Understanding effects of multiple farm management practices on barley performance

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ABSTRACT

Because of the complexity of farming systems, the combined effects of farm management practices on nitrogen availability, nitrogen uptake by the crop and crop performance are not well understood. To evaluate the effects of the temporal and spatial variability of management practices, we used data from seventeen farms and projections to latent structures analysis (PLS) to examine the contribution of 11 farm characteristics and 18 field management practices on barley performance during the period 2009–2012. Farm types were mixed (crop-livestock) and arable and were categorized as old organic, young organic or conventional farms. The barley performance indicators included nitrogen concentrations in biomass (in grain and whole biomass) and dry matter at two growing stages. Fourteen out of 29 farm characteristics and field management practices analysed best explained the variation of the barley performance indicators, at the level of 56%, while model cross-validation revealed a goodness of prediction of 31%. Greater crop diversification on farm, e.g., a high proportion of rotational leys and pasture, which was mostly observed among old organic farms, positively affected grain nitrogen concentration. The highest average grain nitrogen concentration was found in old organic farms (2.3% vs. 1.7 and 1.4% for conventional and young organic farms, respectively). The total nitrogen translocated in grain was highest among conventional farms (80 kg ha−1 vs. 33 and 39 kg ha−1 for young and old organic farms, respectively). The use of mineral fertilizers and pesticides increased biomass leading to significant differences in average grain yield which became more than double for conventional farms (477 ± 24 g m−2 for young and old organic farms, respectively). In addition to the importance of weed control, management of crop residues and the organic fertilizer application methods in the current and three previous years, were identified as important factors affecting the barley performance indicators that need closer investigation. With the PLS approach, we were able to highlight the management practices most relevant to barley performance in different farm types. The use of mineral fertilizers and pesticides on conventional farms was related to high cereal crop biomass. Organic management practices in old organic farms increased barley N concentration but there is a need for improved management practices to increase biomass production and grain yield. Weed control, inclusion of more leys in rotation and organic fertilizer application techniques are some of the examples of management practices to be improved for higher N concentrations and biomass yields on organic farms.

1. Introduction

Nitrogen (N) is one of the major factors limiting grain yield in organic farming systems (Berry et al., 2002; Bilsborrow et al., 2013). Mineralisation of nitrogen from organic matter is relatively more important in organic systems than in conventional systems (Stockdale et al., 2002) since in conventional systems around 50% of crop N uptake comes from mineral fertilizer applied that year (Jarvis et al., 1996). The importance of different N sources varies with cropping system. For example, in organic wheat N in microbial biomass was found to be the dominant N source, supplying between 46 and 172 kg N ha−1 (Petersen et al., 2013). Despite the significant
differences in rate and pattern of N supply from organic matter and organic fertilizers in different cropping systems, their combined relationships with crop performance including crop yields are not well understood. Optimal supply of N and uptake from organic sources are difficult to control and predict as various factors such as management, the cultivar grown, microbial population and environmental conditions (e.g. temperature, soil moisture) interact and influence the mineralization process in organic sources (Jarvis et al., 1996, Shepherd et al., 1996). All these interactions make it difficult to manage the synchrony between N available from organic sources via mineralisation and the demand of the crop. Nitrogen sources in organic farming include atmospheric deposition, biological nitrogen fixation, organic fertilizers produced both on farm (e.g., crop residues or cover crop incorporation), all kinds of manure on mixed farms and off-farm (e.g. purchased manure, compost, etc.). Different N sources and application methods, on both organic and conventional farms, are often used to target improved N supply to the crop and thus improved performance (e.g. grain yield and quality at harvest).

The use of mineral fertilizers on conventional farms makes it easier to supply nutrients according to the crop needs than on organic farms where mineral fertilizers are not allowed. In organic farming systems, the N released from applied organic materials or incorporated residues may not necessarily translate into crop uptake because of the management and environment interactions mentioned above (Jarvis et al., 1996; Shepherd et al., 1996). This mismatch between N availability and supply in the short and the long term may lead to yield losses and inadequate grain quality, and to N losses from the system through leaching (Stopes et al., 2002) or emissions (Brozyna et al., 2013). However, leaching can also occur when applying mineral nitrogen (Stopes et al., 2002; Benoit et al., 2014), especially if applied in excess of crop needs (Riley et al., 2001). A range of management practices are used to keep N losses low and use N efficiently at the farm level, which positively impact the use of N by the crop through nitrogen use efficiency or nitrogen uptake. These management practices include straw incorporation (Thomsen and Christensen, 2004), use of cover crops (Constantin et al., 2010) and optimisation of organic matter application techniques (Huijsmans et al., 2003).

Evaluating the long-term effects of management practices on nitrogen supply and crop uptake is challenging. Although long-term experiments are necessary to generate relevant information on processes that are slow (Bergkvist and Öborn, 2011; Robertson et al., 2014), it is often difficult to maintain the personnel and financial resources needed to conduct such experiments over several decades. On-farm data collection is another useful way to evaluate the long-term effects of management. It has the advantage that the collected data incorporates responses to the ever-changing environment and market to which farmers need to adjust (Martin, 2015) rather than following management practices that are often inflexible, like pre-defined study factors and crop rotations in long-term experiments. Using dynamic models (Li et al., 2010; Grechi et al., 2012; Shah et al., 2013) is also an alternative way of understanding the impact of management practices on a range of agro-ecosystem services.

