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Organic and Biodynamic Agriculture: A Review in Relation to Sustainability

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Authors' contributions

All authors contributed to design and perform the study, read and approved the final manuscript.

Review Article

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ABSTRACT

This paper focuses on organic and biodynamic farming systems - sectors growing rapidly in many countries - and particularly on their relationship with the concept of sustainability. Both technical packages promote and improve the health of the agro-ecosystems related to biodiversity, nutrient biocycles, soil microbial and biochemical activities. In addition to the common tools of organic agriculture, biodynamic agriculture uses specific manure and fermented herbal preparations as compost additives and field sprays. Organic farming and biodynamic agriculture have been regarded as having different provenances and having arisen independently, but the authors suggest to consider organic and biodynamic farming systems as a unique sustainable system driven by a common holistic approach.

Keywords: Biodynamic; organic farming; sustainable agriculture; soil biodiversity; soil quality.

1. INTRODUCTION

During the last decades, agricultural production and yields have been increasing in the industrialized countries along with global fertilizer and pesticide consumption. The growing global trade with agricultural products and the improved access to pesticides and fertilizers have changed agricultural systems. Easier transportation and communication have enabled farms to buy their inputs and sell their products further away and in larger quantities. These developments resulted in increased food security, whereas a greater variety of food has

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been offered and diets have changed towards a greater share of meat and dairy products. However, such trend has led to a growing disparity among agricultural systems and populations, where especially developing countries in Africa have seen very few improvements in food security and production. At the same time, the application of inappropriate farming techniques and the sharp increase of farming inputs use have contributed in more exposed sites to the rise of environmental problems such as drastic reduction in biodiversity, soil degradation, pollution of surface and groundwater with nitrates and pesticides and, to a less extent, global warming [1].

In the more industrialized countries, the growing concern from the consumer community and from part of the farmers on the negative environmental consequences of intensive agricultural activity, also coupled with the increased demand for healthy food, have both contributed to develop agricultural methods based on sustainable farming practices, chiefly targeted to preserve the natural resources while ensuring reliable food productivity. Organic and biodynamic agriculture represent some of the several approaches to sustainable agriculture, and many of the techniques used in such methods (e.g. inter-cropping, rotation of crops, minimum tillage, permaculture, mulching, integration of crops and livestock) are in fact practiced under various agricultural systems. What, however, makes organic and biodynamic agriculture unique, as regulated under various laws and certification programs is that: (i) almost all synthetic inputs are prohibited, (ii) genetically-modified organisms (GMOs) are banned and (iii) `soil building' crop rotations are mandatory [2].

2. ORGANIC AGRICULTURE

The term "organic agriculture" dates back to the beginning of the last century, and it was coined to underline the systemic vision that characterizes this new concept of agriculture. According to Besson [3], the original theory behind organic agriculture integrates ancient philosophy, agronomy and social thoughts on agriculture. The biology of the founders of the concept of organic agriculture in the last century, i.e. A. Howard, R. Steiner, H.P. Rusch, M. Fukuoka, stands between various philosophical and esoteric speculations, empirical observations and scientific approaches. According to the ancient philosophy, these authors are suggesting an imitation of nature based on a cyclic understanding: however, the human intrusion in nature, although a founding element of farming, remains hard for them to legitimate. Indeed the founders were anxious about the agricultural chemistry's consequences on ecology and society. Nevertheless, the holistic ethic of organic farming remains an innovating source for its contemporary development [3]. However, it should be noted that a "doing next-to-nothing" approach became in fashion in the 70s within the international organic movement and it is still followed today by some amateurs. In this exploitative approach, not only pesticides are avoided, sound farming practices that built the soil are also largely ignored. The results achieved on such farms are predictable, as yields are low and the quality is poor. These approaches became collectively known as *organic by neglect* and are quite far from the responsible farming models proposed by the founders of organic agriculture. It is unclear how many farmers actually chose to farm “by neglect” and advertise themselves as organic over the years. However, this extreme representation of organic agriculture was quickly taken up by critics who tried to characterize all of organic agriculture as soil depleting and unproductive. To counter this, current standards for certified organic production require an “organic plan” outlining the use of soil building activities and natural pest management [4].

