Multitrophic effects of organic fertilization and tree-row management in cider-apple orchards

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Abstract

For a sustainable management of cider-apple orchards, a holistic approach is recommended. In such approach, features such as the groundcover management or the fertilization strategy may have a significant influence not only on both tree growth and yield but also in some other cultivation features. To compare the possible multitrophic effects of these features under organic and conventional growing, three new orchards were specifically designed. Here we present the results on the influence of different strategies of both fertilization and tree-row management on tree performance, soil properties, weed community and ground-dwelling natural enemies. Both factors, but particularly tree-row management, affected differentially most of the studied variables.

Keywords: tree performance, soil properties, weeds, epigeic predators

Introduction

Cider is a key economic factor at Asturias (NW Spain), a region where apple was traditionally produced in high-stem orchards. However, tendency is changing and roughly new 100 ha of semi-extensive orchards are planted every year. The sustainable management of these new orchards requires a holistic approach considering multiple interactions among the factors which could affect cultivation of apple trees (Weibel & Häseli, 2003; Dapena *et al.*, 2005). In such approach, features such as the groundcover management or the fertilization strategy may have a significant influence not only on both tree growth and yield but also on some other cultivation features. The aim of the study was to test the influence of different strategies of both fertilization and tree-row management on tree performance, soil properties, weed community and epigeic natural enemies.

Material and Methods

Field studies were carried out during the period 2003-2009 in three experimental orchards at Villaviciosa, Asturias, NW Spain. All the orchards were specifically designed following a split-plot arrangement for analyzing interactions between rootstock, cultivar, fertilization and tree-row management, and for comparing organic and conventional management strategies. In the present study we will focus exclusively on fertilization and groundcover management strategies. The experimental design allowed us to study the interaction between fertilization and weed management. Regarding orchard characteristics, there were some particular differences among orchards, as described in Table 1. With regard to fertilization, the same quantities of nitrogen (≈60 $kg.ha^{-1}.year^{-1}$), phosphorus (≈75 $kg.ha^{-1}.year^{-1}$) and potassium (≈135 $kg.ha^{-1}.year^{-1}$) were applied in the organic and the chemical plots. Organic plots were fertilized with mineral 0-12-18 and compost at planting, and with compost and organic 6-8-15 (Phenix®) in the subsequent annual fertilization. Chemical plots were fertilized with chemical 0-18-0 and 0-0-50 at planting, and with 9-18-27 and 26-0-0 in the subsequent annual fertilization. In orchard 2, we considered another fertilization strategy (organic + mycorrhization) consisting in the same organic strategy with the addition to the tree roots of the mycorrhizal fungi *Glomus mosseae* at planting.

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Table 1: Characteristics of the three experimental orchards.

	Orchard 1	Orchard 2	Orchard 3
Date of plantation	March 2003	March 2007	April 2007
Size (ha)	0.30	0.34	0.44
Cultivars	De la Riega Solarina -	De la Riega Solarina -	De la Riega Solarina San Roqueña
Rootstocks	M7 MM106 MM111 - -	M7 MM106 MM111 Bitterfelder -	M7 MM106 MM111 Bitterfelder MM109
Fertilization	Organic Chemical -	Organic Chemical Organic + mycorrhization	Organic Chemical -
Tree-row management	Tillage Herbicide Mulching	Tillage Herbicide -	Tillage Herbicide -
Subplots*	36	48	60
Nb trees/subplot**	5-7	2-6	2-6

* Result of the factorial combination of cultivar, rootstock, fertilization and management levels.

** Depended on the cultivar and rootstock vigour.

The tree-row management strategies were: mulching (a layer of withered herb 15-20 cm thick applied once a year at the end of the winter), tillage (plots tilled using a inter-row cutter drawn by tractor three times a year) and herbicide (glufosinate-amonium (Finale, Bayer) applied three times a year). For each orchard and application date, tillage and herbicide were applied the same day. Each treatment extended approximately 0.70 m on either side of the row. The alleys were cleaned when necessary (three-four times per year) using a shredder. None of the plantations was irrigated.

