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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 ($80\,\mathrm{kg\,ha^{-1}}$ vs. 33 and $39\,\mathrm{kg\,ha^{-1}}$ 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 ($477 \pm 24\,\mathrm{g\,m^{-2}}$) compared to organic farms (223 ± 37 and $196 \pm 32\,\mathrm{g\,m^{-2}}$ 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 $172\,\mathrm{kg\,N\,ha^{-1}}$ (Petersen et al., 2013). Despite the significant

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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 system, 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 biomasses 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 criteria 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.

Table 1
Farm and field descriptions of the 17 farms. Information on the farm level includes the farm types (FT), year of conversion to organic farming (YCOF) and the farm sizes. Information at the field level includes pH, soil total carbon and nitrogen (%), soil texture (%), humus (%), soil type and field description with landscape heterogeneity index (LHI) in 1 km radius from the field and barley cultivar and type in 2012.

	Farm			Field											
Farm #	FT	YCOF	Size (ha)	pH	TotalC (%)	TotalN (%)	C/N	CLAY (%)	SILT (%)	SAND (%)	Humus (%)	Soil type	LHI[a]	Cultivar	Barley type
1	OOF	2002	168	5.9	12.2	1.0	12	54	43	3	13.7	silty clay		Baronesse	feed
2	CF	–	205	8.0	2.2	0.2	13	52	36	13	4.1	clay	0.7	Tipple	malting
3	CF	–	556	7.5	2.6	0.2	11	66	28	6	2.4	clay	1.3	Tam tam	malting/feed
4	CF	–	700	5.6	3.3	0.3	11	40	55	6	4.0	silty clay loam	−1.4	Tipple	malting
5	CF	–	216	6.6	3.0	0.3	11	42	44	14	5.0	silty clay	0.6	Columbus	malting
6	CF	–	80	7.9	2.0	0.2	11	45	39	16	3.0	clay	2.0	Tipple	malting
7	OOF	1996	79	6.3	2.0	0.2	11	18	33	49	3.9	loam		Mitja	feed
8	OOF	1994	150	7.8	2.7	0.2	13	42	50	8	3.2	silty clay	1.2	Mitja	feed
9	OOF	1989	34	6.3	9.4	0.7	13	33	39	28	9.4	clay loam		Columbus	malting
10	YOF	2009	140	7.1	1.4	0.1	10	47	46	7	2.8	silty clay	0.3	Mitja	feed
11	OOF	1987	110	6.3	4.5	0.5	10	46	48	6	6.2	silty clay		Baronesse	feed
12	YOF	2009	140	6.3	2.8	0.3	11	58	37	5	3.8	clay	0.4	Mitja	feed
13	YOF	2012	250	7.2	2.9	0.3	12	47	36	17	3.0	clay	0.0	Mercada	fodder
14	OOF	1996	36	6.1	2.9	0.3	10	46	49	5	3.2	silty clay	2.0	Gengel	Feed
15	CF	–	310	6.1	1.9	0.2	11	43	47	10	2.9	silty clay	1.0	Tipple	malting
16	YOF	2007	36	5.8	2.8	0.2	12	21	29	50	4.7	loam		Orthega	feed
17	YOF	2008	149	6.5	1.7	0.2	10	50	46	4	3.2	silty clay	0.9	Otira	feed

[a] Among the 17 farms, most were part of the study by Jonason et al. (2011) in which the LHI were determined, but five were included in 2012 in order to have barley fields on all study farms. These fields did not have the LHI although they were situated in similar landscapes.

2.2. Management practices

A questionnaire survey and semi-structured interviews were conducted with the farmers in late 2011 and 2012 to obtain data on management practices on a given barley field for each farm in the present and recent past. Questions were directed to understanding the management at the whole farm level with special focus on the management practices during the period 2009–2012 on one field per farm where barley was grown 2012. General characteristics of the farms and barley fields obtained from the survey are shown in Table 1 along with the cultivar and barley type grown (in 2012). Each of the farmers answered a total of 42 questions of which 28 questions are provided in Table S1, in the Supplementary material, along with the types of answers and corresponding management practices which were considered for the analysis. All the interviews were conducted on farm and there were opportunities to observe the fields and livestock units to ask additional questions, when necessary.