Since its origin, several countries and a multitude of farmers associations and private certification organizations have defined organic agriculture and its operational field standards. In the past, differences among the standards were significant but the demand for consistency by multinational traders has led to great uniformity. The standards of organic agriculture are nowadays internationally adopted, largely unified, regulated and legally enforced by many nations. The International Federation of Organic Agriculture Movements (IFOAM), a non-governmental organization internationally networking and promoting organic agriculture since 1972, has established guidelines that have been widely adopted for organic production and processing by several national legislations (including the EU) [5].

It has to be underlined that the organic standards - as a very first case in the food sector - are subject to control and certification by third-party certification bodies which have in their turn to be internationally accredited in compliance with the ISO 65 (EN 45011) standard norms. The requirements for organically produced foods differ from those for other agricultural products since production and processing procedures are an intrinsic part of the identification, labeling of and claiming for the organic ones [6]. An organic label, obtained through the certification system, indicates to the consumer that a product was produced using certain production methods (Fig. 1). In other words, organic is a *process claim* rather than a product claim [2].

Fig. 1. The new European logo for organic products

IFOAM defines the overarching goal of organic farming as follows: "Organic agriculture is a production system that sustains the health of soils, ecosystems and people. It relies on ecological processes, biodiversity and cycles adapted to local conditions, rather than the use of inputs with adverse effects. Organic agriculture combines tradition, innovation and science to benefit the shared environment and promote fair relationships and a good quality of life for all involved". A more pragmatic definition is provided by the US National Organic Standards Board (NOSB) — the federal advisory panel created to advise the USDA on developing organic legislation (2004): “An ecological production management system that promotes and enhances biodiversity, biological cycles and soil biological activity. It is based on minimal use of off-farm inputs and on management practices that restore, maintain and enhance ecological harmony”.

The Codex Alimentarius, namely the food standards elaborated by the Food and Agriculture Organization of the United Nations and the World Health Organization in 1999 published the "Guidelines for the Production, Processing, Labeling and Marketing of Organically Produced

Foods". The "Guidelines", among others, stress the strong link that organic agriculture must have with the territory and the importance of recycling organic matter and nutrients, also providing a more comprehensive definition: "Organic agriculture is a holistic production management system which promotes and enhances agroecosystem 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, taking into account that regional conditions require locally adapted systems. This is accomplished by using possible cultural, biological and mechanical methods as opposed to using synthetic materials, to fulfill any specific function within the system.

An organic production system is designed to: a) enhance biological diversity within the whole system; b) increase soil biological activity; c) maintain long-term soil fertility; d) recycle wastes of plant and animal origin in order to return nutrients to the land, thus minimizing the use of non-renewable resources; e) rely on renewable resources in locally organized agricultural systems; f) promote the healthy use of soil, water and air as well as minimize all forms of pollution that may result from agricultural practices; g) handle agricultural products with emphasis on careful processing methods in order to maintain the organic integrity and vital qualities of the product at all stages; h) become established on any existing farm through a period of conversion, the appropriate length of which is determined by site-specific factors such as the history of the land and type of crops and livestock to be produced".

3. ORGANIC AGRICULTURE WORLDWIDE

As stated by Willer and Kilcher [7], agricultural land organically managed in the world had exceeded at the end of 2010 the area of 37 millions of hectares.

