Cover crop differentially affects arthropods, but not diseases, occurring on grape leaves in vineyards

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Abstract

Background and Aims: Cover crop has become a common management practice in viticulture. It improves the structure and protects the soil, enhances natural enemy populations and also reduces the vigour of the vine. Here, we investigated the effect of cover crop in vineyards on grapevine diseases and arthropods present on leaves.

Methods and Results: We measured the presence of the pathogens *Plasmopara viticola*, *Uncinula necator* and *Guignardia bidwellii* and monitored six common beneficial/pest arthropods: *Panonychus ulmi*, *Orthotydeus lambi*, *Typhlodromus pyri*, *Scaphoideus titanus* and *Phalangium opilio* in vineyards with cover crop or bare soil in 2014 and 2015. The density of the two pests *P. ulmi* and *S. titanus* and the beneficial mite *O. lambi* was lower in cover crop, while the density of the beneficial predatory mite *T. pyri* was higher in cover crop. We found no influence of cover crop on *P. opilio* and on the presence of grapevine diseases.

Conclusions: These findings point to a simple way to increase the population of beneficial arthropods and reduce pest arthropods, which could help integrated pest management programs.

Significance of the Study: To our knowledge, this is the first study monitoring the cover crop influence on both diseases and arthropods. It would help growers to optimise space management between rows to enhance their natural enemy populations while reducing pesticide application.

Keywords*: black-rot, ground cover, leafhopper, mildew, mites*

Introduction

Growers have used cover crop in orchards and vineyards for centuries (Ingels 1998). Abandoned in the 20th century for synthetic fertilisers, cover crop experienced a widespread resurgence in the 21st century, as a result of the growing interest in sustainable agriculture and biological control (Ingels 1998). Cover crop has been shown to slow down erosion, improve soil structure, increase the development of beneficial microorganisms, smother weeds and regulate minerals, moisture and water supply (Landis et al. 2000, Gurr et al. 2004, Silvestre et al. 2012, Irvin et al. 2016). Despite these benefits, cover crop can also have a detrimental effect on vine growth, yield and grape composition (Caspari et al. 1997, Silvestre et al. 2012).

Cover crop can enhance populations of beneficial insects in agricultural systems and improve pest control as a result (Landis et al. 2000, Gurr et al. 2004, Irvin et al. 2016). In vineyards, it often increases the population of natural enemies of pests, thus reducing spider mite and some leafhopper populations on grapes (Hanna et al. 1996, Costello and Daane 1998, English-Loeb et al. 2003). For instance, Costello and Daane (1998) demonstrated, over 4 years, a lower density of leafhopper nymphs in cover crop vineyards compared with that of control vineyards. In their study investigating both pests (e.g. thrips, leafhoppers and mites) and beneficial arthropods (e.g. earwigs and spiders), Irvin et al. (2016) found that cover crop caused an increase of generalist predators and a migration of beneficial arthropods as well as pests into the grape canopy. Ultimately, both the efficiency and impact of cover crop in vineyards appear highly variable, thus requiring further study (Danne et al. 2010, Pérez-Alvarez et al. 2015).

Cover crop also creates microclimatic changes including a local decrease in temperature and an increase in humidity (Landis et al. 2000). Because temperature and humidity are key conditions for fungal growth, cover crop should also affect grape diseases. Downy and powdery mildew and, to a lesser extent, black-rot are three important leaf diseases causing considerable damage in vineyards (Ficke et al. 2002, Hoffman et al. 2002, Gadoury et al. 2003, Kennelly et al. 2005). These three fungi affect vine growth, yield and fruit composition leading to substantial losses and are managed principally with fungicides (Ficke et al. 2002, Hoffman et al. 2002, Gadoury et al. 2003, Kennelly et al. 2005). To our knowledge, no study has clearly tested the effect of cover crop on grapevine leaf diseases. This is surprising because cover crops are used with increased frequency in vineyards (Ingels 1998), and these diseases can be devastating (Valdés-Gómez et al. 2011), inducing the use of large amounts of fungicides [80% of pesticides used in French viticulture are motivated by grape downy and powdery mildews (Delière et al. 2015)]. By limiting the nitrogen available in the vine and thus reducing its vigour, cover crops could thus decrease to some extent both grape powdery and downy mildew (Hoffland et al. 2000, Mitchell et al. 2003). They could also increase, however, the moisture retention by leaves promoting the plant fungal diseases (Dake 1995, Singh et al. 2011).

