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Arthropod Biodiversity and Abundance in Organically and Conventionally Managed, Cool-climate Vineyards in Orange, New South Wales, Australia

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ABSTRACT

Little work has been done comparing arthropod biodiversity in organically and conventionally managed vineyards in Australia. Hence, we evaluated arthropod biodiversity and abundance in organically and conventionally managed vineyards in Orange Bioregion of New South Wales. Field trials were organized in Tamburlaine, an organically managed vineyard and in Hedberg Hill, a conventionally managed vineyard in spring 2015 and autumn 2016. Abundance and diversity were determined using Margalef's diversity index. A total of 266,798 arthropods belonging to 11 Orders were recorded in both Tamburlaine and Hedberg Hill vineyards during sampling periods. The Collembola, Hymenoptera, Thysanoptera, and Diptera were the most dominant groups in both vineyards, whereas those belonging to Hemiptera, Neuroptera, Lepidoptera, Orthoptera, Coleoptera, Araneae, and the subphylum Myriapoda were the least. Analysis of abundance of arthropods between spring 2015 and autumn 2016 showed that a significant difference occurred in both vineyards. However, the biodiversity of arthropods sampled in both spring 2015 and autumn 2016 showed no significant difference between the populations obtained from either. Although no difference was evident in terms of biodiversity, significantly higher mean numbers of arthropods in Tamburlaine occurred than in Hedberg Hill. This pilot study shows that the management practice has an effect on arthropod abundance, but not on arthropod diversity. The results achieved offer an insight into the role of management practice on arthropod abundance and biodiversity in vineyards.

Key Words: Margalef's Diversity Index; Soil Arthropods; Vagile Arthropods; *Vitis* Ecosystems; Biodiversity.

INTRODUCTION

In agroecosystems, the surrounding vegetation including weeds, tillage practices, and patterns of agrochemical use, bear an effect on arthropod populations that colonize those ecosystems (Nash et al. 2010). Injudicious use of various synthetic chemicals (e.g., pesticides, herbicides) affect populations of beneficial arthropods negatively (Christ and Burritt 2013) on the one hand and lead to development of resistance in pestiferous arthropods to applied chemicals (Whalon et al. 2008) on the other, in agroecosystems including vineyards. Positive effects of organic-management practice particularly on greater biodiversity and abundance of arthropods in agroecosystems are well known (Gaigher and Samways 2010). For instance, organically managed crop ecosystems are known to include about 30% greater biodiversity than conventionally managed crop ecosystems; further, associated organisms such as birds, predatory insects and spiders, soil invertebrates, and non-crop tree vegetation also gain in numbers in organically managed crop ecosystems (Pfiffner and Balmer 2011). In spite of such knowledge, in conventionally managed Australian vineyards, a staggering range of synthetic chemicals is used even today. Thomson (2012) refers to the intensity of chemical use in conventionally managed Australian vineyards and explains how these chemicals have a strongly negative impact on beneficial arthropods.

Some of the more important arthropod species in Australian *Vitis vinifera* (Vitales: Vitaceae) crop systems (Childers et al. 2003, Thomson et al. 2007) are: *Epiphyas post-vittana* (Lepidoptera: Tortricidae), *Agrotis munda*

(Lepidoptera: Noctuidae), *Phalaenoides glycinae* (Lepidoptera: Noctuidae), *Pseudococcus longispinus* (Hemiptera: Pseudococcidae), *Parthenolecanium persicae* (Hemiptera: Coccidae), *Nysius vinitor* (Hemiptera: Lygaeidae), *Calepitrimerus vitis* (Prostigmata: Eriophyidae), *Brevipalpus californicus* (Trombidiformes: Tenuipalpidae), and *Tetranychus urticae* (Trombidiformes: Tetranychidae). In addition, many parasitic Hymenoptera (Braconidae, Trichogrammatidae, Ichneumonidae, Bethylidae, Chalcididae, Encyrtidae, and Pteromalidae), Diptera (Tachinidae), Neuroptera (Hemerobiidae and Chrysopidae), as well as predatory Coleoptera (Coccinellidae, Melyridae), Hemiptera (Pentatomidae), Diptera (Cecidomyiidae), Dermaptera (Forficulidae), Araneae (Theridiidae and Thomasidae), and Acari (Phytoseiidae) are known in Australian vineyards (James et al. 1995). The incidence of a range of parasitic and predatory arthropods reiterates the potential these can have in the long-term sustainable management of Australian vineyards (Magarey et al. 2006).