3.1 Europe

At the end of 2010, 10 million hectares in Europe were managed organically by more than 280,000 farms. In the European Union, 7.5 million hectares were under organic management, with almost 200,000 organic farms. 2.1 percent of the European agricultural area and 5.1 percent of the agricultural area in the European Union is organic. Twenty-seven percent of the world's organic land is in Europe. The countries with the largest organic agricultural area are Spain, Italy and Germany. In Italy there are 1.1 million hectares of organic and under conversion agricultural land. There are six countries now in Europe with more than 10 percent organic agricultural land: Liechtenstein, Austria, Estonia, Czech Republic, Switzerland and Sweden [7].

Support for organic farming in the European Union and neighboring countries includes grants under rural development programs, legal protection, and a European as well as several national action plans. One of the key instruments of the European Action Plan on organic food and farming, an information campaign, was launched during 2008, with the aim of increasing awareness of organic farming throughout the European Union.

3.2 North America

In North America, almost 2.2 million hectares are managed organically, representing approximately 0.6 percent of the total agricultural area and the 7 percent of the world's organic agricultural land. The major part of the organic land in the U.S. is regulated through the National Organic Programme (NOP) that was issued following the Organic Foods

Production Act (OFPA) passed by the Congress on 1990. Interestingly, as clearly stated by the USDA, neither NOP nor OFPA address food safety nor nutrition, rather they are deemed regulations to norm the marketing of organic products in USA.

The year 2009 was an important year for the organic sector in Canada: on June 30, 2009, the Canada Organic Regime was established. It includes mandatory national standards, consistent labeling rules and a new national logo [7].

3.3 Latin America

In Latin America, 270,000 producers managed 8.4 million hectares of agricultural land organically in 2010. This constitutes 23 percent of the world's organic land. The leading countries are Argentina, Brazil and Uruguay. The highest shares of organic agricultural land are in the Falkland Islands (37 percent), French Guiana, and the Dominican Republic. Most organic products from Latin American countries are sold on the European, North American or Japanese markets. Important crops are tropical fruits, grains and cereals, coffee, cocoa, sugar and meats. Eighteen countries have legislation on organic farming and three additional countries are currently developing organic regulations. The types of support in Latin American countries range from organic agriculture promotion programs to market access support by export agencies. In a few countries, limited financial support is being given to pay certification costs during the conversion period [7].

3.4 Asia

The total organic agricultural area in Asia was nearly 2.8 million hectares in 2010, which constitutes seven percent of the world's organic agricultural land. 500,000 producers were reported in India. The leading countries by area are China (1.4 million ha) and India (0.8 million ha). Organic wild collection areas play a major role in India and China, while aquaculture is important in China, Bangladesh and Thailand. Even though most of the production is for export, markets continue to support domestic growth in the region. Mixtures of regulatory frameworks co-exist in the region. Voluntary organic standards by government standard-setting bodies have been set in Laos, Malaysia, Nepal, Thailand, the United Arab Emirates, and Vietnam. Policy makers have begun to integrate organic agriculture into sustainable agriculture development initiatives; as the positive impacts of organic agriculture on local communities and economies, climate change and the carbon footprint of agriculture are increasingly recognized [7].

3.5 Africa

In Africa, there were slightly more than one million hectares of certified organic agricultural land in 2010, which represents about 3 percent of the world's organic agricultural land. 540,000 producers were reported. The countries with the most organic land are Uganda, Tunisia, and Ethiopia. The highest shares of organic land are in Sao Tome and Prince (7.9 percent), Tunisia (1.8 percent) and Sierra Leone (1.9 percent).

The majority of certified organic produce in Africa is destined for export markets. The European Union, as the major recipient of these exports, is Africa's largest market for agricultural produce. In 2011 significant achievements were reached: especially the African Union's (AU) decision to support organic farming and their subsequent leadership in promoting and further developing strategies for organic farming policies such as the African

Ecological Organic Agriculture Initiative and the IFOAM-African Union Conference that took place in November 2011 in Nairobi [7].

