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Influence of Weed Management Practices on Ground-dwelling Arthropod Assemblages in Organic and Conventional Apple Orchards

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유기재배와 관행재배 사과원 내 지표 배회성 절지동물 군집에 대한 잡초 관리의 영향

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ABSTRACT: Ground-dwelling arthropods are important components in apple orchard providing beneficial ecological services of predation and decomposition as well as herbivory. Groundcovers are managed differentially in organic and conventional apple orchards influencing ground-dwelling arthropod assemblages. We conducted 3-year studies to assess the effects of orchard management relative to weed management on the abundance and diversity of ground-dwelling arthropods using pitfall trapping. Most arthropods were classified as higher taxonomical groups and functional feeding guilds, while carabid beetles were classified into species level. Coleoptera was the dominating taxon of all ground-dwelling arthropods. Abundance of herbivores and predators was significantly higher in organic apple orchards than conventional ones. Higher abundance and diversity of carabid beetles were found in organic orchards than in conventional orchards. The abundance of Araneae, Coleoptera, or carabid beetles was negatively correlated to weed management frequency. It was found that ground-dwelling arthropods were more influenced by weed management practices than the farming systems.

Key words: Weed, Companion plant, Agricultural production, Sustainability, Network

초 록: 초식, 포식, 분해 등 생태학적 서비스를 제공하는 지표 배회성 절지동물은 사과원의 중요한 구성 요소이며, 이들의 군집에 영향을 미치는 잡초는 유기재배와 관행재배 사과원에서 다르게 관리된다. 잡초 관리와 관련된 과수원 관리가 지표 배회성 절지동물의 풍부도와 다양도에 미치는 영향을 평가하기 위해 3년간 연구를 수행하였다. 대부분의 절지동물은 상위분류군과 섭식 기능군으로 분류하였으며, 딱정벌레류는 종 수준으로 분류하였다. 지표 배회성 절지동물의 주요 우점군은 딱정벌레목으로 나타났다. 초식자와 포식자의 풍부도는 유기재배 사과원에서 높은 결과를 보였으며, 딱정벌레류의 풍부도와 다양도 또한 관행재배 과원보다 유기재배 사과원에서 높은 결과를 보였다. 거미목, 딱정벌레목 또는 딱정벌레류의 풍부도는 잡초 관리 빈도와 음의 상관관계를 보였다. 지표 배회성 절지동물은 농업 시스템보다 잡초 관리에 영향을 더 많이 받는 것으로 나타났다.

검색어: 잡초, 동반식물, 농업생산, 지속가능성, 네트워크

Biodiversity in agroecosystem performs a variety of ecological services of food production, nutrient cycling, soil conservation, regulation of microclimates and water holding capacities, detoxification of pesticides and suppression of pests and diseases (Altieri, 1999). However intensive farming has

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affected agricultural biodiversity by toxic effects from pesticides and disturbances of the habitat structure as well as chemical conditions through fertilizer and machinery inputs as well, inflicting sustainability of agriculture (House and Alzugaray, 1989; Dennis et al., 1997; Cole et al., 2005; Uchida and Ushimaru, 2014; Vergnes et al., 2014). Unsprayed apple orchards support a large fauna of arthropod species than sprayed orchards (Bleicher et al., 2006; Kondorosy et al., 2010). Application of pesticides adversely affects ground-dwelling arthropod predators by residues, direct contact, and ingestion of contaminated prey or by feeding on dead contaminated weeds (Brown et al., 1983; Chiverton, 1984).

In apple orchards where perennial fruit trees are persistent, ground covers are often considered as important biodiversity bank. Ground vegetation can contribute biodiversity by improving soil fertility through the incorporation and retention of nutrients and water, or by hosting populations of beneficial as well as phytophagous arthropods that can provide significant stability to the agroecosystem. Ground-dwelling arthropods reproduce and mature quickly and are highly sensitivity to changes in microhabitats (Intachat et al., 1997; Ellis et al., 2001). Many are acting decomposers, arthropod predators or seed predators (Stinner and House, 1990; Ball and Bousquet, 2001; Tooley and Brust, 2002; Torres and Ruberson, 2007). Also, some members are involved in soil ecological engineering through decomposition, maintaining soil structure, fertility, and nutrient cycling (Seastedt and Crossley, 1984).

