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Yield loss due to weeds in cereals and its large-scale variability in Sweden

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Abstract

Data was used from 1691 field trials testing herbicides to explore large-scale patterns in yield loss in cereals due to weeds in Sweden. More specifically, we evaluated the relative importance of differences between regions, crops, soils, and years. In a negative hyperbolic function, weed biomass explained 31% of the variation in yield loss due to weeds (calculated from yield in herbicide-treated control plots and in weedy control plots). Variation in the residuals was then partitioned between groups of categorical, environmental variables. Geographic region (8) and crops (5) accounted for most of this variation. Crops which ranked from the most to the least affected by weeds, were spring-barley, spring-wheat, oats, winter-wheat and rye. When adjusted for differing weed abundance, clay soil suffered the smallest and organogenic soil suffered the largest yield losses due to weeds. Differences between years were non-significant. The large unexplained variation in yield loss was the likely result of spatial heterogeneity of weeds, other pests and soil within trials. Considering this large variation, it might be difficult to combine in the same field trial, the two aims of most weed trials: estimating the beneficial/detrimental effect of a treatment and the species-wise responses towards it. We described the association between weed communities and situations with high or low losses with ordination methods. In this way, the weeds could be ranked from the most benign to the most detrimental for cereal yields in Sweden. The worst weed species in autumn-sown crops were *Capsella bursa-pastoris* and *Matricaria perforata*, and in spring-sown *Polygonum* spp. and *Galeopsis* spp.

Keywords: Cereal crop; Sweden; Weed; Yield loss

1. Introduction

Crop yields are subject to variability on various time and spatial scales (Fox et al., 1985; Jaynes and Colvin, 1997; Calderini and Slafer, 1998; Calvino and Sandras, 1999; Diaz-Zorita et al., 1999; Andresen et al., 2001; Costa and Bollero, 2001; Tamado, 2001; White et al., 2002). Understanding the causes for this variability is important and explorations of crop yield variability have focused on factors like weather and soils (Jones and Singh, 2000; Olesen et al., 2000; Wheeler et al., 2000; Silim and Omanga, 2001). It is much more difficult to study the contribution of pests to the large-scale variability in yields. It is relatively easy to map the geographic distribution and abundance of pests (Polley and Thomas, 1991; Jørgensen et al., 1996; Hallgren et al., 1999; Tamado and Milberg, 2000; Gladders et al., 2001), but this gives little information

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on actual detrimental effects. These need to be established in field trials comparing yields in plots where the presence, or abundance, of one or more pest organisms has been experimentally manipulated (e.g. Walker, 1983; Zanin et al., 1992; Oerke et al., 1994; Oerke and Dehne, 1997; Tamado et al., 2002). Although results from such studies are relevant locally, or for a particular cropping situation, it is difficult to extrapolate from such trials to explore large-scale spatial and temporal variability in producers' yield losses. First, the experimental conditions chosen might not be representative for a field situation (Walker, 1987; Savary et al., 1998). For example, one pest organism might have been experimentally manipulated and all the others eliminated; and conditions in farmers' fields and on experimental farms might differ. Second, most series of experiments involve only a modest number of years and sites. Third, there is likely to be a publication bias leading to an exaggeration of detrimental responses to pests (Savary et al., 2000). Hence, to explore the magnitude and variability of yield loss due to pests, data from plots in producers' fields are needed (e.g. Friesen and Shebeski, 1960; Taylor and Lill, 1986).

Weeds are notorious yield reducers that are, in many situations, economically more important than insects, fungi or other pest organisms (Savary et al., 1997, 2000). Nevertheless, due to the above-mentioned methodological problems, it is difficult to estimate, on the large spatial and temporal scales, the yield loss caused by weeds singled out from variability caused by weather, soil type or geographic location, and other pests (Oerke et al., 1994).

The yield loss due to weeds is almost always caused by an assemblage of different weed species, and these can differ substantially in competitive ability (e.g. Weaver and Ivany, 1998). Therefore, it is not easy to evaluate the relative importance of different weed species in causing yield loss for producers. Nevertheless, such an evaluation would be valuable both when making management decisions and when setting research priorities.

