



## The Effects of Different Undergrowth Vegetation on the Types and Densities of Functional Ground-Dwelling Arthropods in Citrus Orchards

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### Abstract

In agricultural lands, citrus orchards, pest feeding and weed seed predation by ground-dwelling arthropods are essential ecosystem services. This research aims to investigate the effects of different undergrowth vegetation, including weed area, bare land, rattail fescue and white clover fields, on the types and densities of functional ground-dwelling arthropods in citrus orchards, using pitfall traps. The captured organisms included carnivorous beetles (*Pheropsophus jessoensis*, *Chlaenius naeviger* and *Dolichus halensis*), wolf spiders (*Lycosidae* sp.), earwigs (*Anisolabididae* sp.), house centipedes (*Scutigera* sp.), herbivorous ground beetles (*Amara* sp., *Harpalinae* sp.), crickets and millipedes. Furthermore, the population of the functional ground-dwelling arthropods was significantly increased by the presence of a live mulch, where a higher number was seen in the rattail fescue or white clover compared to the weed or bare land fields. The cover crops also affected the types of arthropods identified, with the rattail fescue field including more *Pheropsophus jessoensis* while the white clover had an elevated number of wolf spiders, earwigs and *Amara* sp. (a weed seed predator). This discovery indicates that the type of undergrowth vegetation plays an important role in enhancing functional biodiversity. The kind of pests and weeds that these arthropods are effective against, as well as the extent to which their densities can be decreased, is also unknown. Therefore, further research on the feeding habit and predation of these arthropods should be conducted.

**Keywords:** arthropod communities; cover crops; functional biodiversity; herbicide management; nature conservation

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### INTRODUCTION

Agricultural lands conserve the biodiversity of the agroecosystem, which primarily includes an abundance of pests and weeds. Therefore, considering functional biodiversity in farming is essential (Southwood and Way, 1970). A vital ecosystem service, such as conserving and enhancing functional biodiversity in agroecosystems is also assumed to preserve natural-enemy communities and their prey

biodiversity, resulting in biological pest control by their predators (Altieri, 1994; 1999). This “functional biodiversity” is also essential in providing specific agroecosystem services (Altieri, 1999; Moonen and Bàrberi, 2008; Rouphael et al., 2008; Bàrberi, 2015; Duru et al., 2015). Therefore, significant research has been dedicated to the conservation and improvement of this system in agricultural lands (Southwood and Way, 1970; Laureto et al., 2015; Martin et al., 2019). This system has also been globally

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recognized as an important resource for sustainable agriculture, under the 1993 Convention on Biological Diversity (Sakiyama et al., 2013; Ministry of Foreign Affairs, 2021). In Japan, the National Strategy for the Conservation and Sustainable Use of Biological Diversity (2010) and the Biodiversity Strategy of the Ministry of Agriculture, Forestry and Fisheries (MAFF) established in 2007 (MAFF, 2010), both recommend the development of biodiversity indicators to promote sustainable agriculture.

A research project conducted in Japan, regarding the indicators of functional agrobiodiversity organisms (Tanaka and Ihara, 2012; Tanaka, 2016) revealed that a decrease in pesticide usage increased the number of natural plant pest enemies (MAFF, 2012). This research was mainly focused on understanding the relationship between reduced pesticide cultivation and functional biodiversity (MAFF, 2012; Tanaka and Ihara, 2012; Tanaka, 2016). However, European countries have focused on increasing functional biodiversity through habitat management. These findings indicated that semi-natural grasslands observed in and around agricultural lands are suitable habitats for several functional ground-dwelling arthropods (Le Cœur et al., 2002; Grashof-Bokdam and Van Langevelde, 2005). In addition, the edges of agricultural lands, such as field margins, edges and boundaries were noted as important habitats for these organisms (Kleijn et al., 2001; Marshall and Moonen, 2002; Smart et al., 2002; Batáry et al., 2012). The creation of a green area (called "Beetle Bank") in fields has also been proposed to provide an effective habitat for functional ground-dwelling arthropods (Thomas et al., 1991; Sotherton, 1995; Collins et al., 2003; Fischer et al., 2010).