In an orchard system, weed mortality is also governed by seed predation along with chemical control practices (Menalled et al., 2000; Davis et al., 2003; Gallandt et al., 2005; Westerman et al., 2005; Menalled et al., 2007). These alterations may cause direct changes in microclimatic conditions, soil properties, and resource availability (Li et al., 2009).

Early season weed management can help apple tree for competing nutrients and water with ground vegetation (Merwin and Stiles, 1994; Utkhede and Hogue, 1998). In organic farms, physical and cultural weed control techniques are applied (Ock and Pyon, 2011), while clean management, especially desiccating weeds by herbicide or complete bare-ground maintenance is practiced in conventional farming (Choi et al., 2009).

In this study, we monitored ground-dwelling arthropods using pitfall traps in organic and conventional apple orchards. In agriculture ecosystems, Hymenoptera, Coleoptera, and Araneae are dominant ground-dwelling arthropods (Purvis and Curry, 1984; Bhatti et al., 2005). In Coleoptera, Carabid beetles are free-living generalist predators and considered as ground cover indicators because of their sensitivity to habitat alteration (Holliday and Hagley, 1984; Barney and Pass, 1986; Andersen, 1992; Cárcamo, 1995; Cárcamo et al., 1995; Kromp, 1999). Thus, objectives were to evaluate if the ground-dwelling arthropod assemblages, mainly Hymenoptera, Coleoptera, and Araneae are more influenced by farming systems or weed management.

Materials and Methods

Study sites

The study was conducted in 10 apple orchards at five different locations as follows: Buksam in Chilgok (36°03′N, 128°12′E); Dain (36°27′N, 128°23′E) and Oksan (36°21′N, 128°52′E) in Uiseong; Hyeondong in Cheongsong (36°17′N, 129°00′E); Punggi in Yeongju (36°50′N, 128°28′E) in Gyeongbuk province, South Korea (Fig. 1; Table 1). In each location, a pair of organic and conventional apple orchards were chosen within 500 m distance each other. 3 ~ 9-year-old organic orchards were chosen for this study, and “Fuji” was the most dominant apple variety in study sites (Table 1). Weed managements of the two orchard systems are shown in Table 1. In organic farms, weeds (ground vegetation) were remained or trimmed with mowing machine between the rows of trees, while in conventional orchards, herbicide spay or bare-ground maintenance is practiced, in general. Likelihood rate of practices was depicted in Table. 1. If mowing is practiced every year in spring, then “1”, or once in 3 year, then “0.3”.

Sampling of ground-dwelling arthropods

Using pitfall traps (8 cm in diameter of mouthpart, 12 cm in height) ground-dwelling arthropods were collected in the spring (late April-mid May) from each site every year during 2011-2013. Ethylene glycol (50 ml per each trap) was used as preservatives for preservation of collected arthropods. Ten pitfall traps were placed in each site, and the traps were