In the present study, we used data from standardised herbicide trials conducted in cereals in Sweden over 26 years: in total 1691 samples from on-farm trials. We compared yield in un-weeded control plots and plots that had been sprayed with a standard herbicide (a proxy for a weed-free situation). More specifically, we evaluated the differences between regions, crops, soils, and years by using the residuals from a regression of yield loss on total weed biomass. We were also interested in a ranking of weed species, highlighting those associated with large or small losses, and used ordination methods to achieve this.

2. Materials and methods

2.1. The field trials

We compiled information from a total of 1934 herbicide evaluation trials in five cereal crops in a database and used a selection of these trials in the present study. The trials were conducted in Sweden between 1969 and 1994. Each trial consisted of four blocks with randomly-distributed treatment plots within the blocks, and we calculated the treatment means per trial and used these for all further analyses. For each trial, we also noted the geographic region it was located in, the soil type, the crop and the year it was conducted (Table 1).

2.1.1. Treatments

The trials contained many different herbicides and application rates over the years. In all years, however, there were two reference treatments, and it is data from these that are used in the present study. One reference treatment was without any weed control and the other involved the application of a standard herbicide, Oxitril 4 (300 g l^{-1} dichlorprop, 130 g l^{-1} MCPA, 58 g l^{-1} ioxynil, 38 g l^{-1} bromoxynil).

Our analyses of data were based on two assumptions regarding the herbicide treatment: (i) there is no phytotoxic effect on the crop, and (ii) the herbicide controls 100% of the weeds. The latter assumption is not fully realistic as there is selectivity in the herbicide's efficacy. Therefore, we excluded trials with large amounts of difficult to control weeds. Still, it is likely that using the herbicide treatment as a proxy for a weed-free situation underestimates yield loss due to weeds, both through the failure to achieve full weed control and through the possible phytotoxic effect on the crop.

The herbicide was applied at 4.5–5.0 l ha^{-1} when growth commenced in the spring in autumn-sown crops, and at 2.5–3.0 l ha^{-1} when the crop had 3–4

Table 1
Mean residuals per environmental variable in 1483 trials[a]

	Mean residual (%)	95% confidence interval	Number of trials	Percent of weed-rich trials
Geographic region (Fig. 1)				
A	−0.9	−1.7, −0.1	358	58
B	−1.0	−2.2, 0.1	206	64
C	3.5	1.5, 5.4	77	62
D	0.2	−0.7, 1.2	251	50
E	−2.4	−4.4, −0.3	62	47
F	−0.5	−1.3, 0.3	420	34
G	1.5	−0.5, 3.5	98	48
H	6.4	−1.7, 14.6	11	73
Soil type				
Sandy	0.7	−0.7, 2.0	218	57
Fine sand	−0.2	−1.1, 0.7	316	57
Silty	1.1	−0.8, 2.9	66	42
Loamy	−0.8	−1.6, 0.1	311	51
Silty clay loam	−0.7	−1.6, 0.2	314	43
Heavy clay	−0.9	−1.9, 0.1	219	37
Organogenic	4.0	−0.3, 8.3	39	85
Crops				
Rye	−1.4	−2.6, −0.3	203	42
Winter wheat	−1.4	−2.0, −0.7	570	60
Spring wheat	1.4	0.0, 2.7	152	45
Spring barley	1.7	0.8, 2.5	327	40
Oats	−0.1	−1.4, 1.2	231	48

[a] A negative value means a lower yield loss due to weeds than predicted from the function in Fig. 2a. Weed-rich trials had >180 g m^{-2}, the median value in the data set.

leaves in spring-sown crops. This herbicide and these rates are effective against most annual dicot weed species. Less successful control occurs for grass species, perennial species, *Viola arvensis* Murray (autumn-sown crops only) and *Fumaria officinalis* L. (spring-sown crops only). For these weeds (and situations), plots treated with the standard herbicide had more than 25% of the biomass in unsprayed plots (when assessed in late June or early July; Hallgren, 1988). Treatment plot size was 35–50 m^2.