The undergrowth in an orchard serves as an effective habitat for natural enemies and other functional organisms. Orchards with rich undergrowth exhibit a lower incidence of insect pests than their clean cultivated counterparts due to the increased abundance and efficiency of natural enemies (Altieri, 1999). In Japan, some ground-dwelling arthropods, including beetles, spiders and earwigs that consume pests and weed seeds have been identified as indicators of functional biodiversity in citrus orchards (MAFF, 2012). Although the undergrowth has been traditionally maintained to prevent soil

erosion and drought (Yoshioka and Takahashi, 2005; Arita et al., 2008), few reports evaluated the effects of this vegetation on these organisms (MAFF, 2012; Tanaka and Ihara, 2012; Tanaka, 2016). This research aims to investigate the effects of different undergrowth vegetation on the types and densities of functional ground-dwelling arthropods.

The quantity and quality of functional organisms differ based on the vegetation type (Southwood and Way, 1970; Altieri, 1999). The type of weeds growing in a particular land (undergrowth) also influences the kind of arthropod communities observed in that region (Norris and Kogan, 2000; 2005; Barberi et al., 2010). This phenomenon is due to the low dispersal capacity and migration of these organisms from one location to another (Ishitani, 2010). Furthermore, research is being conducted in the United Kingdom to classify weeds as a functional group based on the types of organisms that interact with this plant species (Storkey, 2006). The conservation of this ecosystem by vegetation management at the weed species level is also being promoted. Therefore, this research aims to investigate the effects of vegetation differences on the types and densities of functional ground-dwelling arthropods and not only on the presence or absence of undergrowth in citrus orchards.

## MATERIALS AND METHOD

### Research field

This research was conducted with the Wenzhou mandarin oranges, which have been cultivated in the citrus orchard at the Center for Education and Research in Field Sciences, Shizuoka University since 1974 (Kariyado, Fujieda City, Shizuoka Prefecture, Japan; 34°54'18.8" N, 138°16'19.7" E). Based on the differences in the undergrowth vegetation, the orchard was divided into four test areas of 50 acres, namely: 1) Rattail Fescue field, 2) White Clover field, 3) Weeds area, which is dominated by field horsetail (*Equisetum arvense*) and common crabgrass (*Digitaria ciliaris*) and 4) Bare land (no weed).

According to the local practice, weed areas and bare land plots were treated with a 200-fold diluted glufosinate solution ('Basta', BASF Japan Ltd.) in early June. Meanwhile, the herbicide-mowing management region was sprayed with

200-fold diluted glyphosate isopropylamine salt ('Sanfuron', Taisei Nozai Co., Ltd.) in August and September.

### Pitfall trap

A plastic cup with a diameter and height of 90 mm and 120 mm was embedded in the ground and filled with 100 ml of 70% ethanol to exterminate and preserve the captured insects. Figure 1 illustrates the installation of an 18 cm diameter paper plate over the trap, as a rain shield. Subsequently, five traps were set in each plot and recovered after a week to identify the species of the captured ground-dwelling arthropods and estimate their populations. These devices were set up seven times on April 28, May 23, June 28, July 21, August 21, September 29 and October 30, 2017.



Figure 1. Illustration showing the installation of pitfall traps

### Determination of Shannon-Wiener diversity index

The Shannon-Wiener diversity index ( $H'$ ) was calculated (Shannon and Weaver, 1949; Magurran, 1988), as illustrated Equation 1.

$$H = - \sum_{i=1}^s \frac{n_i}{N} \ln \frac{n_i}{N} \quad (1)$$

Where  $H$  represents the diversity in a circle of  $S$  species, while  $n_i$ ,  $N$  and  $\ln$  denote the number

of individuals in the  $i$ th species, the total number of individuals in all species and the natural logarithm, respectively. The elevated value of  $H$  indicates the richness of higher species and also signifies that the different classes in the quadrat or community are nearly equally abundant.

### Data analysis

The Bell Curve for Excel 5.0 (Social Survey Research Information Co., Ltd.) software was used to analyze the data. Subsequently, Tukey's multiple range test was employed to detect the significant differences between the treatments with a probability of 95% ( $\alpha = 0.05$ ), after conducting an analysis of variance.

