ORGANIC AND BIODYNAMIC VITICULTURE AFFECT SOIL QUALITY AND SOIL MICROBIAL DIVERSITY

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Abstract:

Context and purpose of the study - The production of organically grown crops developed exponentially in the last few decades based on consumer demands for healthy food as well as environmentally friendly farming practices. Current agricultural and environmental policies are reacting to these demands with initiatives limiting the use of synthetic pesticides and thus promoting organic farming. In viticulture, 316,000 hectares of grapes are grown organically, which is a 4.5 % share of the global grape growing area. The effects of organic and biodynamic viticulture on soil quality and soil microbial diversity in comparison to conventional or integrated viticulture are very controversially discussed. The aim of this review is to summarize the outcomes of scientific trials performed on organic and biodynamic viticulture worldwide and hence to characterize the effects of the respective management systems on soil properties and soil microbial diversity.

Material and methods - Literature searches of peer-reviewed published literature were conducted to find studies investigating organic and/or biodynamic viticulture which deal with soil properties and biodiversity of the soil microbiota. Only field trials that used replicates of management treatments with representative plots or studies that used a representative number of samples were included in the review in order to avoid bias in individual studies.

Results – For describing the effect of organic and biodynamic viticulture on soil quality and microbial soil life, authors concentrated on reporting the effects of the respective management systems on biological activity of the soil, macronutrient supply, copper levels in the soil and soil microbial diversity. In several studies an increase of the biological activity of the soil under organic management is reported. Biodynamic and organic vineyards show a higher cumulative soil respiration, a higher content of microbial biomass C and a higher ratio of microbial biomass C to organic C, especially after conversion. The contents of organic C, total N, P and S as well as Cu do not differ among treatments in most of the trials. Fungal endophyte colonization of the roots of grapevines under organic management, species richness, diversity indices and arbuscular mycorrhizal spore abundance were higher compared to conventional management. No difference in fungal species richness was assessed in soils of biodynamically and conventionally managed vineyards in New Zealand. In contrast, management systems differed in the types of species present and in the abundance of the single species. These results are supported by a recent study from Germany, where a fungal community shift under organic viticulture was observed without affecting fungal species richness. Bacterial biodiversity was increased in topsoil under organic management compared to conventional viticulture. The links between soil microbial diversity, biological activity of the soil and macronutrient supply will be discussed. Their importance for organic and biodynamic viticulture will be discussed.

Keywords: Grapevine, biological activity of the soil, macronutrients, copper, soil microbiota.

1. Introduction

Preservation and improvement of soil fertility without any synthetic nitrogen fertilizers is a key principle of organic farming. In the context of global warming and desertification the conservation and improvement of soil quality as well as the preservation of soil microbial diversity must be a primary goal of agriculture and viticulture today, since it provides one pre-requisite for future agriculture and viticulture. The production of organically grown crops developed exponentially in the last few decades based on consumer demands for crops derived from environmentally friendly farming practices (Yiridoe et al. 2005). Current agricultural and environmental policies are reacting to these demands with initiatives limiting the use of synthetic pesticides and thus promoting organic farming (Vidal and Kelly

2013; Wysling 2015; Kucera 2017). The controversial debate on the ban of glyphosate in the EU has lately put even more pressure on herbicide usage (Neslen 2017).
In viticulture, 316,000 hectares of grapes are grown organically, which is a share of 4,5% of the global grape growing area. Most of this organic grape growing area is located in Europe (266,000 hectares). The three countries with the largest organic grape growing area are Spain, Italy and France (Lernoud and Willer 2016).
Food and Agriculture Organization (FAO) defines organic farming as follows: "Organic agriculture is a holistic production management system which promotes and enhances agro-ecosystem health, including biodiversity, biological cycles, and soil biological activity. It emphasizes the use of management practices in preference to the use of off-farm inputs […]. This is accomplished by using, where possible, agronomic, biological, and mechanical methods, as opposed to using synthetic materials, to fulfill any specific function within the system" (Fao 1999). In the European Union (EU) several regulations exist to control organic farming (Regulation (EC) No 834/07 and Regulation (EC) No 889/08). In Appendix II of the latter there is a list of substances allowed in organic farming and thus organic viticulture. Any unlisted substance is forbidden. Furthermore there is a regulation outlining detailed rules on organic winemaking in the EU (Regulation (EU) No 203/12). There are also specific national rules and several organic or biodynamic associations which impose stricter rules than the ones outlined in the EU regulations mentioned above.
The aim of this review is to summarize the outcomes of scientific trials performed on organic and biodynamic viticulture worldwide and hence to characterize the effects of the respective management systems on soil quality and soil microbial diversity. Furthermore, results from the long-term field trial in Geisenheim, Germany, running since 2006, will be put into the context of the available literature on organic and biodynamic viticulture. This review addresses the question of whether conventionally, organically and biodynamically managed vineyards differ in regards to soil properties.

