mediterranean conditions (Pisa, Italy). The results showed the success of the combination of roller-crimper and flaming in inhibiting the regrowth of the cover crop (*Trifolium squarrosum* L.) and preparing a dead mulch in no-till plots (NT) suitable for direct transplanting of tomato. However, weeds were able to regrow shortly after transplanting and no decrease in weed abundance, as percent weed cover, by the dead mulch was registered further in the season, although the clover controlled initially 53% of weed abundance. Among the weed species present, the dead mulch enhanced selectively the emergence of *Artemisia vulgaris* L. and *Daucus carota* L. When used as green manure in conventionally tilled plots (CT), the clover had no residual effect on weeds. Compared with CT, the soil cover of weeds in NT was around 40% higher. Likewise, weed biomass at harvest time in NT was much higher than CT and the resulting competition was highly noticeable on tomato plant biomass. Regarding weed diversity, NT increased weed species richness and induced changes in the weed flora composition during the season. It was well demonstrated that no-till practices are challenging in fields with high weed seed bank and perennial weed species. The dead mulch may offer also good growth conditions for some weed species mainly in terms of nutrients availability and humidity. Effective cover crop suppression strategies are possible in organic conservation systems while good stands of high biomass at the right sowing and killing time remain crucial for a longer weed management.

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Using free range pigs to reduce *Cyperus esculentus* infestation in fields in Switzerland: Encountered difficulties and findings from 3 field trials

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Cyperus esculentus is a difficult to control weed. Introduced about 40 years ago, *C. esculentus* is present now in the main vegetable producing and arable farming areas in Switzerland. This weed reproduces mainly vegetatively via tubers in the soil. Dormant tubers in the soil are not controlled with herbicides and thus *C. esculentus* eradication is difficult to achieve in heavily infested fields. Free range pigs (*Sus domesticus*) are well known for their grubbing and digging activity. About 8% of their daily dry matter intake can consist of soil (Fries et al., 1982). For example Wünsch et al. could show that *Helianthus tuberosus* tuber number in the soil could be effectively reduced by grazing pigs (2011). *Cyperus esculentus* tubers are tasty and nutrient rich. Thus, it is likely that free range pigs will actively search for *C. esculentus* tubers in the soil. Various authors reported that different animals such as pigs can reduce infestation levels of *C. esculentus*. (e.g. Schonbeck, 2013 or MacDonald, 2015). The aim of this study was to investigate whether *C. esculentus* infestation can be reduced by keeping free range pigs for several months in Swiss fields.

3 on-farm field trials were carried out at 2 sites. One trial was carried out on soil with high organic matter content in 2013 to 2014. After grazing started, soil samples (10 l) were taken every month (3 times) at the same spots in the treated field area (with pigs) and in the untreated control area (no pigs). 2 trials were carried out on sandy soil in 2013 to 2014 and 2015 to 2016 at the second site. Soil samples were taken before and after the grazing period in the treated and untreated area. To determine the number of viable i.e. ready to germinate tubers, the soil samples from each trial were put in the greenhouse in the spring or summer following the trial and *C. esculentus* plants were counted after 2 to 4 weeks.

In the first trial a significant reduction of about 70 % of viable tubers was found compared to the untreated control one month after grazing. The determined reduction remained almost the same in the samples taken thereafter. The trial was initiated in autumn and it is likely that the pigs were active in the first month and then grubbing activity declined due to the onset of winter. In the second trial, 16 *C. esculentus* plants germinated in the soil samples taken prior to grazing (average over 'no pigs' and 'with pigs'). No treatment effect was found in the soil samples taken after the grazing period. However, only 4 *C. esculentus* plants germinated on average. Possibly due to the high variability no significant time effect (before and after trial) could be determined. In the third trial, the infestation level was high in the soil samples (on average 130) prior to the trial. No treatment effect was found after the trial. However, a significant time effect occurred: Only 71 *C. esculents* plants germinated per soil sample taken at the end of the trial.

The different findings might be due to the different soil types and different weather conditions during the trials. Possibly the approach works better on soils with high organic matter content than on sandy soils. The grazing and grubbing of the pigs could be further enhanced by loosening compacted soil first or scattering other sources of fodder in the field. During the trials difficulties such as high variability in infestation levels, high variation in general and adverse weather conditions were encountered. Further trials should be carried out under well controlled conditions, in addition a potential decrease in the number of viable tubers due to trial duration should be accounted for.

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The detailed reference list can be obtained from the authors.

Using steam to eradicate *Cyperus esculentus* infestations in vegetable fields in Switzerland

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Cyperus esculentus belongs to the worst weeds worldwide (Holm et al., 1991). In Switzerland it was introduced about 40 years ago. Meanwhile it has spread and is now present in the main vegetable producing areas (Keller et al., 2013). *C. esculentus* reproduces mainly vegetatively via tubers in the soil, but it can also produce viable seeds under Swiss conditions (e.g. Keller et al, 2015). Tubers and seeds are easily transported with farm equipment to pristine fields. Single *C. esculentus* plants remain normally unnoticed first and reproduce. In most cases, the infestation is discovered late, when *C. esculentus* patches of various sizes are already present in the field.