In recent years there have been several studies evaluating the effect of farm management practices on regulation and maintenance ecosystem services (Williams and Hedlund 2013; Bengtsson, 2015; Birkhofer et al., 2016). However, less attention has been given to the evaluation of provisioning ecosystem services that include crop performance and yield for food production (see e.g. van den Belt and Blake, 2014). The spatial and temporal variability in terms of multiple interacting farm management practices most likely influences crop performance. There is therefore a need to evaluate simultaneous effects on several performance indicators. We find Projection on Latent Structures (PLS) (Eriksson et al., 2006a,b,c) to be an easy and straightforward multivariate method to relate multiple management practices to crop performance indicators.

The main objective of this study was to evaluate the effect of multiple management practices on several indicators of spring barley performance. We used a sample of 17 farms, with a high degree of variability as measured by 11 selected farm characteristics and 18 farm and field management practices to indicate which management practices were most important for crop performance. Another aim of this study was to examine the extent to which crop performance can be predicted from information on current and recent past management practices. We used fields of organic and conventional barley (Hordeum vulgare L.) varying in the time since conversion to organic farming in order to include as many divergent management practices as possible from within the studied region while focusing on a standard crop. We focussed on biomass at two growth stages, including grain biomass (yield), and their corresponding N concentrations as a way to follow the N uptake. As a non-destructive N level indicator we used the SPAD technique to investigate how the chlorophyll and N concentration varied through the growing season.

2. Material and methods

2.1. Farm and field descriptions

Seventeen farms in the province of Uppland, in East-Central Sweden were selected for the study. The farms selected included conventional farms as well as organic farms, with varying time since conversion to organic farming (from 1 to 25 years) to be able to evaluate long-term effects of organic farming practices. The farms consisted of 6 conventional farms (CF) and eleven organic farms; five young organic farms (YOF) with less than 6 years since transition from conventional farming practices, and six old organic farms (OOF) with 11–26 years since transition. Thirteen farms were mixed arable and livestock systems with cattle, pigs and/or horses, while four of them were arable farms (farms # 4, 6, 8 and 10 in Table 1).

Land use in Uppland is characterised by a mixture of arable fields, pastures and forests (Jonason et al., 2011). The farms were selected to represent the breadth of the landscape complexity gradient in the region. The distribution went from complex landscapes with non-crop habitats and forested areas to more homogenous landscapes with mainly arable land. Farm size varied from 34 to 700 ha and the average size was 344 ha for CF, 143 ha for YOF and 96 ha for OOF. The major soil type used for agriculture in this region is the Eutric Cambisol (Sarapatka, 2002) with a high clay content. The top soils of arable fields of the study farms had on average 3.5% total carbon, 0.31% total nitrogen and a pH of 6.6. Detailed information on each farm can be found in Table 1. The selected organic farms were certified by KRAV, the most common Swedish Trademark for organic products.

