Original Article

Effect of infestation by *Micrapate scabrata* (Erichson, 1847) (Coleoptera: Bostrichidae) on wood degradation and its impacts on some soil chemistry properties

Efecto de la infestación de *Micrapate scabrata* (Erichson, 1847) (Coleoptera: Bostrichidae) en la degradación de madera y sus consecuencias en algunas propiedades químicas del suelo

Tomislav Curkovic[1]*, Catalina Ferrera[1], Cecilia Baginsky[2] & Oscar Seguel[3]

[1]Departamento de Sanidad Vegetal, Facultad de Ciencias Agronómicas, Universidad de Chile, PO Box 1004, Santiago, Chile.
[2]Departamento de Producción Agrícola, Facultad de Ciencias Agronómicas, Universidad de Chile, PO Box 1004, Santiago, Chile.
[3]Departamento de Ingeniería y Suelos, Facultad de Ciencias Agronómicas, Universidad de Chile, PO Box 1004, Santiago, Chile.
*E-mail: tcurkovi@uchile.cl

ABSTRACT

Micrapate scabrata (Erichson) (Coleoptera: Bostrichidae) is a xylophagous beetle native to Chile. Adults and larvae feed on several native host plants, but also on pruned wood of exotic plants. In this study we assessed the impact of artificial *M. scabrata* infestation on *Vitis vinifera* L. wood degradation and the subsequent changes in soil properties. First, we periodically sampled, during a four-month period, pruned wood from an infested table grape vineyard, finding in average 1 adult/10 cm linear wood. Adults were then placed in large Petri dishes containing uninfested wood samples, and maintained in a climatic chamber for six months. At the end of this period, an average of 65.6% of infested wood had been turned mainly into sawdust. Additionally, the impact of leaving *M. scabrata* infested pruned wood on potted soil for six months, under laboratory conditions, was also evaluated. Afterwards, the surface soil content of macro elements (N-P-K) and organic matter significantly increased, whereas the soil pH decreased. These results document the significant impact of *M. scabrata* infestation on pruning wood degradation and the benefits to the soil if left on the ground in the ecosystem.

KEYWORDS: Ecosystems, soil improvement, wood recycling, xylophagous beetles

RESUMEN

Micrapate scabrata (Erichson) (Coleoptera: Bostrichidae) es una especie xilófaga y nativa de Chile. Las larvas y los adultos se alimentan de madera de varias especies nativas, y también de madera de poda de plantas exóticas. En este estudio evaluamos el impacto de una infestación artificial de *M. scabrata* en la degradación de madera de *Vitis vinifera* L. y los cambios subsecuentes en las propiedades del suelo. Para ello, primero muestreamos madera de poda, durante cuatro meses, en un parronal de uva de mesa infestado, y encontramos en promedio 1 adulto/10 cm lineales de madera. Luego se infestó madera de poda sana, dispuesta en placas de Petri, con adultos, las que se mantuvieron en una cámara climática por seis meses. En ese plazo, un 65.6% de la madera infestada fue convertida principalmente en aserrín. Adicionalmente, se evaluó el efecto de dejar madera de poda infestada por *M. scabrata* en macetas con suelo, durante seis meses, en condiciones de laboratorio. Luego de ese período, se encontró que el contenido de macro-elementos (N-P-K) y materia orgánica en el suelo aumentó significativamente, mientras que el pH disminuyó. Estos resultados muestran el impacto significativo de la infestación de madera por *M. scabrata* en su degradación y los beneficios para la condición del suelo si es dejado en superficie en el ecosistema.

PALABRAS CLAVE: Ecosistemas, escarabajos xilófagos, mejoramiento del suelo, reciclaje de madera.

INTRODUCTION

Micrapate scabrata (Erichson) (Coleoptera: Bostrichidae) is a species found in Chile between Arica and Temuco (18°-38°S), and also in some regions of Peru and Bolivia (Artigas 1994). It is a xylophagous (saproxylophagous, Muñoz-López *et al*. 2016) species that is commonly found in wine grape vineyards (*Vitis vinifera* L.), and more occasionally in table grapes and kiwis (*Actinidia deliciosa* (Chev.) (Prado 1991, Gonzalez & Curkovic 1994, Klein & Waterhouse 2000).

