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DIGITAL IMAGE ANALYSIS OFFERS NEW POSSIBILITIES IN WEED HARROWING RESEARCH

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Abstract

Two field experiments were conducted in winter wheat to determine the optimal intensity and timing of weed harrowing. Each experiment was designed to create a series of intensities by increasing the number of passes at varying growth stages. Visual assessments and digital image processing were used to assess crop soil cover associated with weed harrowing. The study showed that winter wheat responded differently to weed harrowing at different growth stages. In autumn, the crop was severely damaged due to high degrees of crop soil cover and poor recovery resulting in crop yield losses in the range of 7 % to 22 %. In early spring, the crop showed some variability in the ability to recover from soil cover. The best results in spring were obtained at growth stage 22 (BBCH). Increasing number of passes resulted in increasing crop yields in the range of 2 % to 5 % and increasing degrees of weed control in the range of 22 % to 62 %. The role of digital image analysis in future weed harrowing research is discussed.

Key words: winter wheat, winter rye, mechanical weed control, crop resistance, crop recovery, tolerance.

Introduction

Post-emergence weed harrowing is commonly used in organic farming to control annual weeds in cereals. It is ineffective against perennial weeds and limited by low selectivity between crop and weeds. High degrees of weed control are generally associated with crop damages /Kurstjens, Kropff, 2001; Melander et al., 2005/. The crop suffers from soil covering and uprooting associated with harrowing /Kurstjens, Kropff, 2001/, both may reduce crop yield in the absence of weeds /Rasmussen, 1991; Gundersen et al., 2006/. In cereals and other strongly anchored crops, soil covering as the primary cause of crop damage is taken as given /Jensen et al., 2004/.

Rasmussen (2004) found that weed harrowing in winter wheat reduced yield when the weed pressure was low, whereas yield was increased when the weed pressure was high. At intermediate weed levels there was no crop yield response, indicating that the crop yield response is the result of positive impacts from reduced weed competition and negative impacts from crop damages associated with harrowing. An important focus in weed harrowing research is to improve knowledge about these opposite impacts /Jensen et al., 2004/.

Kurstjens & Kropff (2001) developed a general conceptual model, which links the basic mechanisms involved in weed harrowing. This model is a sophistication of the model proposed by Rasmussen (1991), which balances the impacts of weed competition and crop damage. A central element in Rasmussen's model is "crop soil cover" defined as the percentage of the crop canopy that has been buried in soil due to weed harrowing.

Until recently, crop soil cover has been assessed by visual scores. This measure, however, has often been questioned, because visual assessment is influenced by the individuals who perform them /Rasmussen, 1996/. Therefore, the necessity of an unbiased assessment method has been emphasised in a recent paper on guidelines for physical weed control research /Vanhala et al., 2004/.

As one option to develop an unbiased method of assessing crop soil cover, we have developed and tested an automated digital image analysis procedure that determines the green cover of crops. Green cover is defined as the proportion of pixels in digital images determined to be green. The fact that the image processing procedure does not discriminate crop and weeds is considered to be unimportant in the perspective of early post-emergence weed harrowing, because weeds are assumed to make up only a few percent of the green cover.

The aims of this study are: 1) to determine whether winter rye and winter wheat responds differently to weed harrowing, when they are grown in mixed stands, 2) to evaluate the optimal timing and intensity of weed harrowing in winter wheat, and 3) to show how crop soil cover estimated on the basis of digital images may help to interpret crop yield responses to weed harrowing.

Materials and methods

Field experiments were conducted on a sandy loam at Bakkegården, which is an organic experimental farm owned by The Royal Veterinary and Agricultural University, Denmark. Two identical experiments were carried out in two different cropping systems at Bakkegården. One system had slightly higher soil fertility than the other due different manure strategies.