2. Material and methods

Only field trials that used replicates of management treatments with representative plots or studies that used a representative number of samples were included in the review in order to avoid bias in individual studies. Data from non-peer-reviewed sources such as conference proceedings, master theses or doctoral dissertations were also included into this study if they met the criteria mentioned above. In Australia a long-term trial was conducted between 2009 and 2014 whose results were partially published as Honours and Master theses and results were included. Furthermore, unpublished data from a long-term trial in Germany were provided by the authors and were included in this review (Döring et al. 2019).

3. Results and discussion

3.1 Soil quality

Soil quality comprises a wide range of parameters and is difficult to be fully defined. Nutrient supply and soil biological activity are two very important constituents for soil quality and serve as measures for soil quality. The Cu content of soils under organic and conventional management is another important parameter for soil quality, since high Cu contents may have an impact on total carbon, enzyme activities and soil biodiversity, especially on earthworm abundance in the soil.

Physical and chemical soil properties - The most important source of nitrogen as well as other nutrients in organic farming is the use of compost. It supplies the soil with organic nitrogen which has to be converted into inorganic nitrogen compounds to be taken up by the plants (Kauer 1994; Vogt 2007). Therefore the stimulation of soil nutrient cycling is a primary goal of organic farming and of organic viticulture. It is a prerequisite for nutrient supply when synthetic fertilizers are not used. Other key principles of soil management in organic viticulture are the implementation of cover crop mixtures with a wide range of species including legumes and denial of herbicides and mineral fertilizers, as mentioned (Regulation (EC) No 834/07 and 889/08).
The contents of total N, P, K and S do not differ among conventional, organic and biodynamic viticulture (Wheeler 2006, Probst et al. 2008, Collins et al. 2015). In contrast, P contents in the soil rapidly decreased after conversion in a long-term field trial in Southern France. After seven years of conversion a gradual increase of available P contents under organic management was observed (Coll et al. 2011). In the same trial potassium content was increased under organic viticulture. One reason for the increased

contents of P and K in the soil under organic viticulture after conversion could be the increased microbial activity and the increased microbial biomass, since microorganisms were shown to release organic acids which can increase the availability of P and K (Coll et al. 2011). In a trial in Croatia plant available P content was higher for conventional in comparison to organic management showing that results concerning chemical soil properties are not consistent (Radić et al. 2014).

Mineralized nitrogen content in the topsoil layer did not differ among organic, biodynamic and integrated viticulture in a field trial in Germany in the first three years of conversion (Meißner 2015). In the same trial mineralized nitrogen content in the topsoil layer was reported to increase under organic and biodynamic management after four years of conversion (Döring et al. 2015). One possible reason for this might be that stimulation of soil nutrient cycling by compost application, the implementation of cover crop mixtures with a wide range of species including legumes and denial of mineral fertilizers, as practiced in organic and biodynamic viticulture, takes some years to make an impact on microbial activity in the soil and thus on nitrogen levels. This again is in accordance with other findings concerning total N and soil microbial properties under organic management. After 10 years of conversion to organic viticulture total N content increased under organic management in a long-term trial in Southern France (Coll et al. 2011).

Soil quality traits such as microbial efficiency and mineralized nitrogen content in the soil did not differ between organic and biodynamic treatments (Reeve et al. 2005; Döring et al. 2015; Meißner 2015).

Coppercontent - Copper products are among the oldest plant protection agents. Still today they represent an important part of the plant protection strategy against downy mildew (caused by *Plasmopara viticola*) in organic viticulture. However, Cu is accumulated in the soil and high Cu content in vineyard soils is mainly due to anthropogenic inputs in the past decades (Probst et al. 2008; Strumpf et al. 2009). Copper inputs from 1890 to 1940 were up to 50 kg/ha/year in viticulture (Strumpf et al. 2011). In long established vineyards with long-term Cu application, Cu levels in the soil are higher compared to areas where viticulture was developed within the last three to five decades (Strumpf et al. 2009). There is no direct correlation between Cu content in the soil and its plant availability (Steindl et al. 2011) However, mobility of CU is sensitive to pH of the soil (Temminghoff et al. 1997). Furthermore, Cu content in grapes is low even if Cu content in the soil is high (Strumpf et al. 2009). Copper levels in viticultural soils have impact on total carbon, enzyme activities and biodiversity, especially on earthworm abundance in the soil (Paoletti et al. 1998; Mackie et al. 2013). Although amounts of Cu used for plant protection in organic viticulture today are higher compared to the amounts usually used in conventional viticulture, organically managed vineyard soils in France, Croatia and Germany did not have a higher Cu content compared to their conventional counterparts (Probst et al. 2008; Coll et al. 2011; Strumpf et al. 2011; Radić et al. 2014). Beni and Rossi (2009), in contrast, observed higher total Cu contents under organic farming after nine years of conversion in Italy. In another Italian study on organic viticulture Cu amounts in soils, on berries and in wines were below the maximum residue levels (Provenzano et al. 2010). Since vineyard soils under conventional, organic or biodynamic management did not show differences in Cu levels in most of the studies, there were no negative implications for earthworms in the soil according to Strumpf et al. (2011).

