ENHANCING BIOCONTROL IN ORCHARDS BY INCREASING FOOD WEB BIODIVERSITY[1]

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A B S T R A C T

High biodiversity is the key to sustainable biological control in orchard systems. A diverse biological control community is needed to control the large number of pests from many taxonomic groups in orchards. Orchard floor management practices include partial or complete removal of ground covers such as grasses, legumes and weeds with techniques that include synthetic herbicides, tillage, mulch, and flaming. These practices are designed to reduce below-ground competition with the crop but they also alter abiotic and biotic components of the soil and impact orchard food webs. We have investigated increasing biodiversity in the orchard with the addition of compost mulch under the trees. In addition to providing nutrients and organic matter to the soil, the compost also provided weed and insect control. Food web analysis of the soil-based food web revealed that the predator – herbivore ratio in the compost treated apple orchard was 0.85 but without mulch or with mulch and herbicide the ratio ranged from 0.15 to 0.32. It is proposed that the predator – herbivore ratio could be used as a measure of the sustainability of biological control. The use of eugenol as a natural herbicide is proposed as one tool for managing weeds that may be less disruptive to biological control.

Key words: apple, pest management, weed management, functional biodiversity, eugenol, biological control

[1]Mention of trade names or commercial products in this article is solely for the purpose of providing specific information and does not imply recommendation or endorsement by the U.S. Department of Agriculture.

INTRODUCTION

Insect and weed management are integral parts of a sustainable orchard production system. Sustainable production involves maintaining productivity, healthy ecosystem function and environmental quality (Doran, 2002). Biological diversity may contribute to ecosystem balance and sustainability through partial overlap of functional niches among plant and insect populations (Altieri, 1999). Management practices in fruit orchards tend to reduce biological diversity with broad spectrum controls (Epstein et al., 2001; Horton et al., 2003; Miñaro and Dapena, 2003; Mathews et al., 2004; Markó and Kádár, 2005). A less diverse ecosystem often reduces or eliminates the natural ecosystem services derived from beneficial organisms that suppress insect and weed pests (Altieri, 1999). A major challenge for sustainable orchard management is to suppress pest populations and enhance beneficial populations while maintaining high functional biodiversity to take greater advantage of natural ecosystem services (Sansavini, 1997).

Ecosystem services, such as pest suppression, can be thought of as emergent properties of the ecosystem and are of benefit to the agro-ecosystem and to the greater environment as a whole (Altieri, 1999; Robertson and Swinton, 2005). Emergent properties are not the result of any one component of the system but rather the result of the interaction of all the components working together. The emergent properties, therefore, can not be adequately studied with the typical reductionist style of research characteristic of agricultural sciences. Emergent properties are best studied at a holistic level, taking into consideration all biotic and abiotic components of the ecosystem. Examples of ecosystem services that are provided by a healthy, diverse system are filtering of air and water; wildlife habitat; alternate resources for natural enemies; system level resistance to insects, weeds and diseases; nutrient cycling; and aesthetic, recreational or other socially important services (Boller et al., 2004; Robertson and Swinton, 2005; Ishwaran and Erdelen, 2005).

Sustainable insect and weed management are interdependent (Norris and Kogan, 2005). There are many areas in which management at one trophic level has an impact on other trophic levels. With a high arthropod biodiversity, there are many herbivores that may be able to help sustain a balanced plant community where aggressive weeds are selected against and, in return, plant biodiversity can provide food and habitat for arthropods (Schoenly et al., 1991). For example, an ecologically managed ecosystem has a diverse community of carabids (Markó and Kádár, 2005). Carabids are important predators of insect pests but are also important seed predators (Lovei and Sunderland, 1996). A functionally diverse carabid community may be able to help balance the seed bank and help maintain a diverse plant community not dominated by a few weed species. Biodiversity in the plant community also has a beneficial effect on many arthropods (Horton et al., 2003). Plants provide shelter and help modify the microclimate so that it is more conducive to carabid foraging and reproduction (Miñaro and Dapena, 2003; Markó and Kádár, 2005). For this one example, it is easy to see the positive feedback loop between biodiversity of carabids and the plant community in an orchard.

