A sensor-based decision model for precision weed harrowing

NIBIO
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Introduction

Weed harrowing is a traditional method in organic cereals, but could also be used as part of IWM in conventional production. Weed control efficacy can be adjusted by the angle of the tines. The more steep angle, the more intense the weeding. Due to its broadcast nature - both crop and weed plants are physically disturbed -, weed harrowing may have small ratio between weed control and crop injury. Target weeds are generally distributed heterogeneously within cereal fields, so weed harrowing intensity could be adjusted to the actual need across the field. To realize such site-specific weed harrowing, a sensor-based model that takes into account both the intra-field variation in weediness and "soil density" (i.e. draft force of tines) in the upper soil layer, is proposed.

Aim

To develop a sensor-based decision model intended for precision weed harrowing in cereals after crop emergence. Sensor data used are RGB images analyzed with custom made machine vision to estimate total weed cover (and weed control efficacy) per sub-field plot and an electronic load cell to estimate soil density for the same sub-field plot.

Data

were collected during five site-years in 2-row spring barley (*Hordeum vulgare* L.) in SE Norway. The weed flora was dominated by *Poa annua* and common dicot annual weed species (e.g. *Chenopodium album, Lamium purpureum, Stellaria media, Viola arvensis*). RGB images and electronic load cell data were collected before weed harrowing was conducted once at various pre-defined tine angles: 0° (untreated control), 27.5°, 36.5°, 50° and 59° (most aggressive). See caption in **Fig. 1** for more details on the data collection.

Sensor-based decision model

was achieved via statistical data analyses in four main steps :

1) Estimation of parameter 'biological weed damage threshold' (t_o) in non-linear regression of grain yield per plot against mean total weed cover (after weed harrowing) per plot (W_{post}). **Fig. 3** shows that t_o = 2.09% resulted.

2) Estimation of two parameters in a non-linear regression of weed control efficacy (*WC*) per plot against the applied weed harrowing intensity (tine angle) and mean *SD* per plot. **Fig. 4** shows results.

3) Based on the actual pre-harrow mean total weed cover per plot, the target weed control efficacy (WC_o) to reach the biological weed damage threshold, is calculated. See illustration in **Fig. 5**.

4) The parameter values estimated in steps nos. 1 and 2 were then used in the decision model (non-linear regression model) for weed harrowing intensity (*HI*). This model predicts the optimal harrowing intensity (in terms of tine angle) as a function of the actual pre-harrow total weed cover and soil density, and the biological weed damage threshold. **Fig. 6** shows the resulting model.

Results

are given in figs nos. 3 to 6.

Conclusion

With the current non-linear regression model parameter values, the sensor-based decision model (i.e. **Fig. 6**). should be valid for precision weed harrowing in spring barley in Norway and elsewhere with similar conditions. Our next step is to test the model through field trials.

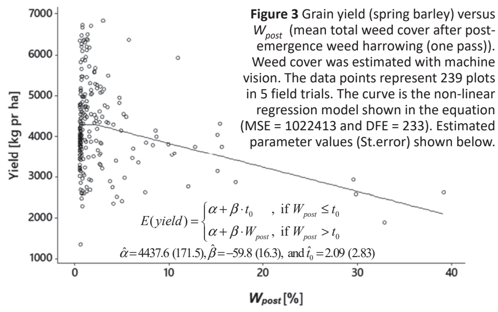
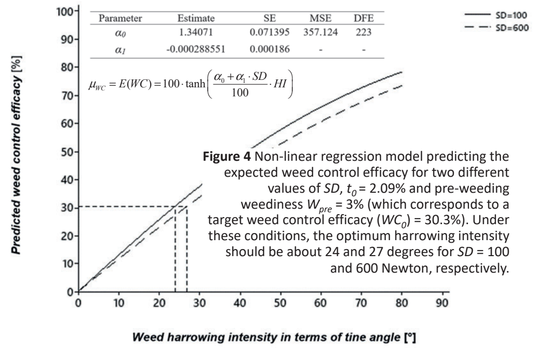


Figure 3 Grain yield (spring barley) versus W_{post} (mean total weed cover after post-emergence weed harrowing (one pass)). Weed cover was estimated with machine vision. The data points represent 239 plots in 5 field trials. The curve is the non-linear regression model shown in the equation (MSE = 1022413 and DFE = 233). Estimated parameter values (St.error) shown below.