Assessment of tree growth and yield

Diameter of tree trunk was measured just after planting and later yearly in winter to estimate tree growth in the previous season. Apple production per tree was also recorded every year.

Assessment of soil moisture and temperature

The percentage of moisture in the soil was assessed in each of the 36 subplots of orchard 1 from July to September of the period 2003-2005. For that, soil samples from 0 to 10 cm deep were collected and weighted before and after the samples were dried. The percentage of humidity was calculated as the difference between the initial and the final weight divided by the initial weight and multiplied by 100. Soil temperature was assessed in orchard 1 in summers 2004-2006 introducing a thermometer into the soil.

Assessment of the weed cover and species composition

Weed cover and species composition in the tree-row was estimated twice in summer 2009 in 0.5m x 0.5m quadrats. All three orchards were sampled (one sampled per subplot).

Trapping of ground-dwelling predaceous arthropods

The effect of fertilization and tree-row management on the activity-density and on the biodiversity of ground beetles (Carabidae), rove beetles (Staphylinidae), ants (Formicidae) and spiders (Araneae) was studied in orchard 1 in the period 2003-2005 as described in Miñarro *et al*. (2009).

Data analysis

Depending on the data set, split-plot ANOVAs (epigeic predators, weed cover), split-plot ANOVARs (soil moisture and soil temperature using sampling date as the repeated factor), ANCOVAs (trunk section, using trunk section at planting as covariable) or Kruskal-Wallis and Mann-Whiney (apple production) models were used. Differences in the weed species occurrence by treatments were assessed by Chi-square tests.

Results

Effects on tree growth and yield

Tree growth in orchard 1 was lower in the tillage plots than in the other two treatments for most of years (Fig 1a). With regard to fertilization, chemical strategy resulted in higher tree growth (Fig 1b).

The total apple production (along the first six years) in the chemical plots doubled that of the organic plots (29.1 ± 2.6 vs. 13.8 ± 1.1 kg.tree^{-1}, respectively; P<0.001). Similarly, apple production in the herbicide-treated plots (25.7 ± 2.5 kg.tree^{-1}) was higher than in the mulched plots (16.8 ± 2.8), although no different than in the tilled plots (19.4 ± 2.0) (P<0.001).

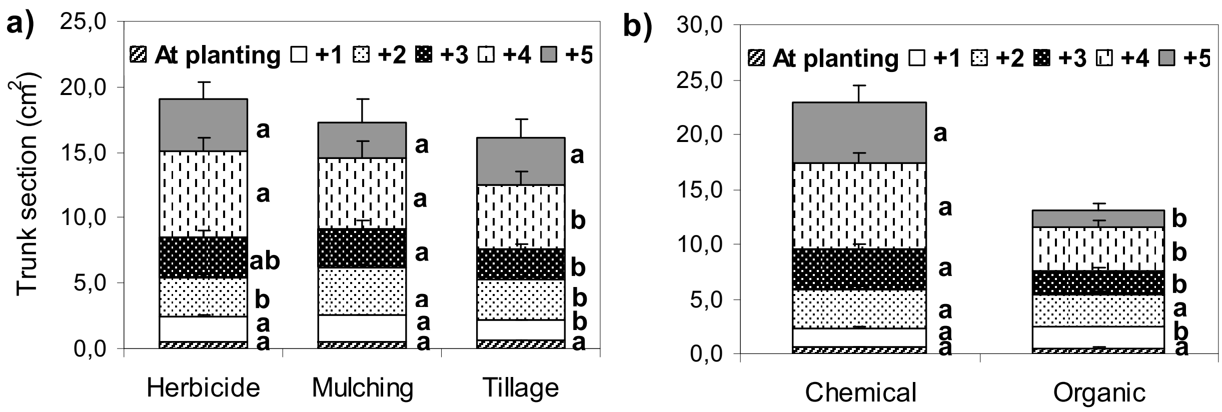

Figure 1: Effect of (a) tree-row management and (b) fertilization strategy on the tree growth in orchard 1. Error bars correspond to standard errors.