2.1.2. Weeds

In late June or early July, weeds were collected from the two reference treatments, sorted by species, and their fresh weight measured in at least two sample plots (each of 0.25 m^2) per treatment plot. According to the sampling protocol for the trials, the sample area should be sufficiently large to include at least 20 plants or shoots of the most frequent species within the untreated reference plots. Occurrence of a species in a trial was only noted when there were at least five plants or shoots m^{-2} or 5 g m^{-2}: species with smaller amounts were grouped together as ‘‘other weeds’’. Data from the four blocks were pooled to give one value per treatment and trial for each species’ abundance, expressed as fresh weight per square metre.

Since we wanted to use the plots sprayed with the standard herbicide as a proxy for a weed-free situation, and since the herbicide used was less efficient in controlling some weed species (Hallgren, 1988), we excluded trials on one or more of the following criteria: more than 25% of the total weed biomass was made up of: (i) grass species, (ii) perennial species, (iii) *V. arvensis* (autumn-sown crops only) or (iv) *F. officinalis* (spring-sown crops only). These exclusion criteria eliminated 243 trials leaving 1691. For the same reason the parameter ‘‘weed biomass’’ used in the following analysis excluded perennials and grasses, and consequently was made up of dicot, annual weeds (including possible self-seeded oilseed crops).

2.1.3. Yield loss

Grain yield was recorded from the central 24–30 m^2 of the treatment plots in both weedy and herbicide-treated reference plots, and treatment means were calculated before calculating yield loss (YL):

$$\mathrm{YL} = 100\left(1 - \frac{Y_{\mathrm{weedy}}}{Y_{\mathrm{herbicide}}}\right) \tag{1}$$

where Y_{weedy}, the average yield in un-weeded plots and $Y_{\mathrm{herbicide}}$, the corresponding average yield in plots treated with the herbicide.

2.2. Analyses

2.2.1. Yield loss vs. weed biomass

The first analysis involved regression of YL on the weed biomass in weedy plots. We used the negative hyperbolic yield loss function proposed by Cousens (1985):

$$\mathrm{YL} = \frac{ID}{1 + ID/A} \tag{2}$$

where D is the weed biomass, I the initial slope of the curve and A the upper asymptote of the curve.

2.2.2. Contributors to variability in yield loss

Apart from the yield loss caused directly by weeds, our large data set also enabled us to evaluate the relative importance of other variables. Since the data available were categorical (Table 1), we used ANOVA. This was done both on yield loss data and on the residuals from the regression above (Section 2.2.1). We only considered main effects (not all combination of factors existed in the data), and used four factors: (i) year (26 different), (ii) geographic location (eight different; see Fig. 1), (iii) soil type (seven different; see Table 1), and (iv) kind of crop (five different). The purpose of these two analyses was (i) to evaluate whether the factors contributed significantly to variability in yield loss due to weeds, and (ii) to partition the variance between the factors to evaluate their relative contribution to this variability. Since several of the 1691 trials lacked information on soil type, data from only 1483 trials were used in these analyses.

To identify agronomic situations where weeds had greater or smaller impact on yield loss, adjusting for differences in weed abundance, we calculated mean residuals.

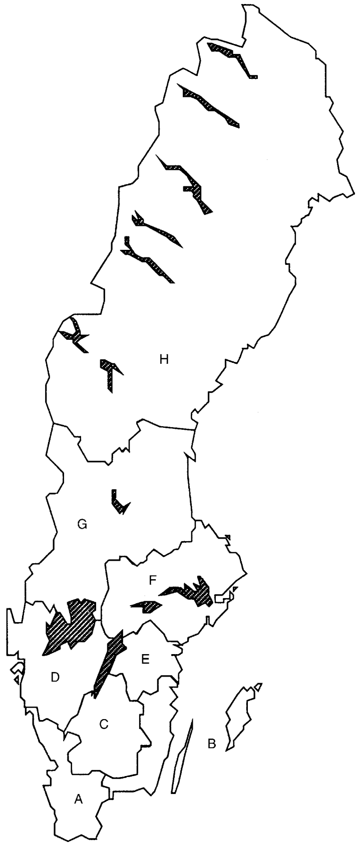

Fig. 1. Map of Sweden with the geographic regions ((A)–(H)) indicated. Shaded areas indicate lakes.