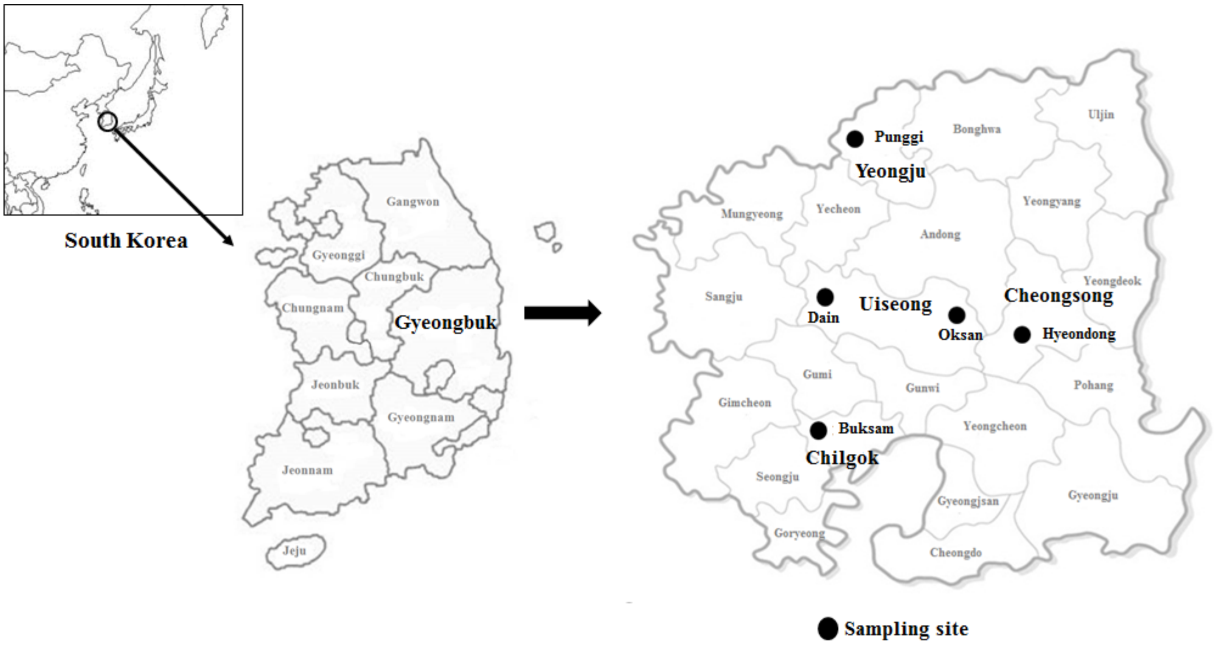

Fig. 1. An illustration of study locations and sampling sites. Black dots represent the sampling locations of organic and conventional apple orchards in Gyeongbuk province, Korea.

Table 1. Description of study sites in relation to geographical information, apple variety and weed managements in organic and conventional apple orchards

Farming system	Location[1]	Latitude	Longitude	Year	Altitude (m)	Variety	WM[2] (times/spring/year)	EFAM[3] (times/year)	Synthetic pesticide (times/year)
Organic	CB	36°03′	128°12′	3	72	Fuji	MW (0.7)	28	-
	UD	36°27′	128°23′	3	148	Fuji	-	10	-
	UO	36°21′	128°52′	5	410	Fuji and others	-	23	-
	CH	36°17′	129°00′	9	284	Fuji, Sinano Sweet	MW (1)	13	-
	YP	36°50′	128°28′	7	548	Fuji, Hongro, Tsugaru	-	21	-
Conventional	CB	36°03′	128°21′	18	78	Fuji	HB (0.7), MW (0.7)	-	13
	UD	36°27′	128°23′	10	137	Fuji	HB (0.3), MW (1)	-	13
	UO	36°21′	128°51′	20	280	Fuji	HB (0.7), MW (1)	-	12
	CH	36°17′	129°00′	15	284	Fuji	HB (0.3), MW (1)	-	12
	YP	36°50′	128°29′	17	542	Fuji	HB (1), MW (1)	-	11

[1] Buksam, Chilgok (CB); Dain (UD) and Oksan (UO), Uiseong; Hyeondong, Cheongsong (CH); Punggi, Yeongju (YP)

[2] WM: Weed management; MW: Mowing, HB: Herbicide, by using only spring season

[3] EFAM: Eco-friendly agricultural materials

replaced by 3 days interval for 9 days in each site. After collection the arthropod samples were classified into the higher taxonomic level (e.g., Order). Coleopterans were further classified into family level, and then carabid beetles were identified into species level based on morphological characteristics.

Statistical analysis

Data obtained for ground-dwelling arthropod abundances between organic and conventional orchards were normalized with a log (N+1) transformation after Shapiro-Wilk test (Macfadyen, 1962). Abundances of functional groups of ground-dwelling arthropods and diversity of carabid beetles between organic and conventional orchards were analyzed by using split plots analysis of variance (ANOVA). For split plots ANOVA, year and location were treated as the split factors. Means were separated by Tukey's HSD test for all parameters (SAS Institute, 2010). Composition and diversity of carabid beetle communities were assessed by species richness (Kessler et al., 2001), Shannon-Wiener diversity (Shannon and Weaver, 1949), evenness (Pielou, 1966), and dominant species. The dominant species category was selected based on an abundance greater than 5% of total (Brockmann-Jerosch, 1907). Pearson correlation was used to examine relationships between number of individuals in major ground-dwelling arthropods and number of weed managements across all three years. Further, non-metric multidimensional scaling (NMS) was conducted to analysis the composition of ground-dwelling arthropods based on Euclidian distance matrix among study sites and study years (PC-ORD ver. 6, MJM Software Design, Gleneden Beach, OR). Multi-response permutation procedure (MRPP) was used to determine the distinctness of ground-dwelling arthropod communities between the different weed managements (McCune and Grace, 2002).

