Does cropping system diversification with legumes lead to higher yield stability? Diverging evidence from long-term experiments across Europe

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1 Introduction

In the face of climate change and to achieve global food security, the resilience of agricultural systems is gaining increasing attention, and is often considered as important as their productivity (Olesen et al., 2011). Temporal yield stability is one indicator of the economic resilience of cropping systems and its analyses have become more important as a decrease in yield stability has been observed for different crops at regional and global scale (Döring and Reckling, 2018). The temporal and spatial diversification of cropping systems with legumes, perennial crops, cover crops and intercrops can be expected to increase crop yield stability and offers an adaptation strategy to the increased climate variability (Liu et al., 2019).

The objectives of this study were to assess the effect of cropping system diversification strategies on yield stability, through (i) integration of perennial leys with and without legumes, (ii) increasing proportion (length, *i.e.* number of years) of the perennial grass-clover leys relative to the entire crop rotation, (iii) varying the order in which crops are positioned in the rotation, (iv) integration of grain legumes and (v) integration of cover crops during fallow periods.

2 Materials and Methods

For the analysis of yield stability, we used yield data of different time periods between 1971 and 2017 of winter wheat, durum wheat and oat from five long-term field experiments from Sweden (Lanna, Stenstugu and Säby), North-East of Scotland (Tulloch) and Southern France (Auzeville). The five sites are characterized by contrasting bio-physical conditions in terms of soil and weather conditions.

Several yield stability indicators were calculated to quantify yield stability considering different concepts of stability i.e. the coefficient of variation (CV), Power Law Residuals (POLAR) (Döring et al., 2015) and Finlay, Wilkinson regression analyses (FW) and the probability of one system outperforming another system (Piepho, 1998).

3 Results

The results showed that cropping systems incorporating perennial grass-clover leys in the Swedish LTEs outperformed systems without leys in terms of winter wheat and oat yields in 60-94% of the cases on average across the sites and depending on the nitrogen fertilizer application rate. Systems with pure grass leys outperformed systems without leys in only 55-80% of the cases. The FW regression analyses showed that oat grown in a cropping system with perennial clover-grass ley and no N fertilization had significantly higher yields in low- and high-yielding years compared to oat grown in the cropping systems with only a grass ley or without a ley (Table 1). The CV and POLAR did not indicate any significant differences in yield stability between the cropping systems.

The yield stability of oat in the Scottish LTE did not differ if oat was grown after a 4-year or a 3-year ley. Oat yields were 33% higher when following directly after the ley compared to oat grown two years later in the crop sequence. The CV and POLAR values indicated a greater stability for the first oat (CV 21%) compared to the second oat (CV 37%) but differences were not significant.

Table 1. Mean grain yield of oat (Mg DM/ha), CV values (%), Finlay-Wilkinson (FW) regression coefficient *bi* and POLAR coefficients for each cropping system (A = with perennial grass-clover ley, B = with perennial grass ley and C = without perennial ley) with no N fertilization at the two Swedish sites Lanna and Stenstugu.

Cropping system	Lanna				Stenstugu			
	Grain yield	CV	FW b_i	POLAR	Grain yield	CV	FW b_i	POLAR
A	1.9	31	1.1 a	0.01	2.0	29	1.09 a	-0.07
B	1.7	36	1.0 a	0.06	1.7	36	1.07 a	0.06
C	1.4	32	0.8 b	-0.11	1.3	33	0.79 b	-0.13

Durum wheat grown in a cropping system with grain legumes in southern France had a significantly higher FW regression coefficient compared to a cropping system without grain legumes and yields tended to be particularly high in low-yielding years. Diversification with cover crops in the French LTE using data from 2005-2016 did not affect yield stability of durum wheat significantly.

4 Discussion and Conclusions

We found that cropping system diversification with legumes can increase the productivity in LTEs across Europe, while the effects of diversification on yield stability were inconsistent. St-Martin et al. (2017) also found that winter wheat in more and less diverse cropping systems led to equally stable yields. Spring wheat in a 'crop-livestock' system with grass-clover and grain legumes tended to perform better in favourable years relative to the less diverse system (St-Martin et al., 2017). In another study, a lentil-oilseed sequence had the lowest variation in yield and was most suitable for high-yielding environments compared with fallow- and wheat–oilseed sequences (Liu et al., 2019). Our FW analyses also point towards a better performance of diversified systems with legumes in high-yielding years compared to systems without legumes.

We conclude that diversification with legumes increase yield of other crops in the rotation but we have not been able to show that the measures investigated have a consistent impact on yield stability. A higher level of diversification could be required in time and space to achieve both, higher yields and increased yield stability.

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