Weed Technology 2014 28:19–27

Decision Support System for Optimized Herbicide Dose in Spring Barley

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Crop Protection Online (CPO) is a decision support system, which integrates decision algorithms quantifying the requirement for weed control and a herbicide dose model. CPO was designed to be used by advisors and farmers to optimize the choice of herbicide and dose. The recommendations from CPO for herbicide application in spring barley in Denmark were validated through field experiments targeting three levels of weed control requirement. Satisfactory weed control levels at harvest were achieved by a medium control level requirement generating substantial herbicide reductions (~ 60% measured as the Treatment Frequency Index (TFI)) compared to a high level of required weed control. The observations indicated that the current level of weed control required is robust for a range of weed scenarios. Weed plant numbers 3 wk after spraying indicated that the growth of the weed species were inhibited by the applied doses, but not necessarily killed, and that an adequate level of control was reached later in the season through crop competition.

Nomenclature: Spring barley, *Hordeum vulgare* L.
Keywords: Dose response, factor adjusted dose, reduced doses, weed control.

Crop Protection Online (CPO, Protección de Cultivos en Línea) es un sistema de ayuda para la toma de decisión, el cual integra algoritmos que cuantifican el requerimiento de control de malezas y un modelo de dosis de herbicidas. CPO fue diseñado para ser usado por asesores y productores para optimizar la selección de herbicidas y dosis. Las recomendaciones de CPO para la aplicación de herbicidas en cebada de primavera en Dinamarca fueron validadas mediante experimentos de campo enfocados a tres niveles de requerimientos de control de malezas. Niveles satisfactorios de control de malezas al momento de la cosecha se alcanzaron con un nivel de requerimiento de control medio, lo que generó reducciones sustanciales de herbicidas (~60% medido como el índice de frecuencia de tratamiento (TFI)) al compararse con el nivel de requerimiento de control de malezas alto. Las observaciones indicaron que el nivel actual de requerimientos de control de malezas es robusto para un rango amplio de escenarios de malezas. Los números de plantas de malezas, 3 semanas después de la aplicación, indicaron que el crecimiento de las especies de malezas fue inhibido por las dosis aplicadas, pero estas no necesariamente murieron, y que un nivel adecuado de control fue alcanzado después en la temporada debido a la competencia del cultivo.

Efficacy of herbicide application is affected by a range of biotic and abiotic factors and therefore the applied rate does not necessarily reflect the actual dose taken up by weedy plants. Temperature and soil moisture affect efficacy, depending on the herbicide mode of action (Caseley 1989; Kudsk and Kristensen 1992). Climatic factors influence herbicide efficacy, but also physical factors such as canopy density play a role. The crop canopy will get denser as the crop growth stage increases, thereby decreasing the actual dose reaching the surface of the weed plants. Furthermore, the optimal herbicide solution is affected by weed species composition, growth stage of the weeds and the required level of control (Klingaman et al. 1992; Kudsk 2008). Several studies have shown that when these factors are all considered, herbicide use can be reduced (Bostrom and Fogelfors 2002; Hamill et al. 2004; Salonen 1993). Although there are both economic and environmental incentives to optimize herbicide composition and dose, it is a very complex decision for individual farmers. Hence, several decision support systems have been developed to assist advisors and farmers. Most systems rely on calculations of yield loss related to weed density with different economical optimizations of herbicide treatment (Bennett et al. 2003; Berti and Zanin 1997; Nordblom et al. 2003). Another approach is based upon herbicide dose models, as in the Danish system, Crop protection Online (CPO). CPO focuses on optimizing the applied dose through detailed information on the expected herbicide

DOI: 10.1614/WT-D-13-00085.1

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efficacy for the individual weed species (Kudsk 2008; Rydahl 2003; Rydahl et al. 2003). CPO has been tested for practical purposes in a range of crops and has been found to provide robust advice and ensure yield.

In CPO, the control level required for each weed species (target efficacy) is estimated for each crop, integrating the aspects which farmers consider important, like competitive ability, seed dispersal rates and interference with harvest procedures. Furthermore, target efficacy is adjusted to season as some weeds in autumn-sown crops are more important to control in autumn than in spring and vice versa under Danish growing conditions.