Because of the low production on the young orchards 2 and 3, only data from the tree growth are presented. Differences in trunk section between tree-row managements were observed in orchard 2 (Fig. 2a): tree growth in the second growing season was higher in the herbicide-treated than in the tilled plots. Similarly, differences due to fertilization treatment were also observed in this orchard (Fig 2c): tree growth was higher in the both organic and mycorrhizated plots than in the chemically fertilized plots. Tree growth in orchard 3 was similar under organic and conventional management (Fig 2b and d).

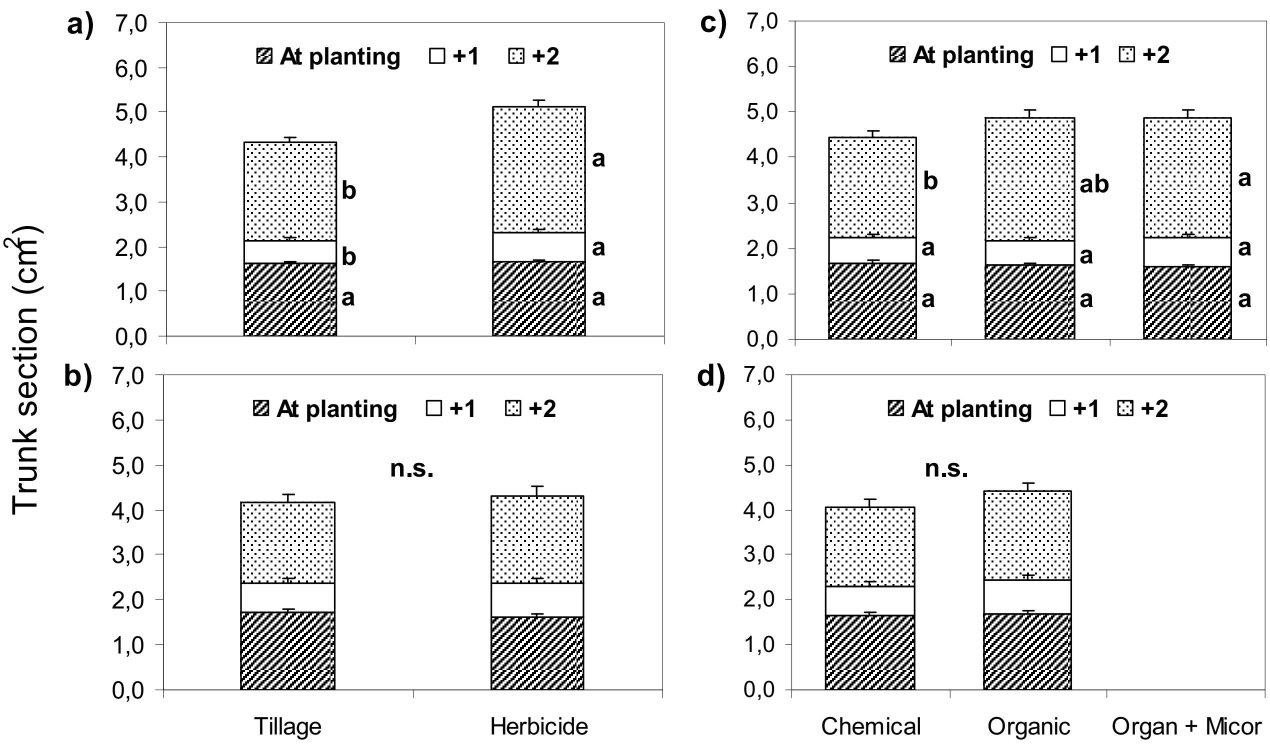

Figure 2: Effect of tree-row management on the tree growth in (a) orchard 2 and (b) orchard 3, and of fertilization in (c) orchard 2 and (d) orchard 3. Error bars correspond to standard errors.

