CONSERVATION AGRICULTURAL PRACTICES

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Conventional management of agroecosystems has often reduced soil quality and altered soil processes involved in the provision of multiple ecosystem services. The combination of intensive tillage and high nitrogen (N) fertilization has increased soil organic carbon (SOC) mineralization, thus mining yield potential and exacerbating the contribution of agricultural soils to the increase of Greenhouse Gases (GHGs) concentration in the atmosphere (UNEP, 2017). To further complicate matters, high pressure mounted on agriculture in recent years to be able to support the world population growth with appropriate food supply (FAO, 2018).

The crucial link between agricultural growth and the Sustainable Development Goals (SDGs) set by the United Nations Development Program is established through the appropriate use of soil and fertilizers. At the same time, the European Commission (2020) recently set ambitious goals for reducing fertilizer use significantly (-20%) at the field level by 2030. Above all, excess of N fertilization (especially if mismatched with plant needs) often leads to high N losses in surface- and ground-water bodies via N leaching and runoff, as well as in the atmosphere via GHGs emission. Therefore, introducing smart and sustainable tools for building resilience of agro-ecosystems is a major need for ensuring an efficient use of agricultural inputs and supporting productivity, while facing the challenge of climate change at the same time.

A recent EU report (European Commission, 2016) stated various strategies to improve C and N cycling at agricultural level. Crop rotation, reduced soil disturbance (i.e. no-till, reduced tillage), and permanent soil cover (i.e. cover cropping, crop residue management) have been widely indicated as recommended agricultural practices to pursue sustainable intensification of agro-ecosystems (FAO, 2013). Considering important variability, transition phases, and system trade-offs, the concomitant adoption of these three main pillars was repeatedly reported to make agroecosystems enable to (i) directly increase the CO_2 binding effect of soil, and (ii) positively affect soil processes to stimulate internal C and N cycling, including the mitigation of GHGs emission.

It has been known that crop rotation has a series of main agronomic advantages, including the improvement of soil fertility and biodiversity, the control of pests and weeds, as well as the enhancement of crop yield and resilience of agroecosystems (Tabaglio *et al*., 2015). Then, reducing soil disturbance may highly reduce soil oxygen exposure, and consequently keep SOC mineralization and losses under control, thus boosting ultimately soil fertility and soil C sequestration potential (Fiorini *et al.*, 2020a). For their part, cover crops during growth may provide a series of agro-ecological functions, such as re-cycling of nutrients (Maris *et al.*, 2021). For instance, the concomitant adoption of no-till and rye (*Secale cereale* L.) as cover crop was shown to sustain yield performance of main crops, while enhancing soil quality parameters, and keeping nitrous oxide emissions under control (Fiorini *et al*. 2020b). Other positive effects are remediation of soil compaction or either the provision of additional N input through biological fixation. After termination, residues of cover and cash crops left onto the soil surface increase the rate of biomass input to the soil, thus promoting soil organic matter accumulation (Fiorini *et al.*, 2020c). Alongside, certain species of allelopathic cover crops are promising tools for controlling sustainably weed development, while reducing herbicide use in the light of the “Farm to Fork” strategy (Tabaglio *et al*., 2008; Schulz *et al*., 2013). In addition, cover crop roots act as “bio-drillers” improving soil structure (Fiorini *et al*., 2018), and indirectly provide pabulum for the entire biotic community in soil (Tabaglio *et al*., 2009). Last but not least, the combined (and continuous) application of these agricultural practices generally increases the water retention (during dry periods) and water infiltration (during wet periods) capacity of soil (Boselli *et al*., 2020), which allows to better matching plant requirements and could be considered as a major feature for adaptation of agro-ecosystems to the climate change.