Ten percent of winter rye (*Secale cereale* cv. 'Caroass') was mixed into the seeds of winter wheat (*Triticum aestivum* L. cv. 'Complet') at sowing in October 2003 to guarantee that the harvested crop could be distinguished from non-organic winter wheat, which was grown on other farms owned by The Royal Veterinary and Agricultural University. Seed rate was adjusted in order to achieve 400 crop plants m^{-2}.
Weed harrowing was done separately at three growth stages (BBCH), 12, 22 and 23 and in a combination of all growth stages (12+22+23). Harrowing was done on 9 December 2003, 14 April 2004 and 30 April 2004. At each growth stage, a progressive series of harrowing intensities was created by increasing the number of passes from 0 to 3 on the same day. Plots that were harrowed at all growth stages were passed 0, 3, 6, or 9 times in total.

In each cropping system there were 16 treatments (4 harrowing intensities x 4 growth stages) arranged as a split-plot design with four replicate blocks. Growth stage was assigned to main plots, with the four intensities of harrowing applied as a sub-plot treatment. Growth stage was on main plots because this saved time when plots were harrowed. Furthermore, the main interest was the interaction between harrowing and growth stage and not the main effect of growth stage. Each sub-plot was 14 m long and 3 m wide of which 10 by 1.5 m was harvested.

The planned targets of the 4 graded levels of harrowing in each of the three specific growth stages were 0 (control), 30, 60 and 90 % crop soil cover in order to cover the whole range of intensities from gentle to aggressive. The aggressiveness of harrowing was adjusted on the basis of visual assessments of the whole plots.

Weed harrowing was done with a 3 m wide weed harrow manufactured by Einböck (Einböck GmbH & CoKG, A-4751 Dorf an der Pram, Austria). At growth stage 12, the angle of tines was adjusted to obtain the least angle between soil and tine /Vanhala et al., 2004/ giving a very gentle treatment. Driving speed was 3 km h^{-1}. At growth stage 22 and 23, the angle of tines was adjusted to the highest possible angle between soil and tine /Vanhala et al., 2004/ giving the most aggressive treatment possible. Driving speed was 8 km h^{-1}. Higher driving speeds were not experienced to give higher degrees of crop soil cover.

In autumn 2003 (growth stage 12), harrowing was done after a rainy period when the soil was just dry enough to be harrowed. In spring 2004, soil and weather were dry.

Weeds were counted in four randomly chosen sub-plots (4 x 0.25 m^2) within each plot in mid May to assess the impact of weed harrowing on weed density. The dominant weed species was Scentless Chamomile (*Tripleurospermum inodorum* (L.) Schultz Bip.), which developed into a weed problem causing crop yield losses. This species produced more than 80 % of the total weed biomass. Shepherd's-purse (*Capsella bursa-pastoris* L.) was also frequent but due to low plant weights, this species was not considered to have any major impact on the crop.

Two weeks before combine harvest, spike density of rye and wheat was assessed to investigate whether the competitive relationship between rye and wheat was influenced by harrowing. In each plot, spikes from 3 random one meter row segments were counted.

Crop soil cover was assessed by two methods, visual assessments and digital image analysis. Visual assessments were carried out immediately after each treatment on a whole plot basis without a standard. Digital images were recorded with an ordinary digital camera immediately after each treatment and two days after the final treatment at growth stage 23. All images, 2288 pixels horizontally by 1712 pixels vertically with 24-bit depth, were taken using an ordinary red, green, blue (RGB) digital camera, Olympus C750UZ (Olympus Optical Co., Ltd.) with automatic white balancing, shutter speed and aperture value. The image plane was parallel to soil surface and each image covered 0.32 m^2. The camera was mounted on a tripod to ensure uniform distance between soil surface and camera. Four pictures were taken in each plot immediately after treatments and on 2 May 2004 two days after the final treatments had been carried out. There were no pictures from autumn 2003.

The automated digital image analysis procedure for estimation of green cover will be described in an upcoming paper in Weed Research.

Analysis of variance and linear regression analyses were carried out by using the PROC GLM of the SAS software programme (SAS version 8, SAS Institute, Cary, USA). Growing system was included as a factor in the models and block effects were nested within growing system. As a consequence of the split-plot design, main-plot effects (timing) were tested against the mean square (MS) of the interaction between main plot and block, while subplot effects were tested against MS error. Weed density was $\log_e$ transformed prior to analysis in order to satisfy the assumption of homogeneity of variance.