2.2.3. Ranking of weeds according to "weediness"

Canonical correspondence analysis (CCA) is a direct gradient analysis technique that can relate species composition to measured variables (McCune and Grace, 2002; Leps and Smilauer, 2003). We used "yield loss" as the only independent variable, hence ordinating the weed community data along a gradient from low to high yield loss. Partial CCA (pCCA) involves ordinating the data after eliminating the variation explained by one or more covariables (ter Braak, 1988; Legendre and Legendre, 1998). In this case, we used "geographic region" and "crop" as a number of categorical covariables (8 and 5, respectively). Permutation tests evaluated the strength of the relationship between weed species composition and the yield loss gradient (Monte Carlo tests with 999 permutations, hence testing at the 0.1% level). Analyses were conducted with the CANOCO 4 software (ter Braak and Smilauer, 1998).

In many trials, annual dicot weeds had not been identified to species but lumped into an ''other weeds'' category. For the ordination analyses, we excluded trials where ''other weeds'' made up more than 25% of the weed biomass, leaving us with data from 1137 trials. Autumn- and spring-sown crops were analysed separately (644 and 493 trials, respectively).

3. Results and discussion

3.1. Yield loss vs. weed biomass

The mean yield loss in the 1691 trials was 5.4% (95% C.I.: 4.9–5.9) and the median 3.8. Not unexpectedly, yield loss increased with total dicot weed biomass and a function (2) described the data well, explaining 31.3% of the variation in yield loss (Fig. 2). The average yield loss in Swedish cereals, confirmed in studies with hand-weeded plots (Boström, Milberg and Fogelfors, unpublished), was low (e.g. Friesen and Shebeski, 1960; Zanin et al., 1992; Oerke et al., 1994; Bourdot et al., 1996; Oerke and Dehne, 1997). This seems to suggest that, in a short-term economic perspective, there would sometimes be no justification for weed control.

In weed-free, or near weed-free trials, yield loss varied ±20% and this variation did not increase much along the weed biomass gradient (Fig. 2). Hence, a substantial variation existed in ''yield loss due to weeds'' (''preventable yield loss''), even in the