Effects on soil moisture and temperature

The fertilization treatment did not influence the averaged moisture in the soil (P=0.635) while significant differences (P>0.001) were found among tree-row management strategies: soil moisture was higher under the mulching (Fig. 3a).

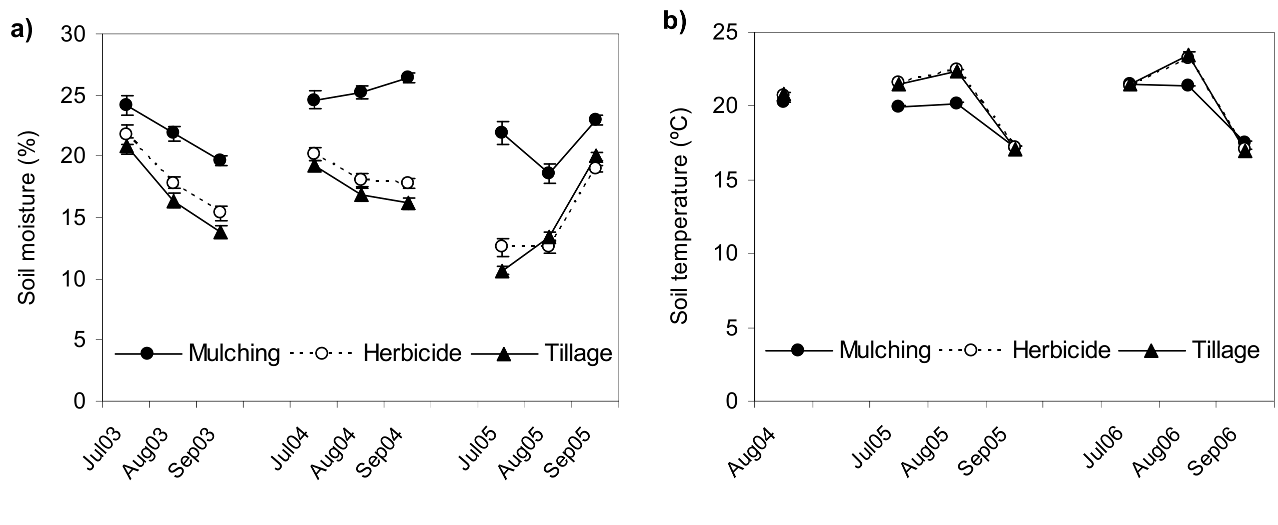

Figure 3: Effect of the tree-row management on soil (a) moisture and (b) temperature in orchard 1 in different sampling dates. Error bars correspond to standard errors.

Temperature in the soil was significantly lower in the mulched plots than in the herbicide and the tillage treatments in the warmest dates (P<0.001; Fig. 3b). Although no significant (P=0.082), a trend to higher temperature under the organic fertilization was intuited.

Effects on weed cover and species composition

Weed cover was strongly influenced by the tree-row management in orchards 1 and 2 in both sampling dates ($P<0.001$ in all cases): weeds emerged earlier after treatment application in the tilled plots than in the herbicide treatment (Table 2). At the end of the summer, weed cover in the mulching was also higher than in the herbicide treatment. Regarding fertilization treatment, a possible trend to higher cover in the organic plots was only statistically confirmed in one sampling date in one orchard (Table 2).

Table 2: Effect of fertilization and tree-row management on the weed cover. Percentage (mean ± standard error) of soil surface covered with weeds in the tree-row. (*days after the previous treatment application).