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In this study, we investigated the effect of cover crop on grapevine leaf diseases and arthropods living on leaves. We monitored three of the most common grapevine diseases in French vineyards and six species of arthropods considered as pests or beneficial organisms over 4 months in 2014 and 2015. Because of microclimatic changes induced by cover crop, we predicted a higher frequency of grape diseases as a result of cover crop management. Moreover, because cover crop increases the population of natural enemies, we predicted a higher density of beneficial arthropods and a lower density of pest arthropods in cover crop management.

Material and methods

Vineyard plot and disease management

The experiment took place in the experimental vineyard of INRA Research Center la Grande Ferrade (Villenave d'Ornon, France). The vineyard plot is planted to Merlot vines (clone 181) and was planted in 1991. The management of the vineyard is a double Guyot training system with leaf and top removal every 14 days, if necessary. The area of the plot is 1383 m^2 containing 16 rows of 42 vines (total of 672 vines) and a density of about 5700 vines/ha. The distance between rows is 1.60 m and between vines 1.10 m. In this experiment, we used only rows 2, 3 and 4. These vines were non-treated (for more than 10 years) against diseases or arthropod pests. In each of the three rows tested, we did not use the two outermost vines because of potential effects from the surrounding grape plots. The 40 vines used in each row alternate five vines with natural cover crop and five vines without cover crop (called bare soil).

Experimental design and sampling

We assessed the effect of cover crop on the presence of disease symptoms and on the presence and density of six species of arthropods present on the leaves. Data were collected on seven occasions from May to August in both 2014 and 2015 (a total of 14 replicates).

Because both diseases and arthropods can be affected by the different environmental conditions between years, we recorded precipitation, temperature and humidity from May to the end of August. In 2014, a monthly average of 2.10 mm of rain fell in the vineyard, the mean temperature per month was 19.14°C (minimum 14.48°C; maximum 24.48°C) and the humidity per month was 72.47% (minimum 48.33%; maximum 93.69%). In 2015, a monthly average of 0.65 mm of rain fell in the vineyard, the mean temperature per month was 21.60°C (minimum 14.89°C; maximum 27.67°C) and the humidity per month was 65.64% (minimum 38.67%; maximum 92.62%).

Grapevine arthropods on leaves. Three mite species (*Orthotydeus lambi*, *Panonychus ulmi* and *Typhlodromus pyri*), the leafhopper *Scaphoideus titanus* and the harvestman *Phalangium opilio* were monitored. These species are common in French vineyards and can be described as pests and/or beneficial arthropods (Sentenac 2011).

Phalangium opilio (Opiliones: Phalangiidae) is the most common harvestman species in disturbed habitats, such as crops (Anderson 2012). This species is considered as an effective generalist predator in vineyards, controlling pest populations (Anderson 2012). Here, the number of harvestmen was visually counted on each vine, and 20 vines were assessed per treatment at each data collection. *Scaphoideus titanus* (Hemiptera: Cicadellidae) is a specialist leafhopper of *Vitis* in Europe and is the only known vector of flavescence dorée, one of the most destructive diseases in European vineyards (Chuche and Thiéry 2014). Flavescence dorée is a wall-less intracellular bacterium restricted to phloem sieve tubes (Papura et al. 2012), highly pathogenic to several major grapevine cultivars and often lethal to the vine. Thus, *S. titanus* is considered a major pest in European vineyards (Chuche and Thiéry 2014). The number of leafhoppers was visually counted on five leaves chosen at random per vine, directly in the vineyard. Twenty vines per replicate were assessed.