Results

Arthropod taxonomic and functional groups

In total 2,825 individuals were collected from 10 orchards for 3 years, and identified as 73 species belonging to 33 families (13 orders). In organic orchards, the 1,659 collected individuals comprised 59 identified species, while in the conventional orchard the 1,166 collected individuals consisted of 47 species. The community structure of ground-dwelling arthropods in two farming systems is presented in Table 2. Similar proportions of arthropod groups were found in the two apple orchard systems and involved Coleoptera, Araneae, Hymenoptera, Diptera, and other arthropods, accounting for 41.5, 38.0, 12.7, 3.8 and 3.9%, and 44.3, 36.5, 13.2, 3.5 and 2.5% in

Table 2. Abundance (mean/sample/trap) of ground-dwelling arthropods found in organic and conventional apple orchards of different study sites

Taxon	Organic						Conventional					
	CB[1]	UD	UO	CH	YP	Mean	CB	UD	UO	CH	YP	Mean
Arachnida												
Araneae	1.32	1.83	1.78	0.56	1.28	1.35	1.06	1.77	0.69	0.59	0.95	0.95
Diplopoda												
Polydesmida	0	0.01	0.06	0.03	0	0.02	0.01	0.01	0	0	0.06	0.02
Nematophora	0	0	0.03	0	0	0.01	0	0	0	0	0	0
Chilopoda												
Lithobiomorpha	0	0	0.02	0.01	0.02	0.01	0	0	0	0	0.02	0
Scutigeromorpha	0	0.03	0	0	0	0.01	0	0.01	0	0	0	0
Insecta												
Coleoptera	0.57	1.71	2.76	1.19	1.17	1.48	0.80	0.87	1.08	1.84	1.14	1.15
Hymenoptera	0.34	0.16	1.64	0.07	0.06	0.45	0.12	0.21	0.58	0.20	0.60	0.34
Diptera	0.06	0.14	0.16	0.19	0.13	0.14	0.03	0.12	0.13	0.08	0.09	0.09
Hemiptera	0.04	0.07	0.07	0	0.08	0.05	0.07	0	0	0	0.03	0.02
Lepidoptera	0	0	0.04	0.04	0	0.02	0.01	0	0	0	0	0
Orthoptera	0	0.04	0	0	0.01	0.01	0.01	0	0.04	0.01	0	0.01
Mecoptera	0	0.01	0	0.01	0.01	0.01	0	0	0	0	0	0
Dermaptera	0	0.01	0.01	0	0	0	0.01	0	0	0.02	0	0.01
Total	2.34	4.02	6.57	2.10	2.77	3.56	2.12	2.99	2.52	2.27	2.58	2.59

[1] Buksam, Chilgok (CB); Dain (UD) and Oksan (UO), Uiseong; Hyeondong, Cheongsong (CH); Punggi, Yeongju (YP)

the organic and conventional orchard, respectively (Fig. 2A). In Coleoptera, the most commonly encountered group were the carabids, accounting for 86.0% (621 individuals belonging to 23 species) and 83.5% (431 individuals belonging to 16 species) in organic and conventional orchard, respectively (Fig. 2B).

Abundance of ground-dwelling arthropods was significantly different between farming systems (*F* = 7.52, df = 1, 16, *P* = 0.01), among locations (*F* = 6.19, df = 4, 16, *P*= 0.003) and among years as well (*F* = 8.06, df = 2, 16, *P*= 0.003) (Table 3). In functional groups, the abundances of herbivores (*F*= 8.55, df = 1, 16, *P* = 0.009) and predators (*F* = 10.21, df = 1, 16, *P* = 0.005) were significantly differed between farming systems but parasite abundance exhibited no difference (Table 3; Fig. 3). By considering locations and years, predators were significantly different among locations (*F* = 3.68, df = 4, 16, *P* = 0.02) and years (*F* = 24.57, df = 2, 16, *P*< 0.0001), but those factors did not different in herbivore abundances (Table 3). Parasite abundances were only significantly different in connection with different years (*F* = 5.95, df = 2, 16, *P* = 0.01)(Table 3). Significant interaction between farming system and location was found for abundance of ground-dwelling arthropods and predators.