		Orchard 1		Orchard 2		Orchard 3	
		June (31-33)*	September (36)*	June (31-33)*	September (36)*	June (69)*	July (34)*
Tree-row management	Herbicide	28.3 ± 4.4 **b**	19.6 ± 3.5 **c**	40.6 ± 3.9 **b**	60.6 ± 5.2 **b**	82.3 ± 3.5 a	32.3 ± 3.5 a
	Tillage	60.4 ± 6.6 **a**	91.3 ± 4.8 **a**	73.5 ± 4.9 **a**	92.3 ± 2.4 **a**	78.3 ± 4.4 a	30.0 ± 3.6 a
	Mulching	20.8 ± 4.5 **b**	62.9 ± 7.7 **b**	–	–	–	–
Fertilization	Chemical	32.5 ± 6.1 a	57.5 ± 9.5 a	53.1 ± 7.4 a	70.3 ± 7.5 a	72.3 ± 4.5 **a**	29.0 ± 3.8 a
	Organic	40.6 ± 5.6 a	58.3 ± 7.3 a	51.6 ± 6.9 a	78.1 ± 5.1 a	88.3 ± 2.7 **b**	33.3 ± 3.3 a
	Org + Mycorr	–	–	66.6 ± 5.8 a	80.9 ± 6.3 a	–	–

The influence of both factors on the occurrence of the five most frequent species in each orchard is represented in Fig. 4. Some species were affected by the tree-row management and occurred preferably in the tilled plots (*Echinocloa crus-galli* and *Taraxacum officinale* in orchard 1 and *Rumex acetosa* in orchard 3) while other species were found preferably in the herbicide plots (*Veronica persica*, *Urtica dioica* and *Plantago lanceolata* in orchards 1, 2 and 3, respectively). The fertilization strategy only affected two weed species (Fig 4d-f): chemical fertilizers increased the abundance of *U. dioica* and *Holcus lanatus*.

Effects on ground-dwelling predaceous arthropods

A total of 4978 individuals were collected along the three years. Carabids (56.8 % of the total catches) were the most abundant taxonomic group, followed by spiders (20.7 %), ants (14.8 %) and rove beetles (7.7 %). With respect to catches, the type of fertilization applied had no significant influence on any of the studied taxa ($P>0.05$ in all the cases). However, tree-row management had a significant effect on the activity-density of all the analyzed taxa except the ants, although the strategy which favoured activity-density depended greatly on the taxonomic group (Fig. 5a).

Tree row management also had a significant effect on the Shannon-Wiener’s diversity index, which was significantly higher in the mulched and herbicide treated plots for the overall predators and carabids (Fig. 5b). For staphylinids, this index was significantly higher on the mulched plots, while no differences were found for ants or spiders. The fertilization strategy had neither influence on the diversity index.