The expected efficacies of herbicides in CPO are based upon dose–response curves for each relevant combination of weed and herbicide. The dose–response curves were estimated on the basis of official herbicide testing and from experiments performed by agrochemical companies. Efficacy was recorded either as biomass reduction, reduction in plant number or visual assessments. In CPO, the dose required to control a given weed species is adjusted to the growth stage of the weeds and the prevailing climatic conditions in the field through a parallel displacement of the standard dose–response curves. The standard curves were obtained in previously conducted field experiments by spraying at the zero- to two-leaf stage at 8 to 14 C and no soil moisture stress. The magnitude of the parallel displacement is specific for each herbicide and based on experimental data (Rydahl 2003). The youngest growth stages of most annual weed species are generally more susceptible to herbicides than more developed plants (Kudsk 1989). The efficacies of some herbicides, however, are independent of growth stage (Andersson 1995; Spandl et al. 1997). In CPO, climatic dose adjustments are controlled by two parameters for temperature and soil moisture, which were parameterized based on small pot semifield experiments. These dose adjustments vary for each herbicide or herbicide group (Kudsk 1999).

Weed flora in a field is often diverse and consequently not possible to control with a single herbicide. Assuming additivity of herbicide mixtures, the additive dose model (ADM) (Green et al. 1995; Kudsk 1999) offers the possibility of calculating efficacy of herbicide tank mixtures, and the implementation of ADM has greatly added to the value and potential of CPO by adding two to four component herbicide tank mixtures to the list of herbicide solutions. Herbicide solutions can be optimized either according to costs or herbicide use.

The objective of this study was to validate the target efficacy levels of weed species in CPO and determine whether there is a potential to lower herbicide doses even further in spring barley in Denmark. An additional objective was to validate herbicide adjustments for increasing weed sizes.

Materials and Methods

Validation Experiments. Three field experiments were conducted following the same basic principles: experiments on target efficacy level, dose reduction potential, and dose adjustments for growth stage. Each experiment was replicated at 15 to 33 locations. The locations were conventional farmer's fields. The farmers were managing their fields by usual practice, except for the herbicide treatments, which were done according to the recommendations from CPO. The fields were located throughout Denmark in order to include a range of different conditions. Weed reports from the locations were made by advisors, who recorded the weed density by species, crop growth stage, expected yield and the spraying conditions in terms of temperature. The weed reports were sent to researchers at Aarhus University, who returned the recommendations to the farmers within 24 hours.

Optimizing herbicide solutions according to herbicide use was done using the Treatment Frequency Index (TFI) rather than the amount of herbicide per hectare. TFI is a measure of herbicide use, which makes it possible to compare herbicide use between fields and years. This index was introduced along with the first Pesticide Action Plan in Denmark in 1986 and has been generally adopted as a standard measure of herbicide use. Standard doses have been established for use of all active ingredients. Application of the standard dose will result in a TFI of 1.0, and a 50% reduction of dose will result in a TFI of 0.5. TFIs can be summed up over products or treatments; for example, if more than one herbicide is used or if the field is sprayed more than once, then the TFI of each treatment or herbicide are summed and might exceed 1.0 (Jørgensen and Kudsk 2006).

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Each field experiment comprised two or three treatments replicated four or five times, with unsprayed treatments added as controls, within each location. Spring barley seeding rates were between 150 and 180 kg ha^{-1}. Weed species and numbers were sampled two times during the season in a randomly placed 0.25 by 0.5 m^2 quadrat in each sampling area; the size of the quadrat was adjusted according to the amount of weed in each field, with smaller quadrats in areas of higher weed density. Sampling was performed at spraying (data for model input) and 3 wk after spraying. Total weed coverage and yield were recorded at harvest for all treatments.

CPO has been developed gradually over the last 25 yr and the early versions were simpler than the current version. The validation experiments on target efficacy level and dose reductions were conducted with an early version of CPO, which did not include the ADM component and the adjustment for climatic conditions. Relevant herbicide mixtures were alternatively designed by dividing the weed population into two; these could be managed by two individual herbicides and thereafter combining them in a mixture. The trials designed to validate the adjustment to growth stage were conducted after the implementation of ADM and climatic conditions, but otherwise conducted in the same manner as the other validation experiments.