After these measurements, five leaves per vine (total of 100 leaves sampled for each treatment per replicate) were haphazardly sampled and brought to the laboratory for mite species determination (Collyer 1982, Bolland et al. 1998, Zhang et al. 2001). Each leaf was brushed with a mite brush, and the mites were collected, counted and identified with a binocular microscope (magnification 20×). We obtained an average number of each species per vine. We identified and focused on three major mite species during this monitoring: *O. lambi*, *P. ulmi* and *T. pyri*. *Orthotydeus lambi* is a mycophagous mite and highly abundant in vineyards (Melidossian et al. 2005, English-Loeb et al. 2007). This species can be considered as beneficial in vineyards because *O. lambi* can reduce powdery mildew on foliage and fruit (English-Loeb et al. 2007). Contrary to *O. lambi*, *P. ulmi* is a phytophagous mite and considered as a pest in vineyards and orchards (Alston and Reding 2011). Populations of *P. ulmi*, however, can be controlled by the predatory mite *T. pyri* commonly used in biological control in vineyards (Marshall and Lester 2001). *Typhlodromus pyri* is also an interesting species because it can use the grape powdery mildew as an alternative food source (Pozzebon and Duso 2008).

For each vine, we counted the number of primary and secondary branches and the number of leaves on these branches. Each sampled leaf was transversely measured with a ruler. We obtained the number of leaves on each vine and the average size of the leaves (precision ± 0.01 mm). Thus, we corrected the number of leafhoppers and mites by both the number and the size of the leaves to obtain a density in cm^2. The vine phenology was recorded at each replicate following the BBCH-scale for grapevine (Lancashire et al. 1991).

Grapevine diseases on leaves. We studied the three more common grapevine diseases present on leaves in French vineyards: the grape downy mildew (*Plasmopara viticola*), the grape powdery mildew (*Uncinula necator*) and the black-rot (*Guignardia bidwellii*).

The grape downy mildew is caused by the oomycete *P. viticola* (Kennelly et al. 2005) and powdery mildew by the ascomycete *U. necator* (Gadoury et al. 2003). These two fungi require specific microclimates for infection (mild temperature with high humidity) (Gadoury et al. 2003, Kennelly et al. 2005). Once infected, the vine suffers numerous injuries, such as a reduction of the photosynthetic capacity caused by a premature defoliation (Pool et al. 1984) and a delay in berry development (Wan et al. 2007). Symptoms of *U. necator* appear as irregular chlorosis of grey-white with white powder on the leaf surface and as black net lines with white powder on the surface of the berry, stalk and tendril, and symptoms of *P. viticola* appear as yellowish, oily lesions on the leaf surface (Wan et al. 2007). The ascomycete *G. bidwellii* causes black-rot. The infection period of this fungus is determined by the correlations between leaf wetness duration and temperature (Jermini and Gessler 1996). Symptoms of *G. bidwellii* appear as spots on the

leaves, tan to reddish-brown circular lesions (Hoffman et al. 2002).

We estimated the presence of each disease by recording at random the symptoms on 15 leaves per vine. Twenty vines per treatment were assessed. An average presence of each disease on each vine was then calculated.

Statistical analysis. The software R v3.1.2 loaded with the packages car, lme4 and MASS was used for all statistical analyses (R Development Core Team, 2011). The corrected number of arthropods on the leaves (harvestmen, leafhoppers and mites) was analysed using linear mixed models (lmer), in which treatments (bare soil or cover crop) and the years (2014 or 2015) were entered as explanatory categorical factors, while the vine number and the grapevine phenology were entered as a random effect.

The presence of each disease (*P. viticola*, *U. necator* and *G. bidwellii*) was tested using a generalised linear mixed model (glmer, with binomial distribution). In these models, the treatments and the years were entered as explanatory categorical factors, while the vine number and the grapevine phenology were entered as a random effect.

All models first included interactions between the two explanatory factors and were then simplified stepwise by removing the non-significant interaction terms (all *P*-values > 0.08). Note that some non-significant interactions are presented here to allow direct comparisons between models, but their removal did not qualitatively change the results.

Results

Grapevine arthropods on leaves

The presence of cover crop in the vineyard shaped the density of the monitored mites, *P. ulmi*, *O. lambi* and *T. pyri*, and of the leafhopper *S. titanus* but not that of the harvestman *P. opilio* (Table 1, Figure 1). Specifically, the two pests *P. ulmi* and *S. titanus* were more dense in bare soil compared with that with

Table 1. Effect of the treatment (bare soil or cover crop) and the sampling year (2014 or 2015) on the density of leaf arthropods tested.

