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SHORT COMMUNICATION

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The role of rabbit density and the diversity of weeds in the development of cover crops in olive groves

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Abstract

Cover crops are an effective means to reduce soil erosion and to provide food and shelter for wildlife. However, in areas of intensive farming, which are characterised by the scarcity of weed communities, wild herbivores may focus their grazing on cover crops, which could make their implementation difficult. In this work, we test whether rabbit grazing can prevent the growth of herbaceous cover crops in olive groves in Southern Spain in addition to assessing the role of rabbit abundance and diversity of weeds in the development of cover crops. This question has been addressed by sowing *Bromus rubens* between the rows of five olive groves in Cordoba province (Spain). We then monitored the surface covered by *B. rubens,* along with both diversity of weed communities and rabbit abundance. Two rabbit exclusion areas were also placed in each olive grove in order to assess the impact of rabbits on the development of cover crops. Our results showed that the surface occupied by *B. rubens* was considerably higher in the rabbit exclusion areas (mean 56.8 ± 5.65 %) than in those areas in which they could feed (mean 35.6 ± 4.32 %). The coverage occupied by cover crops was higher in areas with lower rabbit density, although this relationship was modulated by the weed diversity index, since in areas with the same rabbit abundance the coverage was higher in those with a richer weed community. These findings suggest that high rabbit abundances can prevent the development of herbaceous cover crops in olive groves, particularly in areas in which alternative food resources (measured as weed diversity) are scarce.

Additional key words: agriculture; *Bromus rubens*; crop damage; human-wildlife conflict; grazing; *Olea europea*; *Oryctolagus cuniculus*.

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Olive (*Olea europaea* L.) groves cover a vast surface of the Mediterranean basin, and are an important resource in terms of income and employment in some areas like southern Spain (Gómez *et al.*, 2004) in which agricultural intensification has also taken place, as has occurred on much farmland worldwide. This intensification includes an exhaustive weed control to prevent water competition by the use of herbicides and frequent ploughing that keeps the ground weed-free and bare, thus leading to severe soil erosion (Gómez *et al.,* 2003) and an overall decrease in both plant and animal diversity (McLaughlin & Mineau, 1995). Nonetheless, sustainability is one of the key priorities defined in the new Common Agricultural Policy (Pe'er *et al.,* 2014), and if this goal is to be achieved, it is essential to reduce soil erosion and enhance both plant and animal biodiversity on farmland.

In the light of these considerations, cover crops could be an appropriate tool with which to achieve the aforementioned objectives in woody crops. For instance, and taking olive groves as a model, different studies have evidenced that, in comparison with conventional tillage, cover crops increase soil carbon sink (Marquez-Garcia *et al.,* 2013); significantly reduce soil erosion and runoff (Gómez et *al.,* 2004); improve soil water conservation (Simoes *et al.,* 2014); and harbour higher songbird, soil microbial, pollinators and arthropod species richness (Saunders *et al.,* 2013; Castro-Caro *et al.,* 2014; McDaniel *et al.,* 2014). Furthermore, cover crops can provide an alternative food resource in woody croplands in order to satisfy herbivorous requirements and thereby reducing agricultural damage caused by wildlife. For instance, Barrio *et al.* (2012) suggest that cover crops can reduce crop damage by the European rabbit (*Oryctolagus cuniculus*) in Southern Spanish vineyards, since rabbits find an alternative food resource in cover crops. This means that, in areas characterised by high rabbit densities and a poor weed community resulting from intensive control, rabbit grazing could be also targeted towards the herbaceous cover crops, thus making their implementation difficult. Our objective was therefore to assess the development of cover crops in areas with different rabbit abundances and with varying alternative food resources measured as the diversity of weed species in order to understand in which situations the development of cover crops is viable.

