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PROSPECTS AND LIMITATIONS FOR AGRICULTURAL ENGINEERING IN THE DEVELOPMENT OF SUSTAINABLE WEED CONTROL METHODS – EXAMPLES FROM EUROPEAN RESEARCH

by

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ABSTRACT

This paper gives a brief review of the major achievements in European research on physical weed control methods for agricultural and horticultural crops. Most of the work has emerged from an increasing awareness and concern about pesticide consumption in many Western European countries. Also an increasing interest in organic farming has further pushed the development of more sustainable weed control methods. Generally, the research has been joint projects between engineers and agronomists and the results have so far revealed some prospects as well as limitations for non-chemical methods to become useful solutions, not only for the organic growers but also for the conventional ones. A number of investigations have focussed on rather simple low-tech mechanical weeding principles, such as harrowing, brush weeding, hoeing, torsion weeding, and finger weeding, aiming at describing the weeding mechanisms for a better optimisation of the usage. In some crops, such as transplanted vegetables, potatoes, maize, winter oil seed rape, and partly small grain cereals, mechanical weed control has been quite effective and may become a relevant alternative to chemical weed control. However, current mechanical methods generally work with low selectivity, as they do not distinguish between weed and crop plants when applied into the crop row. Attempts to change the constructions and materials of the weeding tools have not decisively improved the selectivity and more intelligent methods capable of controlling only the weeds are therefore needed. The first step in that direction was the introduction of electronic steering systems for automatic guidance of inter-row hoes. They are based on image analysis of the crop row, and the technology is considered to be a kind of platform for the development of more advanced systems for robotic weeding in the rows of row crops, such as sugar beets, maize, and most vegetables. However, recent studies have shown that such an ambition may be difficult to fulfil because weed plants growing right beside the crop plants are the most harmful ones in terms of suppressing the crop plants. Whether any computer-based system would be able to guide a cutting device with sufficient accuracy and speed to remove those weeds in a practical situation in row crops seems questionable. Hence, other projects have been started with a view to avoid this challenge, trying to look for less complicated methods with more short-termed prospects of being applicable in practice. Steaming the soil prior to crop establishment and in bands corresponding to crop rows appears to have some potential in that context since an almost complete intra-row weed control can be achieved without affecting the crop. However, as with most other thermal methods, high energy consumption is a key-issue that needs to be solved.

INTRODUCTION

Research in techniques for non-chemical weed control in agriculture and horticulture has steadily increased up through the 90'es in many European countries, (notably Sweden, Norway, the Netherlands, Germany, Italy, Austria, UK, Switzerland, and Denmark), mainly as a consequence of an increasing concern about herbicide usage among European populations. Both ground water and surface water have been unacceptably polluted in many cases owing to an intensive pesticide usage, especially in countries like the Netherlands and Denmark. Herbicides are the main reason for those contaminations and moreover they contribute significantly to a general impoverishment of the flora and fauna in the agricultural landscape. Another factor pushing research in alternatives to herbicides is an increasing conversion to organic farming, favourably subsidised by some European governments.

Some of the researches have focussed on the optimisation of rather old methods while others have led to the introduction of new techniques. In this paper, the major results and experiences that have been achieved so far will be presented and analysed according to what can be learned from this work in terms of the perspectives for agricultural engineering of supplying organic cropping with effective and reliable weed control methods and of introducing new methods in conventional cropping that may become true alternatives to herbicides.

MECHANICAL WEED CONTROL

Current mechanical weed control methods are considered low-tech solutions with relatively low purchase and operation costs. Those of them that work the intra-row area of the crop generally operate with low selectivity whether it is cereals grown at narrow row spacing or typical row crops (e.g. maize, sugar beets, and many vegetables) at wider row spacing. Low selectivity means that a high weed control level might be associated with severe crop damages, particularly if large weeds are to be controlled satisfactorily as illustrated in Figure 1.