	Panonychus ulmi		*Orthotydeus lambi*		*Typhlodromus pyri*		*Scaphoideus titanus*		*Phalangium opilio*	
	F	***P*-value**	***F***	***P*-value**	***F***	***P*-value**	***F***	***P*-value**	***F***	***P*-value**
Treatment	9.53	**0.002**	17.13	**<0.0001**	5.17	**0.023**	15.82	**<0.0001**	0.26	0.612
Year	0.67	0.411	19.08	**<0.0001**	0.43	0.513	0.01	0.915	0.22	0.638
Treatment*year	0.02	0.894	6.29	**0.012**	0.44	0.506	0.28	0.594	1.16	0.281

Significant *P* values are in bold.

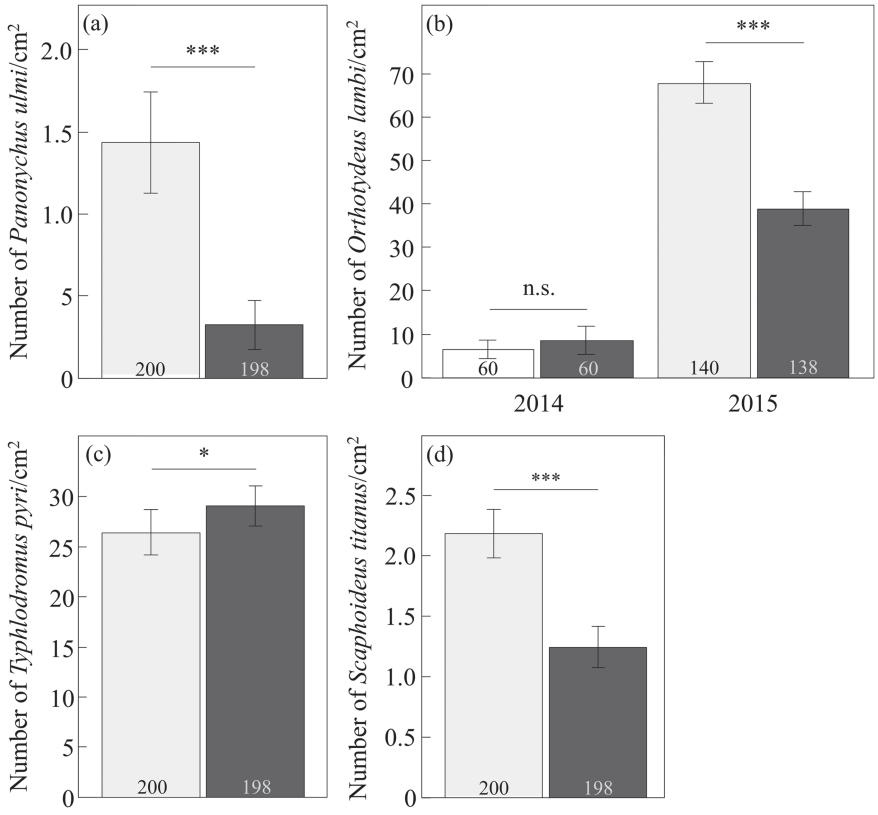

Figure 1. Effect of cover crop (■) on the number of arthropods on grapevine leaves compared with that of bare soil (■): (a) *Panonychus ulmi* (±SE); (b) *Orthotydeus lambi* (±SE) depending on the sampling year; (c) *Typhlodromus pyri* (±SE) and *Scaphoideus titanus* (±SE). The number in the bars represents the sample size. ***,$P < 0.0001$; *, $P < 0.05$; and n.s., non-significant.

Table 2. Effect of the treatment (bare soil or cover crop) and the sampling year (2014 or 2015) on the proportion of diseases on grapevine leaves.

	Plasmopara viticola		*Uncinula necator*		*Guignardia bidwellii*	
	F	***P*-value**	***F***	***P*-value**	***F***	***P*-value**
Treatment	2.44	0.118	0.05	0.826	0.77	0.378
Year	55.52	**<0.0001**	16.29	**<0.0001**	136.14	**<0.0001**
Treatment*year	0.57	0.448	0.01	0.906	2.58	0.108

Significant *P* values are in bold.