Regression analysis was used to describe how green cover, weed density and crop yield was influenced by an increasing number of passes. Regression models were tested against analysis of variance models to test the lack-of-fit. In order to omit non-significant factor or factor combination effects on parameters, successive approximate F-tests were made to reduce the complexity in models.

Crop soil cover was calculated from the green cover estimations by dividing the difference between control plots and harrowed plots within each block replication by the green cover in the control plots.

Results

All results are presented as averages of the two experiments because there were no three-way interactions between harrowing, timing and growing systems ($P > 0.05$).

The proportion between rye and wheat spikes was unaffected by harrowing. Rye contributed with 15 % of the total number of spikes independent of harrowing intensity and timing (Fig. 1). This indicates that weed harrowing did not change the crop species composition. Hence, the crop mixture is assumed to respond as a winter wheat crop because winter wheat dominated the mixture.

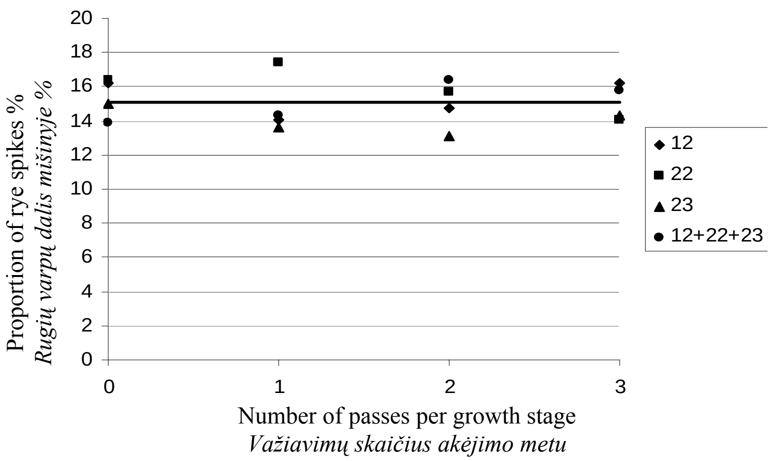


Figure 1. The effects of increasing intensities of weed harrowing at different growth stages on the proportion of rye spikes in relation to the total number of spikes in the wheat-rye mixture

1 paveikslas. *Piktžolių akėjimo skirtingais augimo tarpsniais intensyvumo didinimo įtaka rugių varpų kiekiui bendrame kviečių ir rugių mišinio varpų skaičiuje*

Symbols denote growth stage. The horizontal line indicates that increasing intensity of harrowing had no influence on spike distribution due to the lack of a slope.

In opposite to the relative proportion between rye and wheat spikes, there was found a linear relationship between total spike density and number of passes (data not shown). This relationship was highly influenced by timing. Three passes at growth stage 12 reduced the density of spikes by 21 %, at growth stages 22 and 23 the density was reduced by 7 % and when harrowing was performed at all growth stages, the density was reduced by 35%.

High degrees of crop soil cover were achieved in autumn 2003 but not in spring 2004 (Fig. 2). In spring, the crust of the soil was too compacted to achieve the target range of crop soil cover. Based on visual assessments, about 20 % crop soil cover was achieved after 3 successive passes at growth stage 22 (14 April 2004) and about 10% crop soil cover was achieved at growth stage 23 (30 April 2004) (Fig. 2). Based on digital image analyses, the impacts on the crop were slightly higher (Fig. 2).