Target Efficacy Level Experiment. Three target efficacy levels were tested in this validation experiment: high, medium and low. The early versions of CPO had higher target efficacy levels (high level) than the current version. Those high levels were established by experts, but feedback from users and initial field tests of CPO with the high levels indicated a potential for lowering target efficacies. A medium level was then introduced maintaining relatively high efficacy for high-density weed populations and competitive weed species, but lower levels for low density weed populations and less competitive weed species. Furthermore, a very low level was tested in the validation experiments to investigate whether the medium level was close to the lowest level of acceptable weed control. According to advisory services, acceptable weed control is synonymous to a lack of economic net yield loss, and total weed coverage at harvest time of less than 15%. The field experiment was conducted from 1994 to 1995 in spring barley at 16 locations. The initial weed infestation in the fields ranged from 50 to 294 plants m^{-2} and the time of spraying varied between May 16 and June 2 in 1994 and between May 10 and June 1 in 1995.

Dose Reduction Experiment. Further experiments were conducted to support the medium level of target efficacies. This was done by applying the dose recommended by CPO with medium target efficacy as one treatment, referred to as full dose. Half and quarter of this dose were applied as two additional treatments to examine the robustness of the medium target efficacy level. The field experiment with dose reductions was conducted from 1994 to 1996 in spring barley at 33 locations in total. The initial weed infestation in the fields ranged from 24 to 580 plants m^{-2} and the time of spraying varied between May 13 and 29 in 1994, between May 1 and 29 in 1995, and between May 8 and 30 in 1996.

Weed Growth Stage Experiment. The ability of CPO to adjust the recommended doses to growth stages of weeds was tested by applying herbicides at two spraying times; at the one- to two-leaf stage of the weed species as one treatment and at the three- to four-leaf stage as another treatment. This experiment was conducted from 2004 to 2006 at 15 locations in total. The initial weed infestation in the fields ranged from 73 to 920 plants m^{-2} and the time of spraying at one- to two-leaf stage varied between April 21 and May 11 in 2004, between May 3 and 13 in 2005 and between May 10 and June 9 in 2006. Time of spraying at three- to four-leaf stage was between 9 and 24 d later.

Data Analyses. Yield and weed coverage at harvest were analyzed using generalized linear mixed models with treatment as the fixed variable and year, location and replicate as nested random variables. To calculate the achieved efficacy shortly after spraying the relative plant number 3 wk after spraying was calculated. Only species observed in more than one field and both before and after spraying were included. Differences among treatments were analyzed using generalized linear mixed models for each species with the same fixed variables as above. The level of genus was accepted for deadnettle (*Lamium* spp.) and speedwell (*Veronica* spp.) as the individual species are difficult to distinguish at the very early stages. All statistical analyses were performed using the R statistical software (R Development Core Team 2010) and