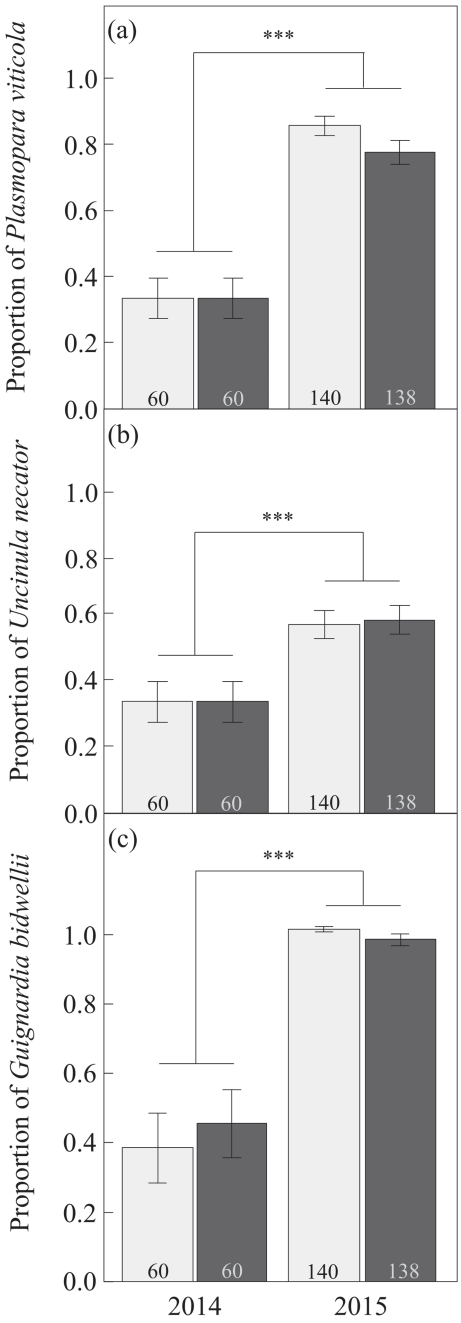

Figure 2. Effect of cover crop (■) and on the proportion of grapevine diseases on leaves/vine compared with that of bare soil (■) for the years 2014 and 2015: (a) grape downy mildew (*Plasmopara viticola*; ±SE); (b) grape powdery mildew (*Uncinula necator*; ±SE); and (c) black-rot (*Guignardia bidwellii*; ±SE). The number in the bars represents the sample size. ***, $P < 0.0001$.

cover crop (Figure 1a,d), whereas the predatory mite *T. pyri* was more dense in cover crop compared with that in bare soil (Figure 1c). The density of *P. ulmi*, *T. pyri* and *S. titanus* was not affected by the sampling year (Table 1). The density of the beneficial mite *O. lambi*, however, was affected by the interaction between year and treatment (Table 1, Figure 1b): the density was higher in bare soil compared with that under cover crop in 2015, but not in 2014 (Figure 1b). Finally, the number of harvestmen on each vine was affected neither by the treatment (bare soil: mean ± SE = 0.28 ± 0.04 *P. opilio*/vine; cover crop: mean ± SE = 0.30 ± 0.04 *P. opilio*/vine) nor by the year (2014: mean ± SE = 0.15 ± 0.11 *P. opilio*/vine; 2015: mean ± SE = 0.18 ± 0.03 *P. opilio*/vine) (Table 1).

Grapevine diseases on leaves

The presence of cover crop in the vineyard did not affect the presence of the three grapevine diseases monitored, *P. viticola*, *U. necator* and *G. bidwellii* (Table 2). In contrast, all diseases were more frequent in 2015 than in 2014 (Table 2, Figure 2).

Discussion

The aim of this study was to determine the effect of cover crop on beneficial or pest arthropods and different grapevine diseases on leaves in a vineyard. Except for the harvestmen, the arthropods monitored were generally influenced by presence of cover crop but in different ways. *Panonychus ulmi*, *O. lambi* and *S. titanus* were more abundant in bare soil, and *T. pyri* was more abundant in cover crop. Grapevine diseases were not influenced by the presence of cover crop but were affected by the sampling year.