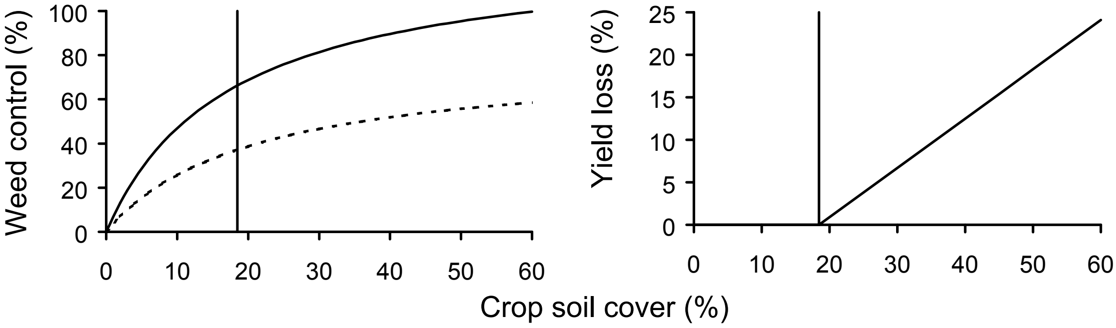

Figure 1. Curves showing the selectivity of brush weeding in direct-sown onions at the two leaves growth stage (12-14 cm tall). The left graph shows the relationship between control of *Sinapis arvensis* at the 0-2 true leaves stage (full-drawn line) and at the 2-4 true leaves stage (dotted line) and crop soil cover of aboveground foliage of onions. The right graph shows the relationship between marketable yield of the same onions and crop soil cover. The vertical line in both graphs show the crop soil cover at which significant crop damages began to appear. Crop soil cover expresses the intensity of brush weeding; high coverage means high intensity. (Adapted from Melander, 1997).

Weed harrowing has been studied in a wide range of crops, particularly cereals and pulse, and most work has been dealing with describing the weeding mechanisms of harrowing rather than improving the weeding ability of the implements (e.g. Rasmussen, 1991; Kurstjens & Kropff, 2001; Kurstjens, 2002). Danish investigations studying the weeding effect of different manufactures of harrows showed that the weeding ability of the harrows was basically not different, although tine configuration and stiffness were different (Rasmussen, 1992). Proper operation of the harrows was much more important to obtain good weed control and the choice of one manufacture in preference to another should be based on other considerations, such as price, user-friendliness, services offered by the company, and robustness. Similar aspects are evident for other mechanical methods, such as torsion weeding, finger weeding, and brush weeding, for intra-row weed control in row crops. However, some types of fingers, tines and brushes may be more appropriate to use than others, depending on the sensitivity of the crop. For example, soft fingers would be easier to operate at small crop growth stages and in a loose soil whereas stiff fingers are more suited for heavy soils and well anchored crop plants.

A number of investigations have focussed on the tactical use of mechanical intra-row methods, and how they can be combined with cultural methods that mainly improve crop competitiveness and crop tolerance to withstand mechanical impact (uprooting and soil covering) from the weeding tools. Some promising weed control strategies in e.g. spring barley, onion, and pulse have been achieved from this work (e.g. Rasmussen & Rasmussen, 1995; Rasmussen & Svenningsen, 1995; Melander, 1998; Melander & Rasmussen, 2001; Rasmussen, 2002). The results have in particular been good in transplants where transplantation itself creates very favourable conditions for weeding with high selectivity; large crop plants established in a newly cultivated soil (Melander, 2000). However, current techniques for transplantation are only profitable in some highly valuable vegetable crops and need to be further developed to become cost effective in other row crops.

Mechanical weed control methods that only work the inter-row space, normally called inter-row hoeing, usually work successfully in most situations, mainly because the crop plants are not directly affected by the weeding tools and moreover can be shielded in different ways (Mattsson et al., 1990). Several new implements have been introduced recently. Although based on known principles they have been improved substantially to solve the inter-row weed problems more effectively. For example the Swedish *Moteska* hoe uses the benefits of combining several weeding principles onto the same implement. One hoeing unit working one inter-row space consists of first, hoe blades configured as a duck's foot; secondly, "L"-shaped blades; thirdly, a roller that evens the soil and crushes the clods; and finally, harrow tines to finish the work. Such a set up has proved to improve the weeding effects under more unfavourable weather conditions and/or when the weeds have become large. Inter-row hoeing is regularly used both in conventional and organic row crops and has in many cases replaced chemical weed control in conventional winter oil seed rape and potatoes.

