Digital images for assessing soil cover of crop plants

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Abstract

The main drawback by using crop soil cover in weed harrowing research is that it is assessed by visual scores, which are biased and context dependent. This problem may be solved by using digital image analysis. In this paper a new image capture standard and digital image analysis procedure was used to illustrate three key issues in relation to weed harrowing; selectivity, resistance and recovery. All issues require reliable assessments of crop soil cover. Crop soil cover was deduced from assessments of leaf cover, which is defined as the proportion of pixels in digital images determined to be green.

Objective assessments of leaf cover and crop soil cover showed that the selectivity of weed harrowing in winter wheat and spring barley was unaffected by timing within a two weeks interval. Crop recovery, defined as the ability of the crop to recover from soil cover was determined in winter wheat and highly influenced by timing of weed harrowing. Increasing intensities of harrowing in growth stage (BBCH) 22 in winter wheat increased crop yields whereas crop yields declined by increasing intensities in growth stage 23 due to differences in the crop recovery capacity. Resistance defined as the capacity of the crop to resist soil cover was tested in barley, field pea and mixtures of barley and field pea. No differences were found between the crops. Future aims in mechanical weed control research are discussed in the context of the availability of unbiased crop soil cover data.

Introduction

A comprehensive paper on research methodologies was prepared in connection with the 2004 workshop in the EWRS working group "Physical and Cultural Weed Control" (Vanhala *et al*., 2004). The importance of crop soil cover as a measure of the immediate crop response to weed harrowing was emphasised. Crop soil cover is the percentage of the above ground crop parts that are buried in soil due to harrowing. It is generally assessed by visual scores, which are context dependent and biased. Therefore, it was stated that biased assessment of crop soil cover had to be overcome before crop soil cover generally would be adopted in scientific work.

Inspired by this, we investigated whether digital image analysis is a feasible method to estimate crop soil cover in the early growth stages of crops under field conditions. Two main questions were examined: (1) how to capture suitable digital images under field conditions with a standard high-resolution digital camera and (2) how to analyse the images with an automated digital image analysis procedure? The importance of light conditions, camera angles and size of recorded areas were investigated in order to establish a standard for the image capture procedure, and an automated image analysis procedure based on the excess green colour index (Meyer *et al*., 1998) was developed. In a submitted paper (Rasmussen *et al*., 2007), we described our work and concluded that our automated digital image analysis procedure provides consistent and unbiased estimates of leaf cover. Leaf cover is the proportion of pixels in digital images determined to be green. A leaf cover index of 0.3 specifies that 30% of the pixels were determined to be green. Crop soil cover may be deduced from leaf cover estimates.

The main components of the image capture standard and the automated image analysis procedure are not outlined in this paper. Based on Rasmussen *et al*. (2007), we consider that objective assessments of crop soil cover now is practicable.

Three key concepts in relation to physical weed control with low selectivity will be exemplified in this paper in order to show the perspectives of integrating objective assessments of leaf cover and crop soil cover into future research. This may act as the starting point in a discussion about future research priorities within weed harrowing and other weed control methods characterised by low selectivity. The emphasised concepts in this paper are selectivity, crop resistance and crop recovery.

Data all originate from experiments with weed harrowing carried out on a sandy loam near Copenhagen. A harrow manufactured by Einböck was used. All experiments except one were carried out on an organic experimental farm (Bakkegården). Details about the experiments presented in Figures 1, 4 and 5 are given in Gundersen *et al*. (2006) and Rasmussen and Nørremark (2006). Figure 2 is from a paper in preparation and Figure 3 is based on unpublished data.

Selectivity

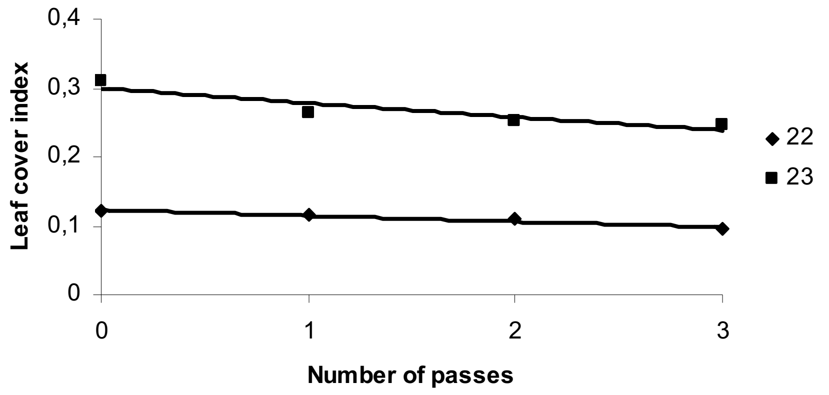
Selectivity is defined as the relation between weed control and crop soil cover, when weed control and crop soil cover both are assessed immediately after treatment (Jensen *et al*., 2004). High degrees of weed control associated with low degrees of crop soil cover reflect high selectivity. A number of factors may influence the selectivity but there is little documentation of the importance of factors like the weeding equipment, row distance, direction of weeding (along or across rows), general growth conditions and timing.