On each farm, one barley field was selected as a standard study crop. Barley and winter wheat are the main cereal crops in Uppland in terms of cultivated area, but spring barley is better distributed among different farm types; arable farms, mixed farms and specialist livestock production farms. For each field, the landscape complexity around the field was determined according to the definition of landscape heterogeneity index (LHI, see Table 1) by Birkhofer et al. (2016) and Rader et al. (2014). In the case of more than one barley field on a given farm, a high landscape index (in the radius of 1 km) was the main criterion for choosing which barley field to study in order to increase the landscape complexity gradient when examining diversified management practices between conventional and organic farms. The LHI index is based on the proportions of semi-natural grassland and field border in the surroundings of the field. Among the 17 farms, 12 were part of the study on biodiversity by Jonason et al. (2011), and in order to increase the sample size, five additional farms were included in 2012. These new fields did not have the LHI determined in the Jonason et al. (2011) study, although they were situated in similar landscapes. However, the PLS method can handle occasional missing values, and hence we included these farms despite the missing LHI values.
A questionnaire survey and semi-structured interviews were conducted with the farmers in late 2011 and 2012 to obtain data on management practices during the period 2009–2012. Table 2 lists all the variables that were used in the analysis from 132 to 29 variables, of which variables in the analysis. In this way we reduced the number of possible variables to reduce the number of independent variables (y). The method consists of relating two data matrices X and Y of explanatory variables (x) was related to the set of barley performance indicators (Y-matrix, 7 variables). PLS is an extension of Principal Component Analysis (PCA) and it derives its usefulness from its ability to analyse data with many, noisy, collinear, and redundant variables. Similar aggregation of data was carried out on many management practices including information on the use of organic fertilizers, mineral fertilizers and pesticides used over the years and within a year. To complete the measurements, N yields at the time of harvest (BBCH 21), DM of straw and grain were separated. Samples were taken at a minimum of 20 m from the edge of the field. In addition, chlorophyll content ("greenness") as SPAD measurements were taken with a handheld chlorophyll meter (SPAD 502 Plus) on a weekly-basis from the 4th June until 16th August. Chlorophyll content in leaves is an indirect measure that correlates well with nitrogen concentration (Chang and Robison, 2003; Lemaire et al., 2008). Percentage weed cover was visually estimated when SPAD measurements were taken. An average percentage weed cover estimated on 18, 25 July and 2 August 2012 (for which data was complete for all the fields) was included as a variable affecting the BPIs beside the management practices. At the harvest, BBCH 87, DM of straw and grain were separated. Samples were taken at a minimum of 20 m from the edge of the field. In addition, chlorophyll content in leaves is an indirect measure that correlates well with nitrogen concentration (Chang and Robison, 2003; Lemaire et al., 2008). Percentage weed cover was visually estimated when SPAD measurements were taken. An average percentage weed cover estimated on 18, 25 July and 2 August 2012 (for which data was complete for all the fields) was included as a variable affecting the BPIs beside the management practices. At the harvest, BBCH 87, DM of straw and grain were separated. Samples were taken at a minimum of 20 m from the edge of the field. In addition, chlorophyll content in leaves is an indirect measure that correlates well with nitrogen concentration (Chang and Robison, 2003; Lemaire et al., 2008). Percentage weed cover was visually estimated when SPAD measurements were taken. An average percentage weed cover estimated on 18, 25 July and 2 August 2012 (for which data was complete for all the fields) was included as a variable affecting the BPIs beside the management practices. At the harvest, BBCH 87, DM of straw and grain were separated. Samples were taken at a minimum of 20 m from the edge of the field. In addition, chlorophyll content in leaves is an indirect measure that correlates well with nitrogen concentration (Chang and Robison, 2003; Lemaire et al., 2008). Percentage weed cover was visually estimated when SPAD measurements were taken. An average percentage weed cover estimated on 18, 25 July and 2 August 2012 (for which data was complete for all the fields) was included as a variable affecting the BPIs beside the management practices. At the harvest, BBCH 87, DM of straw and grain were separated. Samples were taken at a minimum of 20 m from the edge of the field. In addition, chlorophyll content in leaves is an indirect measure that correlates well with nitrogen concentration (Chang and Robison, 2003; Lemaire et al., 2008). Percentage weed cover was visually estimated when SPAD measurements were taken. An average percentage weed cover estimated on 18, 25 July and 2 August 2012 (for which data was complete for all the fields) was included as a variable affecting the BPIs beside the management practices. At the harvest, BBCH 87, DM of straw and grain were separated. Samples were taken at a minimum of 20 m from the edge of the field. In addition, chlorophyll content in leaves is an indirect measure that correlates well with nitrogen concentration (Chang and Robison, 2003; Lemaire et al., 2008).
improves with relevant X-variables that explain the most variation of Y variables. Therefore, we used the filter method with the variable importance in the projection (VIP) for variable selection (Eriksson et al., 2006b; Mehmood et al., 2012). This means that after the first model run including all the 29 X-variables, all variables with a VIP less than 1 were eliminated. A second model run with the remaining variables was done. The PLS model diagnostic of its appropriateness, i.e. a model with optimal balance between fit and predictive ability (see Eriksson et al., 2006c), was based on parameters \( R^2_Y \) (explained variation) and \( Q^2_Y \) (predictive ability). \( R^2_Y \) is a quantitative measure of the goodness of fit telling us how well we are able to mathematically reproduce the data at hand. The predictive ability \( Q^2_Y \) is how reliably we can predict the outcome of future experiments with parameters obtained from the present data. Cross-validation (CV) is a practical and reliable way to test the significance of PLS models that has become a standard in multivariate analysis (Eriksson et al., 2006c). With CV the basic idea is a resampling method where each object at a time is left out and the differences between the fitted error and the predicted error are evaluated. In PLS, the terms \( R^2_Y \) and \( Q^2_Y \) generally refer to the model performance of the Y-data, the responses, rather than the X-data, the predictors, as is the case in PCA. There is a trade-off between the goodness of fit (\( R^2_Y \)) and the goodness of prediction (\( Q^2_Y \)) in the way that at a certain model complexity, during the elimination of the less important variables, we obtain the most valid model exhibiting the optimal balance between fit and predictive ability. We obtained the model fit ability (cumulative \( R^2_Y \), denoted \( R^2_X \) (cum)) and the model predictive ability (cumulative \( Q^2_Y \), denoted \( Q^2_X \) (cum)) for all the dependent variables together and for individual dependent variables. Eriksson et al. (2006c) suggests that a PLS model fit that exceeds 50% of explained variation (goodness of fit; \( R^2_Y > 0.5 \)) is generally acceptable but could be lower depending on the data at hand (Triba et al., 2015). It is also desirable that the difference between the goodness of fit and the goodness of prediction (\( Q^2_Y \)) is between 0.2 and 0.3 for good prediction level (Eriksson et al., 2006c). The goodness of fit and prediction of each response variable are obtained with PLS coefficients and the root mean square error (RMSE, %) was used to assess the predictive ability. The PLS analyses were performed with the software SIMCA-P V 13.0 (Umetrics, Umeå, Sweden). To further test the effects of farm types (CF, YOF and OOF) on BPs, we used analysis of variance (ANOVA) and simple regression and analysis of covariance (ANCOVA). The latter elucidated the farm type effects on SPAD values. SPAD measurements at the late growth stages were excluded (after BBCH 80) because their values declined significantly due to senescence. The statistical software R, version R3.0.2 (R Core-Team, 2013) was used for simple regression, ANCOVA and ANOVA.

