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Single *vs* multiple agroecosystem services provided by common wheat cultivar mixtures: Weed suppression, grain yield and quality

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A B S T R A C T

Cultivar mixtures are a well studied practice to improve common wheat performance by exploiting the potential of genetic diversity to buffer biotic and abiotic stresses. However, their ability to reduce weed interference is still unclear. In this work, crop-weed interactions were studied across two growing seasons under Mediterranean climatic conditions on nineteen common wheat stand types: twelve cultivars including modern and heritage varieties, four three-cultivar mixtures, two six-cultivar mixtures and one high diversity mixture with all twelve cultivars. Wheat morphological parameters, biomass accumulation of wheat and weeds, wheat yield, yield components and grain quality were assessed. Heritage cultivars showed the highest weed suppression (on average −67% weed biomass at harvest compared to modern cultivars) due probably to increased height, above ground biomass and leaf area index. No consistent mixture effects were detected for either weed suppression, grain yield or grain quality, when considered separately from one another. However, when considering the three agroecosystem services altogether based on a rank analysis, mixtures with higher number of components (six and twelve) tended to improve the overall crop performance compared to the average of less diverse wheat stand types. Although the observed benefits of mixtures *vs* component cultivars for individual agroecosystem services (i.e. weed suppression, yield and grain quality) were limited, cultivar mixtures appear as a potential tool to improve overall crop performance, especially with medium to high number of component cultivars. However, increased adoption of cultivar mixtures would require prior identification of key cultivar traits clearly associated with the provision of target agroecosystem services. Enhanced complementarity and synergy among these traits would maximize exploitation of the available genetic agrobiodiversity.

1. Introduction

Common wheat (*Triticum aestivum* L.) is the most widely grown cereal crop worldwide in terms of land extension and it is the staple food for more than one third of the human population (FAOSTAT, 2014). Being widespread in different geographical areas and farming systems, wheat growing ranges from small scale, labour intensive cultivation to large scale, extensive cultivation. Beyond this, wheat is a commodity whose price is determined on the international market, hence being characterized by increasing uncertainty and fluctuation (Haile et al., 2016). In this context, both conventional and organic farmers aim to decrease use of external inputs to keep wheat production costs low. Because of this, one major interest is to develop wheat management strategies able to cope with biotic and abiotic stresses.

Cultivar choice and hence breeding have often been proposed as major tools to improve crop performance under low-input and organic farming conditions (Lammerts van Bueren and Myers, 2012), especially concerning disease and weed reduction. This strategy has mainly been developed by targeted breeding programmes (Lammerts van Bueren et al., 2011), improved Value for Cultivation and Use (VCU) protocols (Löschenberger et al., 2008) and reintroduction of heritage cultivars, which are known to possess biotic and abiotic stress-tolerance traits that have been largely lost through modern breeding (Mason and Spaner, 2006).

Increasing attention is dedicated to the use of cultivar mixtures not only as a strategy to reduce biotic and abiotic stresses but also to stabilize and possibly increase yield (Kiær et al., 2009). The broader framework for cultivar mixture use is given by the widely recognised impact of diversity in ecosystem functioning. Although much of the results, as recently summarised by Barot et al. (2017), come from the ecological literature in which the effect of biodiversity on ecosystems has been investigated by focusing on species number, many biodiversity-related services can also be achieved by manipulating within-species diversity, i.e. utilising different cultivars of the same crop

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species. Services provided by agroecosystems are multiple, including among others food production, regulation of greenhouse gases, C storage, and soil health. Functional diversity exploitation at intra-specific, inter-specific or landscape level supports different services and/or can impact differently on the same services. In this study, we focused on a subset of agroecosystem services that can be provided by the use of intra-specific (i.e. genetic) functional diversity.

In cultivar mixtures, seeds from a certain number of cultivars are blended at sowing. The cultivars composing the mixture need to be similar for traits such as growing cycle length or end-use quality in order to be cultivated together (Wolfe, 1985). At the same time, they need to differ for traits related to the agroecosystem service expected to be improved, e.g. to carry different disease resistance traits (Garrett and Mundt, 1999).