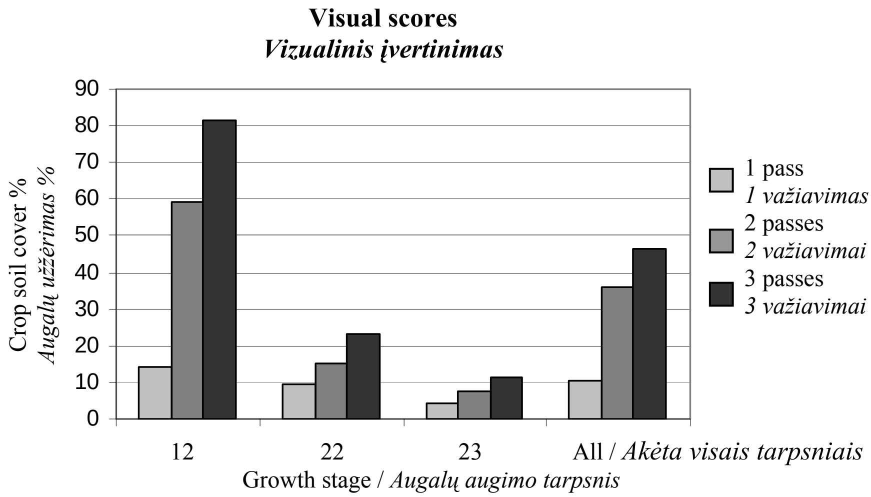
The visual assessments were linear related to digital image assessments but the conversion factor between visual and digital image assessments was influenced by growth stage and the level of crop soil cover. The rest of the presentation will be based on the digital image assessments, because digital image assessments are objective and reproducible.

In Fig. 3, digital image assessments of green cover have been calculated to express the percentage loss of green cover two days after the treatments at growth stage 23.

Regression analysis showed (Fig. 4 A) that weed harrowing in general had negative impacts on the crop in terms of green cover. Harrowing in autumn (growth stage 12) was highly destructive to the crop, whereas harrowing in spring only had small effects. When harrowing was carried out at all growth stages, the crop was badly damaged in terms of loss of green cover.

Fig. 4 B shows that weed harrowing in the autumn stimulated weeds. The weed density as well as the weed biomass (data not shown) was increased by harrowing in autumn. In spring, the weed density was unaffected by timing and weed harrowing at multiple growth stages did not improve weed control.

Fig. 4 C shows that the crop yield was clearly affected by the timing. Only harrowing in the early spring (growth stage 22) increased crop yield. Three passes with the harrow increased yield by 5 % compared to non-harrowed. Three passes later in spring at growth stage 23, however, reduced crop yield by 11 %. In autumn, 22 % of the crop yield was lost after three passes. In the combined strategy, crop yield losses were even higher.



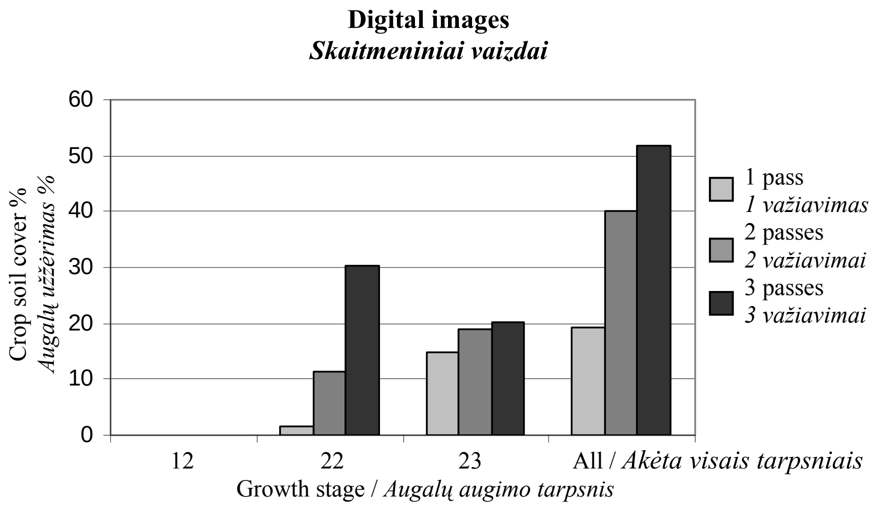
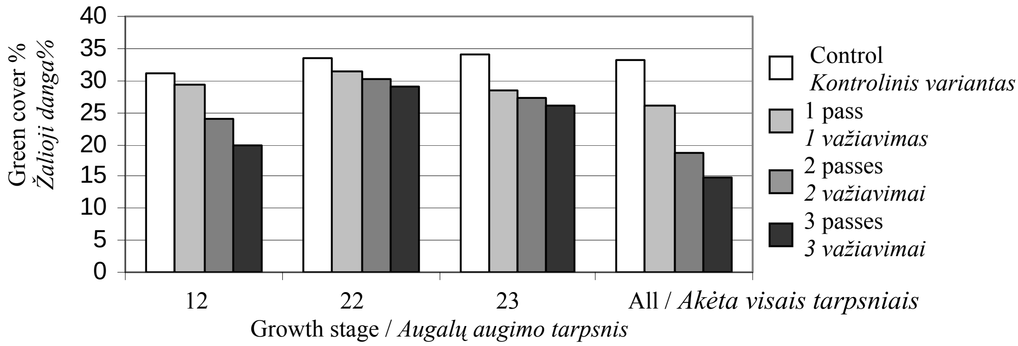