### Table 2

The 29 variables used in the projection to latent structures (PLS): i) farm description, management practices (MP) at the farm and field levels. Each variable has a symbol, its unit given in parentheses, the variable ranges and an explanation. Some of the variables including dummy variables, frequency or indices were dimensionless (–) and their ranges are not given.

<table>
<thead>
<tr>
<th>Farm level description and MP</th>
<th>Symbol (Unit)</th>
<th>Range</th>
<th>Variable explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Time since transition</td>
<td>TST (year)</td>
<td>0–26</td>
<td></td>
</tr>
<tr>
<td>2. Farm size</td>
<td>Size (ha)</td>
<td>34–700</td>
<td></td>
</tr>
<tr>
<td>3. Landscape heterogeneity index 1 km radius</td>
<td>LHI (–)</td>
<td>–1.4–2.0</td>
<td>LHI = ( \sin 45 \times (\text{standardized proportion of SNG} + \text{standardized proportion of field border}) )</td>
</tr>
<tr>
<td>4.Proportion of rotational lys</td>
<td>Leys (%)</td>
<td>0–64</td>
<td>Farm area including pasture and permanent pasture</td>
</tr>
<tr>
<td>5. Proportion of cereal crops</td>
<td>Grains (%)</td>
<td>18–95</td>
<td>Farm area including pasture and permanent pasture</td>
</tr>
<tr>
<td>6. Proportion of other crops</td>
<td>Oocrops (%)</td>
<td>0–35</td>
<td>Farm area including pasture and permanent pasture</td>
</tr>
<tr>
<td>7. Presence of pasture</td>
<td>Pasture (–)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8. Area with organic fertilizers</td>
<td>OFert-area (ha)</td>
<td>0–380</td>
<td>Dummy variable: present (1) or absent (0)</td>
</tr>
<tr>
<td>9. Amount of organic fertilizers</td>
<td>OFert (ton ha(^{-1}))</td>
<td>0–30</td>
<td></td>
</tr>
<tr>
<td>10. Livestock density index</td>
<td>LDI (–)</td>
<td>0–1.5</td>
<td>A measure of livestock per hectare of utilized agricultural area including pasture and permanent pasture</td>
</tr>
<tr>
<td>11. Straw and residue management</td>
<td>SRM (–)</td>
<td>Scale from 1 to 3: where the highest value 3 = always incorporated, 2 = sometimes incorporated and 1 = removed from the farm</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Field level MP (2009–2011)(^{ab})</th>
<th>Symbol (Unit)</th>
<th>Range</th>
<th>Variable explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>12. Frequency of organic fertilizer (OFe)</td>
<td>Freq-OFe (–)</td>
<td>0–1 numbers of organic fertilizer applications over the 3 years divided by 3</td>
<td></td>
</tr>
<tr>
<td>13. OFe application technique</td>
<td>OFe-AT (–)</td>
<td>Scale 1–2: where 2 = Broadcasting and mulched, 1 = either broadcasting or mulched and 0 = none of the two</td>
<td></td>
</tr>
<tr>
<td>14. Mineral N in average</td>
<td>Min-N (kg ha(^{-1}))</td>
<td>0–175</td>
<td>Average of N application over the 3 years</td>
</tr>
<tr>
<td>15. Mineral PK applied</td>
<td>Min-PK (–)</td>
<td>Dummy variable: used (1) or not used (0)</td>
<td></td>
</tr>
<tr>
<td>16. Pesticide application</td>
<td>PEST (–)</td>
<td>Dummy variable: used (1) or not used (0)</td>
<td></td>
</tr>
<tr>
<td>17. Straw and residue management</td>
<td>STR-M (–)</td>
<td>Scale 0–2: where 2 = incorporated and mulched, 1 = either incorporated or mulched and 0 = none of the two</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Field level MP in 2012;</th>
<th>Symbol (Unit)</th>
<th>Range</th>
<th>Variable explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>18. Amount of OFe</td>
<td>Am-OFe12 (ton ha(^{-1}))</td>
<td>0–30</td>
<td></td>
</tr>
<tr>
<td>19. OFe application technique</td>
<td>OFe-AT12(–)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>20. Mineral N application</td>
<td>Min-N12 (kg ha(^{-1}))</td>
<td>0–175</td>
<td>Scale 1–2: where 2 = Broadcasting and mulched, 1 = either broadcasting or mulched and 0 = none of the two</td>
</tr>
<tr>
<td>21. Straw &amp; residues left on the field</td>
<td>SMR-L12 (–)</td>
<td>Dummy variable: left (1) and removed (0)</td>
<td></td>
</tr>
<tr>
<td>22. Sowing date</td>
<td>Sowing (DOY)</td>
<td>121–145</td>
<td>Day of the year</td>
</tr>
<tr>
<td>23. Seed rate sown</td>
<td>Seed (( \text{kg m}^{-2} ))</td>
<td>180–220</td>
<td></td>
</tr>
<tr>
<td>24. Pea as a preceding crop to barley</td>
<td>PC-pea (–)</td>
<td>Dummy variable: pea (1) or other (0)</td>
<td></td>
</tr>
<tr>
<td>25. Leys as preceding crop to barley</td>
<td>PC-leys (–)</td>
<td>Dummy variable: leys (1) or other (0)</td>
<td></td>
</tr>
<tr>
<td>26. Cereals as preceding crop to barley</td>
<td>PC-cereal (–)</td>
<td>Dummy variable: cereals (1) or other (0)</td>
<td></td>
</tr>
<tr>
<td>27. Use of pesticide</td>
<td>PEST-12 (–)</td>
<td>Dummy variable: used (1) or not used (0)</td>
<td></td>
</tr>
<tr>
<td>28. Barley undersown with grass/clover</td>
<td>US-12 (–)</td>
<td>Dummy variable: undersown (1) or not (0) of barley</td>
<td></td>
</tr>
<tr>
<td>29. Percentage weed cover*</td>
<td>Weed (%)</td>
<td>0–33</td>
<td>Averge of the percentage weed cover of 3 assessments</td>
</tr>
</tbody>
</table>