## RESULTS AND DISCUSSION

Carnivorous arthropods, such as beetles (*Pheropsophus jessoensis*, *Chlaenius naeviger* and *Dolichus halensis*), wolf spiders (*Lycosidae* sp.), earwigs (*Anisolabididae* sp.) and house centipede (*Scutigera* sp.) were captured. The earwigs were identified as the most abundant species in the citrus orchard. Also, no nectar or pollen consuming ground-dwelling arthropods were observed, though the test vegetation was provided with this nutrition source. Table 1 shows the number of ground-dwelling arthropods caught by pitfall traps in each test plot during the survey period.

In Japanese agricultural fields, carnivorous ground beetles and spiders are considered important for functional biodiversity (MAFF, 2012). *Pheropsophus jessoensis* were identified as the predominant species of the ground beetles, which are natural enemies of aphids and caterpillars (Sunderland and Vickerman, 1980; Chiverton, 1987; Sunderland et al., 1987; Fuller, 1988; Holland et al., 1996; Sa'adah and Haryadi, 2021). The rattail fescue field had the highest population of this species, followed by the white clover. Wolf spiders were also noted as natural enemies of aphids and planthoppers (Nyffeler and Benz, 1988; Dennis and Wratten, 1991; Holland and Thomas, 1997; Inagaki et al., 2010), with the clover field having the highest populace, followed by the rattail fescue. In addition, the earwig (*Anisolabididae* sp.) shared a similar distribution pattern with the wolf spiders. These results indicate that cover crops, such as white clover and rattail fescue effectively enhance functional biodiversity by increasing the population of natural enemies. However,

the types of functional ground-dwelling arthropods varied depending on the cover crop, with rattail fescue enhancing the number of *Pheropsophus jessoensis* while wolf spiders and earwigs increased in the white clover field. *Pheropsophus jessoensis* and wolf spider

are also polyphagous natural enemies (i.e., natural enemies of a diverse range of pests), that require further investigation to determine the kinds of pests they prey on. The field with weeds had the highest Shannon's diversity index (H') value for carnivorous arthropods.

Table 1. The species and total numbers of ground-dwelling arthropods captured from each test plot in the citrus orchard during the survey period

	Species	Rattail fescue	White clover	Weed (field horsetail)	Bare land	ANOVA	
Carnivorous	Beetle	<i>Pheropsophus jessoensis</i>	38 <sup>a</sup>	10 <sup>b</sup>	3 <sup>b</sup>	6 <sup>b</sup>	**
		<i>Chlaenius naeviger</i>	1	1	1	0 <sup>c</sup>	ns
		<i>Dolichus halensis</i>	0 <sup>b</sup>	1 <sup>b</sup>	6 <sup>a</sup>	0 <sup>b</sup>	**
	Spider	<i>Lycosidae</i> sp.	11 <sup>b</sup>	30 <sup>a</sup>	5 <sup>c</sup>	7 <sup>bc</sup>	**
	Earwig	<i>Anisolabididae</i> sp.	37 <sup>b</sup>	61 <sup>a</sup>	8 <sup>c</sup>	2 <sup>c</sup>	**
	House centipede	<i>Scutigera</i> sp.	3 <sup>a</sup>	2 <sup>ab</sup>	1 <sup>b</sup>	2 <sup>b</sup>	**
	Shannon's diversity index H'	1.09	0.98	1.30	0.94		
Seed predator	Beetle	<i>Amara</i> sp.	13 <sup>b</sup>	41 <sup>a</sup>	9 <sup>b</sup>	10 <sup>b</sup>	**
		<i>Harpalinae</i> sp.	7 <sup>a</sup>	5 <sup>a</sup>	0 <sup>b</sup>	5 <sup>a</sup>	**
	Cricket	<i>Gryllidae</i> sp.	4	2	2	2	ns
	Millipede	<i>Diplopoda</i> sp.	2 <sup>b</sup>	5 <sup>a</sup>	2 <sup>a</sup>	2 <sup>a</sup>	*
	Shannon's diversity index H'	0.60	0.62	0.66	0.95		
Total	Shannon's diversity index H'	1.69	1.60	1.95	1.89		