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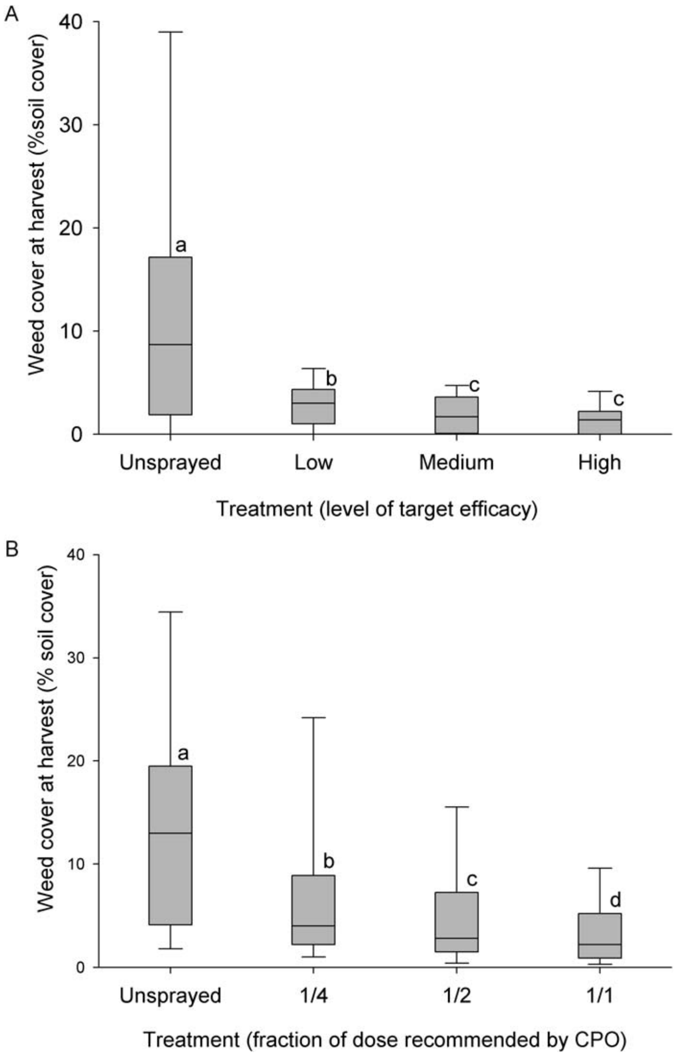

Figure 1. Weed coverage at harvest for spring barley for (A) target efficacy level experiment (16 locations) and (B) for dose reduction experiment (33 locations). Lower case letters indicate significant differences among treatments ($P = 0.05$). Boxes and whiskers represent the minimum, maximum and upper/ lower quartiles, while the median is represented by the horizontal lines.

add-on packages; nlme for generalized linear mixed models (Pinheiro et al. 2009), gmodels for contrast matrixes to determine significant differences between treatments (Warnes 2011). Variance homogeneity was analyzed graphically by residual plotting, and logarithmic or square root transformation was used when appropriate.

Results and Discussion

The general conclusion was that CPO was able to give suitable recommendations for a range of weed scenarios in spring barley, even in the early model version without temperature adjustments and with a very basic herbicide mixture calculation. The weed populations of the experimental fields were regarded as representative for spring barley fields in Denmark. The weed species present in the field trials corresponded with the most frequent species in spring barley fields according to a survey performed between 2001 and 2004 in Denmark, except from the presence of hempnettle (*Galeopsis tetrahit* L.) and corn marigold (*Chrysanthemum segetum* L.) (Andreasen and Stryhn 2008). Annual bluegrass (*Poa annua* L.) and scentless mayweed [*Tripleurospermum inodorum* (L.) Sch. Bip.] were among the most frequent species in the survey of Andreasen and Stryhn (2008), but in the present study annual bluegrass was only observed in a few fields and never both before and after spraying. Chamomile species were not identified to species level in the present study.

Control Level at Harvest. The target efficacy experiment showed that the initial target efficacy levels decided upon by experts (high target efficacy level) could be lowered to a medium level without causing yield loss or unacceptable high weed coverage at harvest (Figure 1A). Spraying increased yield for all treatments ($0.0001 < P < 0.0089$), but the sprayed treatments all resulted in the same yield, average 59.2 ($\pm$ 2.83) t ha^{-1}, ($0.1492 < P < 0.8447$) (all data not shown). The weed coverage at harvest was low for all sprayed fields (less than 5% for most locations), which indicated that the lowest level provided adequate control, but there were some differences among treatments (Figure 1A). Weed coverage at harvest was 1.4 times higher at the low target efficacy level compared to the medium level and 1.8 times higher compared to the high level. Medium target efficacy resulted in 1.3 times higher weed coverage than the high level, but this difference was not significant. The TFI was higher for the high level of target efficacy than for the medium and low level ($P < 0.0001$), whereas the low target efficacy did not result in significant lower TFI than the medium level ($P = 0.109$) (Table 1). Lowering the target efficacies from the high to the medium level resulted in a reduction in herbicide amount of 60% (TFI lowered from 1.28 to 0.55). Lowering the target efficacy level from around 90 to 95% to between 75 to 80% will cause a substantial decrease

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Table 1. Average treatment frequency index (TFI) for target efficacy level, dose reduction, and growth stage experiments with standard error in brackets.

