Give life to your soil

Miriam Zady
Zadco For Quality Gro Pty Ltd
Seven Hills, New South Wales
miriam@zadco.com.au

Introduction

Good vineyard management begins with the soil. There is a major push for growers to maintain sustainability in their vineyards through increasing biodiversity of their soils because soil biology is what orchestrates the nutrient cycles within the soil profile to ensure long-term viability of soil that can be repetitively and productively cropped. Sustainable production depends on establishing soil conditions that maximise nutrient cycling, taking advantage of biological processes that reduce the need for some chemical inputs and enhance soil biological fertility.

In grapevine management, the direct application of mulch, compost and manure around the roots of vines, in particular young vines, during planting is not recommended. This is because these applications may be susceptible to water logging, thereby causing root or collar rots.

This article aims to look at the importance of beneficial micro-organisms as essential and integral components of soil productivity by concentrating on their functions in the soil matrix. Enhancing the natural populations of soil organisms in vineyard soil management can aid in the growth and establishment of young vines, as well as improve soil health and sustainability.

Soil health

Soil health is defined as the capacity of soil to function, although different uses of the term may place differing priorities upon the multiple functions of a soil.

Functions of soil include[1]: sustaining biological productivity; regulating water flow; storing and cycling nutrients; and filtering, buffering and transforming organic and inorganic materials. Soil also functions as a habitat and genetic reserve for numerous organisms. Consequently, management strategies that optimise multiple soil functions have a greater potential for improving soil health over management strategies that focus on a single function[1].

The existence of soil micro-organisms

Soil is a very complex and dynamic medium (1 gram of soil may contain 10 billion micro-organisms and thousands of species, making soil the most biologically diverse ecosystem on Earth[2]). Soil organisms' activity is concentrated in the top 5 to 8 centimetres of soil, where millions of organisms exist but only a fraction have been identified; for example, 5% of fungi, 3% of nematodes and only 5000 of the more than a million species of bacteria, of which 80-90% of soil biological activity is carried out by bacteria and fungi[3].

Many growers question the need of soil amendments containing fungi or bacteria when these micro-organisms already exist in their billions to act out the different stages of the cycle of life in the soil. In natural and properly managed soils, a complex food web exists resulting in balanced 'predator-prey' relationships[3]. Agricultural practices can be both beneficial and detrimental to soil organisms. Likewise, soil organisms can increase or reduce agricultural production. It is important to note, however, that the ubiquity of certain micro-organisms does not necessarily mean that the beneficials or the 'good guys' population numbers outweigh the 'bad guys', or are in high enough numbers to successfully carry out their specific roles.

Manipulating the balance and tipping the scale in favour of beneficials in general and increasing numbers against (for example, potential pathogenic micro-organisms) can be very beneficial to soil and plant health – the benefits of which are outlined in the various processes that micro-organisms undertake with the ultimate goal of producing organic matter (OM) and carbon content in soil.

The importance of soil micro-organisms

There is a two-way relationship between soil organisms and agricultural production. Plant exudates (carbons expelled from the roots of live plants) and plant residues provide sources of energy and nutrients for the organisms, which in turn decompose OM, improve nutrient availability and soil structure, transmit and prevent disease and degrade pollutants[3]. Therefore, a soil lacking microbial activity can be considered a dead soil, as these functions would not be able to be carried out. For example, if one was to apply OM to a crop and the soil is void of microbes, there is nothing there to aid in the decomposition and uptake of the nutrients.

The activity of soil organisms can be divided into five functions[3]:

- organic matter decomposition and nutrient cycling
- interaction with plants effecting both health and production
- maintenance of soil structure
- biological degradation
- disease transmission and management.

Components of soil organic matter and their funtions

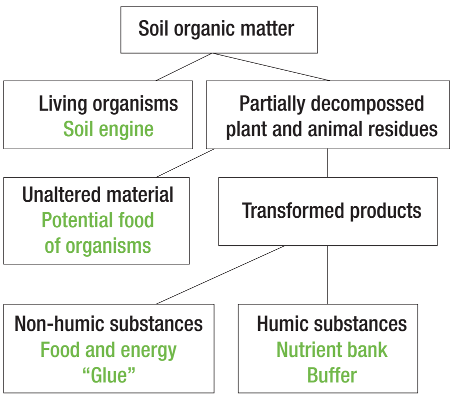

Figure 1. Components of soil organic matter and their functions (green)[4].

Organic matter decomposition

Decomposition makes carbon available – a core element of OM and a vital energy source for soil organisms and plants. The population of micro-organisms is the driving engine for OM decomposition and nutrient release (Figure 1). Soils with high levels of OM support a greater number and a more diverse range of micro-organisms[4]. Albrecht (1938) described organic matter as the "life of the soil" as it is the activity of micro-organisms that makes nutrients available for a new generation of plants[5].

