PREDICTION OF GRAIN YIELD OF SPRING BARLEY VARIETIES BY DISEASE AND GROWTH CHARACTERISTICS FROM VCU TESTING

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Abstract

Fifty spring barley varieties grown under organic as well as conventional growing conditions in experimental fields in four combinations of year and site were studied. The yield varied greatly within and between environments (years and sites) and systems. Furthermore, the variation among varieties was substantial and differed among different environments and systems. Associations between observed grain yield of these varieties and disease and growth characteristics assessed in the official conventional variety testing were compared between the organic and the conventional system. Using factorial regression analysis, the best model was found for predicting the observed grain yield each year from these characteristics in the previous year. In this model, the residual variance component for varieties was lower for observations from the conventional growing system than from the organic growing system, implying that the VCU-characteristics better predicted the results from conventional growing system. The implications for organic variety testing are discussed.

Introduction/Problem

Modern spring barley varieties have been developed with the aim of combining high productivity and standardised product quality under high-input conditions. The organic growing system is a system where pesticides and inorganic fertilizers are generally not allowed. Hence, biotic and abiotic stresses have to be controlled by growing appropriate varieties and by good farm management practices. An important question is whether modern spring barley varieties possess the right combinations of traits to ensure a stable and acceptable yield of good quality when grown under different organic growing conditions. We know that varieties often perform and yield differently in different environments due to genotype-environment interactions, so it may be important to evaluate characteristics of varieties in organic as well as in conventional farming systems. However, it remains unclear to date whether the differences between conventional and organic growing systems are large enough to justify testing of varieties in both environments.

In many countries, varieties are officially evaluated on a number of traits for Values of Cultivation and Use (VCU-testing). This evaluation takes place under conventional conditions and the traits selected are those of relevance for conventional farming. However, in a few countries (e.g. The Netherlands and Austria) testing is also performed under organic conditions. In this case, characteristics of special relevance under organic growing conditions are included. Here we investigate how well disease and growth characteristics from conventional VCU-testing may predict grain yield for a large number of varieties grown under specific organic as well as conventional growing conditions without fungicides.

Methodology

Field trials were conducted on experimental research fields at two Danish locations (Flakkebjerg and Foulum) in two years (2002, 2003) in two types of growing systems resembling either organic or conventional (without use of fungicides) conditions chosen to be optimal for each site and year. As a consequence, the two types of system differed mainly in type and amount of nutrients available and in the way of controlling weeds. The four combinations of years and sites are denoted 'environments'. More than 100 varieties with different expectations for performance in organic systems were included in the trials,

representing current varieties and new varieties becoming available, as well as varieties from other sources regarded as potential 'organic' candidates.

Varietal characteristics of 50 of these varieties were obtained from official conventional VCU-testing for each of the two years 2001 and 2002. These consist of 1) disease severity assessment for each variety for each of four prevalent diseases (barley powdery mildew, barley leaf rust, scald, and net blotch) observed in trials without fungicide treatment; and 2) other growth characteristics assessed in trials with fungicide treatment: culm length, tendency to lodging, tendency to breakage of straw and ear, and date of ripening (Anonymous 2001,2002). In addition, a combined measure for the years 2002-2004 for competitive ability of each variety against weeds (Hansen 2002) calculated from information on canopy height and Leaf Area Index from herbicide-treated trials was included as a competition index. This index has been part of the VCU-testing since 2002.

Variation in grain yield for the 50 varieties in the four enviroments and two types of systems was analysed by analysis of variance, including main effects as well as interactions among the independent variables: varieties, type of system and environment (year x site).

Associations between grain yield and varietal characteristics were analysed by means of slightly modified factorial regression analysis (Denis, 1988). In the analyses shown here each regression coefficient was described as a sum of one or more components, a general one, three specific for the environment (separated into year, site and interaction) and the one specific for the growing system. At first, the parameters of the model were calculated with all varietal characteristics included.

$$Y_{ijkln} = \mu_{jkl} + \sum_m (\alpha_m + \beta_{jm} + \gamma_{km} + \delta_{jkm} + \eta_{lm}) x_{ij'm} + V_{il} + U_{ijkl} + E_{ijkln}$$

Y_{ijkl} = observed yield measurement for variety i, in year j, location k, system l, and replicate n

$x_{ij'm}$ = registered $m'th$ characteristic (or its squared value) from VCU-testing for variety i in year $j' = j - 1$.

For m = 'weed competitive index' values for the two years are identical

Squared terms were only included for 'barley powdery mildew' and 'competition index'

For disease characteristics the 3rd root of the registered characteristics were used

μ_{jkl} = mean yield in year j, location k and system l

$\alpha_m + \beta_{jm} + \gamma_{km} + \delta_{jkm} + \eta_{lm}$

= regression coefficient for the association between yield and $m'th$ characteristic

V_{il} and U_{ijkl} are a random effect of residual variety effect and residual interaction effect which is assumed normal distributed with mean 0 and variance, σ^2_{Vl} and σ^2_{El}, respectively.