Figure 2. Crop soil cover assessed on the basis of visual scores and digital image analysis of pictures taken immediately after weed harrowing at different growth stages. At growth 12 there was no assessment from digital images. In the combined treatment (All), crop soil cover was assessed after weed harrowing at growth stage 23

2 paveikslas. *Augalų užžėrimas įvertintas vizualiai balais ir skaitmeninio vaizdo nuotraukų, darytų iš karto po akėjimo įvairiais žieminių kviečių augimo tarpsniais, analizė. 12 augimo tarpsniu skaitmeniniai vaizdai nebuvo vertinami. Kombinuotame variante (akėta visais tarpsniais), augalų užžėrimas buvo įvertintas po akėjimo 23 žieminių kviečių augimo tarpsniu*

A



B

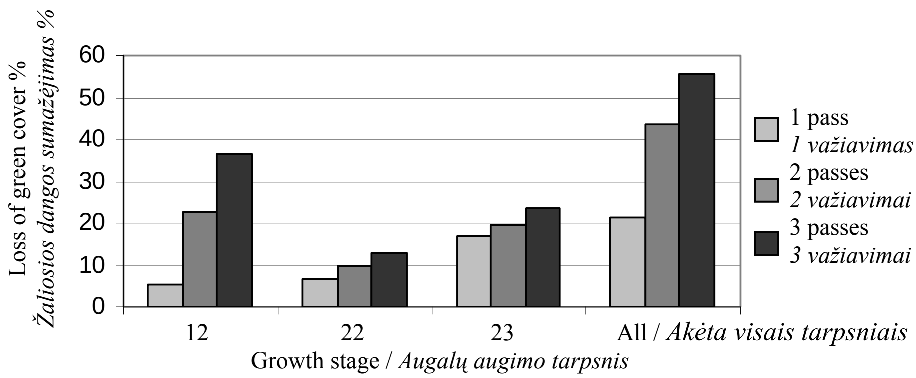


Figure 3. Green cover (A) and percentage loss of green cover (B) two days after weed harrowing at growth stage 23 (2 May)
3 paveikslas. *Dirvos padengimas augalais (A) ir padengimo sumažėjimas procentais (B) dvi dienos po akėjimo 23 žieminių kviečių augimo tarpsniu (gegužės 2 d.)*