Experiment	TFI	Standard error
Target efficacy level		
Low	0.38	(0.064)
Medium	0.55	(0.080)
High	1.28	(0.143)
Dose reduction level[a]		
1/4	0.13	(0.001)
1/2	0.28	(0.002)
1/1	0.54	(0.009)
Weed leaf stage at application		
1–2	0.58	(0.066)
3–4	0.64	(0.049)

[a] Full rate with a medium target efficacy level.

in the applied dose, because the required level is moved from the upper part of a dose–response curve, which is very flat, to the middle part of the dose response curve, which has a steeper slope. Further reductions in the target efficacy level will not cause similar large differences in doses.

The dose reduction experiment showed that quarter and half the dose recommended at the medium target level induced higher weed coverage at harvest than the full dose (Figure 1B). Similar to the target efficacy level experiment, all sprayed treatments had higher yield than unsprayed ($P < 0.0001$). For these experiments, however, yield differed among treatments and was significantly lower when reducing the dose from the full recommended dose by CPO to a quarter dose ($P = 0.0004$). There was no significant difference in yield between full and half of the recommended dose, average 52.5 ($\pm$ 2.37) t ha^{-1} ($P = 0.1538$) (all data not shown). The average weed coverage at harvest for quarter dose was 1.4 higher than half dose and 1.9 higher than full dose. At half dose the weed coverage was 1.3 higher than full dose (Figure 1B). The average weed coverage of the dose reduction experiment was generally higher than for the target efficacy level experiment even though all treatments resulted in weed coverage below the acceptance level of the farmers (< 15%), but weed number before spraying was higher as well. Considering the variability between the two experiments, and the intention of designing a robust decision support system, the risk of weed seed shedding leading to increased weed problems in the future was considered too high to decrease target efficacies below the medium level. Furthermore, as there was no significant decrease in TFI between medium and low target efficacy levels, the environmental benefit of such a reduction would be minimal according to these experiments.

Because lowering the TFI by 70 to 75% did not increase the total weed coverage at harvest to unacceptable high levels underlines the potential for reducing herbicide use in spring barley. It is, however, also relevant to examine the more differentiated responses of the individual species, when evaluating the robustness of a decision support system like CPO.

Effects on Individual Weed Species 3 Weeks after Spraying. In total, nine weed species were found in more than one field both before and 3 wk after spraying in the target efficacy experiment (Figure 2A). The plant number after spraying declined for all species, but the relative plant number after spraying varied among species and treatments. The best effect was observed for hempnettle, chickweed [*Stellaria media* (L.) Vill.], wild buckwheat (*Polygonum convolvulus* L.) and wild mustard (*Sinapis arvensis* L.), where the relative plant number after spraying was below 0.5 (above 50% efficacy) for all treatments. Lower efficacy for the low target efficacy was only significant for chickweed ($P = 0.03$ comparing low to medium level and $P = 0.01$ comparing low to high level). The average standard error of the three treatments was 0.265 for low, 0.169 for medium and 0.147 for high target efficacy, which were not different ($0.093 < P < 0.186$).

In the analysis of relative plant number for the dose experiments, 13 weed species were found in more than one field both before and 3 wk after spraying (Figure 2B). Seven species had efficacies above 50% for the full dose treatment, whereas quarter doses resulted in efficacies less than 50% for all species. Herbicide efficacy observed 3 wk after spraying is expected to be enhanced during the growth season and therefore the control level, in terms of plant numbers, immediately after spraying is often lower than anticipated by many farmers. Low doses of many herbicides, such as the sulfonylureas, inhibit growth, but the plants are not necessarily killed. Sprayed plants can survive for weeks and, depending on the amount of herbicide intercepted by the plant, some plants might even start growing again (Boutin et al. 2000; Ward and Weaver 1996). However,