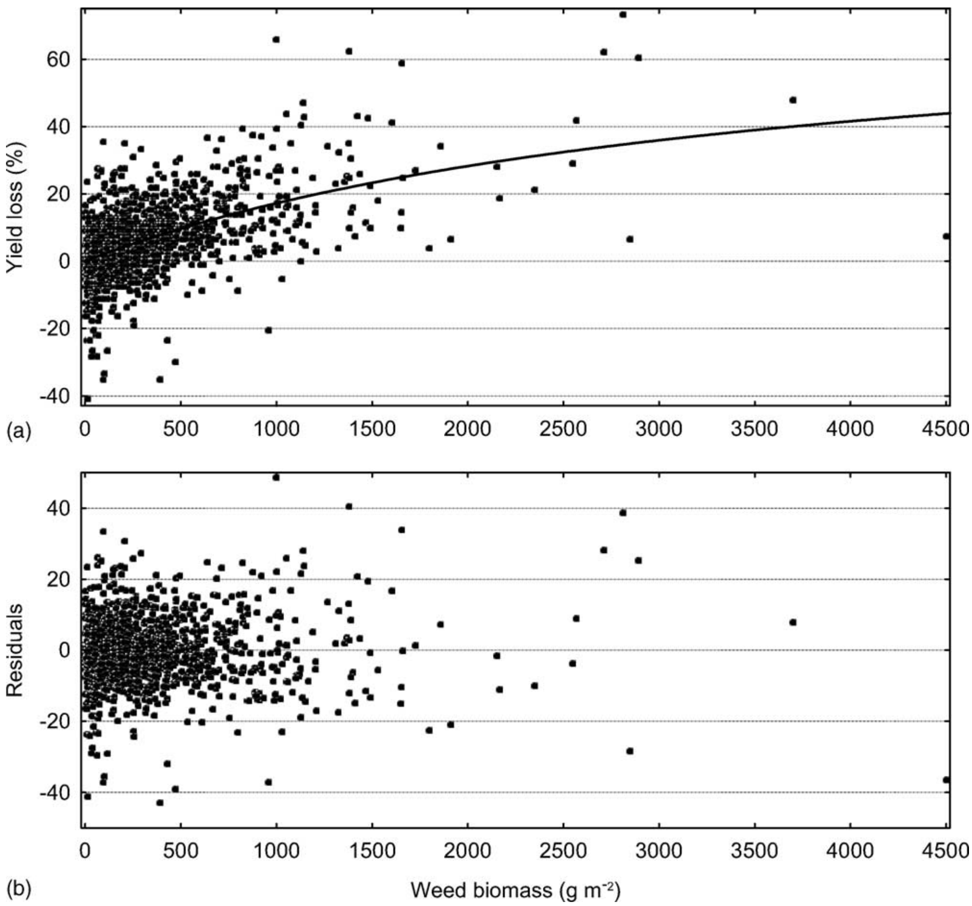

Fig. 2. Yield loss (a) as a function of total weed biomass in 1691 trials; yield loss $= 0.022059x/(1 + (0.022059x)/78.573)$; explained variance: 31.3%. Residuals (b) from the function above.

absence of weeds. This large, base-line variation is important to consider when designing this type of on-farm field experiments and when interpreting results from them. We believe that the main part of this variation manifested in weed-free situations is due to spatial heterogeneity, an aspect that was then only partly accounted for by four replicates and a block design. The spatial heterogeneity of yields within a field trial, as in our data, can be caused by variation in soil type or nutrient availability (Stenger et al., 2002). Personal observations in these trials suggest that small-scale variation in topography or particle size distribution cause spatial variability in water availability. Patches where crop growth has been hampered or damaged by too much or too little water can then be exaggerated by the presence of weeds or other pests. The above-mentioned variation, however, is likely to be smoother and on a larger scale than the uneven distribution of weed biomass (Walter et al., 2002). Weeds are patchily distributed, so the underlying assumption in the present type of design, that ‘‘weed pressure’’ is identical in all plots, is unlikely. It is possible that a non-destructive assessment of weeds before weed control would improve the precision in a trial-wise analysis. If one merges data on all weed species into a single variable, as in the present study, one ignores the fact that weed species differ in the effects they have on the crop. Hence, even if the distribution of the total weed biomass would be relatively even, individual weed species might be patchily distributed. Another source of ‘‘random’’ variation in most weed trial designs is that weeds are harvested in much smaller plots than the crop and often also on different dates (about 1 month time difference in the current trials). Hence, differing spatial scales and harvest dates might contribute to variability.

Results from on-farm trials can be directly extrapolated to a farming situation. Still, it is apparent that there is great uncertainty in an estimated parameter like ‘‘yield loss due to weeds’’, that has to involve two treatment plots and the assumption that the weed flora composition is identical in the two. Considering the large variation (Fig. 2), detailed comparisons of treatment efficacy based on data from a single or a small number of field trials do not allow extrapolation to the farming situation. The trials analysed here were all conducted to compare different herbicides that are all likely to reduce weed biomass by more than 70% (in many cases >90%). Hence, the differences between the relevant treatments should be smaller and pairwise comparisons therefore subject to even larger uncertainty than when comparing a single herbicide with an untreated reference treatment. Consequently, interpretation of results from this type of trials needs to be cautious, especially when dealing with responses of individual weed species.

Another issue to consider is the overall research strategy in weed control trials. We need estimates of potential yield increase as well as information on the response of individual weed species. If we conduct on-farm weed control trials in the ‘‘average’’ farming situation, where weeds are often sparse in Western agriculture, we need a very large number of trials to get meaningful data on responses of individual weed species (Milberg and Hallgren, 2002). On the other hand, if we only conduct trials in weed-rich situations (or artificial situations with a single weed species; Buhler, 1997), it is difficult to extrapolate results to the farming situation for which the control methods are intended. With the low weed population densities occurring today in NW Europe, after decades of herbicide use, it might be appropriate to allow the two aims to be evaluated in separate series of field trials: under normal practice (on-farms) vs. under weed-rich conditions (likely to be artificial).

3.2. Contributors to variability in yield loss

The ANOVA of yield loss, i.e. when differences in weed abundance had not been taken into account, showed greatest differences between soil types and crops, while variation between geographic regions were smaller and that between years insignificant (Table 2). When looking at the ANOVA of residuals, however, geographic location and crops were more important than soil type (Table 2). As the relative explanatory power of soil type was smaller using residuals than yield loss (Table 2), a large part of the variation in yield loss attributed to soil types depended on consistent differences in weed biomass.