Fieldwork was conducted in Córdoba province, Southern Spain, which is characterised by a dry Mediterranean climate (an average annual rainfall of 500 mm and monthly mean temperatures of 8-26 °C). The main crops are olives, grapes (*Vitis vinifera*), wheat (*Triticum* sp.) and sunflowers (*Helianthus annuus*). Rabbit hunting is very popular in the area, and they are also considered to be a pest species owing to the significant crop damage caused and the relative high density that they may attain in some areas (Barrio *et al.*, 2012). We selected five olive grove estates with an area ranging between 2 and 12 ha that were at least 20 km apart from each other. In autumn 2013, *Bromus rubens* (25 kg seeds/ha) was sown between every two consecutive rows in the entire orchard (mean row width 3 m). *B. rubens* has previously been used as a cover crop in Mediterranean regions (Linares *et al.,* 2014), since it is an annual grass which germinates in winter and withers before the dry season (late spring), thus avoiding water competition with olives. In all cases, herbaceous plants growing under trees were killed by herbicides after sowing and before *B. rubens* growth to prevent water competition. Two rabbit exclusion areas (6 × 3 m), fenced 0.5 m below ground and 1 m above ground, were placed in two sown rows on every estate (50 m apart), and located in the middle of the sown area to avoid edge effects.

Rabbit abundance was estimated at the olive grove estate level by counting the number of latrines per kilometre by walking transects of 1 km in length (mean 1.12 ± 0.03 S.E.). This method has been widely used in the literature on rabbits (Virgós *et al.,* 2003; Guerrero-Casado *et al.,* 2013), and it provides a good approximation of rabbit density at least at local scale. The surveys were performed in April, May and June 2014. Since other herbaceous species apart from *B. rubens* grew in the sown rows, the diversity of non-crop herbaceous plants (weed) was assessed by creating two linear sampling transects (100 m in length) in two sown rows, in which 10 points (0.5 m^2) separated by 10-m were sampled in each row. All weed species at these sampling points were identified (see Suppl. Table S1 [pdf online]), and we counted the number of individuals of each species and the coverage occupied by *B. rubens* visually as a proportion of an area, which was calculated by the same three people (J.G.C., A.J.C., and L.M.P), being the final data a mean value of the three fieldworkers. The mean values of the Shannon diversity index (Shannon & Weaver, 1963) for the weed community and the surface covered by *B. rubens* were calculated at the row level per month. Moreover, the coverage of *B. rubens* in the rabbit-proof areas was estimated at two survey points (0.5 m^2).

With regard to statistical analyses, a Wilcoxon paired test was used to check the difference in the average coverage of *B. rubens* between fenced and unfenced areas in the rows in which the fenced area was located (data recorded in May; n=10 pairs). A linear mixed model was then applied using the row as the experimental unit and the coverage occupied by *B. rubens* in each row (excluding the rabbit proof areas) as the response variable. In this model, rabbit abundance, expressed as the number of latrines per kilometre, and the Shannon weed diversity index were included as explanatory continuous variables, whereas 'month' was considered as a three level categorical variable (April, May and June) and plot was included as random factor. The interaction between rabbit abundance and Shannon index was also included in the model in order to evaluate whether the effect of rabbit abundance on cover crops depends on weed diversity. Assumptions of normality and independence were confirmed, and variance structure (varIdent) was added to the model to ensure homogeneity in residual spread. This allowed the residuals to have different spreads across the levels of a categorical variable (in our case, the variance covariate was 'month'). InfoStat software was used in all analysis procedures.

The surface covered by *B. rubens* was considerably higher (Wilcoxon's test, p<0.001) within rabbit exclusion plots (mean 56.8% ± 5.65 S.E.) than in those areas in which rabbits could feed (mean 35.6% ± 4.32 S.E.). In each pair, the differences ranged from 2 to 78% (mean 20.5%). The mixed model showed that the surface occupied by cover crops outside the rabbit exclusion plots depended on date, with the lowest values being obtained in June (Table 1). The interaction among rabbit abundance and the Shannon weed diversity index was significant (p = 0.001), meaning that the effect of rabbit abundance on cover crops depended on the diversity of the weed community (Table 1). More specifically, in areas with similar values of rabbit abundance, the coverage occupied by cover crops was higher in the presence of higher weed diversity (Fig. 1).