Weed management that relies solely on long-term use of herbicides may have detrimental effects on biodiversity, the orchard soil, beneficial insect populations, and fruit tree replants (Brown and Tworkoski, 2004; Tworkoski and Miller, 2001). Tworkoski and Welker (1996) demonstrated that, after twelve years of annual use of pre-emergent herbicides, the amount of organic matter, fungal density, and bacteria populations were all less than orchard sites, which were regularly mown. Orchard management that emphasizes reduced use of synthetic herbicides has limited options, but mulches, flamers, weed-eating geese, and natural product herbicides are possible alternatives (Tworkoski and Glenn, in press). We have used composted poultry litter as a mulch to suppress weeds in peach (*Prunus persica* (L.) Batsch.) and apple (*Malus* x *domestica* Borkh.) orchards, although long-term weed control was not obtained with a single mulch application (Figure 1; Preusch and Tworkoski, 2003). Eugenol, a natural product isolated from cinnamon (*Cinnamomun zeylanicum*), has been found to be active as a contact herbicide and may be compatible with sustainable weed management systems (Tworkoski, 2002).

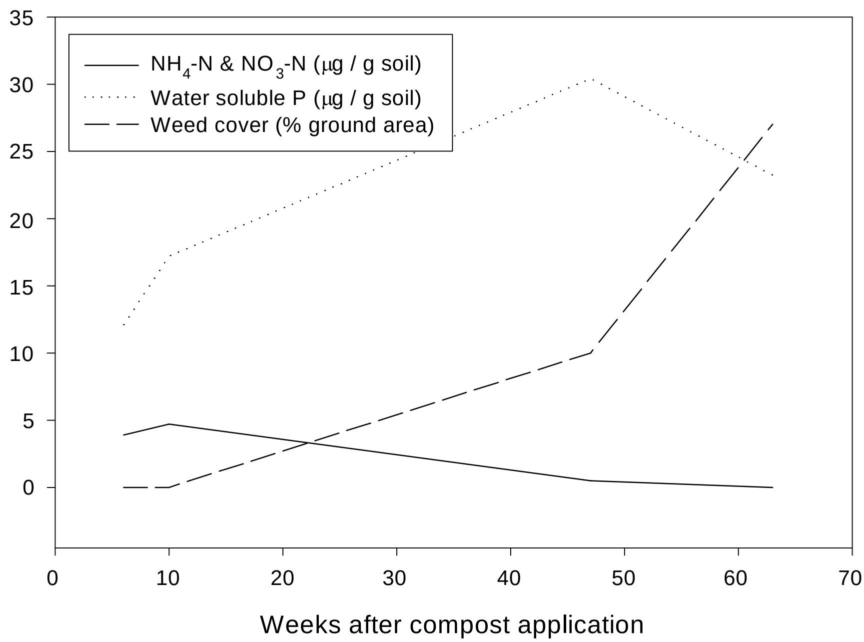

Figure 1. Nitrogen mineralization (solid line), water soluble P (dotted line) and ground area covered by weed vegetation (dashed line) during 60 weeks after application of composted poultry litter as mulch in a peach orchard in West Virginia, USA (derived from Pruesch and Tworkoski, 2003)

This paper provides an analysis of how one management action, the addition of a compost mulch, normally applied to enhance soil health, has beneficial effects on weed and insect management. Food web analysis to compare the effects of compost treatment with an untreated control is presented as an example of how a sustainability analysis of other management actions may be done. We also provide information from an experiment in which we tested whether eugenol application alone or in combination with organic mulch affected weed abundance and yield of apple and peach trees.

MATERIAL AND METHODS

Composted mulch alone

A summary of the research methods are presented here, details can be found in Brown and Tworkoski (2004). Two 16-year-old apple orchards, each 0.15 ha, located at the Appalachian Fruit Research Station, Kearneysville, WV, were used for the study from which the food web data were taken. Half of each orchard had 6 cm deep layer of composted poultry manure applied as a mulch in a 3 m wide strip under the trees in June 1999; some areas received a 12 cm deep mulch treatment, but no pitfall traps were placed in these areas. Half of each mulched and unmulched control plots received a pre-emergent herbicide application of diuron and terbacil prior to compost application. Two pitfall traps in each treatment replicate (16 total pitfall traps) were used to sample the ground-dwelling arthropod community. The traps were open for a one week period in June, August and September 1999, June and August 2000, and June and August 2001. Comparisons among treatments were made using total individuals collected over the three years of the study. Traps were occasionally disturbed by mammals so comparisons were made adjusting the number of arthropods collected per 20 traps per treatment.