The mean residuals (Table 1) revealed agronomic situations where weeds had greater or smaller impact on yield loss, after adjusting for differing weed abundance, and these are discussed below.

Table 2
Partitioning of variance of yield loss and residuals according to years, geographic regions, crops and soil types in 1483 trials[a]

	d.f.	Yield loss			Residuals		
		MS	*F*	*P*	MS	*F*	*P*
Year	25	136.6	1.416	0.08390	48.95	0.725	0.83590
Geographic region	7	357.7	3.709	0.00055	231.6	3.430	0.00121
Soil type	6	666.4	6.909	0.00000	142.5	2.111	0.04936
Crop	4	630.6	6.537	0.00003	302.1	4.474	0.00135
Error	1440	96.46			67.53		

[a] Residuals stem from the regression in Fig. 2.

3.2.1. Years

In Sweden, coefficient of variation (CV) of regional harvest statistics for cereals varies between 17 and 25% (1965–1996; statistics for southern Sweden available at the web page of "Statistics Sweden" http://www.scb.se). Also, variation in total weed biomass can vary greatly between years and CV was 29 and 49% in autumn- and spring-sown crops, respectively, when calculated over a 21-year period (Milberg et al., 2000). Hence, as both yields and weed abundance varies substantially between years, we expected a small but consistent "year" effect on the yield loss attributed to weeds. However, "year" was unable to explain a significant amount of variation in yield loss or in the residuals (Table 2), despite the large number of trials involved.

3.2.2. Geographic regions

Yield loss varied geographically (Table 2), and so did weed biomass (weed-rich trials were unevenly distributed; Table 1). Residuals, however, did also differ between regions (Table 2), indicating that different regions not only have different amounts of weeds, but that their detrimental effect varies too. Regions C and H were the ones where weeds were particularly difficult (high positive residuals in Table 1) while regions A and E distinguished themselves by being less affected by the presence of weeds. Geographic patterns in yield loss due to weeds in Sweden has previously been described by Boström et al. (2003) who recorded increasing loss with increasing latitude.

Why there should be geographic differences in the competitive situation between the weed and crop is unclear. It might be partly explained by differences in agronomic practices (e.g. preferentially-grown crops, crop cultivars chosen, agricultural system dominating), geographic differences in the composition of the weed community (Hallgren et al., 1999) or in prevailing soil types. It is also possible that the "competitive balance" between crop and a weed varies with climate (Oliver et al., 1991; Patterson, 1995; Håkansson, 2003).

3.2.3. Soil type

Soil type explained a lot of the yield loss variation (largest *F*-value in Table 2) but weed biomass was not evenly distributed, with heavy soils having less and organogenic soils more weeds (Table 1). These consistent differences in weed biomass between soil types were also manifested in the fact that the explanatory power of soil type was much larger for the yield loss data than for the residuals (the latter being adjusted for differing weed biomass; Table 2). Nevertheless, soil type still explained a significant part of the variation in the residuals (Table 2), hence, the same amount of weeds had different effects depending on soil type. Mean residuals were largest for organogenic soils, while the more clay-rich soils had small yield loss residuals (Table 1). These differences could be due to the differing weed species composition on soils of different types (e.g. Milberg and Hallgren, 2000), i.e. the proportion of strongly competitive weeds might vary. Also, the "competitive balance" between crop and weeds can shift with soil type (e.g. McGiffen et al., 1997).

3.2.4. Crops

Crops explained a lot of variation in yield loss and especially of the residuals (Table 2). The ranking of crops according to "competitive ability" conforms to the general notions (Håkansson, 1995) with the