Parameter	Estimate	SE	MSE	DFE
α_0	1.34071	0.071395	357.124	223
α_1	-0.000288551	0.000186	-	-

Figure 4 Non-linear regression model predicting the expected weed control efficacy for two different values of *SD*, t_o = 2.09% and pre-weeding weediness W_{pre} = 3% (which corresponds to a target weed control efficacy (WC_o) = 30.3%). Under these conditions, the optimum harrowing intensity should be about 24 and 27 degrees for *SD* = 100 and 600 Newton, respectively.

Figure 1 Data collection in five site-years in spring barley (2-row cultivars). Experimental design was randomized block design, plots were 5-m by 9-m. Nadir RGB images (field of view about 0.27 m × 0.22 m, 2448 pixels × 2048 pixels) were acquired about 0.7 m above ground (while tractor was driving at 4 km h^{-1}) immediately before and after weed harrowing once when spring barley (at normal row distance, i.e. 125 mm) had emerged (BBCH 13-23). About 15 images were taken per plot in each run (either before or after weed harrowing). Images were analyzed (in office) with a custom-made software to estimate total weed cover per image, and mean total weed cover per plot. Soil density was measured with an electronic load cell (Tedea-Huntleigh model 616) connected to a 0.75 m vertical rigid tine pulled at soil depth 30-40 mm. Weed harrowing was conducted with an Einböck weed harrow with flexible bent tines (thickness 7 mm, length 450 mm, tine spacing 25 mm, driving speed 8 km h^{-1}) at pre-defined tine angles incl. zero (i.e. non-harrowed control). At normal time for harvest, crop was harvested with a plot harvester (width 1.5 m) to estimate grain yield.

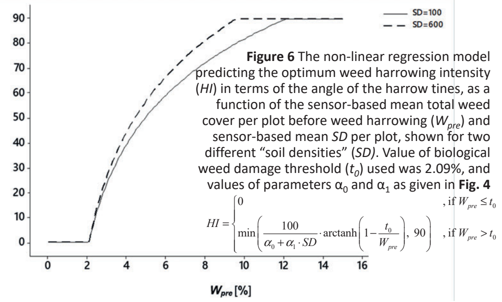


Figure 6 The non-linear regression model predicting the optimum weed harrowing intensity (*HI*) in terms of the angle of the harrow tines, as a function of the sensor-based mean total weed cover per plot before weed harrowing (W_{pre}) and sensor-based mean *SD* per plot, shown for two different "soil densities" (*SD*). Value of biological weed damage threshold (t_0) used was 2.09%, and values of parameters α_0 and α_1 as given in **Fig. 4**

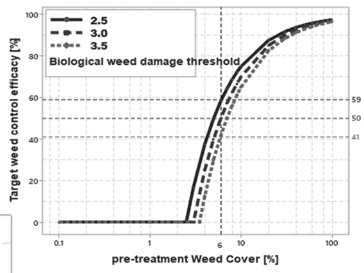


Figure 5 Target weed control efficacy (WC_o) as a function of the mean total weed cover per plot before weed harrowing (W_{pre}) and three different values of the biological weed damage threshold (t_0). For W_{pre} = 6%, the target weed control efficacy (WC_o) are about 60%, 50% and 40% for t_0 = 2.5%, 3% and 3.5%, respectively.

Machine vision

To estimate mean total weed cover and weed control efficacy (*WC*) per plot (5-m by 9-m), images acquired either pre or post weed harrowing were processed (in office) by a machine vision algorithm - 'AI algorithm' - based on deep learning techniques for rapid and automatic quantification of total weed cover (weed species not discriminated) in near-ground nadir RGB images acquired in early growth stages in cereals (cf. www.dimensionsagri.no). The raw outputs of the AI algorithm were calibrated (improved) by using linear regression model parameters between ground truth values (pixels of all weeds in 71 (pre-harrow) +84 (post-harrow) annotated manually; images selected semi-randomly to represent a wide range in total weed cover per image) and the raw algorithm outputs (cf. **Fig. 2**).

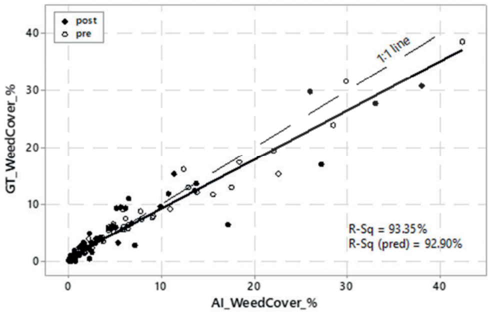


Figure 2 True values (y-axis) versus the 'raw outputs of the 'AI algorithm' for pre-harrow images (open symbols, n=71) and post-harrow images (filled symbols, n=84), the corresponding fitted linear regression model (solid line) and the 1:1 line (dotted lines). The estimated slope and intercept parameters (St.Error) are 0.8632 (0.01863) and 0.51719 (0.16525), respectively.