Due to the diversity of possible answers about management practices and resources used on farm, we selected and aggregated them under a set of synthetic variables to reduce the number of independent variables in the analysis. In this way we reduced the number of possible answers (variables) in the analysis from 132 to 29 variables, of which 11 related to farm characteristics and 18 related to field management 2009–2012. Table 2 lists all the variables that were used in the analysis after aggregation. As an example, the type of livestock present on the farm, which originally would have resulted in five variables including cattle, sheep, horse, pigs, poultry, was simplified by using the livestock density index: a measure of the number of animals converted into livestock units (LSUs) per hectare of utilized agricultural area (Eurostat, 2013). 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. For example, the average frequency of application of organic fertiliser per year was calculated and used rather than individual year information for 2009, 2010 and 2011. For other variables, the indices were determined with regards to the variation of the answers and calculated in a similar way for all the farms. With some of the variables, binary data were used reflecting the presence or absence of management practice.

2.3. Barley performance indicators and weed cover

In 2012, seven barley (*Hordeum vulgare*, L.) performance indicators (BPIs) were measured in one spring barley field on each farm (see above). The BPIs included *nitrogen concentration* in the biomass (grain and whole biomass), and *dry matter* (DM) *production* at two growing stages: BBCH 31(stem elongation) and BBCH 87 (ripening: hard dough) according to Lancashire et al. (1991). Biomass samples (4 random quadrats of 0.25 m^2 per field, in total 1 m^2) were cut at ca. 5 cm above the ground from and oven-dried at 60 °C for at least 24 h. At 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* ("greenness") as SPAD measurements were taken with a hand-held 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 were complete for all the fields) was included as a variable affecting the BPIs beside the management practices. At the harvest, BBCH 87, the number of ears per sample was counted. Nitrogen concentration in the straw and grains were determined with an elemental LECO 2000CN analyzer. To complete the measurements, N yields at the two cutting times were calculated by multiplying the DM of the plant parts with the N concentrations at the corresponding time.

2.4. Statistical analyses

Projections to Latent Structures by means of partial least squares regression analyses (PLS) was used to examine how the set of explanatory variables (x) was related to the set of barley performance variables (y). The method consists of relating two data matrices X and Y to each other (for details, see Eriksson et al., 2006a), where in this case the X consists of management practices (X-matrix, 29 variables) and Y is 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 even incomplete variables in both X and Y. Each farm was considered as an object and the corresponding values of X and Y variables at the farm or field levels were the mean values. The performance of the PLS model

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.

Farm level description and MP;	Symbol (Unit)	Range	Variable explanation
1. Time since transition	TST (year)	0–26	
2. Farm size	Size (ha)	34–700	
3. Landscape heterogeneity index 1 km radius	LHI (−)	−1.4–2.0	LHI[a] = sin45 × (standardized proportion of SNG + standardized proportion of field border)
4. Proportion of rotational leys	Leys (%)	0–64	Farm area including pasture and permanent pasture
5. Proportion of cereal crops	Grains (%)	18–95	Farm area including pasture and permanent pasture
6. Proportion of other crops	Ocrops (%)	0–35	Farm area including pasture and permanent pasture
7. Presence of pasture	Pasture (−)		Dummy variable: present (1) or absent (0)
8. Area with organic fertilizers	OFert-area (ha)	0–380	
9. Amount of organic fertilizers	AOFert (ton ha^{-1})	0–30	
10. Livestock density index	LDI (−)	0–1.5	A measure of livestock per hectare of utilized agricultural area including pasture and permanent pasture
11. Straw and residue management	SRM (−)		Scale from 1 to 3: where the highest value 3 = always incorporated, 2 = sometimes incorporated and 1 = removed from the farm