AUTOMATIC STEERING SYSTEMS

Within the last four years two Danish manufactures, *Frank Poulsen Engineering* (www.fp-engin.dk) and *Eco-Dan* (www.eco-dan.dk), and Silsoe Research Institute in the UK (Tillett et al., 1999) have developed new steering systems for hoes and other implements where one wishes to steer an implement accurately along a crop row. The systems are based on image analyses and have been developed for automatic steering with no need for an extra person to steer the implements, which is sometimes necessary with current steering techniques. The new systems should improve: the working environment for drivers (less concentration); the working capacity by increasing driving speed and width of the implements; the closeness to the crop plants at which the hoe blade can work; and band-spraying techniques. The manufactures are very close to commercialising their products, and they claim that the precision can be lowered to ± 1.5 cm deviation from a centre line at a driving speed of up to 10 km h^{-1}. However, an experimental verification of those claims still remains to be seen for a number of crops and field situations, such as sloping fields, different crop leaf architectures and growth habits, and poor crop stands blurring the row structure.

Besides the obvious benefits of steering inter-row cultivators automatically, such steering systems could also improve nutrient application in growing crops. Investigations have shown that both grain yield and crop competitiveness against weeds were significantly improved when a liquid fertiliser was placed quite precisely along the crop rows of winter cereals (Melander et al., 2001). Similar findings have been found with placement of slurry and mineral fertiliser at the time of sowing of spring-sown cereals and the effects were even stronger than those seen with placement in a growing crop (Rasmussen, 2002; Rasmussen et al., 1996).

ROBOTIC WEEDING

The new steering technology could be the first step in the development of more advanced image analysis systems being able to distinguish crop plants from weed plants. This could be a break through for the development of a robot weeder for row crops. An on going Danish research project is focussing on the possibilities of developing sensors or cameras that might handle such a task (http://www.cs.auc.dk/~api/). Actually, attempts are made to identify individual weed species or at least groups of species with similar morphological characteristics. One of the visions is to develop a machine that can remove the weeds selectively using a cutting device based on either laser technology, water-jet systems or mechanical cutters. The work is at an early stage and the prospects are not fully clarified. Dutch engineers have managed to develop a simple prototype robotic weeder for sugar beets (Bontsema et al., 1998). A rotating flail disc was designed to cut all weed seedlings between the beet plants in the row. The precision of the system had a standard deviation of 2 cm, which sets the limit of how close to the beet plants it is possible to cut weeds without damaging the beet.

However, it is questionable whether robotic weeding will ever become relevant for practice. A PhD-project, finished recently, showed that the closer weed plants were growing to sugar beet plants, the more they lowered beet yield resulting from severe competition (Heisel, 2001; Heisel et al., 2002). Also the time of weed cutting in sugar beets, using just one cut, was studied and indicated that cutting should take place rather late in the season as compared to common weeding time in sugar beets. Earlier cutting would allow for weeds to regrow and later cutting would result in too much weed competition. Since weed plants growing very close to the crop plants have to be removed to preserve crop yield, one would need a weeder being able to work with a very high accuracy and still at a reasonable speed to treat one hectare within a reasonable time. It seems that removing weeds very close to the crop plants would require extremely fast computers to handle the images and simultaneously guide a cutter or another weeding tool, and what will be the costs of such a technology? Robotic weeding might, however, become useful in row crops with a constant and precise distance between each individual plant, such as transplanted cabbage, celery, and lettuce, where there is enough space to operate a cutter without the need for very high accuracy. But still there is a need for another solution in the zone just around each crop plant. Steaming in points or herbicide staining of crop seeds might be possible in that context.

