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Unfolding the potential of wheat cultivar mixtures: A meta-analysis perspective and identification of knowledge gaps

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ABSTRACT

Increasing the biodiversity of cropped plants is a key leverage for agroecology, aiming to replace chemical inputs by ecological processes and regulations. Cultivar mixtures are a straightforward way to increase within-crop diversity, but they have so far been poorly used by farmers and they are not encouraged by advisory services. Based on the methodology developed by Kiær et al. (2009), we achieved a meta-analysis of cultivar mixtures in wheat. Among the 120 publications dedicated to wheat, we selected 32 studies to analyze various factors that may condition the success or failure of wheat mixtures by calculating overyielding, i.e. the difference in productivity of a variety mixture compared with the weighted mean of its component varieties in pure stand. The analysis highlighted a significant global overyielding of 3.5%, which reached 6.2% in condition of high disease pressures. Overyielding was not affected by seeding density or plot size. Under high disease pressure, overyielding increased by 3.2% point per added component variety. Overyielding was respectively 5.3% and 3.3% higher for mixtures heterogeneous in disease resistance or phenology than for homogeneous ones, and did not vary when considering height. Overyielding reached its highest values in the 1980s and 1990s, which reflects the predominance of disease-focused studies during this period. Our results confirm that cultivar mixtures are a potential way to increase yield relatively to pure varieties, especially under low pesticide cropping systems. Literature suggests that mixture practice is impeded by the lack of general rules that could help to mixing varieties. To design such rules it is needed to (1) achieve new experiments manipulating the heterogeneity in variety traits, (2) determine experimentally the ecological mechanisms underlying mixture performance and (3) develop new models allowing testing and analyzing these mechanisms.

1. Introduction

High yield gains have been achieved during the 20th century through the breeding of elite crop lines or hybrids adapted to the homogeneous cropping conditions of modern agriculture (Tilman et al., 2001) that strongly relies on chemical inputs and simplified rotations. However, this agricultural model seems to reach its limits, and many authors point out the side effects of intensification: water and air pollution, greenhouse gas emissions, deleterious impacts on natural ecosystems and human health issues (Carpenter et al., 1998; Robertson et al., 2000; Vitousek et al., 1997). Besides, agriculture is facing global climate changes, which is in part responsible for an increase in annual variability and, for some crops, a stagnation of yields (Brisson et al., 2010; Grassini et al., 2013). Stabilizing the production and switching to a more sustainable agriculture requires a paradigm shift, as advocated by many authors (Altieri, 1989; Malézieux, 2011). Adopting agroecological practices is one of the options for such a shift. Covering a wide range of practices, agroecology aims to replace chemical inputs by ecological processes and regulations. Biodiversity, whether species diversity (Loreau et al., 2001) or genetic diversity within species (Hughes et al., 2008) has been shown to play a critical role for the functioning of natural ecosystems, and increasing diversity of cropped plants has been proposed as a key leverage for agroecology (Malézieux, 2011). Many ecological mechanisms identified in natural ecosystems, such as complementarity and facilitation, are also at play within crop fields, both in co-culture of multiple species (Gaba et al., 2015; Litrico and Violle,

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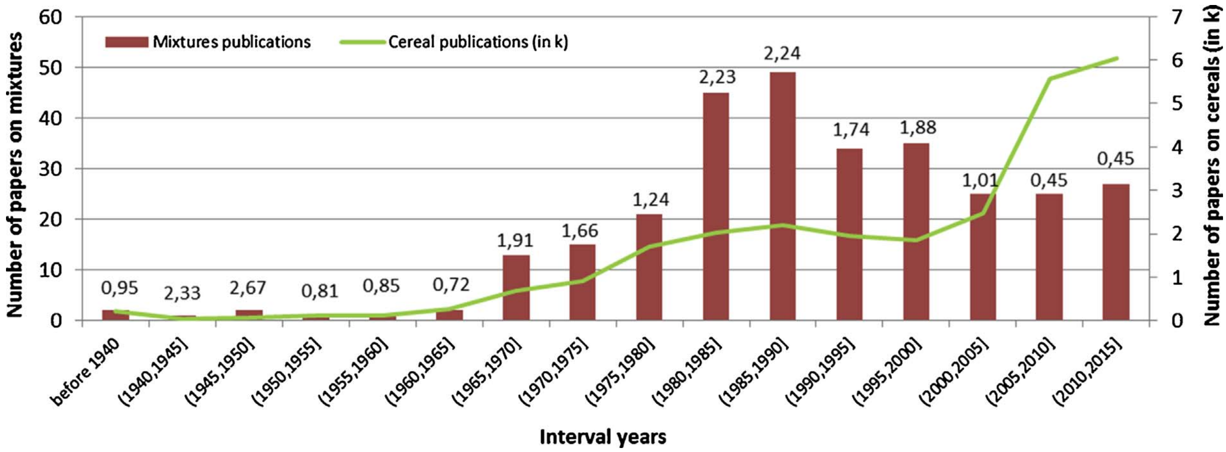

Fig. 1. Global evolution of publications concerning cereal cultivars (26,250 papers) and cereal cultivar mixtures (298 papers) between 1939 and 2015. The proportion of publications on mixtures compared to publications on cereals is represented at the top of the bars.