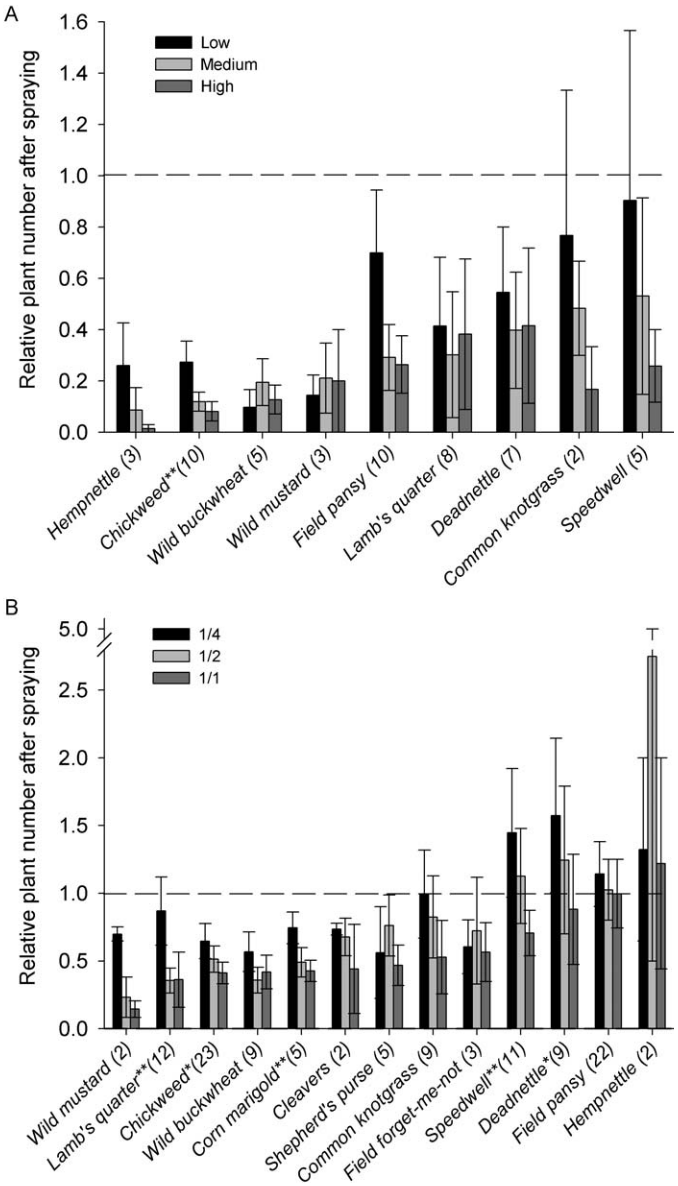

Figure 2. Relative plant number 3 wk after spraying of individual weed species for (A) the three target efficacy levels and (B) fraction of dose recommended by CPO at medium target efficacy. The species are listed after decreasing effect at (A) medium target efficacy and (B) full dose. The horizontal dashed line indicates relative plant number of 1, which equals no change in plant number after spraying. Asteriks following the species name indicate differences ($P = 0.05$) among target efficacies. Only species present in more than one field for at least one of the treatments are presented (number of fields in brackets).

competition from the crop is lethal for many herbicide-treated plants, as spring barley is a highly competitive crop. Optimizing seeding rate can increase the efficacy of herbicides applied in low dosages (O'Donovan et al. 2001). Differences among dose levels were found for five species 3 wk after spraying. For lamb's quarters (*Chenopodium album* L.), corn marigold and speedwell quarter dose resulted in lower efficacy than half and full dose ($< 0.001 < P < 0.034$). For chickweed and deadnettle there were differences between full and quarter dose ($0.028 < P < 0.044$), but half dose was not different from any of the other treatments ($0.113 < P < 0.628$). The standard errors of some of the observations were large, partly because of low densities of the species in few fields. Concern has been raised regarding a larger variability in efficacy at lower rates (Doyle and Stypa 2004), but this was not observed. Even though the full dose, in the dose reduction experiments, was obtained at the medium target efficacy, the standard error did not increase when the dose was reduced to a quarter of this (TFI = 0.13). The average standard error of relative plant number in the three treatments was 0.258 for quarter dose, 0.352 for half dose and 0.229 for full dose, which were not different ($0.414 < P < 0.845$).