Fresh OM, for example manure or mulch, has a much higher carbon-to-nitrogen ratio. In relation to microbial activity, a higher ratio of fuel (carbon) to building material (nitrogen) means the OM decomposes very slowly. If the ratio is less wide between the C:N, decomposition may be more actively carried on. The carbon will then be rapidly used up as fuel while the nitrogen is held without considerable loss[5]. Increasing the numbers of micro-organisms therefore can be a more active way of increasing OM in one's soil. Figure 2 depicts the process of the carbon cycle and the fundamental role of micro-organisms in completing the process.

Nutrient cycling and transformation

The key to soil fertility is mineralisation – the conversion of OM by soil organisms to available nutrients for uptake. While decomposing OM to obtain carbon, micro-organisms release other nutrients into the soil and air. These may be: soluble and leached (e.g. nitrate), volatile and lost to the atmosphere (e.g. nitrogen [2]), or readily available to the plant (e.g. nitrates, phosphates and sulphates).

Interaction with plants

In order to increase the uptake of a specific nutrient, many plants form mutual relationships (symbioses) with soil micro-organisms. Examples of symbiotic relationships include: legumes with the *Rhizobium* bacteria species to fix atmospheric nitrogen gas, and mycorrhizal fungi that form a symbiotic relationship with most plants to absorb water, nitrogen, phosphorus and other nutrients from the soil. Baumgartner *et al.* (2005) mentioned that "over 95% of crops not only respond positively to colonisation by mycorrhizal fungi, but they may suffer in the absence of mycorrhizae".

The importance of mycorrhizal fungi

These fungi have the ability to penetrate roots, spread into soil, form symbiotic relationships and provide the following benefits:

- Increase the surface area and act as an extended root system to draw resources from.

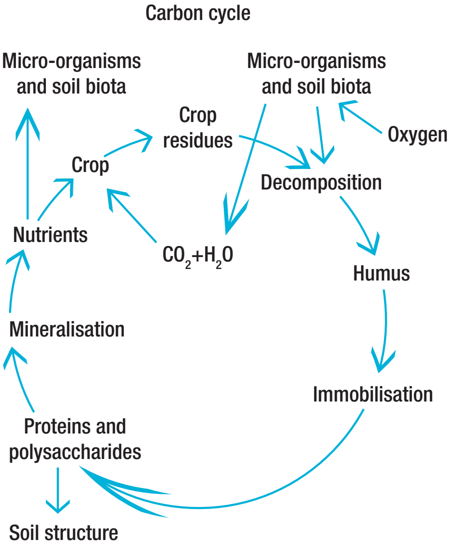

Figure 2. Carbon cycle in soil[4].

- Increase absorption and translocation of essential plant nutrients including P, Ca, Cu, S and Zn.
- Increase tolerance of drought, high salinity and heavy metal conditions.
- Increase growth and vigor.
- Provide greater root retention.
- Provide a physical barrier against root pathogens and nematodes (Figure 3). *Glomus mosseae* and *Glomus intraradices* are particularly effective in preventing *Fusarium*, *Pythium* and *Phytophthora* infections[17].
- Improve aggregation of soil particles, therefore improve soil structure (Figure 4).
- Important application for new plantings and establishment of vines.

A study by Cheng and Baumgartner (2006) suggested that although grapevine roots play a dominant role in the uptake of nutrients from a decomposing cover crop, arbuscular mycorrhizal (AM) hyphae may have a more important role in maintaining soil microbial communities associated with nutrient cycling. The results also display that grapevines in the mycorrhizosphere treatment had the highest nitrogen concentrations, therefore highlighting the importance of a healthy grapevine root system in nutrient uptake[8].

Grapevines have much coarser root systems than annual crops and so are more likely to benefit from a symbiotic relationship with AM fungi[9,10]. Vine roots, in common with roots in general, exude chemical compounds that increase host susceptibility to colonisation by AM fungi. Production of such exudates varies according to the time of the season and to the host's growth stage. Consequently, grapevines vary in terms of their ability to attract specific AM fungal species with season and growth stage. Single plants may host a number of AM fungal species at the same time[11].

Baumgartner (2006) found that AM fungi are important to grapevine nutrition, particularly in marginal soils. Covercrop management strategies can increase the likelihood of fungal colonisation of grapevine roots and can facilitate transfer and uptake of nutrients from covercrops to grapevines. Vineyard management strategies that encourage root growth (such as planting vines in soil with adequate texture and structure, and irrigating vines during periods of rapid root growth) benefit grapevine roots and mycorrhizal fungi[12]. These practices described by the study will likely have greater effects on grapevine nutrition than practices that focus solely on enhancing populations of mycorrhizal fungi, such as the application of fungal inoculants to vineyard soil[12].