Composted mulch and eugenol

Multiple tree plots beneath 'Ace Spur Delicious' apple on M.7 rootstock and 'Redhaven' peach on 'Lovell' rootstock that were planted in 1997 at the Kearneysville station, received four treatments in 2002: 5% aqueous eugenol applied in May and June; composted sawdust (CSD) mulch (8 cm depth) in June plus 5% aqueous eugenol applied in May and June (carrier rate of 450 L ha^{-1}); paraquat (1,1'-dimethyl-4-4'-bibyridinium ion at 0.56 kg ha^{-1}) applied in May, June, July, and August, and untreated control. The experimental unit was a single plot consisting of two apple and two peach trees and all treatments were replicated six times. Mulch was composed of hardwood and pine sawdust that was composted in uncovered windrows for 24 months with occasional turning. Composted sawdust was used in the experiment because it is generally more available and releases less nutrient to soil than composted poultry litter (Tidwell, 1998). Eugenol (2-Methoxy -4-(2-propenyl)-phenol) was included as a natural product herbicide that is contact-active and may be an alternative to paraquat.

By the end of the experiment, 22 October 2003, the mulch depth had reduced to 4 cm (approximately 5.23 kg/m^{-2}).

RESULTS

Composted mulch alone

Here we present only abundances of major trophic groups of arthropods (Tab. 1), more complete taxonomic information on the arthropods collected in this study is available in Brown and Tworkoski (2004). The addition of compost mulch greatly increased the abundance of the detritus-based food web, particularly in the abundance of the detritivore feeding group. The predator trophic level was also increased with the addition of compost. The use of pre-emergent herbicide resulted in a greater abundance of the herbivore trophic level (Tab. 1) which was dominated by migrating first instar *Eriosoma lanigerum* (Homoptera: Aphididae). The food web from plots with compost and no pre-emergent herbicide had a predator: herbivore ratio of 0.85 (Fig. 2). The predator: herbivore ratio in both the compost with herbicide and the no compost and no herbicide plots was 0.32. The food web without compost and with herbicide had the lowest predator to herbivore ratio of 0.15.

Table 1. Abundance, per 20 pitfall traps (percentage of individuals per trophic level within treatment), of soil-dwelling arthropods by trophic group and treatment

Treatment*	Detritivores	Herbivores	Predators	Ants	Total
No Compost, No Herbicide	700 (44.5)	438 (27.8)	142 (9.0)	294 18.7)	1574
No Compost, Herbicide	1400 (49.4)	839 (29.6)	129 (4.5)	468 16.5)	2836
Compost, No Herbicide	2822 (74.0)	327 (8.6)	279 (7.3)	384 10.1)	3812
Compost, Herbicide	2428 (63.5)	810 (21.2)	256 (6.7)	328 (8.6)	3822

*Composted was a 6.0 cm deep layer of composted poultry litter in a 3.0 m strip under the trees; herbicide was a combination of the pre-emergent herbicides of diuron and terbacil applied prior to compost application

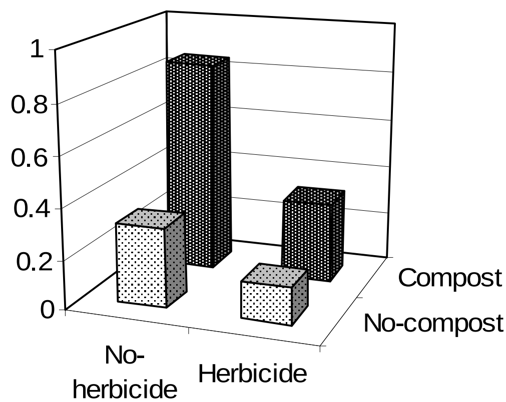

Figure 2. Predator to herbivore ratio based on pitfall trap captures of arthropods in the four compost and herbicide combinations for 1999-2000, Kearneysville, WV, USA

Composted mulch and eugenol

Eugenol gave excellent weed control for one month after treatment but reapplication was needed. Eugenol gave 54% weed cover and CSD mulch plus eugenol gave 8% weed cover by the end of the first season after application (Tab. 2). Paraquat did not differ from CSD mulch plus eugenol, with 2% weed cover. First year results were promising in that a mulch plus post emergence applications of eugenol provided weed control similar to four paraquat applications. However, perennial weeds were present in the CSD mulch plus eugenol treatment, and additional weed control will likely be needed for weed management beyond two years after mulch application.

Weed control treatments did not affect abundance of apple and peach fruit or weight (Tab. 3). Number of fruit, weight, and yield efficiency (on a cm^{-2} trunk cross sectional area basis) were not correlated with percent ground area covered by living weeds or with weed density, as measured by weed dry weight per square meter (data not shown). Weeds can negatively affect yield but these data suggest that young peach and apple trees can withstand a low level of competition.