The timing of the spraying is important, and in the dose reduction experiment four species increased in number after spraying, which indicated a later flush of emerging weed plants. Therefore, it might be necessary sometimes to make a second spraying or to wait with the first spraying until more weeds have emerged. However, if the first spraying is delayed, more weeds will be at a later growth stage and thus more difficult to control. The optimum strategy depends on the weed community composition. In the present field experiments, the first spraying was performed at the optimal growth stage for the first flush of weeds and no need for spraying was observed later even though more weeds emerged.

Compared to the results at harvest, the differences among treatments were less pronounced shortly after spraying, as there were only few significant differences among target efficacies for relative plant number of individual weed species 3 wk after spraying (Figures 2A and 2B). The control level provided by reduced herbicide doses will not always be evident shortly after spraying as with higher doses. A large proportion of the weeds, which survive spraying with reduced doses, will be outcompeted by competitive crops like cereals during the growth season, as the growth of the weeds are inhibited by herbicide application if not killed (Sønderskov 2011; Terra et al. 2007).

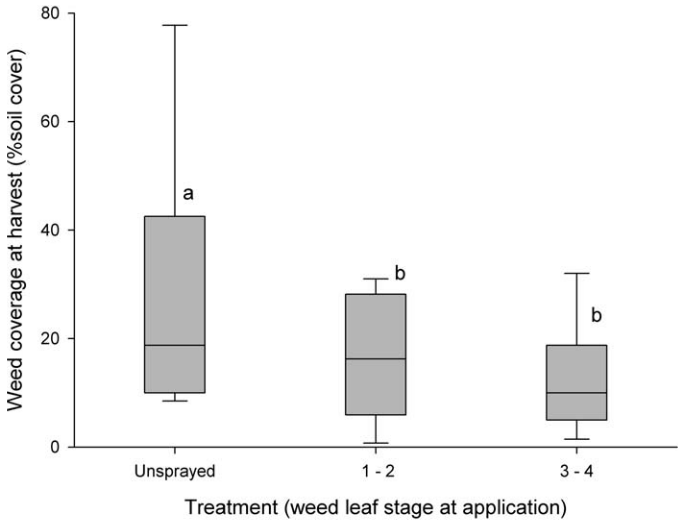

Figure 3. Weed coverage at harvest for spring barley for weed growth stage experiment (15 locations). Weeds were sprayed at two different stages to validate the adjustment factors for weed growth stage. Boxes and whiskers represent the minimum, maximum and upper/ lower quartiles, while the median is represented by the horizontal lines.

Significance of Weed Growth Stages at Spraying. Conditions can arise, when it is not possible to spray at the optimal zero- to two-leaf stage of the weeds, and sometimes the growth stages of the weed species are not uniform. Therefore it is important to know the strengths and weaknesses of CPO under suboptimal conditions. In the weed growth stage experiments, spraying increased yield compared to unsprayed plots ($P < 0.0001$), whereas the yield for plots sprayed at one- to two-weed leaf stage was not different from the yield for plots sprayed at three- to four-leaf stage ($P = 0.4058$). The weed coverage at harvest did not differ between treatments and was 16.5% (± 2.38) soil coverage for the early sprayed plots and 12.0% (± 2.07) soil coverage for the later sprayed plots ($P = 0.5146$) (Figure 3). The treatment solutions from CPO were optimized according to TFI. Because adjustment factors on weed growth stage differ among herbicides, the herbicide solution for the two treatments was not necessarily based on the same active ingredients. Therefore, the two treatments resulted in similar TFIs ($P = 0.5821$). These experiments imply that the adjustment of herbicide choice and dose sufficiently took into account the lower efficacy of many herbicides at larger growth stages. There was a tendency for lower weed coverage at harvest when the spraying was performed at the three- to four-leaf stage rather than at the one- to two-leaf stage. This could be a consequence of higher number of emerged weeds at the time of spraying at three- to four-leaf stage or that the sprayed weeds had less time to recover after spraying. It might also indicate that the dose adjustment was larger than necessary to achieve the same level of control at the larger weed stages.