Figure 1 shows an example of how timing of weed harrowing in winter wheat may influence the selectivity. The selectivity curve (Figure 1c) was estimated on the basis of parameters from curves that describe how leaf cover (Fig 1a) and weed density (Figure 1b) were influenced by an increasing number of passes with a weed harrow. It appears from Figure 1a that the general level of leaf cover increases from growth stage (BBCH) 22 to 23 by a factor 3. The crop reached growth stage 22 in mid April and growth stage 23 two weeks later. The statistical analysis showed that an exponential decay function (Gundersen *et al*., 2006) gave a good description of the relationship between leaf cover and number of passes and that each pass reduced leaf cover by 7% in both growth stages. Statistical analysis also showed that each pass reduced the weed density by 29% independently of growth stage. As the relative reduction of leaf cover and weed density was unaffected by growth stage, the selectivity was unaffected by growth stages as well (Fig. 1c).

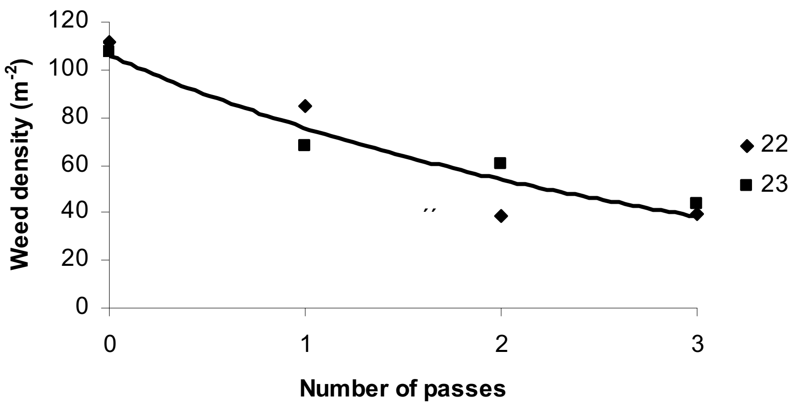
Also in spring barley, which was harrowed with a two weeks interval in growth stage (BBCH) 13 and 21, selectivity was unaffected by timing (Figure 2).

Selectivity reflects the immediate crop-weed responses, but not the long-term effects. Translation of the immediate crop-weed responses into crop yield responses require information about the competitive ability of the weed population and crop tolerance.

(a)



(b)



(c)

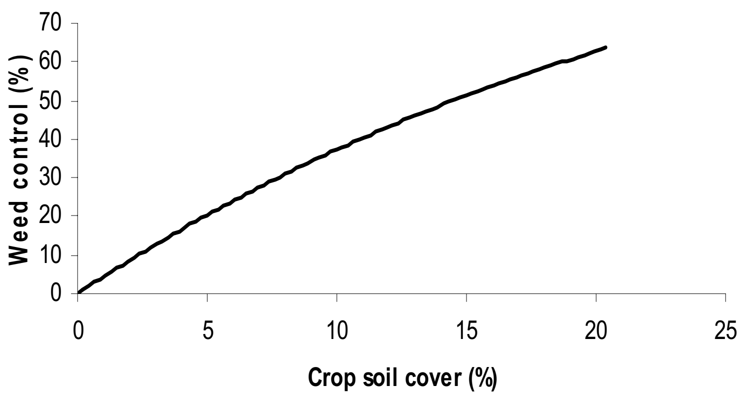


Figure 1. The impacts of weed harrowing in two different growth stages (BBCH) on leaf cover (a), weed density (b) and selectivity (c) in winter wheat. The selectivity curve (c) was estimated on the basis of curve slope parameters from (a) and (b) and it was similar for both growth stages. The experiment is described in detail in Rasmussen & Nørremark (2006).