Definitions

t_o = biological weed damage threshold, defined as the upper mean total weed cover (per sub-field plot) at the time for post-emergence weeding which does not cause loss in crop grain yield (due to weed competition), unit: %; ***HI*** = Harrowing intensity in terms of tine angle of the weed harrow defined as the angle between the upper horizontal plane wherein tines are attached and the straight part of the tine, unit (range): degrees (0-90, where 0° (i.e. horizontal) means no weed harrowing and 90° (i.e. vertical) is the most aggressive intensity); ***SD*** = Mean "soil density" (i.e. draft force of tines) (per sub-field plot) measured in the upper 30-40 mm of the soil, unit: Newton; W_{pre} = Total weed cover (per sub-field plot) immediately before weed harrowing, unit (range): % (0-100); W_{post} = Total weed cover (per sub-field plot) immediately after weed harrowing, unit (range): % (0-100); ***WC*** = Weed control efficacy (per sub-field plot): percentage reduction in total weed cover after weed harrowing (W_{post}) compared to its total weed cover before weed harrowing (W_{pre}), unit (range): % (0-100); WC_o = Target weed control efficacy (per sub-field plot) given by its mean pre-harrow total weed cover (W_{pre}) and the chosen parameter value of biological weed damage threshold (t_o), unit (range): % (0-100).

Acknowledgement to NIBIO staff K. Wærnhus, M. Helgheim, S. Habte, A.R. Alazawy and H. Antzeé-Hyllseth, student F. Potterie, staff in Norsk Landbruksrådgiving Øst, B.I. Rostad and E. Villadsen, staff at SKP Friland/ Norwegian University of Life Sciences, S. Pung and J.A. Randem, for field work. M. Vallestad, Adigo AS, for analysing the images with the AI algorithm. K. Mangerud, L.O. Brandsæter and T.O.T. Hansen are acknowledged for helpful inputs on weed harrowing and load cell measurements. This work was financed by the Norwegian Research Council through the BIONÆR program [project No. 244526/E50: project SMARTCROP], EU Interreg ÖKS, topic Innovation [project No. 001171: project Innovationer för hållbar växtodling] and NIBIO.

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Poster

Weeds may reduce crop yields significantly if managed improperly. However, excessive herbicide use increases risk of unwanted effects on ecosystems, humans and herbicide resistance development. Weed harrowing is a traditional method to manage weeds mechanically in organic cereals but could also be used in conventional production. The weed control efficacy of weed harrowing can be adjusted by e.g. the angle of the tines. Due to its broadcast nature (both crop and weed plants are disturbed), weed harrowing may have relatively poor selectivity (i.e. small ratio between weed control and crop injury). To improve selectivity, a sensor-based model which takes into account the intra-field variation in weediness and "soil density" in the upper soil layer (draft force of tines), is proposed. The suggested model is a non-linear regression model with three parameters and was based on five field trials in spring barley in SE Norway. The model predicts the optimal weed harrowing intensity (in terms of the tine angle) from the estimated total weed cover and SD per sub-field management unit, as well as a pre-set biological weed threshold (defined as the acceptable total weed cover left untreated). Weed cover and SD were estimated with RGB images (analysed with custom-made machine vision) and an electronic load cell, respectively. With current parameter values, the model should be valid for precision weed harrowing in spring barley in SE Norway. The next step is to test the model, and if successful, adjust it to more cereal species.

Keywords: *Cereals, Mechanical weed control, Site-specific weed management*

Acknowledgements: This work was financed by the Norwegian Research Council through the BIONÆR program [project No. 244526/E50: project SMARTCROP], EU Interreg ÖKS, topic Innovation [project No. 001171: project Innovationer för hållbar växtodling].

Cite as:

Berge, T.W., Urdal, F. & Torp, T. 2022. A sensor-based decision model for precision weed harrowing. Poster abstract. In: Book of Abstracts, 19th European Weed Research Society Symposium, 20-23 June 2022, Athens, Greece, 1 page.