Europ. J. Agronomy 76 (2016) 1–16

Contents lists available at ScienceDirect

European Journal of Agronomy

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

Field scale functional agrobiodiversity in organic wheat: Effects on weed reduction, disease susceptibility and yield

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ARTICLE INFO

Article history:
Received 9 November 2015
Received in revised form 22 January 2016
Accepted 25 January 2016

Keywords:
Composite Cross Population
Genetic diversity
Living mulch
Subterranean clover
Weed suppression
Wheat

ABSTRACT

Deployment of diversity at the species and at the genetic levels can improve the ability of crops to withstand a wide range of biotic and abiotic stressors in organic and low-input cropping systems, where the response to stresses through external input is limited or restricted in comparison with conventional systems. Although there are several strategies to use agrobiodiversity in wheat-based systems, their implementation is limited by the lack of a clear relationship between agrobiodiversity and provision of key agroecosystem services. In a three-year field trial in Central Italy we compared common wheat Italian and Hungarian pure lines, Italian old cultivars and Hungarian and British Composite Cross Populations (CCPs), grown with or without a contemporarily sown Subterranean clover living mulch. We aimed at linking crop performance, in terms of yield, weed reduction and disease susceptibility, to three categories of functional diversity: (1) functional identity, represented by the identifying traits of cultivars, (2) functional diversity, represented by the genetic heterogeneity of wheat crop population, and (3) functional composition, represented by the co-presence of wheat and the living mulch.

Concerning cultivars, effects of functional identity were predominant for weed reduction and grain yield. Old cultivars tended to better suppress weeds but to be less yielding. Italian cultivars were more advantaged than cultivars of foreign origin, thanks to a better matching of their growth cycle into local climate. Functional diversity effects on yield and weed reduction were confounded with identity effects, given that all the CCPs were of foreign origin. In fact, the performance of CCPs was generally aligned with a central-European pure line. However, differences in yield components suggest that CCPs can evolve peculiar yield formation strategies. Moreover, CCPs were less susceptible than pure lines to foliar diseases. For functional composition, the living mulch was able to reduce dicotyledonous weed abundance and weed biomass without reducing wheat yield unless wheat was poorly established. Despite the strong morphological and phenological differences among the tested cultivars, no interactions were found between cultivar and living mulch presence, suggesting that, in conditions similar to our experiments, there is room to freely combine elements of crop diversity. Crop diversification strategies in wheat should be further explored and optimized, especially by constituting CCPs from locally adapted germplasms and by improving the feasibility and efficacy of legume living mulches.

1. Introduction

Common wheat (*Triticum aestivum* L.) and durum wheat (*Triticum durum* Desf.) are the leading crops for human nutrition in Europe and in most temperate regions worldwide, and as such, they are facing the challenge of being produced more sustainably, with reduced levels of external inputs. In this respect, wheat is the cereal crop with the largest acreage under organic management. The most recent figures available show that in 2012 the total area grown worldwide with organic cereals totalled to 2,652,864 ha, of which wheat represented ca. 42% (Willer and Lernoud, 2014).

Wheat production faces a wide range of constraints, notably weed competition, diseases, reduced nutrient availability and climate unpredictability. In organic and low-input systems the array of external inputs able to buffer these constraints is limited, which prevents farmers from obtaining high and stable yields. Several authors have been calling for a paradigm shift in wheat production, to facilitate the transition of wheat production from conventional to organic and low-input cropping systems (Wolfe et al., 2008).

Adaptation of wheat crops to organic and low-input cropping systems – these latter intended, in the context of our paper, as cropping systems managed with little or no use of external inputs,

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http://dx.doi.org/10.1016/j.eja.2016.01.012
1161-0301/

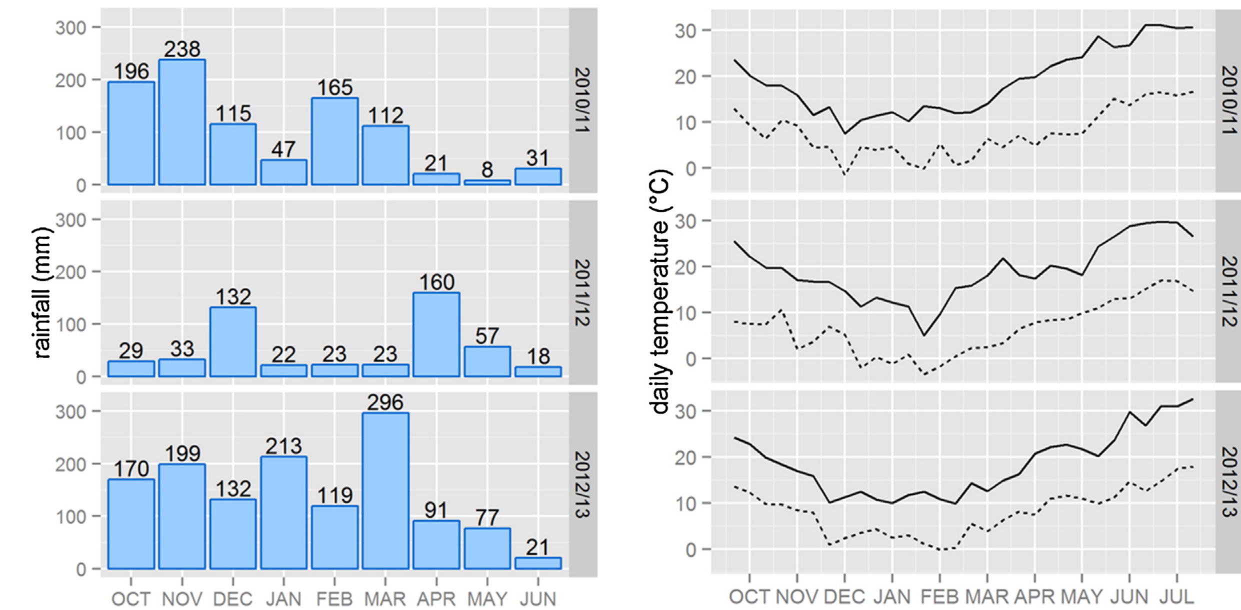

Fig. 1. Monthly rainfall (left) and maximum (—) and minimum (– – –) daily temperature (right) during the three growing seasons.

