European Journal of Agronomy 90 (2017) 43–52

Contents lists available at ScienceDirect

European Journal of Agronomy

journal homepage: www.elsevier.com/locate/eja

Understanding effects of multiple farm management practices on barley performance

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ARTICLE INFO

Keywords:
Farm type
Management practices
Barley performance indicators
Nitrogen supply
Projection on latent structures (PLS)

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}) compared to organic farms (223 ± 37 and 196 ± 32 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

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http://dx.doi.org/10.1016/j.eja.2017.07.003
Received 23 September 2016; Received in revised form 7 April 2017; Accepted 6 July 2017

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.