The adult usually feeds on dry and dead wood (Figure 1A) of several plant species (Barriga *et al.* 1993), but it has also been occasionally found boring live tissues from stressed vines (*e.g.* following water stress) (Ripa & Luppichini 2004). Our understanding of the life cycle of *M. scabrata* is fragmentary. Eggs are apparently laid inside the wood. Larvae (Figure 1B) actively feed inside pruned branches and trunks, consuming mainly xylem and phloem tissues, and producing large amounts of frass in the form of sawdust (Figure 1C). Pupae occur in brief bursts. Apparently there are two or three generations per year (Artigas 1994). The attack on live plants causes branch fractures and reduces plant sprouting and canopy development (unpublished data). The consumption of large amounts of dry wood by adults and larvae, and the subsequent sawdust produced, are usually seen as biodeterioration of a material which otherwise decomposes very slowly (Harmon *et al.* 1986). However, bostrichid species (among other decomposition agents) also act as wood transformers, contributing to its biodegradation (Harmon *et al.* 1986). The objectives of this study were a) to evaluate the abundance of *M. scabrata* adults on infested table grapes prunings, b) to measure wood degradation after *M. scabrata* infestation, and c) to measure the impact of naturally deposited sawdust from infested wood on several soil chemical parameters.
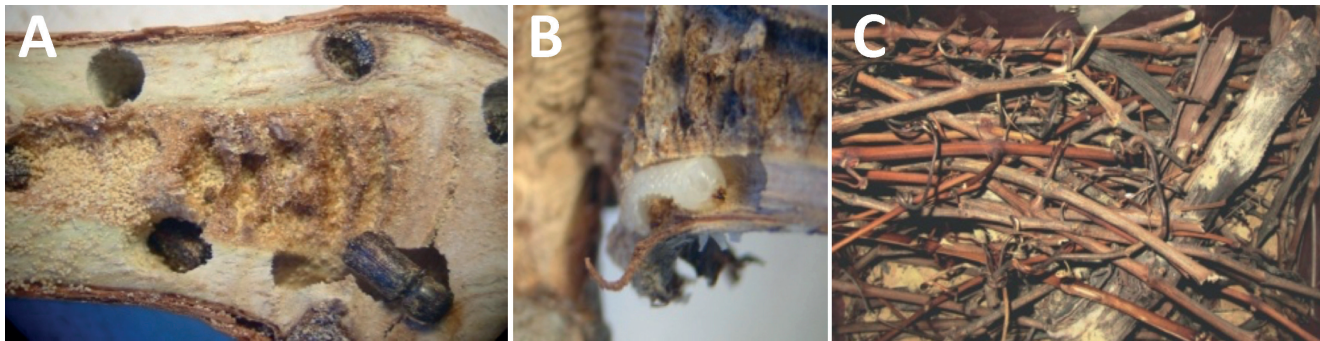

FIGURE 1. *Micrapate scabrata:* adults feeding on *V. vinifera* pruned wood (A); larvae inside a gallery located under bark, boring wood (B); pruned wood and sawdust produced by a severe infestation, in a *M. scabrata* colony under laboratory conditions (C). / *Micrapate scabrata*: adultos alimentándose de madera de poda de *V. vinifera* (A); larva en una galería ubicada bajo la corteza, taladrando la madera (B); madera de poda y aserrín producido por una infestación severa, en una colonia de *M. scabrata* mantenida en condiciones de laboratorio (C).

MATERIALS AND METHODS

WOOD SOURCE AND *M. SCABRATA* INFESTATION. Residual table grapevine wood pieces (from the pruning season) of about 1 cm in diameter and ~ 1 m in length were collected ca. once a week (September through January) from a table grape vineyard (cv. Red Globe) located near "Alto del Carmen" (29° 45' 34" S, 70° 5' 15" W), region of Atacama, Chile. Typically, pruning is conducted at the end of May and the pruned wood is left on the vineyard ground, sometimes forming an extensive cover. *Micrapate scabrata* presence was confirmed in the field. The number of *M. scabrata* individuals (larvae, pupae, and adults) on the wood samples was recorded in the laboratory. The adults were used to start a colony in Flanders batteries on wine grape pruned wood in the laboratory. Recently emerged (less than a week old) beetles were used for experiments 1 and 2 (1:1 sex ratio, based on Artigas 1994).