In spite of a general interest in organic, and therefore sustainable, management of vineyards, only a few empirical studies highlight the advantages of such vineyard management in Australia. A majority of earlier studies made in such a context have measured yield and the cost of production and labour (e.g., Wheeler and Crisp 2011) and nothing significantly biologically. In view of this gap in knowledge in organically managed Australian vineyards, we investigated on a pilot scale, measuring arthropod diversity and abundance in Tamburlaine and Hedberg Hill vineyards near Orange, which are managed organically and conventionally, respectively, over the past 10 years.

We conducted our study over two consecutive seasons. We expected that a significantly greater level of arthropod abundance and biodiversity will occur in Tamburlaine — the organically managed vineyard — than in Hedberg Hill — the conventionally managed vineyard. To test this proposition, we measured arthropod biodiversity and abundance in two consecutive seasons in 2015–2016.

MATERIAL AND METHODS

Study Sites

Field trials were set up in Tamburlaine (33º 26' S, 148º 06' E) and Hedberg Hill (33º 27' S, 149º 03' E) vineyards occurring proximally to Orange town, New South Wales. Both vineyards occur on uneven, undulating terrain at about 850 m above sea level, separated by a distance of 7.5 km. The soils at Tamburlaine and Hedberg Hill are similar, being shallow, well-structured, and well drained clay loams, ranging from red-brown Dermosols to red Chromosols (Isbell 2016). Climate in Orange bioregion (Department of Environment, Government of Australia 2012) is temperate with a mean annual rainfall of 900 mm. Mean maximum and minimum temperatures are 26.4°C and 12.3°C in peak summer (January), and 9.4°C and 0.9°C in peak winter (July), respectively (Bureau of Meteorology 2011).

Tamburlaine (88 ha) is a large-scale vineyard cultivating 13 cultivars of *V. vinifera* under organic management commencing in 2005. From 2006, Tamburlaine has remained a full-fledged organic enterprise (certified by the Australian Certified Organic, Queensland, Australia). Tamburlaine’s organic manage-ment aims at building soil-nutrient levels using organic material, rather than adding synthetic supplements to the vines. Tamburlaine uses biological materials such as seaweeds, worm teas, organic nitrogen, organic acids, phosphate rock, and composted recycled organic waste, and lime–dolomite. It encourages ground-cover crops such as clover, rye, and other companion species between the grapevine rows to add to the organic content and nitrogen (http://www.tamburlaine.com.au/). Hedberg Hill (37 ha) cultivates seven cultivars of *V. vinifera* under conventional management from 1998. Chemical management to control fungal pathogens and pestiferous insects is carried out by applying fungicides (Captain™, Legend™) and insecticides (Proclaim™) fortnightly, further to supplying synthetic fertilizers (http://www.hedberghill.com.au/).

Experimental Design, Sampling, and Determination of Arthropods

The experiment was laid out in a random sampling design in both Tamburlaine and Hedberg Hill. Treatments were replicated twice. The trial consisted of two plots in each vineyard. One plot included *V. vinifera* cv. Chardonnay and the other *V. vinifera* cv. Sauvignon Blanc. The area of each plot was 2,100 m^2. The distance between the two plots in Tamburlaine was 1000 m and that in Hedberg Hill was 500 m. Sampling of vagile, aerial arthropods was done using yellow-sticky and yellow-pan traps, and that of soil arthropods using pitfall traps. The number of traps was the same in both sites.

