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Agro-biodiversity restoration using wildflowers: What is the appropriate weed management for their long-term sustainability?

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A B S T R A C T

Wildflowers have an important environmental impact on rural biodiversity. Their chromatic and shape evolution, to attract pollinators, is the key to their dual benefit in terms of aesthetics and environmental functionality. Their scarcity and/or disappearance in conventional agro-ecosystems have led them to be considered as necessary for the restoration of the agro-environment. We compared the dynamics of wildflower-only and wildflower-weed communities, in outdoor boxes, in order to study the floristic evolution over the course of a three-year experiment. Four agronomic treatments were applied: seeding time, late winter cutting, summer harrowing, summer cutting after senescence. Our hypothesis was that the sustainability of the wildflower community was vulnerable to strong weed interference and that agronomic management is necessary for the long-term survival of wildflowers. The indicators used were: biomass, number of seeds in the seed bank, diversity indexes. Our results showed that the growth of the wildflowers was affected by the weeds, in terms of the biomass and seed bank accumulated. However, various agronomic disturbances, such as cutting and, to a greater extent, harrowing, maintained the balance of the floristic complexity in the wildflower-weed community. The plant equilibrium was confirmed by the Shannon, Simpson and Evenness indexes. We found that long-term wildflower sustainability is closely linked to the agronomic management. Further studies are needed to optimize the anthropic-dependent survival of such wildflower buffer areas, given the “greening” measures encouraged by the new European agricultural policy aimed at biodiversity conservation.

1. Introduction

The increasing problems of agro-biodiversity erosion, the vulnerability of the monoculture to many stress factors such as pests, drought, poor soil fertility, and the long-term decrease in crop productivity (Gomiero et al., 2011), have dramatically changed the role of weeds in the agro-ecosystem. A previous comparison carried out in central-southern England, nearly 40 years after the so-called ‘green revolution’, showed a marked decline, or even disappearance, of wildflowers that were once common (Sutcliffe and Kay, 2000). The restoration of the pre-existing biodiversity is of crucial importance in floristically degraded agricultural areas. In field margins, sowing strips of wildflowers (Blake et al., 2012), or grasses (Cordeau et al., 2012) has shown ecological benefits in terms of biological complexity, such as the improved presence of arthropods (Braman et al., 2002), e.g. butterflies (Haaland and Bersier, 2011), and beetles (Frank et al., 2012). Such activity can have many environmental advantages, including the return of agronomic productivity (Bullock et al., 2001).

Wildflower strips, sown in agricultural areas, can help in providing a diversity of ecosystem services through: i) the regulating services, such as pollination and pest control, with the support of pollinators and natural enemies ii) the production of food and other resources, with the reduced use of external inputs iii) the cultural services related to landscape and aesthetic aspects.

In terms of the regulating services, in the recent past considerable importance was attributed to species, such as *Centaurea cyanus*, which are now used as an indicator of the biodiversity of an agroecosystem (Bellanger et al., 2012). The diffusion of this species and other wildflowers was also considered as crucial in terms of ecological functionality, as in the survival of pollinators (Williams et al., 2015), spiders (Schmidt-Entling and Döbeli, 2009) and birds (Vickery et al., 2002). Indeed, wildflowers, characterized by eye-catching flowers, have usually evolved in such a way to attract pollinators (Mitchell et al., 2009). In addition, they often

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Table 1
Botanical, agronomic characteristics and germplasm collection sites of the species selected for the experiments, all life cycles of the species were annual (Therophyte) except for *Rumex crispus* which was perennial (Hemicryptophyte). (LU = Lucca; PI = Pisa; GR = Grosseto; all sites were in Italy).

Species	Experimental role	Botanical family	Collection site	1.000 seed weight (g)	Seeding rate ($g\,m^{-2}$)	Soil emergence (%)
Agrostemma githago L.	wildflower	Caryophyllaceae	Garfagnana (LU)	12.7	0.85	75
Alopecurus myosuroides Huds	weed	Poaceae	Asciano (PI)	1.45	0.12	62
Ammi majus L.	weed	Apiaceae	Lavoria (PI)	1.67	0.14	58
Anthemis arvensis L.	wildflower	Asteraceae	Roselle (GR)	1.63	0.18	45
Centaurea cyanus L.	wildflower	Asteraceae	Garfagnana (LU)	3.82	0.27	72
Chrysanthemum segetum L.	wildflower	Asteraceae	Asciano (PI)	0.85	0.09	48
Consolida ajacis (L.) Schur	wildflower	Ranunculaceae	Garfagnana (LU)	1.68	0.56	15
Galium aparine L.	weed	Rubiaceae	Asciano (PI)	11.24	1.31	43
Lolium multiflorum Lam.	weed	Poaceae	Asciano (PI)	1.57	0.15	52
Nigella damascena L.	wildflower	Ranunculaceae	Agnano (PI)	1.85	0.20	73
Rumex crispus L.	weed	Polygonaceae	S. Piero (PI)	2.21	0.18	61
Sinapis arvensis L.	weed	Brassicaceae	Lavoria (PI)	1.82	0.11	86

have specializations such as nectarines placed at the base of the flower's calyx which together with the pollen, provide food for many invertebrates (Johnson and Steiner, 2000). The plant-insect co-evolution has increased the attention on insect-pollinated flora, and the depletion of either the plants or pollinators, or both due to a feedback relationship (Potts et al., 2006; Nicholls and Altieri, 2013). The biological complexity also acts as a buffer against pathogens and parasites thanks to the various antagonistic organisms (Ferron and Deguine, 2005) for example wildflower strips can help in supporting aphidophagous hoverflies (Diptera: Syrphidae) (Hatt et al., 2017).