Note: Total number of 5 traps  $\times$  7 times (April to October). \*\*, \* indicates significant difference at 1% level and 5% level individually in ANOVA after arcsine transformation and ns implies no significant difference. Different letters indicate significant differences among treatments based on Tukey's multiple range tests at 5% level

The majority of research on ground-dwelling arthropods in functional biodiversity has focused on the carnivorous predators of pests. In Japan, weed seed predators are not listed as an indicator species for functional biodiversity, due to the limited reports available on the functions of herbivorous arthropods (MAFF, 2012). However, herbivorous ground-dwelling arthropods are known predators of weed seeds (Pausch, 1979; Holland, 2002), which occupies an important position in the agroecosystem (Ichihara et al., 2015). Recently, crickets have been reported as the major weed seed predators in Japanese agricultural lands (Ichihara et al., 2011; 2012; 2014a; 2014b; 2015). The number of herbivorous ground beetles in this research was observed to be higher than crickets in the citrus orchards. Furthermore, members of the Harpalinae subfamily have been reported to consume major weed seeds in agricultural lands (Yahiro et al., 1992; Yamazaki et al., 2003; Kagawa et al., 2008; Lee et al., 2008). These

herbivorous ground beetles are expected to promote weed control in citrus orchards. The population of *Amara* sp. was also statistically higher in the white clover field than in other vegetation types while *Harpalinae* sp. was not observed in the crop with weeds. In the test plots, no difference in the number of crickets was observed. Although millipedes and woodlice are considered decomposers that feed on plant residues, recent studies showed they prey on weed seeds (Saska, 2008; Koprđová et al., 2010). In this research, millipedes were observed in all the plots while woodlice were not detected, though similar research reported that a large number was captured in tea gardens (Inagaki dan Saruta, 2021). The Shannon's diversity index (H') for seed predators was highest in the bare land, while the value for the total functional ground-dwelling arthropods was elevated in the field with weeds or bare land compared to that with a cover crop.

Figure 2 shows the seasonal variations in the emergence of major functional ground-

dwelling arthropods, including carnivorous and herbivorous beetles, wolf spiders, as well as earwigs. The carnivorous beetles were observed briefly in the white clover terrain in July but were present in the rattail fescue field for a prolonged period (between May and July). In bare land and weed area, the incidence of carnivorous beetles peaked in June, with a limited number. However, this population increased between July and October for the weed area. The herbivorous ground beetles had different peaks in both areas, where it increased in May

and June in the rattail fescue and white clover fields, respectively. These organisms were also reported in lower numbers in the weeds and bare land fields. The prevalence of wolf spiders in the white clover and rattail fescue terrains peaked in June and between September and August. These organisms were also observed less in the field with weeds and bare land. Moreover, the earwigs had their highest population in June in the white clover field but were not observed in bare land, rattail fescue or weed areas.