\(^{a}\) The LHI index is based on the proportions of semi-natural grassland and field border in the surroundings of the field (see text for references).

\(^{b}\) Indicator of the efficiency of weed control.

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14 management practices retained (Table 3). In addition, the relation-
ship between management practices and barley performance
indicators with the retained management practices associated with
model parameters given in Table S1.

Among the 14 important management practices retained, five were
at the whole farm level, two at the field level 2009–2011 and seven at
the field level 2012 (see their respective VIP in Table 3). To show
similarities among farms and correlations between management prac-
tices and barley performance, we show PLS scores, groups or trends, of
the farms (Fig. 1a) and the PLS loadings describing the correlation that
PLS component has with the original variable (Fig. 1b). From the
loadings, the first sampling (58%). Predicted values deviated from the observed values by approximately 20, 19 and 16% for N-concentrations in total DM, grain and straw, respectively. How-

3. Results

3.1. Effects of farm and field management practices on barley performance

Out of the 29 management practices included in the PLS analyses
(see Table 2), fifteen had a variable importance in the projection less
than 1 (VIP < 1) and were eliminated after the first modelling of
barley performance indicators using all the 29 management practices
and farm characteristics. The elimination improved the model from 47
to 63% explained variation (R^2X) with two principal components and
14 management practices retained (Table 3). In addition, the relation-
ship between management practices and barley performance indicators
(R^2Y) was improved from 54 to 57% after elimination. At the whole
model level, the cross-validation reached a goodness of prediction (Q^2Y) of 31% explanation of the variation of the barley performance
indicators with the retained management practices associated with
model parameters given in Table S1.

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tices and barley performance, we show PLS scores, groups or trends, of
the farms (Fig. 1a) and the PLS loadings describing the correlation that
the PLS component has with the original variable (Fig. 1b). From the
scores and loadings simultaneously, we see that out of the six OOF,
farms number 1, 7, 9, 11 and 14 were clustered together (Fig. 1a) and
their management practices were related to high nitrogen concentra-
tions in barley (Fig. 1b). Crop biomass and the number of ears and
grain were more related with management strategies on conventional
farms 2, 3, 4, 5, 6 and 16 which were also grouped together (Fig. 1b).

The PLS analysis results shown in Fig. 1 illustrate the difficulty in
managing weeds using organic farming management practices. Weed
cover was generally related to yield (DM1 and DM2) along the first
principal component (Fig. 1b). The negative values of the presence of
pasture and the percentage ley of the farm area along PC1 illustrate their
use in the rotation on organic farms. These specific management practices were correlated with high grain N concentration. On the other hand,
in conventional farms, application of mineral fertilizers and pesticide were the management practices most correlated with high yields at both growing stages.

3.2. Barley performance indicators and nitrogen dynamics under different
farm types

The PLS analysis grouped the farm types (Fig. 1a), and consequently
the analysis of variance showed that they differed significantly in terms of

dry matter (DM) production and nitrogen (N) concentrations (P < 0.0001 in all cases, Fig. 2a and b). The amount of above-ground
plant biomass at both development stages (BBCH 31 and 87) was higher
on conventional farms (CF) than on old (OOF) and young organic farms
(YOF) by approximately 50%. For example, the average grain yield on
CF was 477 ± 24 g m^-2 while the grain yields on OOF and YOF were
196 ± 32 and 223 ± 37 g m^-2, respectively (Fig. 2a). Nitrogen concentrations were also affected by farm types (Fig. 2b). Nitrogen concentrations in the shoots at the stem elongation BBCH 31 (N-bio-I)
and in grain at ripening (BBCH 87, N-Grain-II) were lowest in young
(YOF) and highest in old (OOF) organic farms, and intermediate in
conventional farms (CF). Straw of CF and OOF (N-Straw-II) had higher
nitrogen concentration than straw in the YOF. The average nitrogen
yields are summarized in Table 4 and reflect the amounts of N uptake
by the crop. At both growth stages, YOF had lower N uptake and CF the
highest.