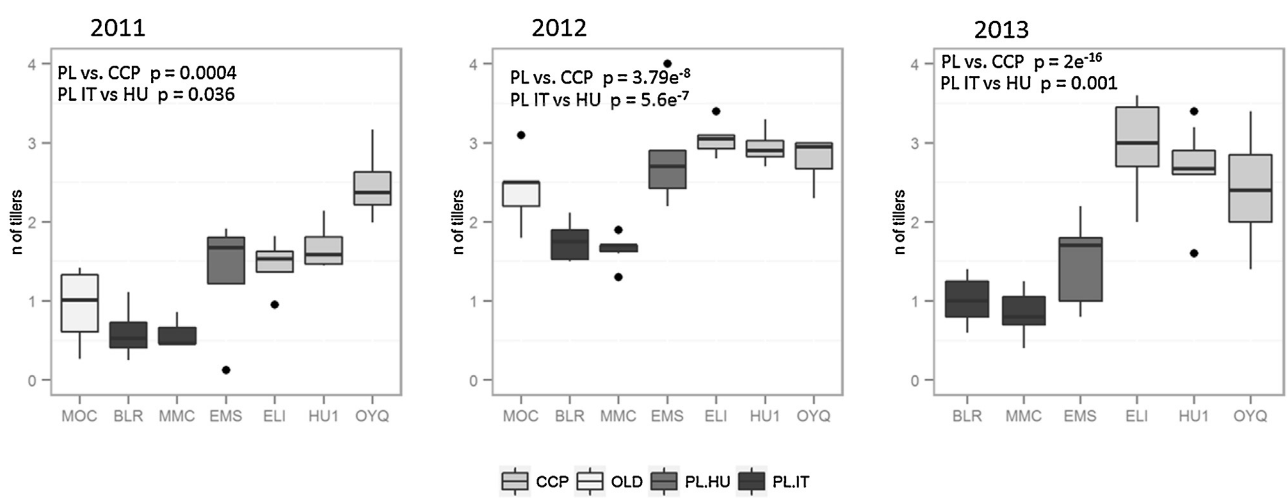

Fig. 2. Average number of supplementary tillers plant^{-1} during full tillering stage of wheat cultivars in Year 1 (16 April 2011), 2 (22 February 2012) and 3 (15 January 2013) of Trial #1. P-values of orthogonal linear contrasts are indicated.
MOC = Mix of Old Italian Cultivars; BLR = cultivar Bolero; MMC = Mixture of Modern Cultivars; EMS = cultivar Mv Emese; Eli = Elite CCP; HU1 = Hungarian CCP 1; OYQ = Organic Yield-Quality CCP. 'OLD vs MOD' = Old vs. Modern cultivars; 'PL vs CCP' = Pure Lines vs CCP; 'PL IT vs HU' = Pure Lines Italian vs Hungarian Cultivars.

including these managed by resource-poor farmers (Ceccarelli, 1996) – and to local agro-climatic conditions at a finer scale (Ceccarelli, 1989) have generally emerged as the main targets of novel wheat breeding approaches. As a result, Value for Cultivation and Use (VCU) testing protocols and breeding programmes dedicated to organic farming are now available (Foletto, 2008; Jones et al., 2003). Further, more interest on old wheat cultivars is re-emerging (Mason and Spaner, 2006; Stagnari et al., 2013).

Diversification of the crop stand is part of the overall strategy to improved wheat performance in organic and low-input systems, based on the potential of diversity to deliver agroecosystem services (Newton et al., 2009). Regarding diversification at the genetic level, there is a vast literature on cultivar mixtures (Kiær et al., 2009; Mundt et al., 1995, 1994; Wolfe, 2000) and there is an increased attention on new types of cultivars characterized by high genetic diversity (Wolfe et al., 2008). The most important example of the latter approach is the use of Composite Cross Populations (CCP): progenies of half-diallel crosses between a given number of parental genotypes, left growing in field conditions and reproduced through a cycle of harvest and re-sowing. This is expected to make the crop able to adapt to local environmental and management conditions through natural selection (Goldringer et al., 2006; Rhoné et al., 2008), according to the approach of Evolutionary Breeding (Döring et al., 2011; Phillips and Wolfe, 2005; Suneson, 1956). Regarding diversification at the species level, the strategy of mixing wheat with other crop species has also been explored. In this respect, the use of legume species as intercrops of living mulches is mainly focused on improving weed reduction (Hartwig and Ammon, 2002) and nutrient use efficiency (Stern, 1993).

Overall, crop and cropping system diversification, both at the genetic and at the species level, appears as a key strategy to buffer environmental variation and to optimize resource use efficiency. However, advantages of diversity are not to be taken for granted, as not necessarily higher diversity results in better provision of agro-ecosystem services (Ratnadass et al., 2012). Several tradeoffs between different services may emerge, e.g., the creation