EXPERIMENT 1. WOOD INFESTATION WITH *M. SCABRATA* IN PETRI DISHES. Ten pieces of table grapevine wood (~ 61–71 cm long) without signs of *M. scabrata* infestation were selected and one end of each piece was cut, weighed (fresh), and dried in a muffle at 70º C until constant weight. Then, the water content/cm of wood end pieces was calculated ([fresh – dry] weight (g)/length (cm)). The remainder of each wood piece (~ 60 cm long each) was also weighed and the initial dry weight estimated (individually corrected for water loss). Each remaining 60 cm wood sample (the section not dried in the muffle) was cut in six smaller pieces (~ 10 cm ea.) and placed inside a large Petri dish (n=10). Five Petri dishes (replicates) were randomly chosen and six *M. scabrata* adults/dish were added to group 1, whereas the other five Petri dishes were not infested with insects - group 2. All Petri dishes were then sealed and placed inside the climatic chamber (25±2 °C, 45±5% RH, 14 h of light) for 180 days (May to October), at the Insect Behavior and Chemical Ecology Laboratory, Department of Crop Protection, College of Agricultural Sciences, University of Chile. Afterwards, the wood pieces from each Petri dish were cleaned with a brush (to remove the sawdust) and taken into a muffle until stable weight (final dry weight). The transformed wood weight (initial-final) after the six-month period was calculated.

EXPERIMENT 2. WOOD INFESTATION WITH *M. SCABRATA* IN

pots with soil samples. The soil used in this experiment was collected from the table grape vineyard as described above. This soil is an Aridisol (CIREN 2007) developed from stony colluvial deposits in the Huasco Valley, with a loamy sand texture. A preliminary soil analysis showed values of total N and organic matter (OM) of 0.07% and 2.17% respectively, 18.5 mg kg^{-1} of P-Olsen, 0.21 cmol kg^{-1} of K and pH=7.98. Soil samples (taken at 0 to 15 cm in depth**)** were collected and placed in 4.3 L plastic pots (n=10). In order to maintain the wood/topsoil proportion close to that of the field conditions, 100 cm of uninfested pruned wood pieces (1 cm in diameter and ca. 50 g) were left on the surface of each pot. Two groups of five pots were randomly chosen and ten *M. scabrata* adults/pot were added to one group (infested treatment), whereas the other one was not infested. All pots were then covered with an anti-aphid mesh to prevent further infestation (or escape) and kept under room conditions (20±5°C, 40±5% RH, 10-14 h of light) for 180 days (June to November). Subsequently, the soil chemical properties mentioned above were measured in a sample collected from the first 5 cm of soil.

Evaluation of soil parameters. Soil properties were evaluated according to the methodologies proposed by Sadzawka *et al.* (2004) adapted to Chilean soils: total N was measured by modified Kjeldahl method, available P by P-Olsen method, exchangeable K by NH$_4$-Ac (1 mol/L) at pH 7.0 and determination by atomic emission spectrometry, OM by acid combustion (Walkley-Black), and pH by potentiometry in soil to water ratio of 1:2.5.

Experimental design and data analysis. Data for *M. scabrata* infestation is presented as the mean value. A completely randomized experimental design was used, with five replicates for each experiment (1 and 2). Data were analyzed by using one-way ANOVA (p ≤ 0.05). In the first experiment, we compared the weights of the wood samples between (infested vs. uninfested) and within (initial vs. final dry weight) treatments (Ott 1992). For the second experiment, after the six-month period, the macronutrients, OM content, and soil pH were contrasted between treatments. The ANOVA was conducted based on the assumption of independence among the variables measured on the same soil samples (Nielsen & Wendroth 2003). ANOVA assumptions were confirmed for most data. For total OM, the values were transformed to square root to accomplish normality. The nitrogen content was not normal, thus the Kruskal-Wallis nonparametric test was used to contrast data (Steel & Torrie 1985).

RESULTS

Experiment 1: Wood infestation and Degradation. About 20 m of infested pruned wood were collected and dissected between September and January. *Micrapate scabrata* was the only xylophagous species reared from the samples, resulting in an average of 1.35 exit holes, 0.40 larvae, 0.18 pupal chambers, 0.01 pupae, and ca. 1 adult, per 10 linear cm of wood. Therefore, this density of adults was used for experimental infestation of Petri dishes and potted soil. No parasitic or predatory species were found.