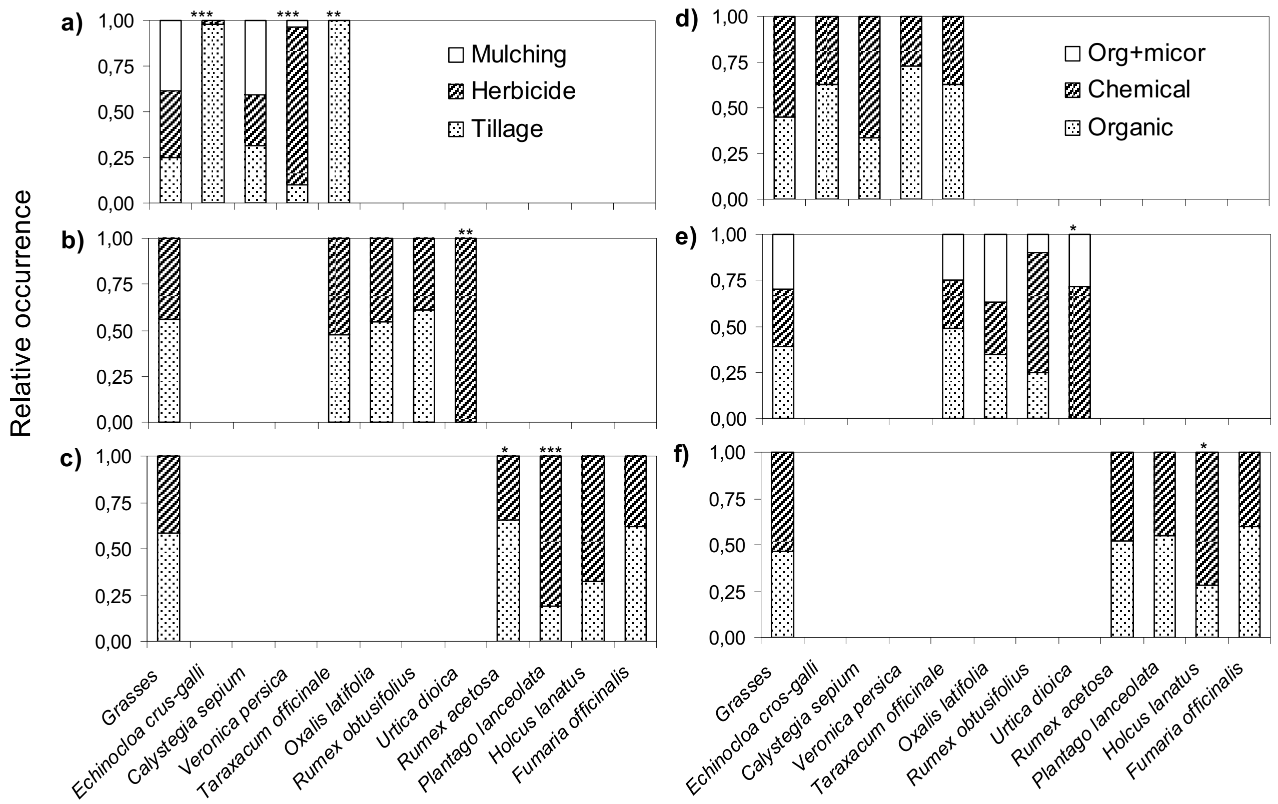

Figure 4: Relative occurrence (surface occupied by each species) depending on the tree-row management in (a) orchard 1, (b) orchard 2 and (c) orchard 3, and depending on the fertilization strategy in (d) orchard 1, (e) orchard 2 and (f) orchard 3. Only the five more important species in each orchard were considered.