Cover crop reduced the density of the two pests *P. ulmi* and *S. titanus*, which is consistent with other studies on *P. ulmi* in orchards (Brown et al. 1997) or leafhoppers in vineyards (Costello and Daane 1998, 2003). Cover crop can indeed provide alternative food and shelter against natural enemies (Landis et al. 2000), shifting the density of arthropods from grapevine leaves to crop cover, as found in leafhoppers (Trivellone et al. 2012, 2013). Conversely, by favouring establishment of natural enemies, cover crop increases pests predation and then may further decrease arthropod numbers on grapevine leaves (Landis et al. 2000, Thomson and Hoffmann 2009, Tirello et al. 2013). Cover crop can also affect grapevine physiology (Caspari et al. 1997, Landis et al. 2000, Silvestre et al. 2012) and indirectly affect arthropod biology. For instance, Costello and Daane (2003) suggested that the lower density of leafhoppers in the cover crop treatment resulted from poorer host plant quality because of the competition between ground cover and grapevines.

Contrary to the other arthropod species, cover crop improved the density of the predatory mite *T. pyri*. In both

vineyards and orchards, cover crop promotes the colonisation of phytoseiid mites such as *T. pyri* (Duso et al. 2005, 2014, Aguilar-Fenollosa et al. 2011). Cover crop and adjacent vegetation around crop indeed increase the availability of alternative food sources, such as pollen (Duso et al. 2005, 2012). Because phytoseiidae mites, such as *T. pyri*, are known to be mobile (Tixier et al. 2000), it might be a good strategy for them to switch from vine leaves to adjacent vegetation when there is less food available. These results reinforced the positive involvement of cover crop on control of pests in vineyards. *Typhlodromus pyri* is an efficient biocontrol agent used in vineyards and orchards (Gerson et al. 2008, McMurtry et al. 2013). Cover crop appears to positively affect the population establishment of this predatory mite and negatively affects pests such as *P. ulmi* and *S. titanus* and thus favours biocontrol. Surprisingly, the density of the predator *P. opilio* was not influenced by cover crop. Contrary to spiders that are favoured by cover crop and display little mobility between vines (Costello and Daane 1998, 2003), we hypothesised that harvestmen can disperse more and then easily switch from one vine to the other.

The density of the mycophagous mite *O. lambi* was higher in 2015 compared with that in 2014. In 2015, the temperature over the season was higher than that in 2014 with a relatively high humidity level. These conditions should have favoured the development of fungi in the vineyard, not only on grapevine leaves but also in cover crop. Even though the variation of the density of tydeid mites between years is well-known (English-Loeb et al. 2007), tydeid mites, such as *O. lambi*, are also known to be abundant in the presence of grape downy and powdery mildew (Duso et al. 2005, Melidossian et al. 2005, English-Loeb et al. 2007), meaning that the density of *O. lambi* might be related to the presence of these diseases.

In 2015, the density of *O. lambi* was higher in bare soil compared with that in cover crop. As shown before for *P. ulmi* and *S. titanus*, cover crop can provide alternative food and shelter against natural enemies (Landis et al. 2000), inducing a shift of arthropod density from grapevine leaves to the cover crop.

The grape downy and powdery mildew and black-rot were not affected by the treatment but were influenced by the sampling year. Management practices such as vine training have been shown to affect diseases through microclimate changes. For example, Guyot training, in Bulgaria, favoured *B. cinerea* infection because of poor air circulation and temperature inversion, while the high leaf temperature of high-trained vines favoured powdery mildew infection (Draganov and Draganov 1976). Hence, we expected that microclimate changes induced by cover crop management affected grapevine leave diseases. These conditions appear, however, to affect the grapevine diseases but at the year scale. In our experiment, the significant presence of diseases in 2015 might be due to the higher temperature compared with that in 2014 with a high level of humidity. In all three diseases monitored, the presence and intensity of these pathogens are indeed highly dependent on the year and consequently the climate (Spotts 1977, Jailloux et al. 1999, Madden et al. 2000, Harms et al. 2005). For instance, Jailloux et al. (1999) monitored grape powdery mildew during 5 years in a French vineyard of Merlot and found a strong influence of the April weather conditions (rainfall and temperature) on disease severity on berries by enabling good growth of the pathogen on leaves.

To conclude, we found that grapevine diseases on leaves were not affected by cover crop but by the climate between years. Moreover, except for the harvestmen, leaf arthropods were differentially influenced by cover crop. These results could prove useful in vineyard management because we showed an increased density of the predatory mite *T. pyri* and a decreased density of pests such as *P. ulmi* and *S. titanus*. Such information would help growers to best manage the ground cover between rows to promote and enhance their natural enemy populations while reducing pesticide application.

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