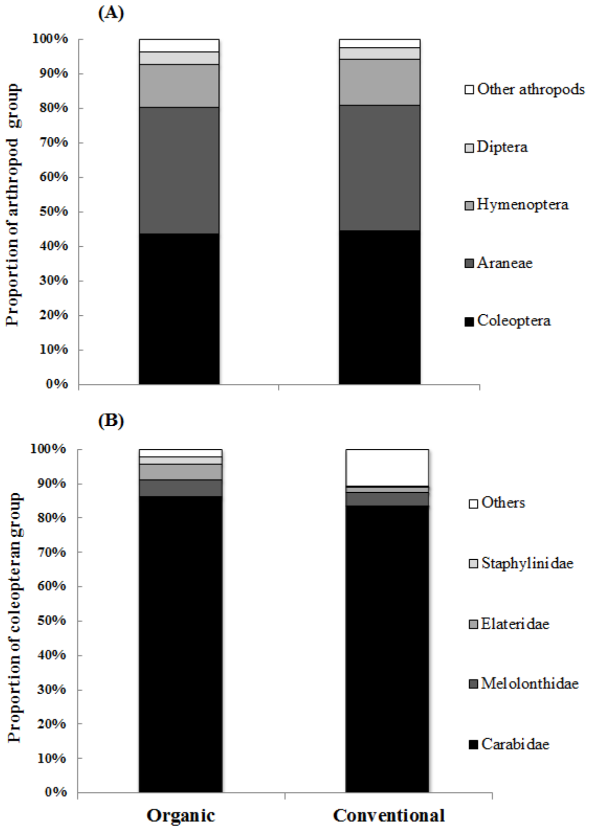

Fig. 2. Proportion of ground-dwelling arthropod (A) and coleopteran (B) groups in organic and conventional apple orchards from 2011 to 2013.

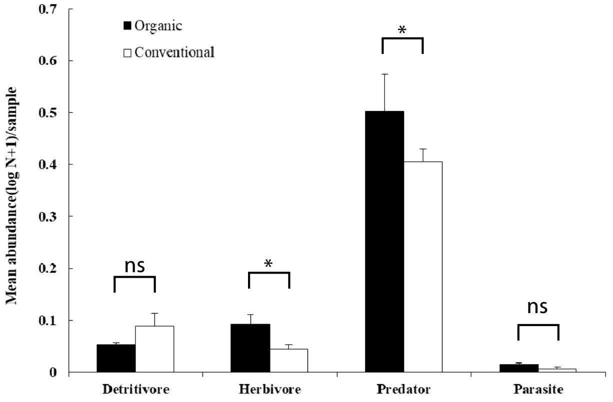

Fig. 3. Mean abundance of functional groups on ground-dwelling arthropods in organic and conventional orchards from 2011 to 2013 ($P < 0.05$).

Table 3. Split-plot analysis of variance (ANOVA) testing the effects of farming system, location and year on the abundance of total ground-dwelling arthropods and each functional group

Sources*	Ground-dwelling arthropods	Detritivore	Herbivore	Predator	Parasite
Farming system (F)	0.01	ns	0.009	0.005	ns
Location (L)	0.003	ns	ns	0.02	ns
F × L	0.004	ns	ns	0.006	ns
Year (Y)	0.003	0.01	ns	< 0.0001	0.01
F × Y	ns[1]	ns	ns	ns	ns

[*] Two farming systems (organic and conventional), five locations (Buksam, Chilgok; Dain and Oksan, Uiseong; Hyeondong, Cheongsong; Punggi, Yeongju), and three years (2011, 2012, and 2013)

[1] ns = no significant ($P < 0.05$)

Carabid beetle diversity

Species richness of carabid beetles was significantly different between farming systems (F = 16.88, df = 1, 16, P = 0.0008) and among years (F = 11.38, df = 2, 16, P = 0.0008) (Table 4). Abundance was also significantly different between farming systems (F = 12.40, df = 1, 16, P = 0.002), among locations (F = 6.30, df = 4, 16, P = 0.03), and interaction as well. Diversity and evenness were significantly different between farming systems (Diversity: F = 6.54, df = 1, 16, P = 0.02; Evenness: F = 15.18, df = 1, 16, P = 0.001) (Table 4).