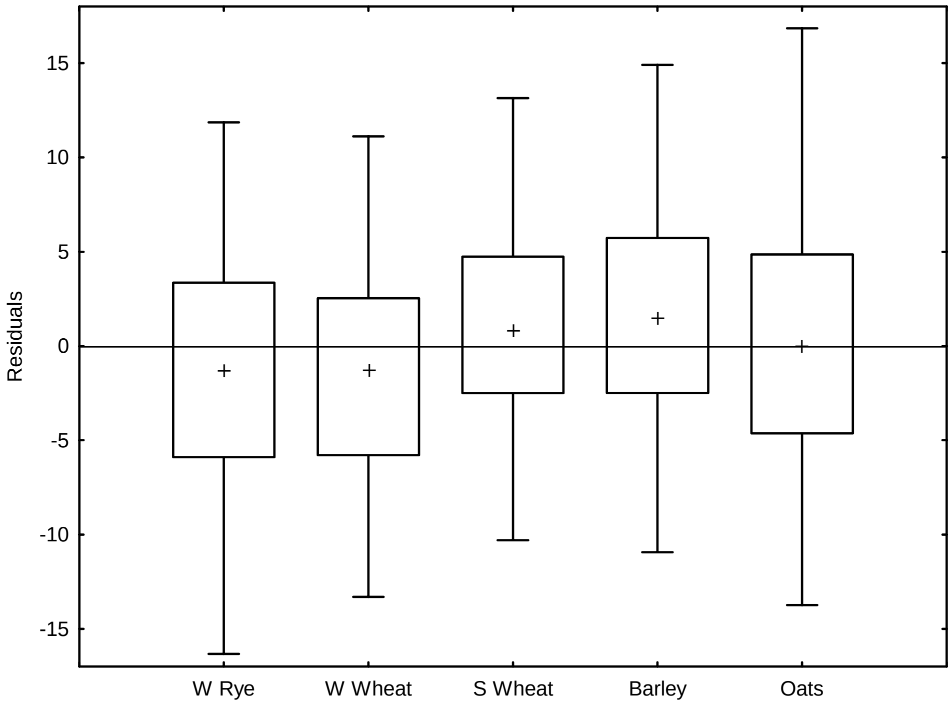

Fig. 3. Yield loss residuals from Fig. 2b summarised by crops. The crosses are the median values; the boxes include 50% of the data points and the bars 90%.

autumn-sown crops as the best and the spring-sown as worst (Fig. 3 and Table 1). The length of the growth period, height of the crop and light interception is likely to be important, but also the fact that summer annual weeds rarely grow in large numbers in autumn-sown crops (Milberg et al., 2000). This is due to at least two factors: the lack of stimulatory soil disturbance in the spring and the density of the crop at the point in time when summer annuals emerge in the spring, giving such weeds a poor starting point.

The ranking of spring-sown crops, according to ‘‘competitive ability’’, differed from previous notions as Håkansson (1995, 2003) considered barley to be the best while our data suggest the worst (Table 1). Nevertheless, it should be noted that variation was large in our data, with substantial overlap of the ranges of residuals recorded per crop (Table 1, Fig. 3), suggesting that selection of crops in itself has a relatively small influence on the subsequent yield loss due to weeds. It is also worth pointing out that since our data span 26 years and a large geographic area, the cultivars used have varied and remain uncontrolled for in our analyses.

The range of the residuals gives an indication of yield stability as affected by weeds. The range was largest in oat (90% range in Fig. 3 was widest). In Sweden, oat is often grown on organogenic soils that often have more weeds (Table 1) and weeds that have greater effect on the crop (see Section 3.2.3), contributing to the observed variability in yield loss. In other areas too, oat yields vary more between years than other cereals (Eghball and Power, 1995).

3.3. Ranking of weeds according to ‘‘weediness’’

Table 3 presents the ranking of weeds, for autumn-sown and spring-sown crops separately, according to their association with yield loss. A low score (negative) means that the species consistently occurred in situations with small yield loss, and the ‘‘explained variance’’ indicates how much of the variation in abundance is mathematically explained by yield loss. For autumn-sown crops, the spring-germinating *Bilderdykia convolvulus* and *Polygonum aviculare* seemed to be the most benign weed species, while

Table 3
Results from ordination tests conducted on data from weed control trials where "yield loss due to weeds" was the only explanatory variable[a]