E_{ijkln} is the error associated with the experimental design which is assumed normal distributed with mean 0 and variance σ^2_E

The model was reduced step by step by leaving out the least significant term until all remaining terms were significant at the 5% level of significance. In the reduction steps some restrictions were imposed to ensure that higher order terms were removed before lower order terms could be considered as candidates for removal. Terms including interactions were assumed to be of higher order than their components, and square terms were considered to be of higher order than linear terms.

Results and brief discussion

The observed grain yield varied between the environments and systems with the highest yield in the conventional system at Flakkebjerg in 2003 and the lowest yield in the organic system at Flakkebjerg in 2002 (Table 1). In both years, the site Flakkebjerg was superior in the conventional system.

Table 1. Mean grain yield (hkg/ha) for 50 varieties according to system and environment

	2002		2003	
	Foulum	Flakkebjerg	Foulum	Flakkebjerg
Conventional	51.7	55.9	54.2	63.2
Organic	55.7	50.9	53.8	53.8

The analysis of variance showed a very significant effect for all main effects and interactions except for year*site*system (Table 2). The largest contribution to variation in yield measured by mean squares was due to the interaction between site and system. The largest interaction between varieties and any of the other factors was between varieties and sites; a somewhat smaller value was found between varieties and years and an even smaller one between varieties and systems.

Table 2. Analysis of variance for observed grain yield in different growing systems and environments

Source	DF	Mean Square	F Value	Pr >F
year	1	731.58	196.50	0.0000
system	1	722.82	194.15	0.0000
site	1	438.80	117.86	0.0000
site*system	1	2002.33	537.81	0.0000
year*site	1	577.28	155.04	0.0000
year*system	1	479.97	128.92	0.0000
year*site*system	1	0.06	0.02	0.8783
variety	49	108.80	29.22	0.0000
variety*site	49	12.10	3.24	0.0000
variety*year	49	11.07	2.98	0.0000
variety*system	49	10.20	2.75	0.0000
variety*year*system	49	9.94	2.68	0.0000
variety*site*system	49	8.88	2.39	0.0000
variety*year*site	49	7.46	2.00	0.0001
variety*year*site*system	49	8.74	2.35	0.0000

Factorial regression analysis showed that many VCU varietal characteristics (all disease assessments, ripening date, and competition index) had a significant effect on prediction of grain yield the following year (Table 3). For powdery mildew and net blotch, the regression coefficients were significantly different between sites and years, respectively; none of the coefficients was significantly different between growing systems. The latter implied that the best linear combination of VCU-characteristics to predict grain yield production were identical in the two systems.

Table 3. Significant parameter values in the factorial regression

	General effects		Changes in linear effect for environment			
	Linear	Quadratic	2002	2003	Flakkebjerg	Foulum
Powdery mildew	3.53	-3.49			0.59	-0.59
Leaf rust	-3.52					
Net blotch	-6.54		1.27	-1.27		
Scald	1.62					
Date of ripening	-1.14					
Competition index	5.64	-0.028				

When this best regression model was used for predicting yield, the residual variance component for varieties was lower for observations from the conventional compared with the organic growing system (Table 4). Thus, the characteristics observed in the official conventional VCU-testing, including the competitive index, better predicted the grain yield of varieties within the conventional growing system. In conclusion, a variation of 2.5 hkg/ha (organic) compared to 2.1 hkg/ha (conventional) was not accounted for in the prediction of variety yield. The interaction between varieties and environments was, on the other hand, better described by the VCU-data for the organic than for the conventional system. This may be because the prediction of difference in yield between two varieties in one environment compared to another environment was better in the organic system.

Table 4. Variance components for variation among varieties and for interaction between varieties and environments when variety characteristics are used to describe grain yield

	Variance component	
	Variety	Variety×environment
Conventional system	4.45	6.39
Organic system	6.19	4.63

The results depend on the varieties and systems chosen. A broad spectrum of varieties was included; however, most of the varieties were conventional varieties bred for high-input conditions. Further, the systems considered may differ from each other by less than actual conventional high-input farms compared with certified organic farms. Therefore, even bigger differences may be found between the explanatory value of VCU-test characteristics for conventional and organic systems.

Conclusions

Many conventional VCU-testing varietal characteristics had a significant influence on grain yield; this influence was for most characteristics not significantly different for the different environments and was not significantly different for the two systems. However, the traits used for official variety testing that were shown to have a significant influence on the prediction of yield the following year described the observed grain yield better in the conventional system considered than in the organic system. This indicates that a traditional VCU-testing supplemented with the competition index as defined by Hansen (2002) is not fully sufficient to predict variety yield when varieties are grown under organic farming conditions. Other characteristics of special importance for organic farming may be included in the conventional variety testing, e.g., nutrient uptake efficiency. However, the final decision for implementation of independent organic VCU-testing is based on an evaluation of the economic costs and benefits, including assessment of quality traits. The possible establishment of organic VCU-testing in Denmark starting in 2006 will be decided partly based on these trials.

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