The water content (g/linear cm of wood) found in the samples, before *M. scabrata* infestation, ranged between 0.028 and 0.043 g cm^{-1} (group 1) and 0.025 and 0.043 g cm^{-1} (group 2). After subtracting the water content, the corrected dry weight of wood samples ranged between 24.08 and 28.14 g cm^{-1} of wood (group 1) and between 24.63 and 28.28 g cm^{-1} (group 2), without significant differences between groups (p=0.57) (Table 1). Six months after *M. scabrata* infestation in group 1 dishes, the dry weight of wood ranged between 6.70 and 11.39 g cm^{-1}, whereas in the uninfested wood (group 2) it ranged between 23.99 and 27.40 g cm^{-1}, the treatments being significantly different (p<0.0001). There were no significant differences within group 2 (uninfested wood) before and after six months (p=0.33), whereas highly significant differences were found when comparing wood weight in group 1 of infested dishes before and after placing the adults in the dishes (p<0.0001). An average of at least 65% of infested wood, after correction for water loss, was converted mainly into sawdust by *M. scabrata* after six months of exposure (neither *M. scabrata* final biomass, nor density was measured). In contrast, only 4.7% of the weight was lost during the same period in uninfested wood.

Table 1. Weight and water content (g) of pruned wood of table grapevines, with and without *Micrapate scabrata* infestation, after six months inside a Petri dish in a climatic chamber (25±2 °C, 45±5% RH, 14 h of light). / Peso y contenido de agua de madera de poda de vides de mesa, con y sin infestación de *Micrapate scabrata,* después de seis meses almacenadas en placas de Petri en una cámara climática (25±2 °C, 45±5% HR, 14 h de luz).

Treatment	Fresh	Water Content[1]	Initial Dry[2]	Final Dry	Δ Dry[3]
Infested	27.72 a	2.12 a	25.60 aA	8.80 bB	16.81 a
Uninfested	28.50 a	2.15 a	26.35 aA	25.18 aA	1.18 b

[1] [(fresh – dried wood weight of end piece)/end piece length] * 60 cm; [2] initial fresh weight – water content; [3] initial dry weight –final dry weight. Small letters show statistically significant differences between treatments within a column, while capital letters show significant differences between dry wood weights (initial vs. final), one-way ANOVA (p ≤ 0.05).

Infested wood at the end of the experiment turned into a large amount of sawdust (frass), due to the consumption of most wood (i.e. mostly xylem + phloem) by *M. scabrata*, while only a thin layer of bark persisted almost unchanged externally, except for the holes bored by the adults. These holes allowed sawdust to exit and end up on the dish bottom. The uninfested wood pieces remained unchanged after six-month period.

EXPERIMENT 2. EFFECTS ON SOIL PROPERTIES. The impacts of *M. scabrata* infestation on the macro elements (N-P-K), OM content, and soil pH of wood pieces placed in pots with soil samples are shown in Table 2. The main effects should be caused by the sawdust produced by the infestation and released on the soil, since it should correspond at least to 92% out of the total weight (beetles should be under 8%,

estimated based on unpublished data). When looking at the original values for soil characteristics, most parameters showed equal or greater values in the treatment with infested wood, whereas the opposite occurred with uninfested wood. Only pH values were higher in the uninfested treatment. Although the differences between both treatments were not very large, all measurements, except pH, were statistically greater when wood was infested with *M. scabrata* adults. The higher increases (with regard to the level found in uninfested wood) were obtained in OM content (ca. 63%) and P (40%), whereas the lowest variations were observed in N (17%) and K (11%). The pH showed a small but significant reduction of 3%, taking the soil from a moderately alkaline condition to a value < 8.0 in the *M. scabrata* infestation treatment.

TABLE 2. Macro elements (N-P-K), OM content, and pH levels in soil samples with pruned wood infested (with *M. scabrata)* or uninfested, and kept for six months in pots under laboratory conditions (20±5 °C, 40±5% RH, 14 h of light). / Niveles de macro-elementos (N-P-K), contenido de materia orgánica y pH, en muestras de suelo con madera de poda de vides infestada (con *M. scabrata*) o no infestada, y mantenida por seis meses en macetas bajo condiciones de laboratorio (25±2 °C, 45±5% HR, 14 h de luz).