Vegetable farms are especially affected by *C. esculentus*, as only few herbicides with some efficacy against this weed are available. Most vegetables are weak competitors and thus *C. esculentus* thrives in these crops. In heavily infested fields vegetable production cannot be continued at all. As a consequence, the eradication of *C. esculentus* patches using steam is considered a valid alternative compared with a yearlong struggle against this weed. Several techniques are available to steam soils. The aim of this study was to test different techniques as provide farmers with hands-on experience.

A hood steaming prototype equipped with long injectors was tested at two sites in 2012. The injectors allowed to discharge the steam 30 cm deep into the soil. The upper soil layer was treated during 15 minutes. The soil temperature reached 80 to 90°C. A sheet steaming system treating a sol layer of 25 cm was tested in 2013 at one site. The steam was discharged under the sheets (80 up to 190 m^2) during 6 to 8 hours. The sheets remained for other 12 hours on the treated area. In 2015 a steaming station was used to eradicate *C. esculentus* patches in an asparagus plantation. In this approach the infested soil was removed from the field, transported to the farm and steamed in the station by transporting the soil through the hot steam with a flat conveyor. The pits were refilled with the treated soil. The efficacy of the different techniques was determined by checking the treated sites regularly after the trials.

Steaming was very effective: No new *C. esculentus* plants emerged neither from the areas treated with the hood steaming prototype nor from the soil treated with the steaming station. For the sheet steaming system the determined efficacy was 95% compared with the control. The efficacy was reduced by tubers germinating from below the treated layer. Possibly, the heat activated deeply buried (up to 0.4m) dormant tubers. Webster (2003) and others (e.g. Samatni et al, 2012) showed already that tubers can be inactivated by heat i.e. by steam, which was confirmed in our study.

With steam all tubers in the treated soil layer can be controlled, in contrast to herbicides which control only germinating tubers and/or young plants. Further, no residues remain in the soil. After the intervention, the treated area and the field should be further monitored. Steaming soil is energy intensive and expensive. Nevertheless, considering its efficacy, the losses and costs caused by *C. esculentus*, it can be a valid approach for fields where the infestation is limited to distinct patches.

Acknowledgement and disclaimer
The trials were carried out in collaboration with Inforama Ins, Fachstelle Pflanzenschutz und Ackerbau SG Salez and Seifert Dämpftechnik. The findings have been already presented in a leaflet (Total et al, 2016) targeted to advise farmers (available in German and in French). The detailed references can be obtained from the authors.

Spring cereal variety mixtures and their relevance for weed suppression in agroecological conditions of Latvia

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This report includes some results from the ERA-NET Core Organic PLUS project "Crop Diversification and Weeds (PRODIVA)".

Good weed suppression ability is required characteristic for crops grown in organic conditions. Some authors report that crop variety mixtures can be more effective in weed suppression than the varieties in pure sowings (Didon and Rodriguez, 2006). Some other studies show that variety mixtures do not suppress weeds better than their pure components (Kaut *et al*., 2008).

To compare the performance of spring cereal variety mixtures with their components in pure stands in agroecological conditions of Latvia, field experiments were established with four spring barley and three spring oat varieties in organic crop rotation in Priekuli. Crop plant height was measured at several crop growing stages. A number of crop plants and a number of crop productive stems were counted once per growing season. Green biomass of weeds was weighted at crop harvesting. Crop grain yield was also measured.

Results of two-year study showed, that green biomass of weeds was statistically significantly affected by crop plant height, but not by number of crop plants or number of crop productive stems. However, nor spring barley, neither spring oat variety mixtures had statistically significantly better ability to suppress weeds than had their pure components. In variety mixtures interaction among plants is related not only to competitiveness with weeds but also among the crop plants that can reduce the ability to suppress weeds (Ločmele *et al*., 2016). The effect depends on the composition of the mixture. Additional studies would be necessary to evaluate root development and allelopathic activity of crop and weed plants.

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Demonstration of an autonomous photo-optical weed mapper

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In the future, the world's agriculture will be strongly influenced by the effects of precision technologies. This economical and environmentally friendly way of farming is based on many geolocated samples (DGPS) required for the optimal, site specific treatments.

The sampling methods of the conventional agriculture many times are not suitable for precision farming, the processing is generally expensive and time consuming.

As an answer to some of the problems, we have developed an autonomous, programmable vehicle with fast data transfer capability. The vehicle is moving on the field towards the preprogrammed locations, stops and is capturing georeferenced, perfect quality images of the canopy. The images are processed by an expert in the office and a prescription map is generated. This tool allows us to significantly increase the number of samples, without walking on the field. At this moment, we consider the expert's image analyzing in the office a safer solution than computer image processing.

The autonomous electric weed mapper can be fitted with other remote sensors, like soil scanner, different samplers and various other tools for providing input data.

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