Field level MP (2009–2011)[a];		Range	Variable explanation
12. Frequency of organic fertilizer (OFe)	Freq-OFe (−)		0–1: Number of organic fertilizer applications over the 3 years divided by 3
13. OFe application technique	OFe-AT (−)		Scale 1–2: where 2 = Broadcasting and mulched, 1 = either broadcasting or mulched and 0 = none of the two
14. Mineral N in average	Min-N (kg ha^{-1})	0–175	Average of N application over the 3 years
15. Mineral PK applied	Min-PK (−)		Dummy variable: used (1) or not used (0)
16. Pesticide application	PEST (−)		Dummy variable: used (1) or not used (0)
17. Straw and residue management	STR-M (−)		Scale 0–2: where 2 = incorporated and mulched, 1 = either incorporated or mulching and 0 = none of the two

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

[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.

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^2Y (explained variation) and Q^2Y (predictive ability). R^2Y 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^2Y 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^2Y and Q^2Y 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^2Y) and the goodness of prediction (Q^2Y) 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^2Y, denoted R^2X (cum)) and the model predictive ability (cumulative Q^2Y, denoted Q^2Y (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; $R^2Y > 0.5$) 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^2Y) 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 BPIs, 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 3
Ranking of the retained management practices, according to their variable importance in the projection (VIP[a]), of the second PLS model. The standard errors (cvSE) of the VIP after cross-validation of the PLS model are also given.

Management practice	Symbol	Rank	VIP	cvSE
Farm level				
Proportion of other crops[b]	Ocrops	5	1.09	0.87
Proportion of rotational leys	Leys	7	1.04	0.49
Landscape index (1 km radius)	LHI	8	0.96	1.14
Time since transition	TST	10	0.90	0.51
Presence of pasture on farm	PP	14	0.82	0.56
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

[a] 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.
[b] Other crops include oilseeds, peas and others that were not mentioned.

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 relationship 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.

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 practices 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 concentrations in barley (Fig. 1b). Crop biomasses 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 negatively 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 $477 \pm 24\ \mathrm{g\,m^{-2}}$ while the grain yields on OOF and YOF were 196 ± 32 and $223 \pm 37\ \mathrm{g\,m^{-2}}$, 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, respectively). 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. However, the deviation was around 38% for biomasses at the later developmental 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 (Supplementary 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