SPAD-values, an index of chlorophyll content, were not related to
farm types (P-value = 0.53) or developmental stage (P-value = 0.11).
Fig. 3 shows the mean changes of SPAD-values among farm types over
time. Within each farm type, SPAD values did not change significantly
over time (P-values of 0.96, 0.13 and 0.37 for CF, YOF and OOF, re-
spectively). The changes of SPAD-values among farms within the same
farm type are shown in Supplementary material (Fig. S1).

3.3. Effects of farm and field management practices on individual barley
performance indicators

In terms of the individual barley performance indicators (BPI), the
goodness of fit (R^2Y) was over 50% for five out of seven BPIs, including
all the three N concentration estimates (BBCH 31, straw and grain at
BBCH 87) and amount of total DM and grain at BBCH 87. The goodness
of prediction (Q^2Y) was low for DM at BBCH 31 and the number of ears
at BBCH 87 while the grain yields on OOF and YOF were
196 ± 32 and 223 ± 37 g m^-2, respectively (Fig. 2a). Nitrogen concentrations were also affected by farm types (Fig. 2b). Nitrogen concentrations in the shoots at the stem elongation BBCH 31 (N-bio-I)
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SPAD-values, an index of chlorophyll content, were not related to
farm types (P-value = 0.53) or developmental stage (P-value = 0.11).
Fig. 3 shows the mean changes of SPAD-values among farm types over
time. Within each farm type, SPAD values did not change significantly
over time (P-values of 0.96, 0.13 and 0.37 for CF, YOF and OOF, re-
spectively). The changes of SPAD-values among farms within the same
farm type are shown in Supplementary material (Fig. S1).

3.3. Effects of farm and field management practices on individual barley
performance indicators

In terms of the individual barley performance indicators (BPI), the
goodness of fit (R^2Y) was over 50% for five out of seven BPIs, including
all the three N concentration estimates (BBCH 31, straw and grain at
BBCH 87) and amount of total DM and grain at BBCH 87. The goodness
of prediction (Q^2Y) was low for DM at BBCH 31 and the number of ears
at BBCH 87 while it was above 30% for the other five barley performance
indicators (Fig. 4). Predicted values of each individual BPI is
given in relation to observed values (Figs. 5 and 6). Predicted values deviated from the observed values by approximately 20, 19 and 16% for N-concentrations in total DM, grain and straw, respectively. How-

er, the deviation was around 38% for biomasses at the later develop-
mental stages and largest for the first sampling (58%). Predicted values were obtained by using PLS-coefficients associated to each of the
retained management practices (Table S2, Supplementary material).
The significance of these PLS-coefficient indicates, for example, that the
use of leys and methods of weed control practised on different farm
types significantly affected the biomass from early growth (DM1) while
differences in fertilizer affected later crop development, leading to the
observed differences in biomass and grain N concentrations (Supple-
mentary material, Table S2).

4. Discussion

4.1. Significance of management practices on barley performance indicators

Our results highlight the importance of evaluating the effects of
multiple combined management practices on crop performance rather
than simply comparing between organic and conventional farms. The
use of PLS allowed us to distinguish the effects of different management
practices even within the same farm type. For example, in the PLS
analysis (Fig. 1a), one old organic farm (OOF farm 8) was found to
deviate from the others in this group by having characteristics more
similar to conventional (CF) and young organic farms (YOF) on a large
farm with 150 ha. Chongtham et al. (2017) studied crop choice and

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**Table 3**

<table>
<thead>
<tr>
<th>Field level</th>
<th>Symbol</th>
<th>Rank</th>
<th>VIP</th>
<th>cvSE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proportion of other crops</td>
<td>Ocrops 5</td>
<td>1.09</td>
<td>0.87</td>
<td></td>
</tr>
<tr>
<td>Proportion of rotational leys</td>
<td>Leys 7</td>
<td>1.04</td>
<td>0.49</td>
<td></td>
</tr>
<tr>
<td>Landscape index (1 km radius)</td>
<td>LHI 8</td>
<td>0.96</td>
<td>1.14</td>
<td></td>
</tr>
<tr>
<td>Time since transition</td>
<td>TST 10</td>
<td>0.90</td>
<td>0.51</td>
<td></td>
</tr>
<tr>
<td>Presence of pasture on farm</td>
<td>PP 14</td>
<td>0.82</td>
<td>0.56</td>
<td></td>
</tr>
</tbody>
</table>

**Field level 2009–2011**

| Application technique of organic fertilizers | OFe-AT 2 | 1.12 | 0.62 |
| Mineral fertilizers used | Min-N 12 | 0.87 | 0.69 |

**Field level 2012**

| Leys as preceding crop | PC-leys 1 | 1.14 | 1.14 |
| Cereal as preceding crops | PC-cereal 3 | 1.11 | 0.64 |
| Straw and crop residues left on the field | SRM-L12 4 | 1.11 | 0.74 |
| Use of pesticide in 2012 | Pest-12 6 | 1.08 | 0.77 |
| Percentage weed cover | Weed 9 | 0.95 | 0.25 |
| Barley undersown with grass/clover | US-12 11 | 0.88 | 0.39 |
| Amount of mineral N | Min-N12 13 | 0.83 | 0.67 |

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*Note that VIP does not indicate whether the effect is positive or negative, and that it relates to the whole model rather than the effect on individual barley performance.