Table 2. Effect of two and four applications of eugenol alone or in combination with composted sawdust mulch on weed cover and weight during two growing seasons in an apple and peach orchard

Herbicide	Mulch	Weed cover		Weed weight	
		October 2002	October 2003	October 2002	October 2003
		% ground area covered by vegetation		[kg/m^2 dry weight]	
Eugenol	no	54 b	97 a	1.9 ab	1.2 ab
	yes	8 c	65 b	0.1 b	1.3 a
Paraquat	no	2 c	11 c	0.1 b	0.2 b
Control	no	95 a	97 a	3.0 a	1.6 a

Table 3. Effect of two and four applications of eugenol alone or in combination with composted sawdust mulch on fruit number, weight and yield efficiency after two growing seasons of weed control in an apple and peach orchard

Herbicide	Mulch	Apple yield		Peach yield	
		[no./tree]	[kg/tree]	[no./tree]	[kg/tree]
Eugenol	no	43 a*	8 a	22 a	4 a
	yes	44 a	8 a	21 a	4 a
Paraquat	no	49 a	9 a	10 a	2 a
Control	no	47 a	8 a	11 a	2 a

*Means within a column followed by the same letter do not differ at the 0.05 level based on the Bonferroni (Dunn) t-Test

DISCUSSION

The high predator to herbivore ratio of 0.85 predators for every herbivore suggests an elevated level of biological control in the treatment with compost and no herbicide. The compost treated portions of the experimental orchard did have a 69% reduction in first generation *Phyllonorycter blancardella* (Lepidoptera: Gracilariidae) population and a 45% reduction in the number of migrating *E. lanigerum* nymphs as compared with the portion of the orchard without compost (Brown and Tworkoski, 2004). The overall predator to herbivore ratio may be one of the emergent properties of the system that could be used to predict the sustainability of arthropod biological control in any given management practice. If this is the case, the reduction in the predator: herbivore ratio resulting from long-term use of pre-emergent herbicides cannot be considered as conducive to sustainable biological control in orchards.

Although compost sawdust mulch suppressed weeds into the second season after application, eventually new weeds developed (Tab. 2). Weed growth in mulch likely could be suppressed by additional compost mulch applications but practical limits of depth might intervene and release of environmentally-labile, water-soluble P could pollute surface waters (Fig. 1; Preusch and Tworkoski, 2003). Organic mulches that reduce nutrient release, such as composted sawdust, may be amended to mulches that release high levels of nutrients, such as composted poultry litter. A rotation of composted mulch applications with intervening periods of ground cover, tillage, or acceptable herbicide application could enhance both soil health and arthropod biodiversity. Future weed management systems in orchards may tolerate some weeds. It is possible that a range of weed control prescriptions could depend on environmental and cropping conditions and result in reduced inputs for weed management.

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ZWIĘKSZENIE ZWALCZANIA BIOLOGICZNEGO POPRZEZ POWIĘKSZENIE BIORÓŻNORODNOŚCI ŁAŃCUCHA POKARMOWEGO

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STRESZCZENIE

Duża bioróżnorodność jest kluczem do zrównoważonego zwalczania biologicznego w sadach. Zróżnicowane zespoły organizmów biorących udział w zwalczaniu biologicznym są konieczne do ograniczania dużej liczby szkodników należących do różnych grup taksonomicznych. Praktyka uprawy gleby w sadzie obejmuje częściowe albo całkowite usunięcie takich roślin okrywowych, jak trawy i chwasty przy wykorzystaniu różnych technik, takich jak syntetyczne herbicydy, mechaniczna uprawa, ściółkowanie, wypalanie. Celem takiej praktyki jest redukcja współzawodnictwa z roślinami uprawnymi, ale jednocześnie powoduje zmiany abiotyczne i biotyczne komponentów gleby, co wpływa na zmiany w łańcuchu pokarmowym w sadzie. Przeprowadzono badania nad wzrostem bioróżnorodności w sadzie, w którym pod drzewami zastosowano okrywę kompostową. Dodatkowo, oprócz zaopatrzenia gleby w substancje odżywcze i materię organiczną, kompost umożliwiał także zwalczanie chwastów i szkodników. Analiza łańcucha pokarmowego w glebie wykazała, że stosunek drapieżców do roślinożerców w sadzie z kompostem wynosił 0,85, natomiast w sadzie bez okrywy kompostowej albo z okrywą i herbicydami od 0,15 do 0,32. Zaproponowano, aby stosunek drapieżców do roślinożerców stosować jako wskaźnik trwałości zwalczania biologicznego. Proponuje się stosowanie eugenolu jako naturalnego herbicydu umożliwiającego regulowanie zachwaszczenia, a jednocześnie mniej zakłócającego proces zwalczania biologicznego.

Słowa kluczowe: zwalczanie biologiczne, bioróżnorodność, łańcuch pokarmowy, mechaniczna uprawa, ściółkowanie, wypalanie, eugenol