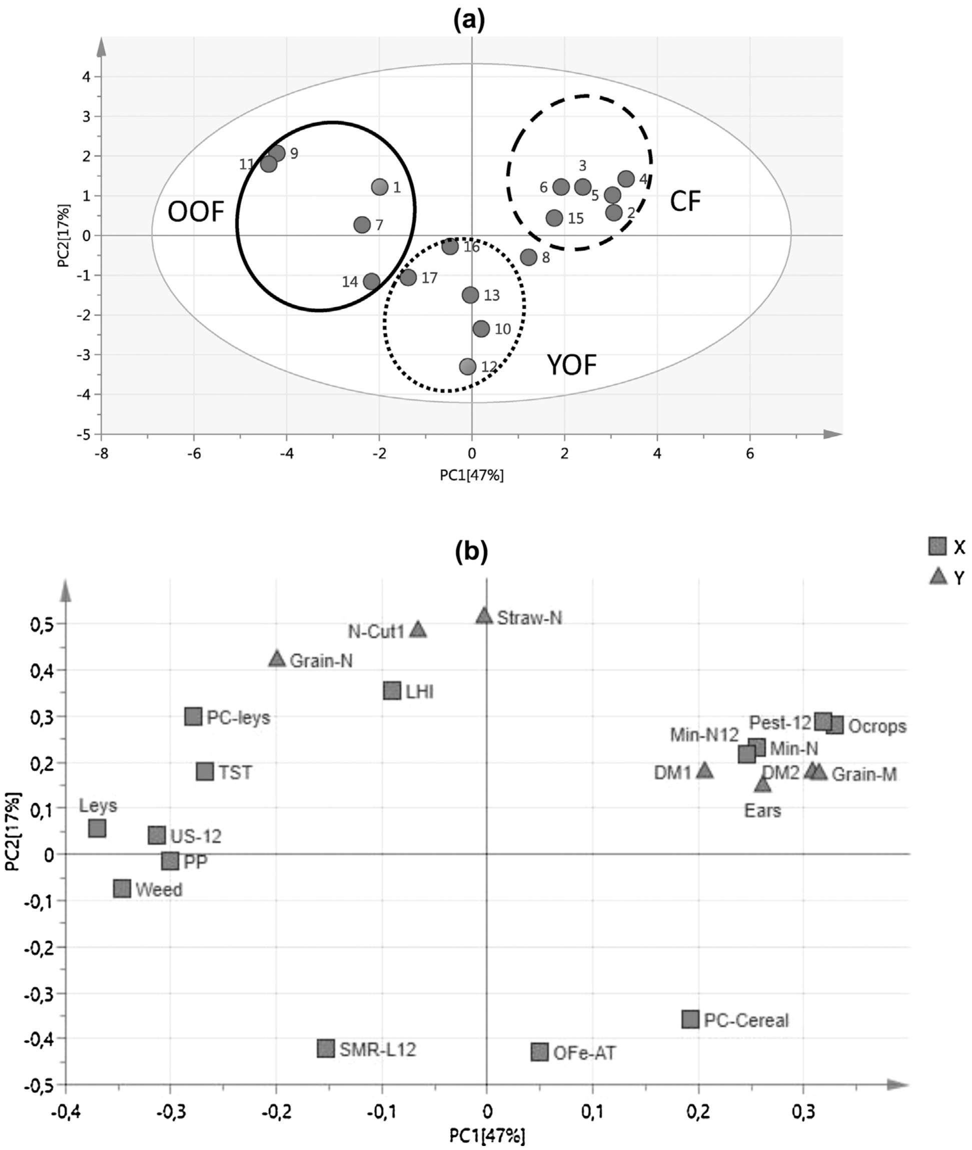

Fig. 1. Relationships between farm management practices, field management from 2009 to 2012 and BPIs for all the farms: (a) PLS scores with three clusters: OOF in circle with continuous line except farm 8 that falls outside, YOF with ellipse in dots and CF with dashed circle; (b) PLS loading of X (management practices) and Y variables (BPIs, response variables). Y variables are: dry matter at stem elongation BBCH 31 (DM1) and its N concentrations (N-Cut 1), total dry matter (DM2), grain dry matter (Grain-M) and its N concentrations (Grain-N), N concentrations in straw at grain ripening BBCH 87 (Straw-N) and the number of ears per square meter (Ears). The meaning and explanations of the symbols of the important management practices retained in the PLS analysis are given in Table 2.

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.