	CCA score	Explained variance (%)	pCCA score	Explained variance (%)	Weighted abundance
Autumn-sown crops (644 trials)					
Eigenvalue	0.0203		0.0180		
F-ratio	3.038		2.871		
P-value	0.001		0.002		
Biladerdykia convolvulus (L.) Dumort.	−2.73	1.9	−2.01	0.94	203
Polygonum aviculare L.	−1.65	0.68	−1.68	0.62	177
Galium aparine L./*spurium* L.	−0.67	0.28	−0.90	0.44	669
Myosotis arvensis (L.) Hill	−0.33	0.08	−0.26	0.04	628
Stellaria media (L.) Vill.	−0.26	0.14	−0.40	0.29	1528
Veronica spp.	−0.058	0.00	−0.40	0.08	484
Galeopsis spp.	0.39	0.04	0.80	0.15	365
Lamium spp.	0.63	0.16	0.58	0.12	320
Matricaria perforata Merat	0.75	1.1	0.85	1.3	1654
Capsella bursa-pastoris (L.) Medic.	1.59	0.42	1.53	0.35	118
Spring-sown crops (493 trials)					
Eigenvalue	0.045		0.037		
F-ratio	4.72		4.126		
P-value	0.001		0.001		
Lamium spp.	−2.12	2.7	−1.89	1.8	191
Erysimum cherianthoides L.	−1.68	1.4	−1.78	1.3	110
Biladerdykia convolvulus	−1.21	1.7	−0.91	0.78	279
Matricaria perforata	−0.82	0.34	−1.00	0.42	184
Galium aparine/spurium	−0.68	0.22	−0.67	0.18	168
Thlapsi arvense L.	−0.65	0.15	−0.65	0.12	117
Stellaria media	−0.41	0.51	−0.50	0.64	750
Myosotis arvensis	−0.12	0.01	−0.14	0.01	231
Viola arvensis Murray	−0.077	0.01	−0.25	0.10	447
Chenopodium album L./*suecicum* J. Murr.	−0.076	0.02	0.039	0.00	1019
Oilseed crops	0.057	0.00	0.18	0.02	323
Spergula arvensis L.	0.72	0.30	−0.036	0.00	208
Galeopsis spp.	0.77	1.6	0.82	1.5	939
Polygonum lapathifolium L./*persica* L.	2.76	8.1	2.80	6.9	380

[a] A larger CCA or pCCA score means that the species is associated with trials with larger yield losses. Only species with a total weighted abundance larger than 100 are listed. The pCCA was conducted with soil type and crops as covariables.

the facultative winter annuals *Matricaria perforata* and *Capsella bursa-pastoris* were the most detrimental (CCA; Table 3). For spring-sown crops, several species were clearly associated with the gradient from high to low yield loss. Benign species were *Lamium* spp., *Erysimum cherianthoides* and *B. convolvulus*, while *Polygonum lapathifolium/persica* and *Galeopsis* spp. were the most detrimental (Table 3).

Although there were significant relationships between yield loss and weed community, the amount of variation in species' abundances explained by the yield loss gradient remained small (eigenvalues were 0.02; Table 3). The "explained variance" of weed species abundances was also small (Table 3), in most cases less than 2%.

It is noteworthy that there was not much difference between the CCA and the pCCA (Table 3), i.e. before and after eliminating variation that could be mathematically explained by soil type and crops. This suggests a relatively robust ranking of "weediness" that should be consistent over various agricultural situations in Sweden and neighbouring areas.

Single-weed-species/crop tests are one way of ranking species according to competitive ability (e.g. Weaver and Ivany, 1998). However, since weed species very rarely occur alone, such an approach ignores interactions among species and in their effects on the crop. Also, the artificial weed densities used in single-weed-species/crop tests might not be realistic for a field situation. A potentially more realistic ranking can be achieved by using information on natural weed assemblages and yield loss estimates from a wide range of situation (e.g. Taylor and Lill, 1986; Swinton et al., 1994). In the present study, the ranking was achieved with the aid of an ordination method, i.e. mathematically relatively insensitive to the fact that most species are missing in most samples, something that otherwise enables only the most abundant species to be evaluated. By using a wide range of field data and relating observed weed communities to a ''yield loss gradient'', we reached a seemingly stable solution (CCA and pCCA gave similar results; Table 3). Scores from the CCA, or other ordination method, could be used to give different weight to weed species in models developed to assist management decisions and that use species-wise data as input (e.g. Berti and Zanin, 1994; Kwon et al., 1998). However, tests need to be done to evaluate whether a ''global'' ranking like the one in Table 3 might lead to improved yield loss predictions.

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