Improvement of soil structure

Soil structure and soil micro-organisms

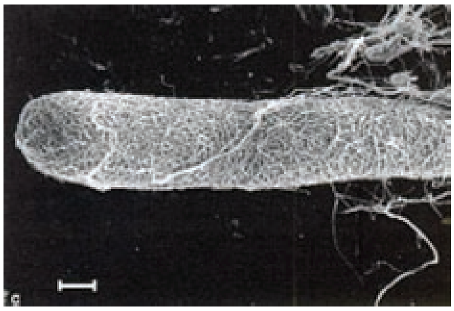

Figure 3. Mycorrhizal hyphae form a compact mantle that covers the root acting as a physical barrier to potential pathogens.

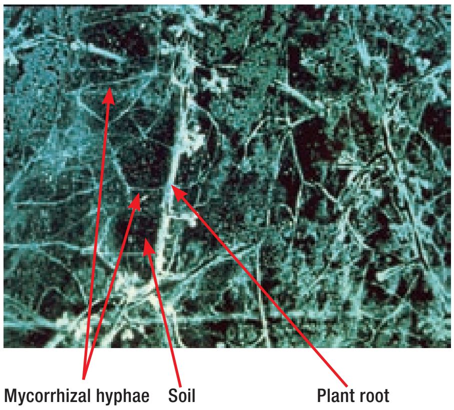

Figure 4. Mycorrhizal hyphae networked in an intricate web holding the soil aggregates together while acting as an extended root system[18].

are interdependent[3]. The mucus coverings of soil micro-organisms mix with the soil and help stick the particles together, forming soil aggregates, which in turn provides a better living environment for roots and soil organisms. Soil-borne fungi not only add mucus, but the vast network of thread-like hyphae hold the soil particles together, improving stability[3]. Larger organisms (e.g. earthworms) move through the soil, improving the structure by mixing and aerating and increasing water infiltration.

The composition and breakdown rate of OM by micro-organisms also influences the water-holding capacity of soils[3].

Biological degradation

Soil organisms act as biological filters by degrading soil pollutants[3]. Many agrochemicals are broken down by soil micro-organisms, however, their effectiveness will be modified by the soil environment. Toxic elements (e.g. mercury) can be 'locked' in the soil by microbial activity, preventing further pollution[4].

Disease management

The degree of root damage by pathogenic micro-organisms generally relates to the number and type of disease pathogens present, which in turn will be directly related to the presence or absence of a well-balanced soil web. There are many studies in grapevines, such as Chen (2007), which show the use of beneficial fungi and bacteria inoculations in an integrated pest management (IPM) program, i.e. biological control of disease.

Disease suppression and prevention

Living plants provide soil micro-organisms with a readily available source of carbon and nutrients called exudates. Approximately 20-35% of all carbon energy or exudates (simple sugars produced by photosynthesis) are pushed out of the roots into the soil to attract bacteria and fungi that will protect the plants from pathogens. This is a natural condition which can be disrupted by excessive chemical applications, often resulting in pathogenic species becoming dominant[3,4].

Soils with high levels of OM and organism activity, or a specific group of antagonistic micro-organisms, seem to prevent more aggressive pathogens from taking hold. These soils are termed suppressive soils[4]. Suppressive soils are thought to be the result of predator-prey relationships[4].

Microbes which inhabit the plant *Rhizosphere* are important contributors to plant disease status and general soil disease 'suppressiveness', reducing the effect of many soil-borne diseases[13]. Disease control by *Rhizosphere* microbial communities has also been shown to extend to systemic and foliar diseases through the activation of the plant's chemical or physical defence mechanisms[14]. *Rhizosphere* and bulk soil microbial communities with high diversity are more likely to have a larger number of candidates with the ability to compete with pathogens[15].

Conclusion

Micro-organisms play a crucial role in soil biological, chemical and physical processes. The addition of beneficial micro-organisms such as beneficial bacteria and fungi (e.g. mycorrhizal fungi) not only assist in maintaining soil health and therefore plant health, but are necessary to maintain the dynamic and complex soil cycles being carried out at a more efficient rate for providing a better soil environment rich in nutrients, organic matter, soil stability, fertility and structure, and general soil health for continuous and sustainable production. Through these processes, micro-organisms provide the following benefits:

- Micro-organisms digest agricultural residues that have built up in the soil.
- Micro-organisms help move the pH toward neutral, whether the soil is acidic or alkaline.
- Micro-organisms improve cation exchange for better movement of nutrients in the *Rhizosphere*.
- Micro-organisms help improve biological control of soil-borne pathogens through differing modes of action: competition, antagonism or parasitism; inhibition factors, e.g. secretion of antibiotics and/or plant-induced resistance.
- Micro-organisms reduce fertiliser input requirements.
- Micro-organisms increase seed germination and/or increase root retention and increase root network to source nutrients and/or act as extensive root systems for the plant in a symbiotic relationship, e.g. mycorrhizal fungi.
- Micro-organisms aid in improving the physical properties of the soil such as increasing aeration, drainage, cation-exchange capacity (CEC), and increased organic matter, and therefore increased carbon.
- Micro-organisms aid in carrying out the biological, chemical and physical properties of the soil.

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