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BIOMASSES & BIOSTIMULANTS

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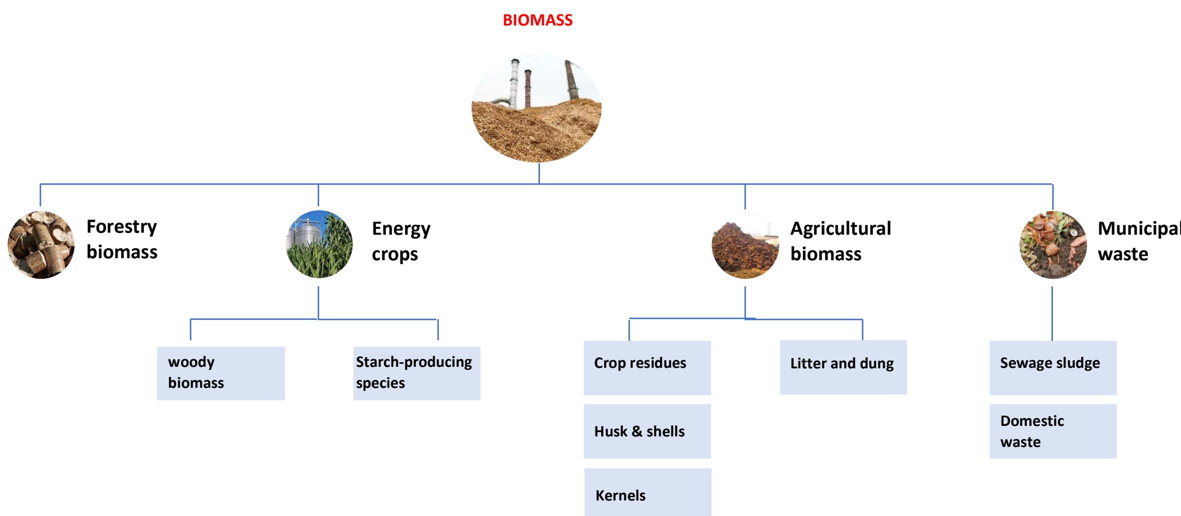
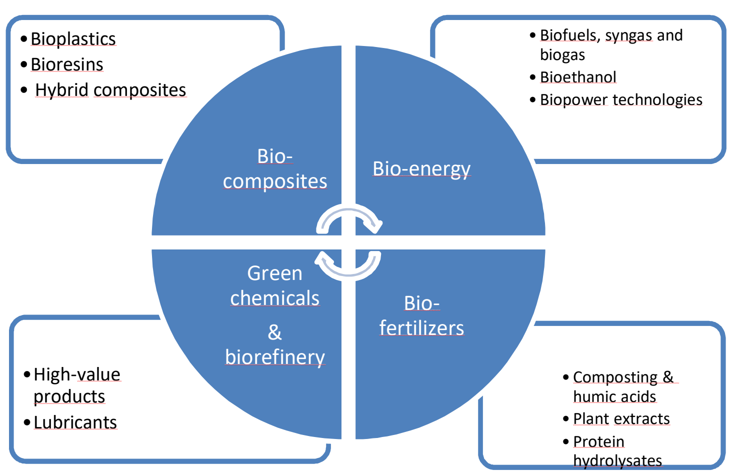
Under the term biomasses we include a set of diverse materials, differing for origin and therefore also for their composition. The Directive 2009/28/EC classified them as "the biodegradable fraction of products, waste and residues from biological origin from agriculture (including vegetal and animal substances), forestry and related industries including fisheries and aquaculture, as well as the biodegradable fraction of industrial and municipal waste".



This organic, non-fossil material of biological origin can find applications in producing energy (heat or electricity), as feedstock, rather than as a source of valuable ingredients under a bioeconomy framework. Among agricultural biomasses, cereals, fodder crops and oil-bearing crops typically provide the largest amounts of biomasses. Biomass is usually measured in units of energy (e.g., gram calories or kJ per square metre per year), or weight (e.g., tons of carbon per square km per year). A summary of the possible applications related to biomasses is provided as follows:



Among others, the direct application in agriculture as bio-fertilizers is emerging as an interesting alternative to bio-energy and biorefinery solutions, because it represents a way to recycle carbon in agriculture that may provide important benefits in terms of resilience to climate change detrimental effects. Indeed, plant biostimulants are emerging fast as an interesting class of agricultural products arising from biomasses. These products, recently regulated by EU in the Regulation 2019/1009, are natural products that can improve plant's nutrient use efficiency or access to confined nutrients, resistance to abiotic stresses and/or improve quality of the produce. Interestingly, the most used biostimulants are humic acids from biomass decomposition, protein hydrolysates and seaweed extracts, thus circularly arising from biomasses. These products are in the spotlight because they can improve crops yield under non-favourable conditions such as soils with low fertility, saline soils, low-inputs agriculture, and in general under abiotic stress conditions (including climate change related stresses such as drought, high temperature or flooding). Therefore, the inclusion of biostimulants in agriculture may represent a valuable solution to increase sustainability without compromising the yields.

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BENEFICIAL MICROORGANISMS

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Microorganisms are permeating and governing any ecological and biological process on Earth, and this is particularly relevant for the sustainability of agriculture. Soils beneath our feet host the biggest biodiversity on Earth: recent estimations indicate that a single gram of soil can contain more microbial cells than humans on Earth (>10 bilion) belonging to more than 100,000 different species. This immense diversity was shaped and selected by millions of years of evolution and serves a plethora of roles. As outlined in Figure 1, most of the functions of an healthy soil are depending by microbial presence and activity: these include the recycling of nutrients, the physical and chemical quality of soils, the emission and the mitigation of greenhouse gases.

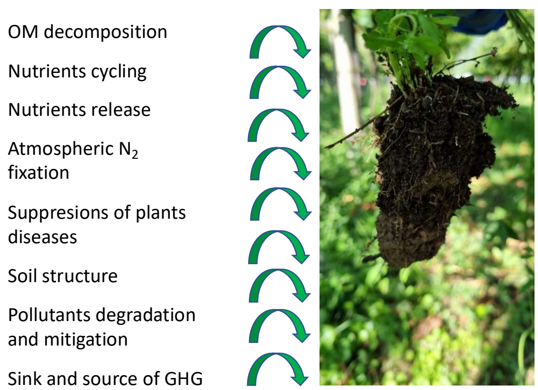

Figure 1. Soil fertility and quality processes depending on direct or indirect microbial activity

Such system was overlooked for a long time, also because of its complexity: traditional intensive agriculture has considered soils as inherent substrates that can support plants growth and health if adequately provided with increasing amounts of chemical fertilizers and pesticides. This paradigm has now become obsolete: soil scientists know very well that a sustainable integrated agriculture should rely on a correct management of microbial structure and functions.