Wheat cultivar mixtures have largely been studied for reducing the effect of airborne disease outbreaks (Cox et al., 2004; Finckh et al., 2000; Finckh and Mundt, 1992). Cultivar mixtures out-yielded single cultivar stands in different contexts and field experiments (Smithson and Lenné, 1996; Finckh et al., 2000; Gallandt et al., 2001; Cowger and Weisz, 2008; Kiær et al., 2009; Döring et al., 2015). Also, mixtures have been shown to stabilize yield over time (Smithson and Lenné, 1996; Finckh et al., 2000; Cowger and Weisz, 2008; Kaut et al., 2009; Mengistu et al., 2010; Döring et al., 2015). In some cases mixtures also improved grain protein content and bread-making quality (Finckh et al., 2000; Sarandon and Sarandon, 1995). Overall, use of cultivar mixtures appear as an insurance strategy for farmers, as they tend to buffer the impact of fluctuating environmental conditions on crop performance. Nevertheless, most of the experiments that studied the performance of wheat cultivar mixtures focused on a single agroecosystem service, e.g. yield, yield stability, quality or disease reduction. In these experiments, mixtures were assembled to ensure complementarity and synergy among component cultivars for just one target service. However, in real farming conditions wheat mixtures should be able to achieve results comparable to or better than those of the best available pure line varieties for a plurality of agroecosystem services. In fact, wheat cultivar mixture experiments did not always demonstrate a positive mixture effect. In some experiments, only few of the tested mixtures were successful (Finckh and Mundt, 1992; Kiær et al., 2012). In other experiments, mixtures did not outperform their individual components for yield (Finckh et al., 2000; Kaut et al., 2009), grain quality (Cowger and Weisz, 2008; Kaut et al., 2009) or disease reduction (Kaut et al., 2009). The wheat mixtures used by Dai et al. (2012) were unsuccessful for yield, grain quality and disease reduction at the same time. These outcomes make it difficult to promote use of cultivar mixtures by farmers until a clear approach on how to create successful mixtures in any growing conditions will be available (Kiær et al., 2012). In this work, several common wheat cultivar mixtures and single component cultivars were tested for their potential to provide target agroecosystem services, viz. weed suppression, grain yield and grain quality, under Mediterranean conditions. Weed suppression has rarely been investigated in wheat cultivar mixtures (Kaut et al., 2009) and never under Mediterranean conditions. Kaut et al. (2009) showed no evidence of weed suppression by any of the cultivar mixtures tested and the effects studied were more related to weed tolerance (reduced effect of weed competition on crop performance) than weed suppression (the ability of the crop to reduce weed abundance and/or biomass).

Variation in competitive ability against weeds has been observed in bread wheat germplasm (Coleman et al., 2001; Lemerle et al., 1996). The weed suppression ability of more competitive cultivars is usually not due to a single trait but rather to a series of interacting traits that need to coexist to determine suppression (Hoad et al., 2012). Andrew et al. (2015) described plant height, early vigour, tillering capacity and canopy architecture as the most important above ground traits that have been associated with wheat competitive ability against weeds. In Hoad et al. (2012), increased plant height, rapid growth rate, wide leaf laminae, high yield potential and allelopathy are listed among the desirable traits, whereas a planophile habit and high leaf area index are reported as highly desirable traits. Good plant establishment, high early season ground cover and high tillering capacity were mentioned as essential for good competition against weeds. Although developing a ranking system for competitiveness of wheat cultivars would be desirable (Andrew et al., 2015), studies that investigated the contribution of wheat traits to crop competitive ability against weeds are sporadic (Lemerle et al., 2006; Mason et al., 2008; Murphy et al., 2008).

In this work, the effect of wheat stand type on the interference with weeds was investigated by looking at the role of a series of competition-related traits in the provision of the weed suppression service.

We tested the following three hypotheses on selected common wheat cultivar mixtures and stands of single component cultivars:

(1) Weed suppression, grain yield or grain quality can be improved by introducing a given set of homogeneous traits into the wheat stand, according to the mass-ratio hypothesis (Grime, 1998). This hypothesis intended to test the role of functional identity (Costanzo and Bàrberi, 2014) in determining the weed suppression, grain yield or grain quality potential of the wheat stand types.
(2) Weed suppression, grain yield or grain quality can be improved by increasing the diversity of given traits within the crop stand through a niche differentiation effect, according to the diversity hypothesis (Fornara and Tilman, 2008). With this hypothesis we tested the effect of the functional composition of the mixtures on the weed suppression, grain yield, or grain quality potential (Costanzo and Bàrberi, 2014).
(3) Increasing the diversity of cultivars within the crop stand, and consequently their trait diversity, is expected to improve the overall crop performance, i.e. the provision of the three target agroecosystem services (weed suppression, grain yield and grain quality) altogether. With this hypothesis, we tested the effect of specific trait combinations on the provision of selected agroecosystem services (Barot et al., 2017).

2. Materials and methods

2.1. Study site and experimental design

The experiment consisted of a field trial replicated across two growing seasons (2013/14 and 2014/15) at the Interdepartmental Centre for Agri-environmental Research (CIRAA) of the University of

Table 1
Soil properties of the experimental fields used in 2013/14 and 2014/15.

	pH	conductivity microS	CSC meq 100 g^{-1}	total N[a] mg kg^{-1}	organic matter[b] %	P[c] ppm	clay %	silt %	sand %
2013/14	8.03	101.17	2.97	1.43	2.03	6.32	17.51	47.54	34.95
2014/15	8.15	85.20	2.22	1.77	2.64	7.39	27.40	38.14	34.46

[a] Kjeldahl method.
[b] Walkley-Black method.
[c] Olsen method. Samples collected on 06/11/2013 on both fields.