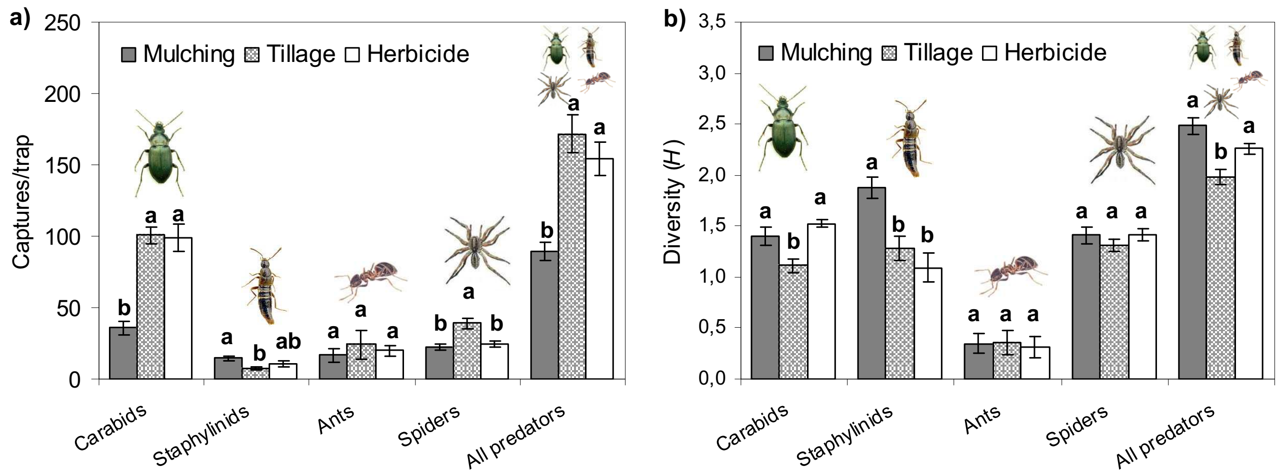

Figure 5. Effect of the tree-row management on (a) captures of epigeic predators (mean captures/trap over the sampling period) and (b) Shannon-Wiener's diversity index (H) in orchard 1. Error bars correspond to standard errors.

Discussion

Tree-row management affected all the studied factors. For instance, groundcover management had an effect on soil characteristics such as temperature and humidity, which, in its turn, could explain some of the differences observed in the weed cover or in the ground-dwelling predator community, as some species (both of weeds and arthropods) have preferences for particular temperature and moisture conditions (Van Dijk, 1996). Apart from this soil-mediated effect, a direct effect of the groundcover management strategy is also supposed. In the case of weeds, despite the fact that tillage and herbicide were performed at the same time, herbicide applications delayed soil colonization by weeds in comparison with tillage. We also observed that as the season progressed the mulched plots were also progressively colonized by weeds. This relation between management and weed cover would partially explain the lower tree growth in the tilled plots observed in orchards 1 and 2, since weeds are known to be strong competitors of trees for water and nutrients (Merwin, 2003).

The fertilization strategy had not a strong influence on the studied factors with the exception of tree performance, the most important factor from an agronomical point of view. In the oldest orchard (orchard 1) the use of organic fertilizers was associated with lower tree growth and yield in comparison with chemical fertilization. However, in orchards 2 and 3 there were no differences between organic and chemical fertilization strategies. These different results could be explained by the fact that orchard 1 suffered flooding in late winter most of the years and then fertilizers could not be applied until May, which poses a disadvantage for organic fertilizers due to the low biological activity in the soil and the habitual slower process of mineralization of these fertilizers. However, in orchard 2 and 3, where the first fertilizer application was done in February, organic and chemical fertilization had a similar effect on tree growth, which was even higher when organically-fertilized trees were mycorrhizated at planting.

Regarding the influence on epigeic predators, a precise knowledge of the role that each taxon plays in pest control is needed for recommending the strategy which could increase more efficiently the activity-density of these biological agents.

Summarizing, both factors, but particularly tree-row management, affected differentially most of the studied variables, and therefore, the cider-apple production system as a whole. However, the study is not finished yet and therefore some results are not definitive.

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References

Dapena, E., Miñarro, M. & Blázquez, M.D. (2005). Organic cider-apple production in Asturias (NW Spain). *IOBC/wprs Bulletin* **28 (7)**: 142-146.

Merwin, I.A. (2003). Orchard-floor management systems. *In* Apples: Botany, Production and Uses (ed. Ferree, D.C. & Warrington, I.J.), pp. 303-318.CABI Publishing.

Miñarro, M., Espadaler, X., Melero, V.X. & Suárez-Álvarez, V. (2009). Organic versus conventional management in an apple orchard: effects of fertilization and tree-row management on ground-dwelling predaceous arthropods. *Agricultural and Forest Entomology* **11**: 133-142.

Van Dijk, T.S. (1996). The influence of environmental factors and food on life cycle, ageing and survival of some carabid beetles. *In* Arthropod Natural Enemies in Arable Land. II. Survival, Reproduction and Enhancement (ed. Booij, C.J.H. & Nijs, L.J.M.F). *Acta Jutlandica* **71**: 11-24.

Weibel, F. & Häseli, A. (2003). Organic apple production-with emphasis on European experiences. *In* Apples: Botany, Production and Uses (ed. Ferree, D.C. & Warrington, I.J.), pp. 551-583.CABI Publishing.