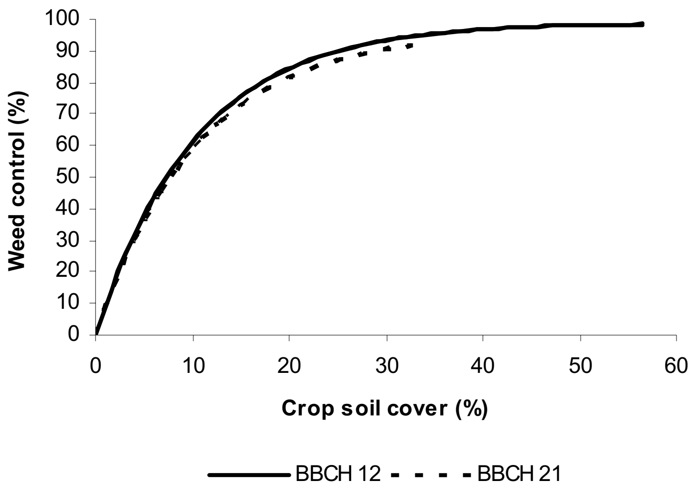


Figure 2. Relationships between weed control and crop soil cover due to weed harrowing in two growth stages in spring barley. The estimated selectivity curves are based on assessments of leaf cover and weed density (data not shown). There is no statistical evidence of different curves, which means that the selectivity was unaffected by growth stage.

Resistance

Gundersen *et al*. (2006) defined crop tolerance as the combined capacity of the crop to *resist* crop soil cover and to *recover* from it. Figure 3 shows an example of the resistance of different crops to post-emergence weed harrowing. Barley, field pea and an intercrop consisting of a mixture of barley and pea was harrowed with the same intensity at the same day when barley was in growth stage (BBCH) 13. In a series of experiments, both crops and the mixture showed the same resistance, because the reduction of leaf cover was unaffected by the crop. In all crops, weed harrowing reduced leaf cover by 6%, which corresponds to 6% crop soil cover.

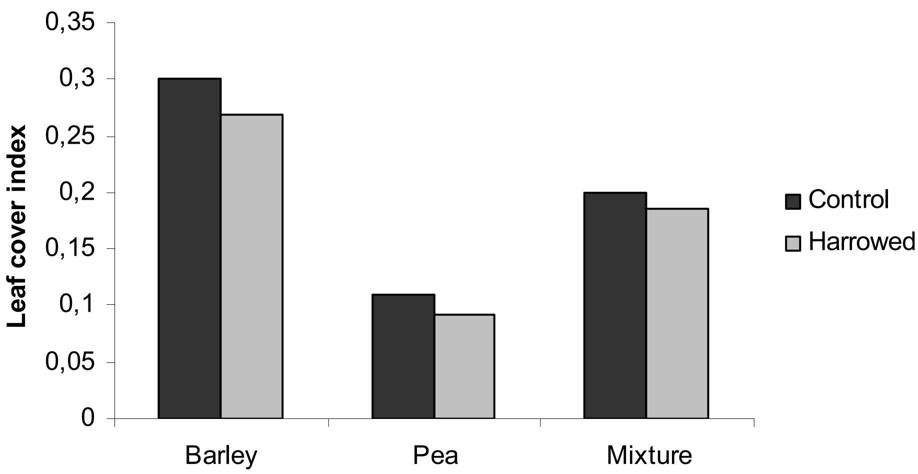


Figure 3. Resistance to post-emergence weed harrowing in spring barley, field peas and a mixture of barley and field peas expressed as the reduction of leaf cover due to post-emergence weed harrowing. The intensity of harrowing was the same in all crops and there was no interaction between harrowing and crop in terms of leaf cover (log transformed data) (P=0.59).

In order to be able to evaluate whether different crops hold different capacities in terms of resistance, it is required that they are subjected to the same intensity (or intensities) of harrowing. In consequence, it is not possible to quantify the importance of growth stage in terms of resistance as it appears in Figure 1a unless there is a guaranty that the crop was subjected to the same intensity of harrowing in both growth stages.

Recovery

Recovery reflects the ability of the crop to recover from crop soil cover. Gundersen *et al.* (2006) showed that different species of spring cereals hold different recovery capacities (Figure 4). In weed free environments, barley had the poorest recovery capacity whereas triticale had the highest.

Little is known about the recovery of crops because crop soil cover has not been integrated as a common response parameter in physical weed control research. Jensen *et al.* (2004) realized that it is very difficult to make accurate estimations of the recovery capacity of different crops based on visual assessments of crop soil cover.