*Other crops include oilseeds, peas and others that were not mentioned.*
rotations on 16 farms in Uppland, of which five were included in this study, and reported that several YOF grew relatively few crop species and relied on practices such as the use of machinery for weed control and purchase of organic fertiliser for nutrient supply. For the case of farm 8, the survey showed a high application of Biofer, which is a commercial and certified organic fertilizer, at the rate of 600 kg ha\(^{-1}\) per year. Biofer from different certified sources used in the Uppland region contain between 6 and 10% N (Jordbruksverket, 2016).

Chongtham et al. (2017) reported that OOF 8 in this study (numbered as Farm 2 in Chongtham et al., 2017) was a farm with a highly specialised and intensive production system. This may explain why the grain yield in this organic farm was higher (506 g m\(^{-2}\)) than the average of the CF (477 ± 24 g m\(^{-2}\)), this effect could also be seen in the number of ears per square meter that was higher for farm 8 (190 ears m\(^{-2}\)) compared to other organic farms (80 ears m\(^{-2}\)). The increased N availability on this farm may be associated with the frequency of organic fertilizer use on the whole farm, improved organic fertilizers application techniques, residue management in the previous years (2009–2011) by ploughing and growing crops other than cereals.

Farm 8 had dairy cows until 2007 and the crop rotation included leys (Chongtham et al., 2017) but in 2012 oilseed rape replaced leys on third of the arable area indicating a diverse rotation on the farm. These management practices can be challenging to achieve on larger farms but were apparently working on this farm. Other studies, in France and USA, have found that organic farms tend to be small in size as it can be difficult to adapt management practices based on organic principles at larger scales (Delbridge et al., 2013; Latruffe and Nauges, 2014).

The general clustering of farm types, grouped according to the time since transition, indicates the importance of the temporal dimension associated with the response to management practices. YOFs and OOFs had lower barley yield than CF (Fig. 2a) and this may be due to the use of high input management practices, which was also found in previous studies (see e.g. de Ponti et al., 2012). Management practices associated with CF include mineral fertilizer and pesticide applications whereas OOFs were characterized by greater use of rotations for soil fertility and weed, pest and disease management. Chongtham et al. (2017) reported that weeds were perceived as the most important problem in YOFs and these farms tend to have strict crop rotations to control weeds. Several OOFs seemed to focus mainly on the adaptation to changing environmental and economic conditions and hence have more flexible crop sequences than YOFs. In addition, most livestock farmers use crop rotations with leys to produce sufficient feed for the livestock. However some livestock farmers prefer to buy feed so that they can grow more cash crops for profit. These examples demonstrate the complex set of factors which determine farm management practices chosen on different farms.
Besides the weed challenge on organic farms (Fig. 1b), our analysis suggests that several other management practices deserve more attention. For example, crop diversity on the farm, landscape complexity, management of straw and residues and application techniques of organic fertilizers were found to be important factors affecting barley performance (Table 3, Fig. 1b). The most influential and thus retained management practices in our data (Table 3) allowed the satisfactory prediction of most of the indicators of barley performance (Figs. 4–6). Five out of seven barley performance indicators, including all the N concentrations, DM at the second cut, grain yield biomass and DM of grain (Fig. 4) satisfied the requirement of having a goodness of fit over 0.5. However, the retained factors were less appropriate to predict DM at BBCH 31.

### 4.2. Relationships between barley grain yield and N in grain and farm type

The PLS analysis showed that it is too simplistic to classify farms only as conventional or organic due to the interactions between management practices and also because many management practices are used in both farm systems. A reduction in grain yield of approximately 50% compared to CF agrees with earlier comparisons of barley yield on conventional and organic farms in the same study area (Östman et al., 2003). This magnitude of yield differences between organic and conventional farming is also supported by regional statistics with barley yields of 3.90 and 2.05 t ha\(^{-1}\) for CF and OF, respectively (SCB, 2012). Other studies including barley yields from long-term experiments in Sweden (Kirchmann et al., 2007) and other cereals elsewhere (de Ponti et al., 2012; Seufert et al., 2012) have shown similar differences. This study analyses instead alternative management practices within farming systems that would improve a given crop performance. Management practices on a farm are dynamic and respond to a range of other factors including operational, tactical and strategic decisions along with both short-term market fluctuations and climate variability. The short-term market fluctuations and climate variability are examples of factors revealed by interviews with organic farmers (Chongtham, 2016). Because of variation in management practices among years on individual farms, it is important to know how different management practices at different points in time (prior to crop sowing or during crop growth stages) affect grain yield and nitrogen concentration of the harvested product.