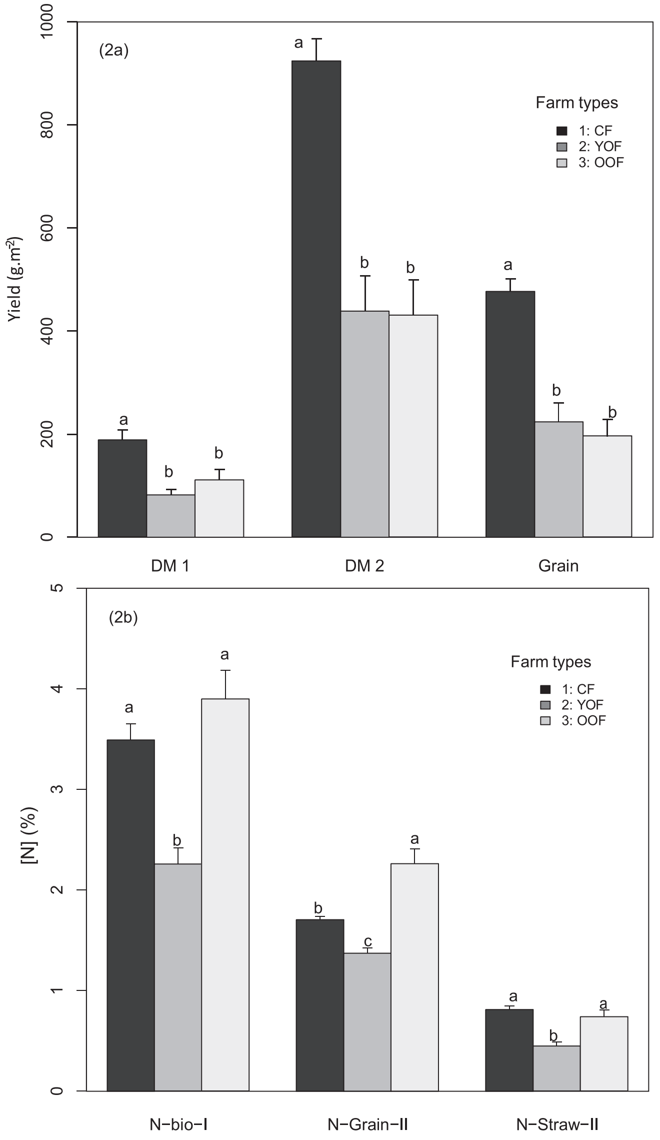

Fig. 2. Effects of farm type on (2a) barley dry matter at the stem elongation (BBCH 31, DM1) and ripening stages (BBCH 87, DM2) and (2b) nitrogen concentrations at BBCH 31(N-bio-I), in harvested grain at BBCH 87 (N-Grain-II) and in straw at BBCH 87 (N-straw-II). Compared farm types were conventional farms (1: CF), young organic farm (2: YOF) and old organic farms (3: OOF) including farm 8. Bars with different letters are statistically significant (p-value < 0.05). The error bars represent the standard error.

Table 4
Average nitrogen yields and their standard errors (kg ha^{-1}) at the stem elongation (BBCH 31), in grain and total biomass at the grain ripening (BBCH 87) for conventional farms (CF), young organic farms (YOF) and old organic farms (OOF). Average nitrogen yields with different letters, in each column, are significantly different at the level of P-value < 0.05.

Farm type	BBCH 31	Grain BBCH 87	Total biomass BBCH 87
CF	64 ± 11^{a}	80 ± 6^{a}	116 ± 9^{a}
YOF	20 ± 8^{b}	33 ± 14^{b}	44 ± 19^{b}
OOF	36 ± 11^{b}	39 ± 12^{b}	54 ± 16^{b}

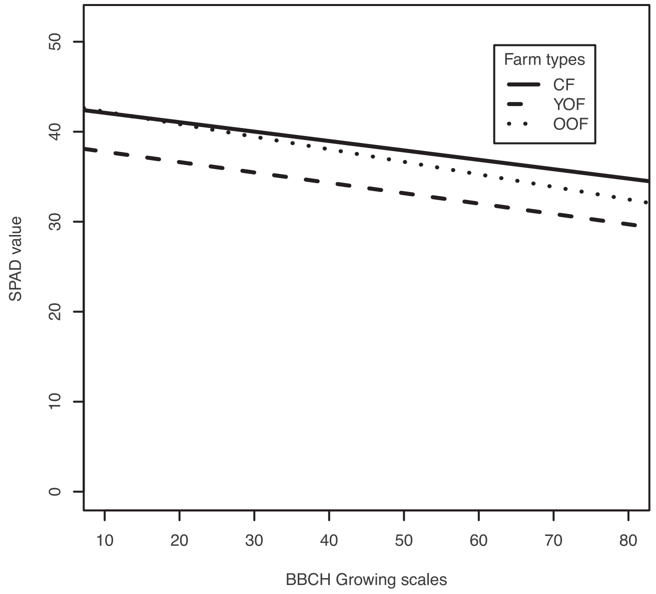

Fig. 3. Changes of SPAD values (chlorophyll concentrations) over different growth stages of barley on conventional farms (CF), young organic farms (YOF) and old organic farms (OOF) obtained by linear regression.