Plastic cylinders (8.5 cm diameter, 12 cm deep) sunk into the ground with their mouths flush with soil surface were used as pitfall traps. They were half filled with ethanol: water (50:50) + 10 drops of domestic detergent. Seven traps were set up randomly in 10 rows in each plot. The total number of such traps used in Tamburlaine and Hedberg Hill was 28. For use as sticky traps, transparent, 30x21 cm plastic sheets were painted yellow on one side and the unpainted side was coated with commercial glue (Tangle-trap Sticky Coating, The Tanglefoot Company, Grand Rapids, MI). These were suspended on the trellis frame of the vineyards at 1.5 m above the ground. Seven traps were set up randomly in 10 rows in each plot. The total number of yellow sticky traps used in both vineyards was 28. The yellow pan traps were custom made using plastic ice-cream tubs (17x11.5x6 cm). The tubs were spray-painted yellow externally. The tubs were suspended on the trellis wires of the vineyards at 1.5 m above ground. The tubs were filled to the brim with 50% aqueous ethanol plus a few drops of domestic detergent. Seven pan traps were installed in each plot. The total number of yellow pan traps used in both vineyards was 28.

All traps thus set up were left in the field in September–October 2015 (spring 2015) and again in February–March 2016 (autumn 2016). The traps were cleared weekly through the season, achieving arthropod collections from 112 traps of each trialled category. Arthropods from the pitfall traps were sieved and stored in 70% aqueous ethanol for later examination. The yellow sticky traps were replaced weekly through the season, thus accounting for 112 traps overall. Such traps after collection were individually stored in plastic bags for determination and further analysis in the laboratory. The yellow pan traps were cleared weekly through the season, thus accounting for collection from 112 traps overall.

The arthropods caught using pitfall and yellow-pan traps were separated by filtering them through 18.5 cm wide Whatman filter paper (GE Healthcare Australia, Parramatta, New South Wales, Australia) placed in a 5 cm wide glass funnel. The filtrate including filter papers were spread out and dried; the specimens were isolated swiftly by examining them under a stereo-binocular microscope (Olympus Instruments, Model # C011, Tokyo, Japan). The filtered materials were stored in 80% alcohol. The isolated specimens were determined to their respective Orders following Goode (1980), Grigg and Grigg (1977), and New (1996). This procedure was repeated for the arthropod samples obtained through yellow sticky traps and yellow pan traps. The numbers of arthropods were counted physically. We recognize that determination of arthropods to their species would have been ideal. However the volume of arthropods extracted (close to 270,000 individuals in a two season period) was so staggering that we decided to determine them up to their higher taxonomic categories, viz., Orders, since the Orders of arthropods are generally indicative of their nutritional guilds, a practice followed in many other biodiversity studies (e.g., Siemann et al. 1999).

Statistical Analysis

Arthropod biodiversity was determined using the Margalef diversity index (DMg) (Morris et al. 2014):

$$DMg = (S-1) / \ln N$$

where, S was the numbers of arthropod Orders, ln was the natural logarithm, and N was the total number of individuals. Arthropod numbers were square-root transformed to meet normality assumption. The number of collected arthropods during each season in both sites was compared. Analysis of an unbalanced design was done to compare the mean differences of arthropod biodiversity and abundance in Tamburlaine and Hedberg Hill. All analyses were done using GENSTAT® (v.16) (Payne et al. 2011).