The use of mineral fertilizers and pesticides were among the most important variables that positively affected the biomass on CF. In OF, a high proportion of rotational leys, high weed cover percentage and the time since transition positively affected the N concentrations. As described above it is well documented in the literature that grain yields are higher in CF than in OF, but differences in grain N concentration...
have received less attention. Higher protein concentrations were found in OF than CF for oat and rye but lower for barley by Menkovska et al. (2014). However, another study in Denmark with similar conditions as our study showed lower protein concentrations in OF than in CF for wheat (Petersen et al., 2013). In the present study, the CF grew malting-barley, which is generally known to have lower grain N concentrations than feed-barley (Guo et al., 2016). However, different target protein concentrations cannot explain the higher N concentrations observed in OF in this study as grain N concentration was lower for YOF than CF (Fig. 2b). In addition, organic farm 9 that grew malting-barley had the highest grain N concentration. Management practices might partly explain the variation in N uptake and N concentration in grain between farm types. At BBCH31, N concentrations for CF and OF were not affected by the farm type but the difference emerged later in the growing season (Fig. 2b). This indicates that barley on the fertilised CFs produced more tillers that increased N demand and uptake at later development stages, as shown by Hawkesford, (2014). The high grain yield and N demand in CF resulted in a lower N concentration in the grain than on OOF, which relied on mineralisation from organic fertilizers, crop residues, etc. It suggests that the relatively low soil N availability early in the season on OOF in combination with a higher competition from weeds decreased the biomass production and nitrogen use efficiency, i.e. the ability to take advantage of late N mineralisation for grain yield was poor. The N grain amount was lower on YOF than on OOF, possibly indicating less N mineralisation throughout the growing season.

4.3. Barley performance across phenological stages

The increasing differences in DM biomass between OF and CF over the season might suggest that the timing of N supply and the amount of N mineralised in OF did not match the crop demand. However, the comparison between the changes in biomass from the first to the second sampling (Fig. 2a) and the N concentrations from the first to the second sampling (Fig. 2b) indicates that plants grew at different rates (with higher biomass in CF) and the number of tillers was higher for CF than OF (Fig. 1b). The latter suggests dilution of available N in higher biomass and hence a lower concentration of N. Other studies have shown that protein concentration in barley decreased with increases in density of tillers or sown seed (O’Donovan et al., 2012) which is in agreement
with the difficulty of maintaining high protein levels and high yield (Hawkesford, 2014). The higher percentage weed cover in OF found in this study, but also in other studies (Kirchmann et al., 2007), is another factor that may have influenced the reduced biomass in OF as weeds compete with the crop for N and the dilution occurs. Averages of percentage weed cover, in this study, were around 1, 22 and 26% for CF, YOF and OOF, respectively. Alaru et al. (2014) found that only 37% of all supplied N was taken up by the crop in organic farms, which means that in order to reach a target of 120 kg N ha$^{-1}$ supplied to the crop (optimal mineral fertilizers, see Hawkesford, 2014) approximately 350 kg N ha$^{-1}$ in any organic fertilizer and/or through N-mineralisation would be required to result in similar performance of CF and OF. Although this may be unreasonable to achieve, it clearly indicates that for increased and timelier mineralisation of organic material/organic fertilizers and improved yields, more effective management practices are needed on organic farms.

The chlorophyll concentration measurements in the leaves (SPAD) showed similar trends as the analysis of N concentrations. At the early growth stages, the levels of N related performance indicators were quite similar for CF and OOF (See chlorophyll concentrations at BBCH 10 in Fig. 3 and N-bio-I in Fig. 2b). Later in the season, chlorophyll concentrations tended to be significantly different (P-value = 0.11) thus a higher decrease of OOF chlorophyll than that of CF. The same trend was observed for the measurements of grain N concentrations which resulted in significant differences for grain N yields with highest N concentration in OOF (Fig. 2b). This can also be seen for the chlorophyll levels of individual farms that decreased towards the grain filling time (Supplementary material 2, Fig. S1). Our results are rather different to those of Stalenga (2007) who found that at earlier growth stages, SPAD measurements of winter wheat were lower for organic than conventional farms. Our study shows this only for YOF while Stalenga (2007) did not distinguish time since transition. However, Stalenga (2007) showed that SPAD values increased with the growing stages (up to the BBCH 59) while there was a general decreasing trend in this study. The decrease in SPAD, also supported by N concentrations at BBCH 87, can be interpreted as N translocation to grain, as indicated by lower N concentrations in straw at BBCH 87 than BBCH 31. Limited N supply to the crop from the soil, or other factors limiting crop growth such as deficiency of other nutrients, weeds, pest or diseases, could be other explanations of the decrease in SPAD-values. The analysis of individual

5. Conclusions

Beside the use of external inputs in CF (fertilizers, pesticides and herbicides) that promote biomass in a given year, there are management practices that potentially can reduce the gap between barley yields on conventional and organic farm types. These management practices include the diversity of crops on the farm (including high proportion of legys and presence of permanent pasture on the farm), the application techniques of organic fertilizers, the management of straw and residues over time and improved weed control techniques. These were all shown to be important in terms of improving N supply to the crop. If these techniques are more effectively used, they can be utilised in any farming system and can improve the efficiency with which N is used on farm. Finally, the PLS approach was clearly able to identify management practices that were more or less relevant for a given number of barley performance indicators in relation to farm types.

Acknowledgments

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.eja.2017.07.003.