How can we do this? Do we know enough of soil microbiology to govern these processes? The answer is mostly yes, and benefits also from knowledge on microbial processes gained in the last years in other disciplines, especially Medicine. Our health state is indeed also strongly correlated to the billions of microbial cells that live in symbiosis with us, especially in the intestine. In the last years we have in fact learned to select and apply beneficial microorganisms (the so-called "probiotics") that contribute to our state of health, as well as useful nutrients ("prebiotics") that positively modulate the microbial communities that live in symbiosis with us.

This paradigm and approach can now be translated and applied to agricultural sustainability: we are now indeed able to isolate, select and apply beneficial microorganisms, soil probiotics that stimulate plant growth and protect them from abiotic stresses and attacks from fungi and insects; similarly to prebiotics, we can add useful substances to the soil (primarily forms of organic matter) capable of supporting the number and abundance of beneficial microorganisms in the soil, as well as reducing greenhouse gas emissions.

While many processes through which microbes stimulate plant growth and defense are well-known (nutrients fixation and solubilization, inhibition and competition with pathogens, production of plant hormones), others are still poorly understood, and this pose intriguing research challenges. This is the case of induced systemic resistance (ISR), a process through which certain beneficial microorganisms (bacteria or fungi) elicit in the plant the activation of metabolic pathways related to plant defense, the most important being the production of jasmonic acid and ethylene. Even though several microbial ISR-elicitors have been proposed, the mode of action by which beneficial microorganisms initiate ISR is not fully understood.

These processes are already an industrial reality, and hold promising scenarios for Developing Countries: the exploitation of local biodiversity can indeed bring to the discovery of novel local beneficial microorganisms that can sustain local production while reducing the dependence on chemical fertilizers and pesticides. Novel technologies for local production and propagation of these microorganisms, also in synergy with local biomasses are also being developed.

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RESISTANT CROP VARIETIES

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Plant disease control has been strongly dependent from chemicals. According to the Directive 2009/128/CE on the sustainable use of pesticides, the use of plant protection products (PPPs) has to be limited (Rossi et al., 2012) through an integrated approach (Integrated Pest Management, IPM) where all the available plant protection methods and measures have to be combined in order to reduce or minimize risks to human health and the environment. Among these measures, the use of resistant plants is very promising, because their use is simple, inexpensive for farmers, compatible with other management options, and does not have negative environmental impacts. The use of resistant varieties is a component of an IPM strategy; their stand-alone use is associated with a high risk of erosion of the resistance because of the pathogen evolution. The strategic decision of growing resistant plants has consequences in the management actions. For instance, the plant material being less susceptible to disease, might enable some (temporal) leeway for decision.

Different studies have been performed so far for exploring the effect of plant resistance on the development of epidemics in several plant-pathogen systems. For instance, studies have been performed to assess quantitatively the extent to which partial resistance (a kind of plant-resistance providing durable resistance) on grapevines are able to control downy mildew (*Plasmopara viticola*), and to understand the mechanisms leading to that control from an epidemiological point of view. The efficiency of different resistance components (i.e. elementary processes in an infection cycle) in their contribution to the overall resistance has been measured through monocyclic experiments covering the time span of a single infection cycle (Bove et al., 2019; Bove & Rossi 2020). These components of partial resistance where then implemented in a simulation model (Fig. 1; Bove et al., 2020a) to simulate partial resistance on grapevine in different scenarios (Bove et al., 2020b) and to identify components of resistance that better predict field resistance in the grapevine - downy mildew pathosystem (Bove et al., 2021). The results of these works are being used to calibrate a model able to forecast the disease risk on grapevine, to take the best advantages of both plant resistance and forecasting modelling in an IPM approach, allowing preserving both yield production and quality in a sustainable way.

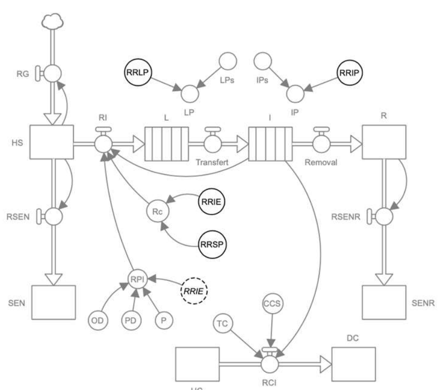

Fig 1: Simplified structure of an epidemiological model for grapevine downy mildew previously developed including the components of resistance on monocyclic processes: relative resistance for infection efficiency (RRIE), relative resistance for latency period (RRLP), relative resistance for infectious period (RRIP) and relative resistance for sporulation (RRSP). Boxes represent state variables, valves represent rates, and circles represent parameters

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