RESULTS AND DISCUSSION

Arthropod populations and abundance

A total of 97,487 arthropods belonging to 11 Orders were collected in Tamburlaine, whereas, a total of 75,490 arthropods belonging to 10 Orders were collected in Hedberg Hill in spring 2015 (Table 1). Thysanoptera was the most dominant group in both Tamburlaine and Hedberg Hill with populations at 31.5% and 30.6%, respectively. This was followed by the Collembola (13.7%–Tamburlaine and 6.1%–Hedberg Hill), Hymenoptera (7.2%– Tamburlaine and 4.5%– Hedberg Hill), and the Diptera (2.5%–Tamburlaine and 1.9%– Hedberg Hill). The Lepidoptera, Neuroptera, Orthoptera, Araneae, and Myriapoda included numbers less than 1% in both Tamburlaine and Hedberg Hill (Table 1).

A total of 51,299 arthropods from 11 Orders were collected in Tamburlaine, whereas, 42,522 arthropods from 11 Orders were collected in Hedberg Hill in autumn 2016. Collembola were the most dominant group in both Tamburlaine and Hedberg Hill with populations at 30.1% and 22.1%, respectively. This was followed by the Hymenoptera (9.8%– Tamburlaine, 10.5%– Hedberg Hill). The Hemiptera, Neuroptera, Lepidoptera, Orthoptera, Coleoptera, Araneae, Myriapoda included numbers lesser than 1% in both Tamburlaine and Hedberg Hill (Table 1).

Table 1. Arthropod numbers in Tamburlaine and Hedberg Hill vineyards.

Orders	Tamburlaine Spring 2015	Tamburlaine Autumn 2016	Hedberg Hill Spring 2015	Hedberg Hill Autumn 2016
Thysanoptera	54,549	4,805	52,965	5,308
Coleoptera	23,721	28,269	10,535	20,762
Hymenoptera	12,417	9,241	7,704	5,268
Diptera	4,400	8,731	3,338	9,874
Coleoptera	1,644	79	137	842
Hemiptera	523	38	649	351
Lepidoptera	113	56	96	39
Araneae	104	58	60	61
Neuroptera	14	16	0	2
Orthoptera	1	5	3	13
Myriapoda (subphylum)	1	1	3	2

The analysis of abundance, comparing the data of both spring 2015 and autumn 2016 showed that a significant difference occurred in populations obtained from Tamburlaine and Hedberg Hill (df=1,4, F=8.17, P= 0.046). Tamburlaine included greater mean numbers of arthropods than those from Hedberg Hill in spring 2015 and autumn 2016 (Figure 1). Tamburlaine included greater mean numbers of arthropods compared with Hedberg Hill, irrespective of the *Vitis* varieties, whether Chardonnay or Sauvignon Blanc (Figure 2).

Greater mean numbers of arthropods occurred in Tamburlaine than in Hedberg Hill in spring 2015 (48,743–Tamburlaine; 37,743–Hedberg Hill) and autumn 2016 (25,647–Tamburlaine; 21,254.5–Hedberg Hill). Lower numbers of arthropods in the Hedberg Hill does not surprise because of periodical application of synthetic chemicals (e.g., Success™ and Proclaim™), as against no application of any synthetic chemical in Tamburlaine. That the application of synthetic chemicals in agroecosytems negatively affects arthropod populations including the beneficial arthropods is well known. For instance, populations of the predatory mite *Euseius victoriensis* (Acari: Phytoseiidae) declined when treated with synthetic chemicals in vineyards in Victoria, Australia (Bernard et al. 2010). Similar results, altering the populations of beneficial arthropods, occur while testing the effects of pesticides on arthropod populations in 61 vineyards in Victoria (Nash et al. 2010).