BAND-STEAMING

Steaming the soil prior to crop sowing has the potential of eliminating weed seedling emergence completely provided that a maximum soil temperature of 70-80^{o}C or more can be reached (Figure 2). Thus, steaming might be a perspective technique for intra-row weed control in non-herbicidal row crops of high value, where manual weeding otherwise can be very laborious. An ongoing project, involving both biological and technical aspects of steaming, is focussing on the prospects of using steam only in the intra-row area (Melander et al., 2002). The overall objective is to develop an applicable technique for applying steam in bands corresponding to the intra-row area of a row crop, typically bands of 7-8 cm width and 5-6 cm soil depth. Band-steaming is expected to use much less energy compared with current steaming techniques for

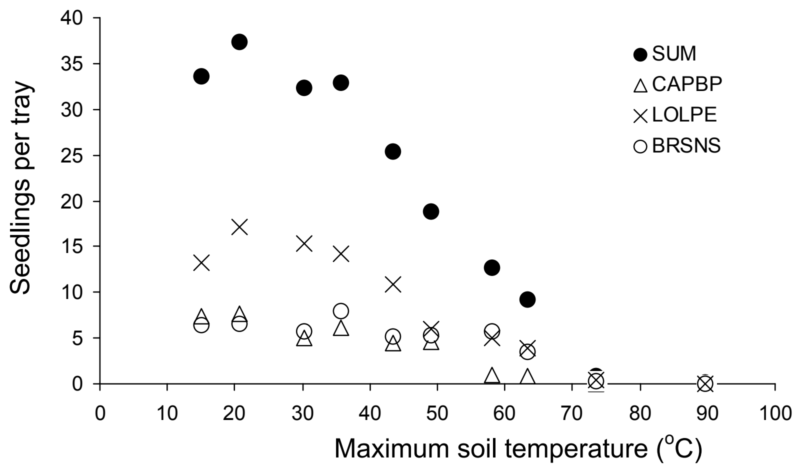

Figure 2. Steaming of soil samples of a sandy loam containing seeds of *Capsella bursa-pastoris* (CAPBP), *Lolium perenne* (LOLPE), and *Brassica napus* (BRSNS). Numbers of emerged seedlings six weeks after steaming are plotted against the maximum soil temperature obtained at different steaming times in the laboratory.

arable usage, where the entire surface is treated down to 10-15 cm soil depth. The band-steaming techniques could be further extended to point steaming to create a weed-free zone around the crop plants as mentioned above. Both steaming and crop sowing could be integrated whereby both steaming and sowing could be done in the same pass, which would solve the problems of retrieving the steamed area and simultaneously one field operation is saved. The first investigations indicate that there should not be a biological barrier to do so, as many crop seeds seem not to be as sensitive to heated soil as weed seeds are. However, more research is needed to clarify the potential of band-steaming for practical implementation

CONCLUSIONS

The following brief conclusions can be drawn from the European work on physical weed control methods for arable crops:

- It seems not possible to radically improve the current techniques for mechanical intra-row weed control as long as both crop and weed plants are affected by the tools. Thus engineers and agronomists will have to introduce new ideas to overcome this problem.
- Techniques for transplanting could be further developed to become profitable for mechanical weed control in a wider range of row crops than seen at present.
- Robotic weeding might be a possibility in the distant future but seems not profitable or even not possible within the next 5-10 years. However, electronics and computer capacity are developing extremely fast and there might be an entirely different situation within the next 5 years or so.
- Fertiliser placement has a potential to improve crop yield and weed control effects but is not fully utilised yet.
- The sustainability of steaming is currently questionable in terms of energy-consumption and sometimes precautions. These also apply to other methods, notably flaming (Ascard, 1995), hot-water (Hansson, 2002), UV-radiation, and electricity at high voltages. More attention should be paid

to lowering these disadvantages. Band-steaming, point-steaming and other approaches aiming at targeting the control to the areas of relevance and nowhere else might be promising.

- Conventional growers do not commonly use physical weed control methods. There is still a strong reliance on herbicide use, although full mechanical weed control seems to become more common in potatoes and winter oil seed rape. Factors such as working capacity, cost effectiveness, weeding effectiveness, reliability, user-friendliness, education, and skill are often barriers for a broader extension of physical weed control methods in conventional cropping. In contrast, most of the methods are widely used in organic cropping.

SELECTED REFERENCES

Ascard J. (1995). Thermal weed control by flaming: biological and technical aspects. PhD thesis, Swedish University of Agricultural Sciences, Alnarp, Sweden.

Bontsema J., van Asselt C.J., Lempens P.W.J., van Straten G. (1998). Intra-row weed control: a mechatronics approach. In: N. Sigrimis and P. Groubos (Eds.), Control Applications and Ergonomics in Agriculture, Proceedings 1st IFAC Workshop, Athens Greece, June 15-17, 93-97.