4. ORGANIC AGRICULTURE WITHIN THE SCIENTIFIC PARADIGM

According to Raviv [8], organic agriculture is still perceived by the majority of people as a simple "back to nature" trend, whereas it is not well known that it actually consists of a complex production process based on sound scientific principles and careful observation of natural phenomena occurring on the farm. In his review, Raviv stresses the need for organic agriculture to close the knowledge gap due to a period of 170 years of extensive research devoted to conventional agriculture: this gap is actually having a tremendous impact on the performance of organic agriculture as implemented in the various agro-ecosystems, which exposes it to critics by its opponents when some drawbacks arise (e.g. lower yields, higher management costs, higher agronomic complexity, need of further knowledge on control and certification issues, etc.). Nevertheless, over the last 20 years scientific research in organic agriculture has been gradually spreading in the industrialized countries as response to the growing demand from farmers, policy-makers and the increasing global market. Among the various typologies of experiments, the comparative long-term trials are particularly worthy to be mentioned because they offer the advantage of studying the effect over the time of the combination of various farming practices, as typically provided by the organic standards, on animal and crop production as well as environmental aspects (e.g. soil biology; biodiversity; water and soil pollution, etc.,). Raupp [9] reported about 25 running long term experiments in organic agriculture worldwide. These kinds of experiments allow study of farm performance in an agro-ecosystem perspective, consistently with the "organic" vision; in addition, the long-term approach permits observation of the evolution of certain phenomena (e.g. soil organic matter dynamics; pests population; etc.) that otherwise in short experiments would not significantly vary. On the other hand, such experiments present the limitation to be strictly site-specific thus not yielding outcomes to be applicable in diverse agro-ecosystems [10].

An interesting long term experiment is the "DOK trial", the oldest long term farming system comparison in Europe, carried out in Switzerland by the Research Institute of Organic Agriculture (FiBL): it has been comparing the effects of bio-dynamic (D), organic (O) and conventional (K) arable farming systems in a randomized plot experiment since 1978 [11]. Interesting to note, it was the farmer's idea to initiate the DOK trial: three groups of farmers participated actively in planning the management of the respective farming systems and many of them are still guiding the staff running the experiment. Today several research groups are working in the field of soil fertility, soil carbon transformation, soil-plant interface, crop yields and quality, etc. The results obtained so far show that although the yields of the organic-biodynamic systems have been systematically lower than the conventional ones over 28 years (on the average - 20%), the fertilizer input (total N, P, K) has been reduced by 35 to 40% in the organic systems. In addition, several soil fertility indicators showed more favorable values for the organic systems, pointing out the higher sustainability of the organic method basically based on organic fertilization and a 7 year crop rotation [11].

Another relevant long-term field experiment is being run by the Rodale Institute (USA) in collaboration with several universities and public and private research bodies: the Farming Systems Trial (FST) started in Pennsylvania (USA) in 1981. The FST compares three strategies, or 'systems,' for grain production: one conventional, one livestock-based organic and one legume-based organic. The conventional system follows a 5-year rotation typical of many farms across the Midwest, namely corn and soybeans. They receive fertilizer and pesticide applications according to the local standard recommendations. The livestock-based organic system follows a 5-year rotation of corn, soybeans, corn silage, wheat, red clover and alfalfa hay with aged cattle manure applied in the two corn years. The legume-based organic system is structured around a 3-year rotation of hairy vetch/corn, rye/soybeans and wheat. The two organic systems receive no chemical inputs for fertility, weed or pest control. As documented by Pimentel et al. [10], in year 2002 after 20 years of observations, it had emerged that: (i) average yields of corn and soybeans in the two organic systems were significantly lower with respect to the conventional ones, during the initial 5 years conversion period, but in following years yields were the same in all the three systems; (ii) in the drought years, grain yields of the organic systems were higher than the conventional ones; (iii) the level of soil carbon was significantly higher in the two organic systems: even if the aboveground biomass input of the conventional and the legume-based organic system was almost the same, the latter retained in the soil organic matter (SOM) a higher amount of the applied carbon. A significant correlation was observed between the increased soil carbon and the higher soil capacity to retain water in both the organic systems; (iv) nitrate leaching was almost the same in the three systems and peaked when mineral nitrogen fertilizer, and farmyard manure and green manuring were applied prior to sowing corn, in the conventional and the organic systems, respectively. It is emphasized by the author that any kind of heavy nitrogen input (either mineral or organic) is likely to leach in case the subsequent crop is not able to uptake it for some reason; (v) in general, weeds could be mechanically controlled in the organic systems, except for soybean that rather suffered from the competition.