Both organic and conventional apple orchards, *Anisodactylus punctatipennis, Amara congrua, Nebria coreica, Harpalus discrepans, Anisodactylus* sp. and *Chlaenius pallipes* were dominant (Table 5).

Influence of weed management on arthropods

The correlation between abundance of ground-dwelling arthropods and number of weed managements (herbicides and mowing) is presented in Table 6. Abundances of Araneae, Coleoptera and carabids were negatively correlated with the

Table 4. Split-plot analysis of variance (ANOVA) testing the effects of farming systems, location and year on the diversity indices of carabid beetle communities

Sources	Species richness	Abundance	Diversity	Evenness
Farming system (F)	0.0008[1]	0.002	0.02	0.001
Location (L)	ns	0.03	0.01	0.04
F × L	0.008	0.003	ns	ns
Year (Y)	0.0008	ns	< 0.0001	0.003
F × Y	ns	ns	ns	0.006

[1] ns = no significant (P < 0.05)

Table 5. Relative abundance (%) of dominant species of carabid beetle in organic and conventional apple orchards

Species	Organic						Conventional					
	CB[1]	UD	UO	CH	YP	Mean	CB	UD	UO	CH	YP	Mean
Anisodactylus punctatipennis Morawiz, 1862	44.8	15.4	17.4	9.3	19.0	19.7	33.8	23.3	11.3	15.9	29.8	21.3
Amara congrua Morawiz, 1862	16.1	28.0	6.8	14.4	21.0	16.3	30.8	19.2	33.9	6.6	12.3	17.6
Nebria coreica Solsky, 1875	0	10.5	8.2	23.7	0	9.3	0	9.6	0	20.5	10.5	12.3
*Harpalus discrepans*Morawiz, 1862	13.8	0	14.2	8.2	20.0	11.4	0	0	9.7	20.5	12.3	12.3
Anisodactylus sp.	11.5	13.3	22.8	5.2	8.0	14.1	7.7	16.4	16.1	15.2	15.8	14.5
Chlaenius pallipes Gebler, 1823	0	7.0	3.9	23.7	15.0	8.8	7.7	0	0	7.3	15.8	7.8

[1] Buksam, Chilgok (CB); Dain (UD) and Oksan (UO), Uiseong; Hyeondong, Cheongsong (CH); Punggi, Yeongju (YP)

Table 6. Pearson's correlation matrix between weed managements and abundance of ground-dwelling arthropods in sampling sites

Taxon	Herbicide	Mowing
Araneae	-0.408^*	-0.443^*
Coleoptera	-0.456^*	-0.430^*
Carabidae	-0.476^*	-0.454^*
Hymenoptera	-0.110	-0.165
Diptera	-0.302	-0.156
Nematophora	-0.241	-0.483^*

*indicates the significance at P < 0.05

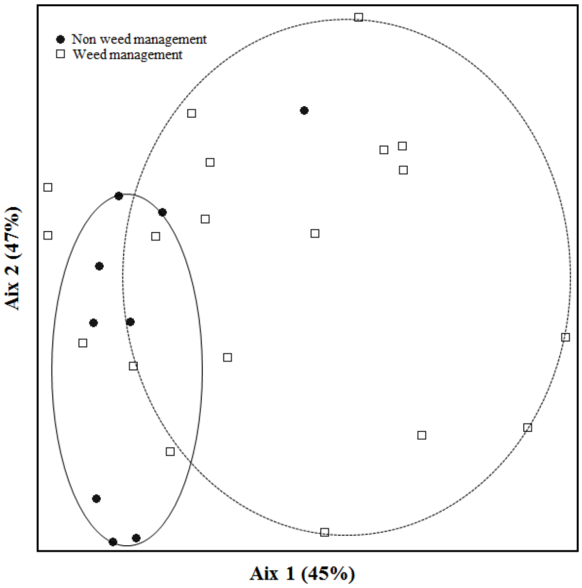

Fig. 4. Non-metric multidimensional scaling with major ground-dwelling arthropod communities by weed managements in organic and conventional apple orchards. Each point represents the mean abundance of ground-dwelling arthropod communities from weed managements in organic and conventional orchards in ordination space.

weed management frequencies. Furthermore, the presence of diplopod, Nematophora was negatively correlated with mowing.