Hansson D. (2002). Hot Water Weed Control on Hard Surface Areas. PhD thesis, Swedish University of Agricultural Sciences, Alnarp, Sweden.

Heisel T. (2001). Weeds in sugar beet rows. I. Influence of neighbour plant on the beet yield. II. Investigation of a CO_2 laser for in-row weed control. PhD thesis, Danish Institute of Agricultural Sciences, Research Centre Flakkebjerg, Denmark.

Heisel T., Andreasen C. & Christensen S. (2002), Sugar beet yield response to competition from *Lolium perenne* or *Sinapis arvensis* growing at three different distances from the beet and removed at various times during early growth. Weed Research (in press).

Kurstjens D.A.G. (2002). Mechanisms of selective mechanical weed control by harrowing. PhD thesis, Wageningen University, the Netherlands.

Kurstjens D.A.G. & Kropff M.J. (2001). The impact of uprooting and soil-covering on the effectiveness of weed harrowing. Weed Research 41, 211-228.

Mattsson B., Nylander C. & Ascard J. (1990). Comparison of seven inter-row weeders. Veröffentlichungen der Bundesanstalt für Agrarbiologie, Linz/Donau, 20, 91-107.

Melander B., Rasmussen K., Rasmussen I.A. & Jørgensen M.H. (2001). Radrensning med og uden ukrudtsharvning i vintersaed om foraaret i samspil med forskellige dyrkningsfaktorer. (Row hoeing followed by weed harrowing in winter cereals in the spring under the influence of different cropping factors. With English summary). In: Proceedings 18th Danish Plant Protection Conference I, Nyborg, Denmark, 211-225.

Melander B. (1997). Optimization of the adjustment of a vertical axis rotary brush weeder for intra-row weed control in row crops. Journal of Agricultural Engineering Research 68, 39-50.

Melander B. (1998). Interactions between soil cultivation in darkness, flaming, and brush weeding when used for in-row weed control in vegetables. Biological Agriculture and Horticulture 16, 1-14.

Melander B. (2000). Mechanical weed control in transplanted sugar beet. Proceedings of the 4th EWRS Workshop on Physical Weed Control. Elspeet, NL, 20-22 March, p. 24. (http://www.ewrs.org/physical–control/meeting.htm).

Melander B. & Rasmussen G. (2001). Effects of cultural methods and physical weed control on intrarow weed numbers, manual weeding and marketable yield in direct-sown leek and bulb onion. Weed Research 41, 491-508.

Melander B., Heisel T. & Joergensen M.H. (2002). Band-steaming for intra-row weed control. 5th EWRS Workshop on Physical Weed Control. Pisa, Italy, 11-13 March, 4 pp. (available on CD, for ordering contact: Danish Institute of Agricultural Sciences, Research Centre Flakkebjerg, DK-4200 Slagelse, Denmark).

Rasmussen J. (1991). A model for prediction of yield response in weed harrowing. Weed Research 31, 401-408.

Rasmussen J. (1992). Testing harrows for mechanical control of weeds in agricultural crops. Weed Research, 32, 267-274.

Rasmussen K. (2002). Influence of liquid manure application method on weed control in spring cereals. Weed Research (in press).

Rasmussen J. & Rasmussen K. (1995). A strategy for mechanical weed control in spring barley. 9th EWRS Symposium. ”Challenges for Weed Science in a Changing Europe”. Budapest 1995, 557-564.

Rasmussen J. & Svenningsen T. (1995). Selective Weed Harrowing in Cereals. Biological Agriculture and Horticulture 12, 29-46.

Rasmussen K., Rasmussen J. & Petersen J. (1996). Effects of fertiliser placement on weeds in weed

harrowed spring barley. Acta Agriculturae Scandinavica. Section B, Plant and Soil Science 3, 192-196.
Tillett N.D., Hague T., Blair A.M., Jones P.A., Ingle R. & Orson J.H. (1999). Precision inter-row weeding in winter wheat. In: *Proceedings The 1999 Brighton Conference – Weeds*, Brighton, England 3, 975-980.