Results reported in this paper that organically managed vineyards include higher numbers of arthropods match well with those of Berry et al. (1996) and Puech et al. (2014). The greater abundance of arthropods in Tamburlaine is highly likely not only because of the nil application of synthetic chemicals, but could also be due to availability of food resources and lesser levels of ecosystem disturbance (Feber et al. 1997). Abundance of arthropods was greater in spring 2015 than in autumn

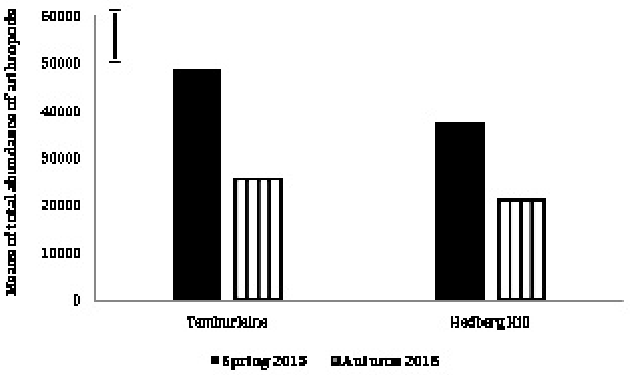

Figure 1. Mean abundance of total arthropods in Tamburlaine and Hedberg Hill in spring 2015 and autumn 2016 using yellow sticky, yellow pan, and pitfall traps. Error bars represent SE

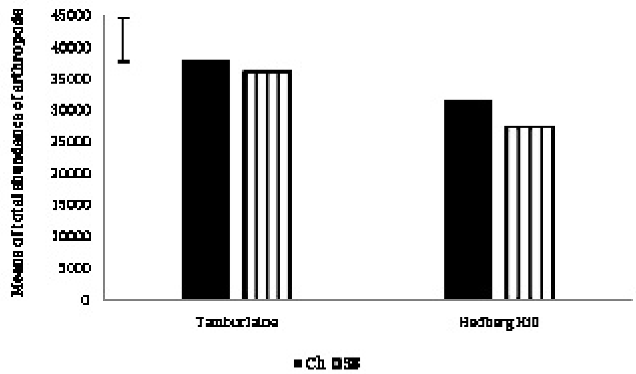

Figure 2. Mean abundance of total arthropods in Tamburlaine and Hedberg Hill in Chardonnay and Sauvignon Blanc. Error bars represent SE. Ch: Chardonnay; SB: Sauvignon Blanc.

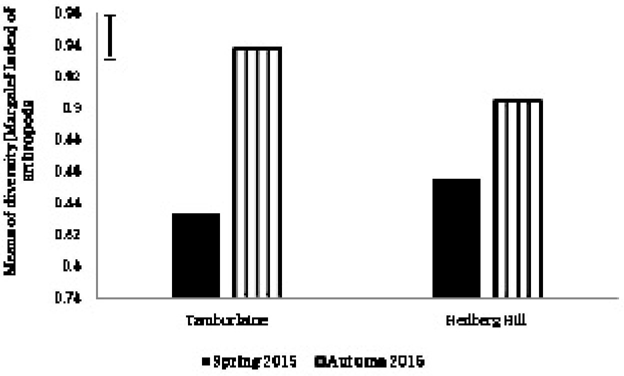

Figure 3. Mean diversity of total arthropods in Tamburlaine and Hedberg Hill in spring 2015 and autumn 2016 (pooled data). Error bars represent SE of total diversity.

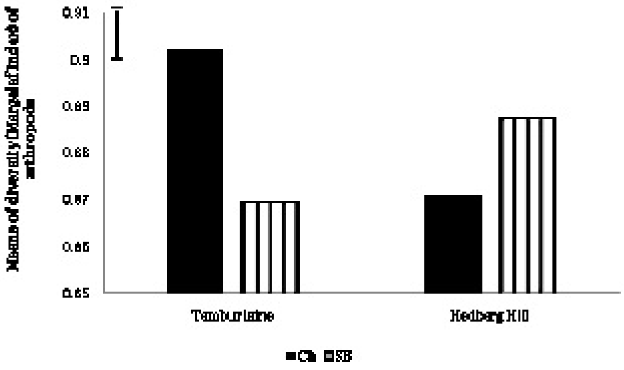

Figure 4. Mean diversity of total arthropods in Tamburlaine and Hedberg Hill in Chardonnay and Sauvignon Blanc (pooled data). Error bars represent SE of total diversity.