The Raviv's review [8] on latest research outcomes obtained on organic horticulture gives emphasis to progress on several agro-environmental aspects:

1. Energy use efficiency in organic farms is usually higher because of the non use of mineral nitrogen [12], however in some cases the necessary mechanical weed control drastically decreases the output/input ratio, thus suggesting to dedicate more investigation to identify ways to optimize energy-efficient weed control measures [10,13].

2. Common organic agriculture practices such as crop rotation, minimum tillage, animal manuring and cover crops especially when applied at once have been shown to enhance soil fertility in terms of nutrients availability, soil organic matter accumulation, impulse to soil life (microflora and soil fauna), prevention of soil erosion and re-establishment of the top soil (if lost due to intensive farming) [14,15,16]. However, Raviv recommends assessing the actual extent of soil restoration by these practices with respect to the individual site, crop and season. More research is still needed to investigate short- and long-term availability of plant nutrients from organic and raw mineral fertilizers usually characterized by low solubility and scarcely predictable release rates. In fact, the application of high amounts of animal manure in certain soil types and season is likely to cause serious nutrient leaching and pollute the water table, however it has been demonstrated that through proper integration between crop and animal production, proper application of soil protection measures and careful organic matter recycling within the farm it is possible to conserve and minimize the losses of plant nutrients [17,18]. The optimization of use of various natural sources of nutrients - chiefly nitrogen - in diverse agro-ecosystems, like green manuring, inter cropping, symbiotic nitrogen fixation by legumes and soil organic matter decomposition is another very relevant topic to be addressed by targeted research.

3. The beneficial effect of organic agriculture on biodiversity has been demonstrated by many authors [19] consistently with the goal to replace the use of external inputs with

reinforced local ecosystem autonomy. Enhanced biodiversity in fact is a concrete tool to strengthen farm efficiency by enabling important ecological services as pollination, pest control and maintenance of soil fertility. However, as demonstrated by Scherber et al. [20], increased biodiversity in organic farms not always suffices to adequately control harmful pests, which forces the farmer to use organically-accepted pesticides that are likely to negatively affect the biodiversity. Further investigation is thus required to identify site-adapted strategies to suppress the pests in organic systems while keeping high the degree of on farm biodiversity. Biodiversity also performs other key ecological services and - if correctly assembled in time and space - it can lead to agroecosystems capable of sponsoring their own soil fertility and productivity.

A key strategy for enhancing sustainability in organic agriculture is to restore functional biodiversity of the agricultural landscape and to avoid mono-cropping [21]. In fact, the accumulation of residues from a sole crop disrupts the humification process, inducing odd decompositions that delay stabilization and release toxic metabolites [22,23,24]. These, in turn, may induce specific allelopathic effects (dispathy) accounting for 'soil sickness' [25,26,27], an event recorded in rice too [28]. Root absorption, in particular, may be hindered by these toxins [27] ensuing dystrophies and root die-back. The presence of diversified residues is the base for humification. Humification is a direct result of processes which may happen only in the presence of some factors and conditions, which both organic and biodynamic agriculture have, if well applied. Humification needs polygenicity (a substrate with very diverse origins), diverse populations of microorganisms, and microaerobic conditions [27]. All together these conditions determine coenotrophysm (i.e. to have nutritional functions in a group of individuals). When coenotrophic conditions are set it is possible to create humic compounds with a great efficiency (low carbon loss). The process starts from degradation, but with low production of soluble molecules, and very rapidly goes through polymerisation and polycondensation to create more complex structures. From an agronomical point of view, the processes of decomposition, immobilisation and mineralization liberate nutrient elements according to plant growth, but the synchronization is not always matched with the cultivated plant needs. Thus, losses by leaching can be limited by the presence of several species as plants absorb necessary elements in a variable way along their growing cycle, and crop growth control and production can be improved by appropriate external nutrient inputs according to the type of used organic fertilizer.