Table 1. Parameter estimates (± S.E.), *t* and *p* values of the variables included in the mixed model explaining coverage of cover crops. DF shows the degree of freedom of the denominator. The parameter estimate for the level of the fixed factor 'Month' was calculated using 'April' as a reference value

Parameter	Estimate	S.E.	DF	*t*–value	*p*–value
(Intercept)	110.13	15.64	20	7.04	<0.0001
May	3.46	2.16	20	1.61	0.1236
June	–28.96	2.53	20	–11.42	<0.0001
Shannon index	–88.91	20.18	20	–4.41	0.0003
Rabbit abundance	–4.32	1.12	20	–3.85	0.001
Shannon index * Rabbit abundance	6.23	1.61	20	3.85	0.001

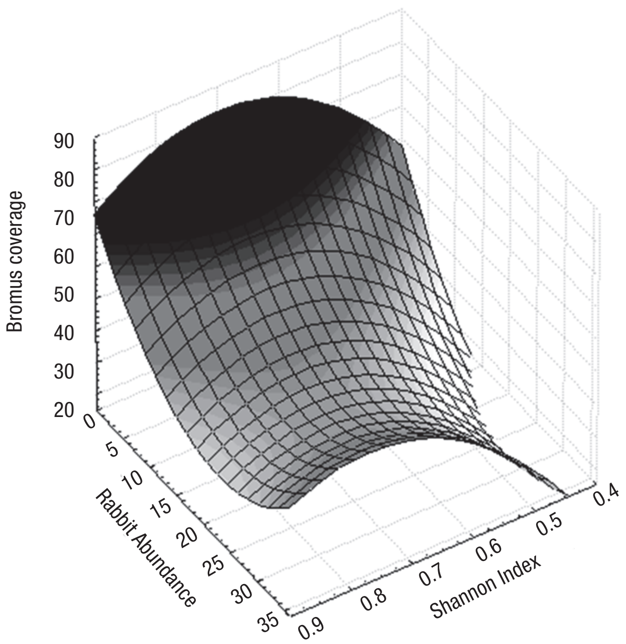

Figure 1. 3D graph showing the relationship between the coverage of cover crops (%), the rabbit abundance (latrines/km) and the Shannon index of weeds. Darker areas represent higher values of *Bromus rubens* coverage.

Agricultural intensification has led to an impoverishment of herbaceous weed communities, which may be problematic in agro-ecosystems in which weeds are important food resources for wildlife (Barrio *et al.,* 2013). The aforementioned authors suggest that the scarcity of alternative food resources can promote rabbit damage to woody crops, since they are almost the only resource available, and are thus more susceptible to rabbit damage. Concerning cover crops, we have found similar results, since, as expected, rabbits caused more damage to cover crops in areas with lower weed diversity. In fact, although the highest damage occurred in high rabbit density areas, in areas with similar rabbit abundance, the development of cover crops was much higher in those with a richer weed community (Fig. 1). The grazing exclusion areas allowed quantifying the use of cover crops by rabbits: as the rabbit is the main herbivorous mammal in the study area, the differences probably result solely from rabbit grazing. Indeed, in some pairs, the differences in the coverage of cover crops between fenced and unfenced areas was as much as 78%, which highlights the agricultural damage that rabbit can cause in the context of food scarcity, when they might be forced to consume crops.

Agro-environmental measures should therefore be applied to maintain weed species on farmland and thus increase food resources and overall orchard biodiversity. Simoes *et al.* (2014) recently proposed that cover crops controlled by mowing before water shortage could be an environmentally friendly management tool, since this practice may favour plant communities and soil water conservation without negatively affecting olive production. Furthermore, the lack of negative effects of cover crops on olive yield would make their implementation optimal in terms of cost-benefits from both an environmental and agronomic point of view as a consequence of its ecosystem services such as soil and water conservation (Duarte *et al.,* 2014; Simoes *et al.,* 2014).

Although cover crops have agro-environmental advantages, in this work we showed that high rabbit abundance can prevent their development. However, rabbit grazing is shown to be modulated by rabbit abundance and weed diversity. This entails that the implementation of cover crops in areas of high rabbit abundance and low weed diversity may be not viable, and it would thus be advisable to select plots with low rabbit density and/or a weed community with high diversity. Our results argue in favour of agricultural practices that are compatible with wildlife conservation, in which the development of a diverse weed community fulfils wildlife requirements, which in turn allow the development of cover crops and their intended benefits.

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