These regulation services can have a direct impact on production. Indeed, the diversity of the spontaneous vegetation growing in cultivated fields can play a positive agronomic role in crop protection against noxious weeds (Storkey and Cussans, 2007). The biological vacuum generated by the overuse of herbicides, in some cases, facilitates the development of aggressive weeds, which rapidly colonize all the empty ecological niches (Mortensen et al., 2000). Many crops are insect-pollinated and consequently the lack of pollinators increases the risk of a productivity decline (Kevan and Viana, 2003). On the other hand, most wildflowers, which in many cases are archeophytes, are now rare and their disappearance is due to the excessive agronomic pressure of intensive cropping systems (Kohler et al., 2011). Such biodiversity plays a crucial role in the long-term sustainability of agricultural productivity (Tscharntke et al., 2005).

A further advantage of sowing wildflower strips and preserving natural field margins, is the embellishment of the rural landscape (Junge et al., 2009; Aviron et al., 2010). Some segetal species, most of which are aesthetically pleasing wildflowers (Bretzel et al., 2016), are characterized by a poor degree of crop competitiveness and easy agronomic management. However, they can be part of the trophic web of the agro-ecosystem with no marked crop interference (Benvenuti et al., 2008). Field margins in both arable and grassland farming, typically have some form of boundary structure, usually with associated herbaceous vegetation, adjacent to the crop (Marshall, 2002). Today the rural landscape of the productive plains, which is largely devoted to monoculture (i.e. large fields sown with one crop species), is impoverished and devoid of the formally abundant and flowered species (Richner et al., 2015). In fact, several poorly-competitive arable weeds, which often survive in boundary edges (Fried et al., 2009), are "key species" ("the loss of these species leads to serious changes in the remaining biocoenosis via habitat and food chain relationships" (Albrecht, 2003)), which show the ecological complexity of the agroecosystem.

One of the critical aspects of the "green innovation" based on sowing wildflower strips, is due to their sustainability over time. Indeed, many pre-existing competitive weeds present in the soil seed bank, tend to dominate strongly, leading to the almost total disappearance of wildflowers, already two or three years after sowing (Basteri and Benvenuti, 2010). However, wildflower archeophytes, depend on a moderate amount of agronomic disturbance (Marshall and Moonen, 2002; Sutcliffe and Kay, 2000). In other words, the long-term sustainability of wildflower communities appears to be linked to a moderate agronomic management, which restrains the weeds (dominant undesired species) in a more balanced way. Basically the coexistence mechanisms (wildflowers and weeds) require some agronomic support (e.g. mowing, grazing, soil tillage) to contribute significantly to the maintenance of biodiversity. The intermediate disturbance hypothesis implies patterns of peak diversity under intermediate disturbance regimes, to maintain the diversity (Shea et al., 2004). Such agronomic disturbance can reduce the invasiveness potential of the most competitive (Zimdahl, 2004) and prolific (Norris, 2007) species, thus making the survival of a complex plant community possible. Nevertheless, very few studies have been carried out on the influence of agronomic disturbance on weed communities in relation to their long-term dynamics (Gross et al., 2015).

Monitoring the dynamics of the floristic complexity of a plant community over time is challenging, since the biomass assessment of each species constitutes only a "photograph" of the full plant development time, rather than the effective evolution of the plant community. Conversely the quantity of seeds accumulating in the soil, summarizes the wide range of interactions that have occurred over time among the plant community. Indeed, the soil seed bank stores several quiescent species as a consequence of the previous "seed rain" (Webster et al., 2003). The seed accumulation in soil depends not only on the annual seed production but also on the specific characteristics of germination and dormancy, since often, this latter feature assumes a crucial role in terms of persistence (Thompson et al., 2003a). Consequently, the seed bank is a key parameter of the survival sustainability of each species over time especially in a prevailing annual plant community. Thus the seed bank was assessed in order to evaluate the long-term plant community dynamics (Menalled et al., 2001).

The aims of this work were to verify: 1) the survival dynamics of a mix of wildflowers-only, and wildflowers with weeds, thus simulating field conditions 2) to investigate wildflower sustainability, using the soil seed bank to study the plant community biodiversity, managed with different agronomic techniques.

2. Material and methods

2.1. Plant material and germplasm collection

Previous surveys have identified some wildflowers that were cultivated traditionally in rural areas, in central Italy and which are now rare in the agro-environments (Benvenuti et al., 2008).