5. BIODYNAMIC AGRICULTURE IN THE ANTHROPOSOPHIC VISION

Biodynamic agriculture has much in common with organic farming: in particular, it relies heavily on composted farmyard manure (FYM) as main fertilizer [29]. Additionally, biodynamic farming uses field sprays and compost preparations consisting of specific minerals or plants treated or fermented with animal manure, water and/or soil.

Biodynamics can be understood as a combination of “biological dynamic” agriculture practices. "Biological” practices include a series of well-known organic farming techniques that improve soil health, whereas “dynamic” practices are intended to influence biological as well as metaphysical aspects of the farm (such as increasing vital life force), or to adapt the farm to natural rhythms (such as planting seeds during certain lunar phases) [30].

The first conception of what today we recognize as "organic agriculture" stemmed at the very beginning of the 20th century from the philosophical thought of Rudolf Steiner, the undisputed founder of the biodynamic method, who in the 20's anticipated the nowadays mainstream concern for environmental pollution and food insecurity when due to the overexploitation of natural resources [31]. Steiner assumed a fundamental knowledge of Anthroposophy, the spiritual science developed by himself. Without such knowledge, biodynamic agriculture can be applied but not fully understood with its essentials, e.g. the biodynamic preparations. The fact that a fundamental background exists means that deeper involvement in biodynamic farming should be accompanied by a study of Anthroposophy. This is valuable to scientists as well as to farmers, advisers or even to consumers, as it offers another approach also to human nutrition [32]. According to the Antroposophy's doctrine, Steiner suggested that crops and livestock are strongly subjected to cosmic influences, biological laws cannot be the only agents governing the agricultural performance: most importantly, there is the need to be aware and to understand the function of the forces, the impulses and the organizing principles that play a crucial role behind the visible matter. Interesting to note that according to Steiner the farm has to be conceived as an "autonomous individuality", within which closed cycles of nutrients and organic matter are enabled [33]. The idea of the farm as an "organism" will be next taken up by the agriculturalist Lord Northbourne in 1940, who asserted that "the soil and the microrganisms in it together with the plants growing on it form an organic whole" [34], and nine years later by the agronomist A. Draghetti suggested looking at the farm through the metaphor of the human body, that is an unique entity but also a whole of self-organized organs, thus requiring a physiological approach to study it [35]. According to Steiner, the farm must have a certain degree of internal diversification that is similar to the one of the wild natural environment, since the links among the parts (both in farm and natural environment) are of the same nature and complexity [36].

Another aspect emphasized by Rudolf Steiner in his famous eight agricultural lectures held on 1924 is the paramount importance of soil fertilization, the main goal of which is not just to supply the soil with nutrients but to provide it with a certain extent of vitality, which cannot be obtained by the simple mineral manures: "Fertilization can be accomplished by using organic matter only, and processed in a such a way that it will organize and give life to the solid component of the soil" [31]. As a consequence, the livestock (producing farm yard manure FYM), wide crop rotations inclusive of fodder plants and minimum soil disturbance represent the most characteristic aspects/strategies of the biodynamic farm prototype. By adding composted organic manure to the soil, the farmer would facilitate the concentration in it of the "vital forces" coming from the Cosmos: such forces will induce plant growth and ensure food quality [37]. To successfully allow such a determinant "bridging action" between Cosmos and land, as operated by the organic matter, specific biodynamic preparations have to be added to the FYM or directly to the soil, in minimal concentration (homeopathic dilutions).