2015) and in cultivar mixtures (Barot et al., 2017). Cultivar mixtures (variety blends) are certainly the most straightforward way to increase within-crop diversity and their documented use in agriculture dates back to the eighteenth century (Wolfe, 1985). The interest of scientists for genetic diversity and cultivar mixtures in cereals rose in the late 1960s and remained constant during twenty years, as illustrated by the number of publications on the subject (Fig. 1).

However, after the 1990s the number of publications on cultivar mixtures dropped to approximately 4 publications/year since year 2000. Indeed, such stagnation denotes a declining interest of scientists for the subject, when compared to the strong increase in publications dealing with cereals genetics and agronomy in general (Fig. 1). Interestingly, the main themes addressed by publications on cereal mixtures also varied across years (see Fig. 2 and also supplementary material). First, one predominant question has been whether mixtures can outperform in yield their pure component varieties, i.e. present “overyielding”. Second, the burst in cultivar mixtures studies between 1970 and 1990 was mainly carried by phytopathologists encouraged by success stories such as spring barley mixtures in Germany that reduced powdery mildew incidence and fungicide use by 80% during 1984–1990 (Wolfe et al., 1992). Third, more recently, new interests for cultivar mixtures have emerged due to raising concerns about the sustainability of agriculture, leading to a diversification of research themes (Fig. 2), more oriented towards a better understanding of the ecological mechanisms involved in the ecosystem services potentially provided by mixtures (Gaba et al., 2015). Examples include exploitation of water (Adu-Gyamfi et al., 2015; Fang et al., 2014; Wang et al., 2016), control of insect pests (Shoffner and Tooker, 2013; Smith et al., 2014) and weed suppression (Kiær et al., 2009).

Despite some success stories in the past (Finckh et al., 2000), there has been a very limited use of cultivar mixtures by farmers in developed countries, and an even more limited incitation by most farm advisory services. Besides practical and legal barriers in the wheat chain that can impede cultivar mixture adoption, two main explanations can be proposed for the poor use of cultivar mixtures. First, the strong positive effects of cultivar mixtures might have been demonstrated under specific environmental and cropping conditions that do not correspond to dominant cropping systems. For example, mixtures could present positive effects under high disease pressures and low input levels that are not common under intensive agriculture. Indeed, according to the stress gradient hypothesis (Lortie and Callaway, 2006), overyielding should increase with disease pressure and abiotic stress because stresses can foster positive interactions and complementarity and compensation between the varieties of the mixture (Creissen et al., 2013). Second, academic researchers might have missed to address key questions on mixtures, partly because the development of alternative studies (as in agroecology) has stayed on the margins of dominant policy and research objectives, leading to a lock-in situation (Vanloqueren and Baret, 2009). For example, multi-resistant varieties that can contribute to the reduction of pesticides use have a little commercial success, partly due

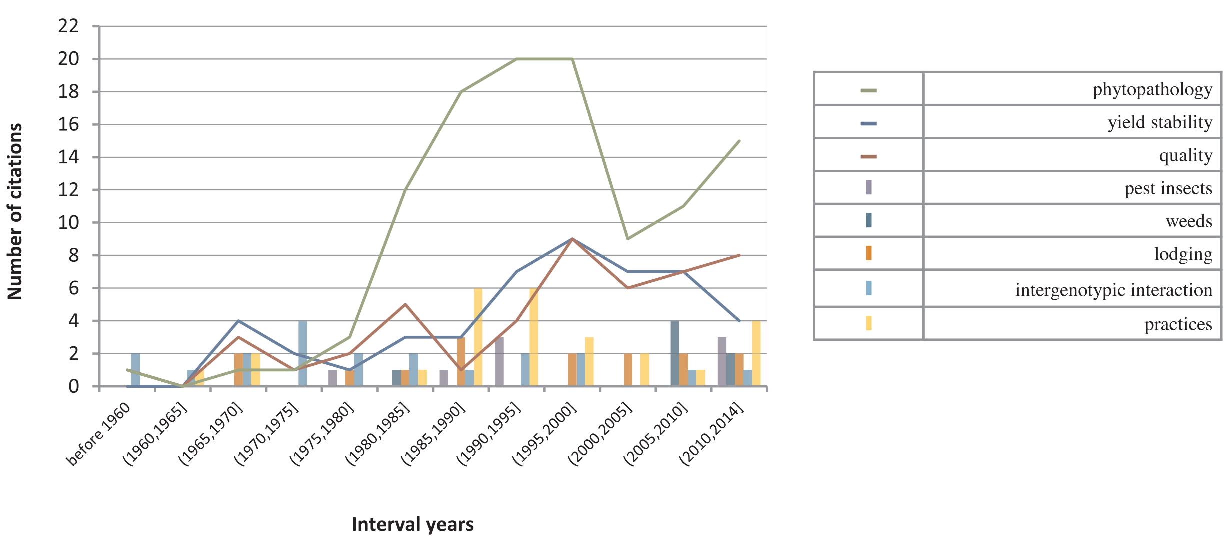

Fig. 2. Evolution in the main themes addressed by publications dedicated to cultivar mixtures. (298 papers analyzed).