2016 in both Tamburlaine and Hedberg Hill. This result is consistent with that of Buchanan (1977), who found arthropod populations in Australian vineyards were the greatest in spring 2015.

Arthropod Biodiversity

Analysis of biodiversity, comparing data of both spring 2015 and autumn 2016 showed no significant difference in Tamburlaine and Hedberg Hill (df=1,4, F=0.01, *P*=0.916). The conventionally managed Hedberg Hill included a greater mean diversity of arthropods than Tamburlaine in spring 2015, whereas in autumn 2016, Tamburlaine showed the greatest mean diversity of arthropods (Figure 3). In terms of Chardonnay or Sauvignon Blanc, the tested cultivars, Tamburlaine showed the greatest mean diversity of arthropods in Chardonnay field site, whereas the Hedberg Hill showed the greatest mean diversity of arthropods in the Sauvignon Blanc field site (Figure 4). The Araneae, Collembola, Coleoptera, Diptera, and Hymenoptera presented critical variations in numbers in Tamburlaine and Hedberg Hill in spring 2015; on the contrary, the Collembola, Coleoptera, Hemiptera and Hymenoptera presented critical variations in numbers in Tamburlaine and Hedberg Hill in autumn 2016.

Arthropod diversity was greater particularly in the Chardonnay plot than in Hedberg Hill, although not in the Sauvignon Blanc plot in Hedberg Hill. Incidence of greater level of arthropod diversity in the Chardonnay plot of Hedberg Hill evoked curiosity, since in the other three tested plots – Chardonnay and Sauvignon Blanc in Tamburlaine and Sauvignon Blanc in Hedberg Hill – a lesser level of arthropod biodiversity occurred. The proximity of the Chardonnay plot at Hedberg Hill to a 20-year old shelterbelt possibly explains the greater arthropod diversity in this plot, given that greater diversity of arthropods in crop areas that occur proximally to shelterbelts and windbreaks is well known (Thomson and Hoffmann 2009, Mbuthia et al. 2012). Shelterbelts and windbreaks close to crop areas provide innumerable benefits to the agroecosystem, such as, moderated microclimate, shelter, supporting alternate hosts or prey organisms, overwintering sites, food and appropriate oviposition locations (Gámez-Virués et al. 2009), which in turn has a bearing on the diversity and abundance of arthropods. Lack of significance in the measured arthropod diversity values in Sauvignon Blanc plot at Hedberg Hill and Chardonnay and Sauvignon Blanc plots at Tamburlaine indicates that the management tactic did not bear any effect on arthropod diversity.

We recognize that this investigation is less conclusive than what we expected to achieve. Further investigations are necessary. However, this study offers a pointer into the strengths of organic management of vineyards, by measuring one component of agro-ecosystem health.

CONCLUSION

We explored the question whether a significantly greater level of arthropod abundance and biodiversity will occur in Tamburlaine, an organically managed vineyard, than in Hedberg Hill, a conventionally managed vineyard. We found that Tamburlaine included greater mean numbers of arthropods than the conventionally managed Hedberg

Hill, when tested in spring 2015 and autumn 2016. In terms of arthropod biodiversity, the greatest mean diversity occurred only in the Chardonnay plot of Hedberg Hill in spring 2015, whereas the Sauvignon Blanc plot in Hedberg Hill and the Chardonnay and Sauvignon Blanc plots in Tamburlaine showed low arthropod biodiversity. We infer that the proximity of a suitable tree cluster habitat (e.g., shelterbelt, windbreak) assists mitigating direct impacts of a conventional management regime. The inclusion of such a habitat could be a way of promoting the biological health of conventionally managed vineyards. In terms of seasonal variation, both Tamburlaine and Hedberg Hill showed greater mean abundance of arthropods in spring 2015 than in autumn 2016. We conclude that management practices bear an effect on the arthropod abundance, but not on arthropod diversity.

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