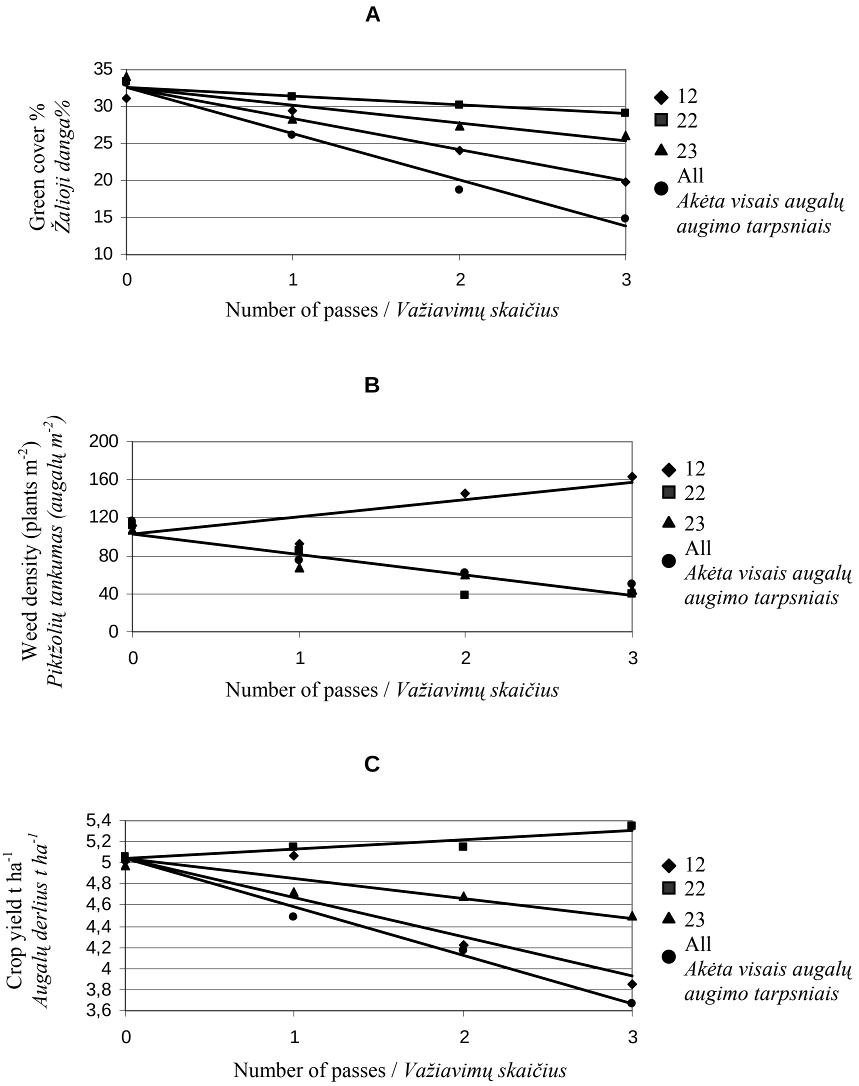


Figure 4. The effects of increasing intensities of weed harrowing at different growth stages on (A) green cover after the final treatments (2 May), (B) weed density and (C) crop yield. Number of passes refers to the number of passes carried out at each growth stage and symbols denote growth stage

4 paveikslas. *Akėjimo skirtingais žieminių kviečių augimo tarpsniais intensyvumo didinimo įtaka (A) padengimui augalais po paskutiniųjų akėjimų (gegužės 2), (B) piktžolių tankumui ir (C) augalų derliui. Važiavimų skaičius reiškia važiavimų skaičių, atliktų kiekvienu žieminių kviečių augimo tarpsniu, o simboliai reiškia augimo tarpsnį*

Discussion

In this study, increasing intensities of weed harrowing was created by increasing number of passes with the harrow on the same day. Number of passes, however, gives a poor general description of the intensity, especially when harrowing is performed at different growth stages. Even if the same number of passes was carried out at different growth stages, it is meaningless to say that the same intensities were represented at each growth stage.

Intensity may be expressed by the technical performance of the harrow and by the immediate crop impact expressed as crop soil cover. In this study, it was not relevant to maintain the same technical performance of the harrow through all growth stages. Treatments that were considered as a highly aggressive in autumn appeared to be very gentle in spring. In autumn, it was virtually possible to approach 90 % crop soil cover by three passes, and with an adjusted performance, it would most likely have been possible to approach 100 % crop soil cover. This was not achievable in spring even if the harrow was used in its most aggressive adjustment, because a crust formatted during winter made it impossible to cultivate soil enough to achieve such high degrees of crop soil cover (Fig. 2). Hence, driving speed and tine angles varied between treatment times in order to make reasonable treatments. In consequence, intensity and timing was mixed up in the experiments, which make it impossible to determine the main effects of these factors.

Opposite to the technical performance of the harrow, crop soil cover appears to offer an appropriate specification of the intensity of weed harrowing, and digital image analysis makes it possible to quantify crop soil cover in an objective way.