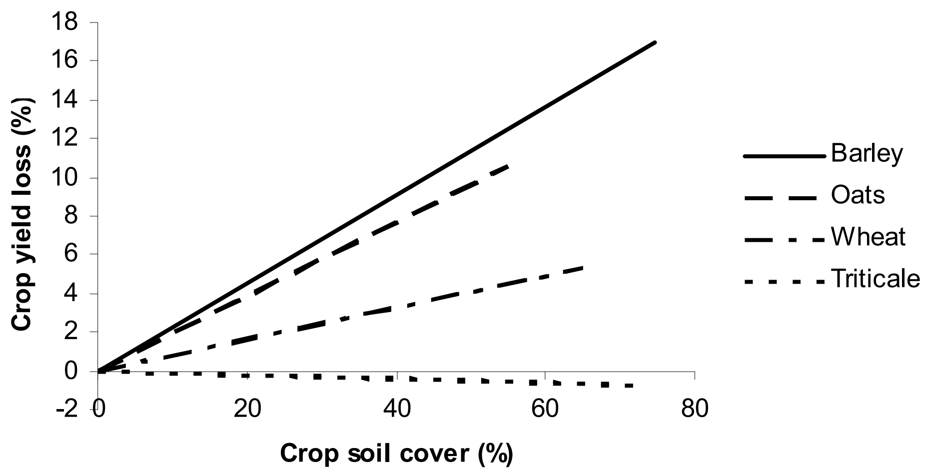


Figure 4. Estimated recovery curves in four species of spring cereals expressed as crop yield loss relative to crop soil cover (Gundersen *et al.*, 2006).

The importance of reliable information about crop recovery is illustrated in Figure 5. The figure shows that the crop yield response to an increasing number of passes of a weed harrow was highly influenced by growth stages. Data are from the same experiments as presented in Figure 1. From Figure 5 it is evident that crop yield in winter wheat increases by an increasing number of passes in growth stage 22, whereas it decreases in growth stage 23. Increasing crop yields may be a consequence of reduced competition from weeds (Figure 1b) and an adequate crop recovery capacity. Decreasing crop yields may be a consequence of a poor recovery capacity that dominates the reduction in weed competition. This can be deduced from Figure 1 where the impacts on the crop in both growth stages were similar in terms of crop soil cover (Figure 1a) and weed control (Figure 1b). Possible growth stimulations due to weed harrowing were ignored from the above reasoning.

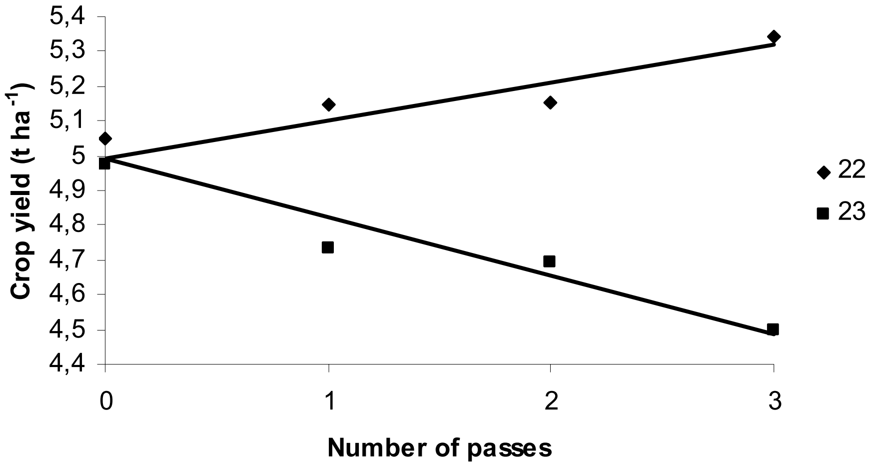


Figure 5. Crop yield response to weed harrowing in growth stage (BBCH) 22 and 23 in winter wheat. Data are from the same experiments as presented in Figure 1. The experiment is described in detail in Rasmussen & Nørremark (2006).

Discussion

If future research shall contribute to the improvement of the knowledge base of weed harrowing, selectivity, crop resistance and crop recovery should not be neglected. For example, how should one be able to predict the best timing of a treatment without knowing how the selectivity and the crop recovery capacity are influenced by timing? In the above examples there was no evidence that the selectivity is sensitive to timing within a time span of two weeks (Figures 1c and 2) but the crop recovery capacity was highly affected in winter wheat (Figure 5). Therefore, early treatments gave significant better results in terms of crop yield than later treatments. It is, however, questionable whether these finding are general and whether there exists a distinct optimum in terms of a crop recovery parameter in terms of timing. However, the results indicate that the crop recovery parameter plays an essential role that should be subjected to analysis in future research.

Objective assessments of crop soil cover make it possible to obtain the required knowledge. It also may change the way of presenting future research challenges associated with weed control methods with low selectivity like weed harrowing. Instead of carrying out classical field experiments where data on weed control as well as crop yield are acquired in the same experiments, it should be considered whether if would be advantageous to break down the research questions into sub-items related to selectivity, resistance or recovery. The two first mentioned items require experiments that can be terminated in the early growing season and thereby release resources to more or bigger experiments.

It is, however, important that the research in sub-items related to physical weed control are connected in modelling frameworks that secure that the practical aspects and perspective are not lost in reductionism.

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