Biological activity of the soil – As mentioned above, the biological activity of the soil is crucial in organic viticulture for nutrient supply. Preservation of soil biological activity leading to enhanced soil fertility is one major goal of organic farming.

The biological activity of the soil and the feeding activity of soil organisms are reported to increase under organic and biodynamic viticulture in comparison to conventional management (Gehlen et al. 1988; Reinecke et al. 2008; Okur et al. 2009; Freitas et al. 2011). The contents of soil organic C does not differ among treatments (Wheeler 2006; Probst et al. 2008; Collins et al. 2015). In contrast, Okur et al. (2009) report an increase of soil organic C under organic management. In this trial farmyard manure of N equivalents of 450 kg N ha^{-1} was applied every two years leading to an increase of soil organic C. Coll et al. (2011) observe an increase of soil organic matter under organic viticulture, although no detailed information about the management of the single plots is given. Biodynamic and organic vineyards show a higher cumulative soil respiration, a higher content of microbial biomass C and a higher ratio of microbial biomass C to organic C, especially after conversion (Gehlen et al. 1988; Probst et al. 2008; Okur et al. 2009; Coll et al. 2011; Freitas et al. 2011; Collins et al. 2015). In addition, organic and biodynamic treatments show a lower metabolic quotient for CO_2 (qCO_2 values) (Probst et al. 2008; Freitas et al. 2011). Low qCO_2 levels indicate high microbial substrate-use efficiency (Probst et al. 2008).

This is in accordance with the results of Mäder et al. (2002) who showed that higher microbial substrate-use efficiency in combination with a higher availability of soil organic matter to soil microorganisms are a characteristic result of organic farming. The positive effects of organic and biodynamic vineyard management on soil microbial properties are reported to increase together with the time-span since conversion (Probst et al. 2008; Coll et al. 2011). Yet indicators of microbial activity in the soil are strongly dependent on the vineyard location and its management.
Enzyme activity was higher in organic compared to conventional plots including protease, alkaline phosphatase, urease and dehydrogenase activities (Okur et al. 2009). In the long-term trial comparing integrated, organic and biodynamic viticulture in Geisenheim, Germany, soil emzymatic activities were analysed 10 years after conversion. Results revealed that β-glucosidase, dehydrogenase and catalase activity was significantly higher in organic and biodynamic plots, whereas phosphatase and urease activities were not influenced by the management system. Soil enzymatic indices (Al3 and BIF) were significantly higher under organic and biodynamic management (Di Giacinto et al. *in prep*.).

3.2 Soil microbial diversity
Abundance of arbuscular mycorrhizal fungi is one widely used biological soil indicator. It increased under organic management in two different environments (Freitas et al. 2011; Radić et al. 2014). In contrast, arbuscular mycorrhizal fungi indicator (NLFA 16:1ω5) was lower under organic and biodynamic viticulture 10 years after conversion (Di Giacinto et al. *in prep*.). Fungal endophyte colonization of the roots of grapevines and associated weeds under organic management, species richness, and arbuscular mycorrhizal spore abundance were higher compared to conventional management. Fungal endophyte diversity indices were higher for organically managed vineyards (Radić et al. 2014). In soils of biodynamically and conventionally managed vineyards in New Zealand no difference in fungal species richness was assessed (Morrison-Whittle et al. 2017). In contrast, the management system had a strong effect on the types of species present and on the abundance of the single species. These results are supported by Hendgen et al. (2018), who recently observed a fungal community shift under organic viticulture in the topsoil layer without affecting fungal species richness in a long-term field trial in Geisenheim, Germany. Bacterial biodiversity was increased in topsoil under organic management compared to conventional viticulture (Hendgen et al. 2018).

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