Treatments	N (%)	P (mg kg⁻¹)	K (cmol⁺ kg⁻¹)	OM (%)	pH
Infested	0.07 a	20.4 a	0.21 a	2.39 a	7.94 b
Uninfested	0.06 b	14.6 b	0.19 b	1.47 b	8.16 a

Small letters show statistically significant differences between treatments within a column. Data were submitted to one-way ANOVA (p ≤ 0.05). Data were square-root transformed for total OM. The Kruskal-Wallis nonparametric test was used to contrast nitrogen content.

DISCUSSION

The presence of large larvae and pupae infesting sampled wood suggests the infestation begun several months earlier, probably at the beginning of the autumn, during the last generation of the season based on Artigas (1994) and Ripa & Luppichini (2004). The wood consumption by *M. scabrata* has not been studied, but our results showed wood pieces about 1 cm diameter (fine debris following Brin *et al.* 2011) were intensively damaged. Field observations also suggest that *M. scabrata* prefers wood pieces of smaller diameters (1-3 cm) to bore and reproduce. Wood size determines preference in many xylophagous beetles (Grove 2002). For instance, *Stephanopachys quadricollis* (Marseul), a relatively small-sized bostrichid (~6 mm length), is reported to attack mostly large logs (Brin *et al.* 2011), whereas *Dexicrates robustus* (Blanchard), a larger bostrichid (up to 18 mm), mainly bores trunks and branches in young orchards (González & Curkovic 1994). *Micrapate scabrata* seems to present an unusual strategy, boring small diameter wood pieces.

Based on our data, the transformation of grapevine pruned to degraded wood (mostly turned into sawdust) and

its contribution to soil fertility were significant in a period of six-month under experimental conditions. These results support the idea that this type of species significantly aid in nutrient conservation in the ecosystems by modifying both, physically and chemically woody debris (Chen & Forschler 2016). This is well recognized in xylophagous species such as termites (Isoptera), but considerably less known and studied in the case of Bostrichidae, usually one of the least abundant families in ecological studies (Muñoz-López *et al.* 2016). Despite the fact that bostrichid species have been reported as important wood pests, they are also considered wood transformers (Harmon *et al.* 1986). Both larvae and adults feed on dry wood, being able to digest starches and sugars (Liu *et al.* 2008), having endosymbiotic relationships with microorganisms that can provide cellulolytic enzymes and aid for digestion of other important wood constituents (Beaver *et al.* 2011) such as cellulose, lignin, and hemicellulose. Bostrichid feeding activities generate large amounts of feces or frass (sawdust) due to a partial digestibility (50%). Studies on xylophagous frass content have shown important significant lignin transformation and oxidation of elements after passing through the insect´s alimentary canal. In fact, bostrichid frass showed

significantly greater concentrations of phosphorus than the original wood (pinewood). On the other hand, nitrogen and potassium were not different from the wood the insects fed on (Chen & Forschler 2016). Ulyshen (2016) states that wood degradation is largely driven by microbes. However, invertebrates play an important role as well (10-20% wood degradation) by performing enzymatic digestion, substrate alteration (*e.g.* tunneling), biotic interactions, and nitrogen fertilization, having a cumulative effect that speeds up the degradation process.

According to Wang & Shuchardt (2010), vineyard pruning residues can contain an average of 7.2 g kg^{-1} of N, 1.1 g kg^{-1} of K and 5 g kg^{-1} of P, with high OM content (>90%). Assuming the production of 0.75 kg (dry weight) of pruned grapevine wood/plant (Lavin 1981, Ortega-Farias *et al.* 2007) and considering the average proportion of wood transformed into sawdust and *M. scabrata* (65.6%, see above), we estimate a potential of about 0.50 Mg (1,000 plants/ha for table grape vineyard) to 1.23 Mg (2,500 plants/ha for wine grape vineyard) of available OM to be incorporated into the topsoil. The addition of organic debris on the soil surface has beneficial effects on soil properties, such as higher water retention and porosity, and lower compaction (Hartge & Bachmann 2004, Mulumba & Lal 2008). However, in materials with high (*e.g.* 49%) lignin content and high (*e.g.* 60 to 89) C/N ratio, such as table grapevine prunings (Sanchez *et al.* 2002, Wang *et al.* 2005), the residue pieces persists for longer time, thus the temperature of the soil tends to decrease (Wang & Schuchardt 2010), leading to nutrient depletion (Powlson *et al.* 2011). In this sense, the activity of *M. scabrata* on prunings promotes nutrient recycling by a faster initial decomposition, improving ecosystem conditions. Regarding OM, in a study conducted by Tahboub *et al.* (2008) where pecan wood chips were incorporated into the soil in amounts ranging from ca. 4.5 Mg to ca. 18 Mg of wood ha^{-1} (fresh weight), no significantly increasing levels were observed after one year, regardless of the amount of incorporated wood. However, when chipped wood was incorporated the second study year, significantly greater OM levels were obtained. In our case *M. scabrata* speeded up the process of wood degradation and incorporation into the soil within a relatively short period (six months), increasing the OM content compared with the initial soil condition (2.17% OM measured immediately before setting Experiment 2) while in the uninfested treatment the OM decreased. In this sense, high commercial yields (along with greater pruned wood production) in the vineyard under study (>24 Mg ha^{-1}), allowed a high addition of pruned wood on the topsoil, causing beneficial effects on the soil if *M. scabrata* infestation occurs on the wood debris. Exchangeable K was moderate to low in both treatments, requiring a supplement for the grapevine production (Havlin *et al.* 2005). Finally, the P-Olsen values showed a significant increase, changing