Potential of Crop Protection Online. Overall, the potential for herbicide reductions will vary among fields and is highly dependent upon weed community composition. Consequently, in a field with a diverse community of weed species, several of the weed species will be controlled to a higher level than required by CPO. As many of the available herbicides can control a broad spectrum of weed species, the weed species requiring the highest efficacy will determine the recommended dose and thus more susceptible species will be controlled at a higher efficacy level than required to maximize yield and minimize seed return. So even though the target efficacies for some easy-to-control species are low, the recommended dose will always be determined by the combination of weed species and growth stage, which is the least susceptible to the herbicide in question. In a study conducted in spring barley in Finland, the general reduction potential was estimated to be 30% when the weed population consisted of relatively sensitive species (Salonen 1992). Several studies have found that reductions of herbicide label rates are possible when considering the composition of the weed population. Even a 50% reduction is feasible and optimizing other management practices will support such a reduction (Blackshaw et al. 2005; Fernandez-Quintanilla et al. 2006; Spandl et al. 1997). Optimizing agricultural practices will also reduce the long term risk of increasing the density of hard to control species (Bostrom and Fogelfors 2002).

Experiences with other decision support systems support the assumption that decision support systems can be of great benefit for optimizing herbicide rates with no yield loss or increased weed densities in subsequent years compared to full rate applications (Berti et al. 2003; Hamill et al. 2004; Nordblom et al. 2003). CPO is unique in the sense that the recommendations are based on dose–response curves estimated on basis of data from field experiments. Like the other programs, CPO takes into consideration the competitiveness of the weed

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species. The herbicide reductions obtained by using CPO are based primarily on relatively low target efficacies for noncompetitive weed species, whereas strongly competitive weed species require doses closer to the maximum. Additionally, optimizing tank-mixtures of complementary herbicides can further increase the potential for dose reductions. The importance of tank-mixtures increases with increasing number of weed species in the fields.

Recently, several publications have highlighted the relationship between herbicide rate and evolution of herbicide resistance, and in particular nontarget site resistance (Busi and Powles 2009; Manalil et al. 2011; Renton et al. 2011). The conclusion evolving from these publications is that sublethal herbicide rates can accelerate the selection of nontarget site herbicide resistance also referred to as "creeping resistance". So far, in Denmark this has only been observed in a few grass weed species that generally are not a problem in spring barley (Mathiassen et al. 2013). Should this become a problem, it can easily be addressed in CPO by increasing the target efficacy level for the resistant biotypes of the weed species in question.

Recommendations from a system like CPO can be combined with other integrated weed management (IWM) strategies, such as nonchemical weed control or sowing densities and thus further increase the potential for reducing herbicide inputs (Blackshaw et al. 2005; O'Donovan et al. 2007). In Denmark, CPO was commercialized in 2003 with temperature, soil moisture stress and ADM for herbicide mixtures implemented. It is currently used by approximately 1,000 farmers and advisors, and in the agricultural schools future farmers are taught how to use CPO. Furthermore, CPO has been adjusted to conditions in several other countries, with the decision support system in Norway (VIPS-Ugras) being the most developed system beside the Danish (Netland et al. 2005).

In summary, CPO was able to give reliable advice for a range of spring barley fields without causing any yield loss, compared to the highest dose applied, or leaving unacceptable high levels of weeds at harvest. The medium target efficacy was established as sufficient for weed control and significant herbicide use reductions were observed with this early model without ADM and climatic adjustments. Further reductions would be expected with the model including ADM for more specific herbicide mixtures. The fact that CPO has been used for the last twenty years both by farmers and advisors consolidates its value for agronomic advice. The next step for CPO is to implement resistance guidance and possibly mechanical weed control measures, thereby allowing farmers and advisors to get proper advice including the adoption of IPM strategies.

Acknowledgements

The authors want to thank the Danish Knowledge Centre for Agriculture and all the local advisory services participating in the field experimental planning and sampling.

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Received May 6, 2013, and approved August 20, 2013.