Non-metric multidimensional scaling showed overlaps among different weed managements in organic and conventional apple orchards (Fig. 4). In this NMS ordination, axis 1 and axis 2 were explained by 45 and 47% of the variance, respectively. MRPP confirmed that the composition of ground-dwelling arthropods between two weed management practices was significantly different ($A = 0.04$, $P < 0.05$).

Discussion

This study confirmed that the abundance of total ground-dwelling arthropod is highly variable depending on farming system, locations of orchards and even among years. This imply that the ground dwelling arthropod assemblages are not stable but vulnerable to environmental changes (Intachat et al., 1997; Ellis et al., 2001). In functional guild analysis, abundance of predator group was the highest compare to other groups, such as detritivores, herbivores, or parasites, which indicate that the majority of ground arthropods play roles in predation and could be beneficial as natural suppressors of insect pests (Marc et al., 1999). This is partly due to the higher abundance of spiders and carabid beetles (Kromp, 1999). Other results that the herbivore and predator groups were significantly high in organic apple orchards than in conventional ones may indicate the complex biological diversity and food web structures in organic orchards where minimum chemical perturbations are applied. Hasin and Booncher (2020) reported larger occurrence of rove beetles and spider in organic farms than in conventional ones. Similar results applied to herbivores including primarily Acrididae, Membracidae, Melolonthidae, and Cetoniidae. Many herbivore groups are not only grass feeders but also deciduous tree foliage, pollen and nectar feeders. Since organic apple orchards are less disturbed by chemical pesticides, large sized herbivores could escape from pesticide spray and invade into apple orchards (Lee et al., 1996). The abundance of detritivores did not differ between the two orchard systems. In another study (Kim, 2016), detritivore abundance and richness were primarily governed by the organic input into the orchards such as in organic straw mulching or chopped bark. In this studied orchards, organic input was not systematically differed between two farming system. Also, even limited dispersal capacities, detritivores are often influenced by the large and complex landscape context rather than on-farm management (Flohre et al., 2011).

Abundance and diversity of carabid beetles in organic and conventional orchards are linked to weed management practices, physical conditions of ground such as temperature and humidity, types of groundcover, and food resources as well. In general, carabid beetle adults live on the soil surface and are highly mobile, while larvae live in the soil, and possess limited dispersal capacity (Kromp, 1999). In this aspect, as underground weeds in orchards provide valuable ecological services such as moderating the spatio-temporal habitat conditions and providing herbivores or seeds as foods for ground-dwelling arthropods including predators, and eventually supports biological diversity within cultivated fields (García-Ruiz et al., 2018). For example, species belonging to *Amara*, *Anisodactylus* and *Harpalus* are known to prefer habitats with increased humidity due to their suitability for oviposition or larval development (Holland, 2002), especially in regard to species that as larvae and adults rely on seeds for food (Luff, 2002). The similarities of the fauna might be related to the movement of carabid beetles from overwintering sites of surrounding habitats in spring season and their longevities (Willin, 1985; Coombes and Sotherton, 1986; Purtauf et al., 2005). It is likely that the abundance of carabid beetles is related to ground vegetation maintenance. Now in May orchard system, therefore, ground weeds are needed intentionally management of underground vegetation, such as companion plants (Kishinevsky et al., 2017).

Overall, ground-dwelling arthropods taxonomically and functionally were significantly affected by farming systems as well as weed management frequencies in this study. In organic farming, the weed management frequency is one of important factors in the farming systems, because the removing ground vegetation more altered the ground habitat structure drastically compared to other the organic farming, which is more focused on foliage protection with restriction of chemical pesticides and fertilizers. It is clear that even though organic farming could counteract the detrimental effects of agricultural intensification on farmland biodiversity for sustainability, functional diversity of arthropod could be better achieved through intentional engagement of habitat manipulation using companion plants to facilitate the preemptive occupation of agricultural ecosystem.

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Statements for Authorship Position & contribution

Kim, J.W.: Gyeongbuk Agricultural Research & Extension Services, Researcher; Design, data collection, analysis, manuscript writing and editing.

Jung, C.: Andong National University, Professor, Ph.D; Funding, design, data analysis, reviewing MS.

All authors read and approved the manuscript.

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