from moderate content without *M. scabrata* infestation to high content in the treatment with infested wood. In practical terms, considering an Ap horizon of 20 cm deep, the treatment with *M. scabrata* provided an extra supply of 26 kg P$_2$O$_5$ per hectare, a beneficial effect (ecological service) in P availability for plants. Soil pH levels decreased significantly due to the activity of *M. scabrata* on pruned wood. Tahboub *et al.* (2008) find no statistical differences even after three years of reiterative amendments of pecan wood (not infested by xylophagous insects) into the soil; however, when inorganic N was added, pH values dropped significantly. In our study, the reduction of pH from 8.16 to 7.94, though small, is still relevant because agricultural crops respond better to soil pH below 8.0; otherwise, many nutrients are not available and Na$^+$ excess can make the absorption of bivalent cations difficult (Havlin *et al.* 2005).

Mulching of pruning debris on the ground, between the rows of a table grape vineyard, is a common and practical procedure with positive impacts on the soil properties under the semiarid Chilean conditions, particularly in terms of soil fertility, structure, and water retention (Baginsky *et al.* 2010). Our results showed that the activity of *M. scabrata* accelerated wood residue decomposition, increasing macro elements availability. This is particularly important in areas such as the Atacama Region, a semiarid zone, where soils are shallow and low in OM content, significantly reducing yields if these conditions are not improved. Besides, although there is a risk of *M. scabrata* attacking weak or stressed plants (Ripa & Luppichini 2004), no *M. scabrata* infestation was observed on live plants during the sampling period in the vineyard. Therefore, these results stress the usefulness of leaving pruned wood infested with xylophagous insects on the vineyard soil, provided the grapevines are not stressed and, therefore, susceptible to *M. scabrata* damage. Similar results should be expected if the wood debris were left on non-agricultural soils (*e.g.* in wild areas) in Chile where *M. scabrata*, among other wood decomposers, causes wood degradation. Unlike cultivated species, the risk from *M. scabrata* to the natural vegetation is considered very low since this species has been reported attacking only dead wood in a restricted range of native host plants (*Baccharis linearis* (Ruiz & Pav.)*, Chusquea culeou* Desv.*,* and *Prosopis chilensis* (Mol.) Stuntz., Barriga *et al.* 1993) and there are no reports of damage on indigenous stressed plants by this insect. However, in other countries the activity of bostrichids in forests produces large amounts for organic compounds that end up in the soil (Harmon *et al.* 1986, De Souza 2010). Bostrichids are considered among the key species responsible of improving soil fertility by nutrient recycling in woods and energy flow in many ecosystems (Harmon *et al.* 1986, Nadeau *et al.* 2015). However, forest management can reduce their densities and affects their role in wood decomposition (Grove 2002).

In conclusion, *Micrapate scabrata* as described in here,

had a significant and positive impact on the degradation of wood (table grapevine prunings), turning at least 65% mainly into sawdust within a six-month period and providing significant ecosystem services in nutrient recycling. This resulted in a significant increase of both the OM and macro element contents (N-P-K) in the surface soil layer, and in a significant decrease of soil pH. All these changes are considered to be a significant improvement of the soil conditions for growing crops, agroecosystems, or wild ecosystems (as native forests) where *M. scabrata* should play a significant role in its sustainability.

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