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 approximatively 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 are 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. Asa 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

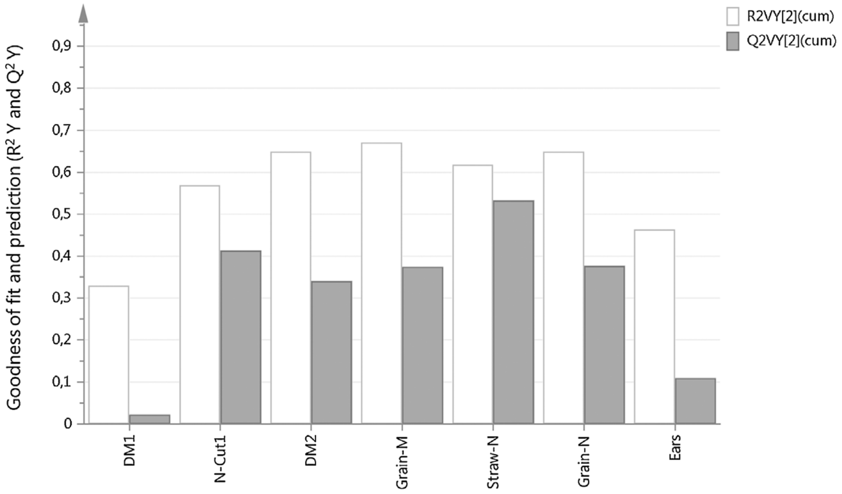

Fig. 4. Goodness of fit (R^2Y) and the goodness of prediction (Q^2Y) for individual barley performance indicators (dry matter at stem elongation BBCH 31 (DM1) and its N concentrations (N-Cut 1)), total dry matter (DM2), grain dry matter (Grain-M) and its N concentrations (Grain-N), N concentrations in straw at grain ripening BBCH 87 (Straw-N) and the number of ears per square meter (Ears). Y-axis shows the goodness of fit and prediction in the range of zero to one (0–100%) of explained variation for each indicator.

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 OOF 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