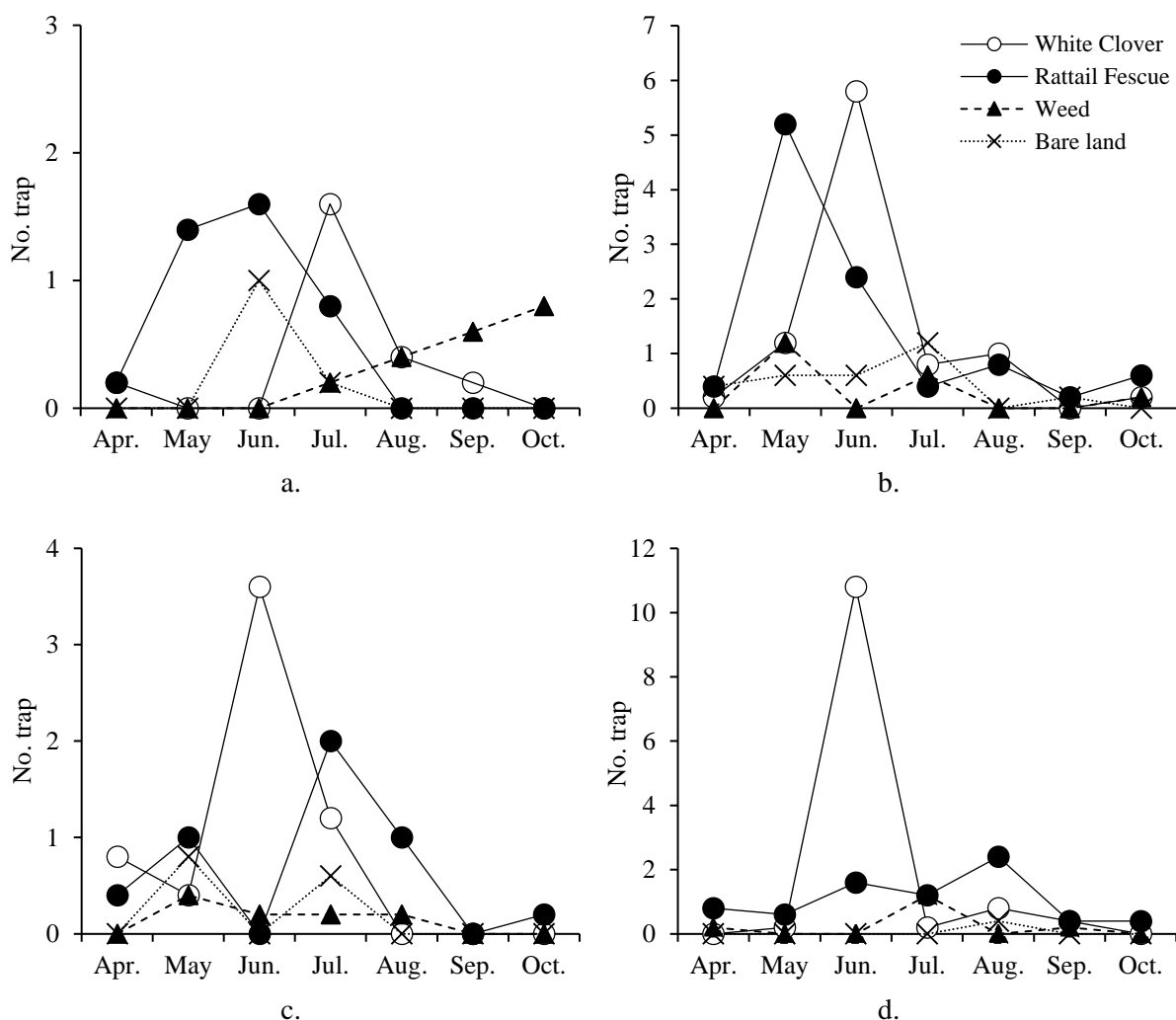


Figure 2. Seasonal variations in the emergence of major functional ground-dwelling organisms in citrus orchards: a) Carnivorous beetle, b) Herbivorous beetle, c) Wolf spider and d) Earwig

An interesting shift was observed in the peak timings for the occurrences of the wolf spiders, carnivorous and herbivorous beetles in the rattail fescue and white clover fields. The detailed research on the food of each functional ground-dwelling arthropod is essential,

as the types and timing of these organisms' appearances differ depending on the vegetation. In addition, the feeding patterns of wolf spiders, carnivorous and herbivorous beetles in citrus orchards should be clarified in the future.

## CONCLUSIONS

According to this research, the number of functional ground-dwelling arthropods, such as predators of pests and weed seeds, increased in citrus orchards with rattail fescue or white clover as a cover crop. This means the type of undergrowth vegetation plays an important role in the enhancement of functional biodiversity. The types of functional ground-dwelling arthropods also differed depending on the type of cover crop. In addition, the number of *Pheropsophus jessoensis* was high in the rattail fescue field, while wolf spiders and earwigs were elevated in white clover. The pest species and weed seeds that serve as food resources for these functional ground-dwelling arthropods and how these organisms effectively control their population and reduce their density remain unclear. Therefore, further research into the food types and predators of these arthropods is necessary.

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