In future research, two parameters seem important in order to improve knowledge about how the positive and negative crop impacts from harrowing should be balanced. The ability of the crop to resist soil covering in relation to weed control is of major importance, and the ability of the crop recover from soil covering, is also important. As outlined in Gundersen et al. (2006), these parameters are not necessarily correlated when different crop species are compared. Gundersen et al. (2006) found marked differences among four different cereals in terms of their ability to resist soil covering and recover from it.

This study shows that the ability of winter wheat to recover from soil cover is influenced by timing. Therefore, predictive models that hold the ability to describe how well crops are able to recover from soil cover at different growth stages are highly appreciated. This would help to find the most suitable timing of harrowing. In this perspective, digital image analysis may play a vital role in order to make reliable and reproducible assessments of crop soil cover.

The fact that harrowing at growth stage 22 improved crop yield, whereas harrowing two weeks later reduced crop yield (Fig. 4 C) cannot be explained by higher weed control at growth stage 22 (Fig. 4 B) or lower crop soil cover (Fig. 2). The main reason seems to be that the ability of the crop to recover from soil cover is time dependent. This time dependent mechanism, however, is poorly understood due to lack of research.

Harrowing in autumn is a risky business in terms of crop damage and crop yield losses as previously shown by Rasmussen (1998). Harrowing in autumn inflicted long lasting crop damages and stimulated weed germination, which resulted in increased weed problems (Fig. 4 B).

In future, new experimental setups should be considered aiming at separating and quantifying important issues related to the crop-weed responses to weed harrowing. Among the most important issues are changes in weed competition due to harrowing, crop resistance to soil cover and crop recovery from soil covering. In this perspective, digital image analysis offers new possibilities in weed harrowing research.

Conclusion

Based on the impacts on spike densities, the competition between winter wheat and winter rye was unaffected by weed harrowing. The experiments showed that timing of weed harrowing plays a key role in terms of optimizing weed control and crop yield response to harrowing in winter cereals. Harrowing in autumn created severe crop damages, which resulted in major crop yield losses and stimulation of weed growth. Timing in spring was also important, because harrowing at crop stage 22 resulted in crop yield gains whereas harrowing at growth stage 23 resulted in crop yield losses. The results indicate that differences in crop recovery from damages associated with harrowing explain the differences. In future, the recovery ability of crops should be emphasized and digital image analysis offers new possibilities in this perspective.

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SKAITMENINĖ VAIZDO ANALIZĖ SIŪLO NAUJAS GALIMYBES NAIKINANT PIKTŽOLES AKĖJIMU

J. Rasmussen, M. Nørremark

Santrauka

Žieminių kviečių pasėlyje atlikti du lauko bandymai siekiant nustatyti optimalų akėjimo intensyvumą ir laiką. Kiekviename bandyme tirti keli akėjimo intensyvumai didinant važiavimų skaičių įvairiais žieminių kviečių augimo tarpsniais. Augalų užžėrimas, taikant skirtingo intensyvumo akėjimą, buvo vertinamas vizualiai ir analizuojant skaitmeninį nuotraukų, darytų iš karto po akėjimo, vaizdą. Tyrimai rodo, kad žieminiai kviečiai skirtingais augimo tarpsniais nevienodai toleravo akėjimą. Rudenį pasėlis buvo smarkiai pažeistas dėl didelio augalų užžėrimo dirvožemiu ir prasto atsinaujinimo, – dėl to žieminių kviečių derlius sumažėjo nuo 7 % iki 22 %. Ankstyvą pavasarį pasėlyje buvo pastebėti skirtumai tarp kultūrinių augalų gebėjimo atsinaujinti. Geriausi rezultatai pavasarį gauti 22 BBCH žieminių kviečių augimo tarpsniu. Didinant važiavimų skaičių, augalų derlius didėjo nuo 2 % iki 5 % ir daugiau buvo išnaikinama piktžolių – nuo 22 % iki 62 %.

Reikšminiai žodžiai: žieminiai kviečiai, žieminiai rugiai, mechaninis pikžolių naikinimas, augalų atsparumas, augalų atsinaujinimas, akėjimo toleravimas.

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