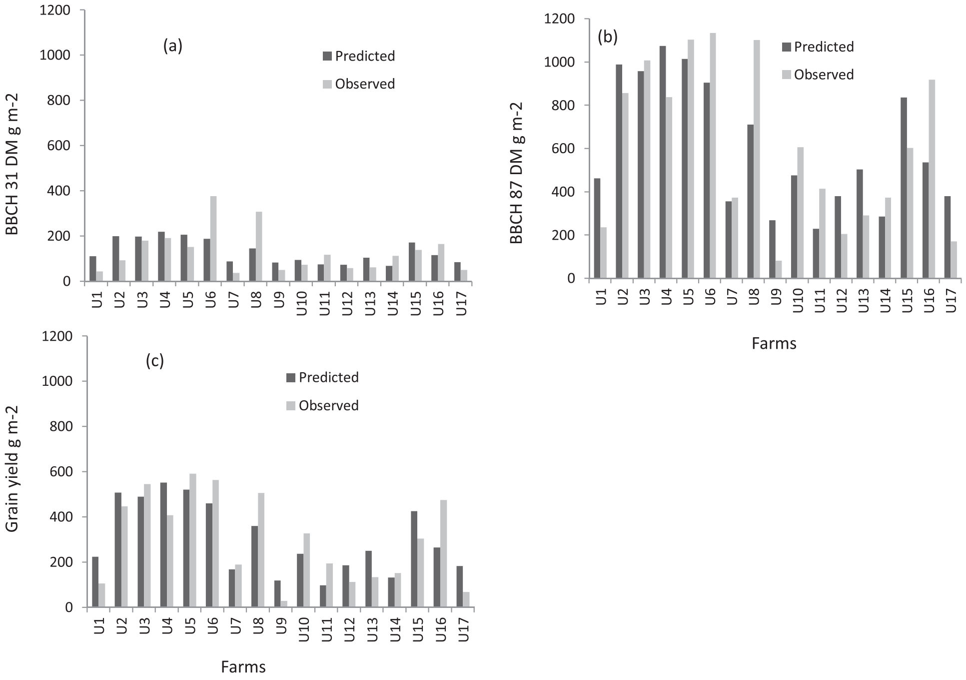

Fig. 5. Comparisons between observed dry matter (DM) of barley and their corresponding predicted values with the 14 retained management practices: a) DM at the BBCH 31, b) DM at the BBCH 87 and c) grain yield at the BBCH 87. On the X-axis U1-U17 represent individual farms.

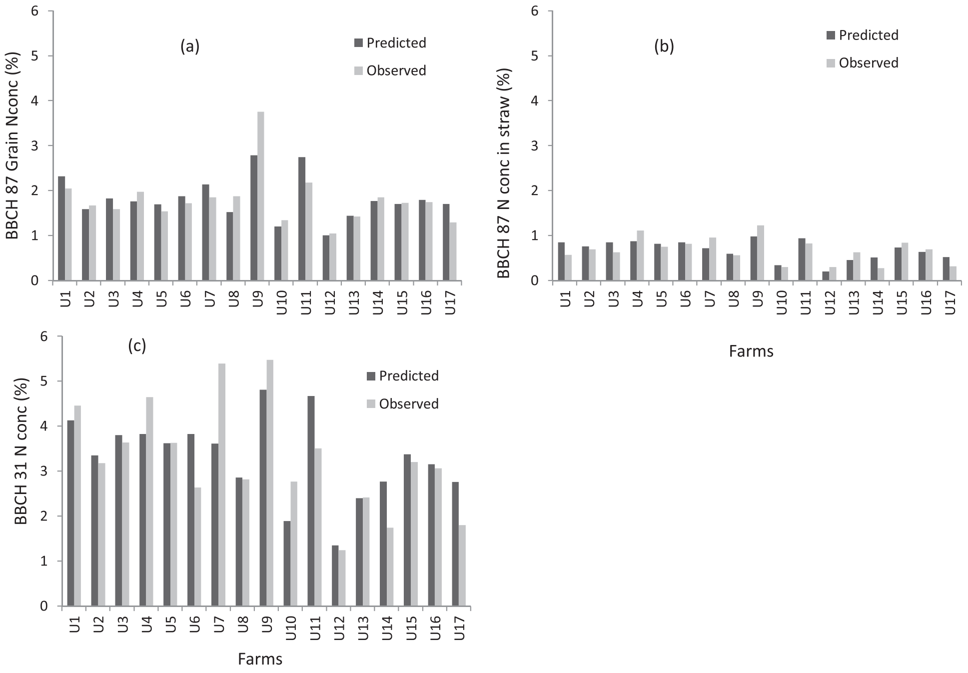

Fig. 6. Comparisons between observed N concentrations of barley and their corresponding predicted values with the 14 retained management practices: a) at BBCH 31, b) at BBCH 87 in straw and c) at BBCH 87 N concentrations in grain. On the X-axis U1-U17 represent individual farms.

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 SPAD measurements for Farm 8, which deviated from other OOF, showed lower N concentrations and also lower chlorophyll concentrations, especially during the growing stages BBCH 30–55 and after BBCH 75 (Supplementary material, Fig. S1). This farm used higher amounts of purchased organic fertilizer (ca. 600 kg ha^{-1} of biofer) and other management techniques to increase crop N availability, improved organic fertilizer application techniques and other crops than cereals on 30% of the farm.

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 leys 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.

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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.

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