5.1 The Biodynamic Preparations

The preparations are classified as "technical means" by the international standards on organic farming; they are not to replace common farming practices nor remedy possible technical mistakes. The preparations result from conditioning - in general within the farm - both plant and animal organic matter according to definite procedures, and mostly they are under highly humified form; they are deemed active under infinitesimal concentrations [38]. According to the way of use, biodynamic preparations belong to two classes: preparations sprayed directly onto the soil or crops (500 and 501) and preparations added to composting FYM (502 - 507) [32]. Table 1 presents the preparations and their ingredients, as described by Steiner in his lectures (1924). The preparation 500 consists of high quality FYM, fresh or aged, put in bovine horns, then buried at the end of September and dug up in April; after that it can be stored under controlled conditions for some months and finally sprayed to the soil.

From one horn, 60-80 grams of "horn manure" can be obtained that, dissolved in 20-30 liters of water at 35℃, are enough to treat one hectare [39]. The horn manure is energetically dissolved in water by clockwise and counter-clockwise stirring, manually or through a mechanical device according to a specific procedure, named "dynamization", that should ensure a good penetration of the "cosmic forces" inside the liquid mixture [38]. Then the mixture is distributed on the bare or freshly-tilled soil in big drops through a knapsack sprayer or a tractor-pulled big sprayer. Ideally, all the cultivated fields receive horn manure twice a year (springtime and autumn).

Table 1. The biodynamic preparations after Steiner (1924b)

Spray preparations applied to soils and crops:	
500	Horn manure
501	Horn silica
Compost preparations:	
502	Yarrow (Flower heads from *Achillea millefolium*)
503	Camomile (Flower heads from *Matricaria chamomilla*)
504	Stinging nettle (stalk from *Urtica dioica*)
505	Oak bark (*Quercus robur*)
506	Dandelion (flower heads of *Taraxacum officinale*)
507	Valerian (juice of flowers of *Valeriana officinalis*)

Horn silica (501) is powdered quartz (rock crystal) put in a bovine horn and processed as horn manure. A very small quantity of the 501 is then dynamized in water and sprayed on the standing crop, mostly at flowering stage: it would reinforce the plant against pests and diseases and improve its nutritional properties, flavours and shelf-life [39,33].

Besides the two traditional preparations described above, the Australian agriculturalist Alex Podolinsky devised in the 70' a new preparation with the goal to better adapt the classic biodynamic method to the Australian agricultural conditions, characterized by very extensive fields that would require high amounts of composted FYM usually not available. The Podolinsky's method is actually based on frequent polyphytic green manuring, crop rotation and conservative soil tillage plus the use of the new "Prepared 500" preparation. The new Podolinsky's preparation derives in fact from the combination, via a specific procedure, of the original Preparation 500 + all the compost preparations, as provided by Steiner [31]. After dynamization in water, the "Prepared 500" is sprayed to the tilled soil, just prior to sowing: the "Prepared 500" would induce - together with all the above mentioned farming practices - a sort of "sheet composting" [40,41,42], through which the fresh organic matter accumulated by crop residues and green manuring would quickly turn into stable organic matter, as it happens in a composting heap of FYM.

It has to be stressed that biodynamic preparations are added to the soil or to composting organic material always in very low doses of a few grams per ton of soil/compost material: therefore, it is hypothesized that the primary purpose of these compounds is not to add nutrients, but to stimulate the processes of nutrient and energy cycling, to affect decomposition/building of humus and to improve soil and crop quality [32].

5.2 The Biodynamic Preparations and Main Interactions with Soil Properties and Crop Yield

Carpenter-Boggs et al. [43] studied the effect of biodynamic preparations (BD) on compost development of cow manure and wood shaving bedding, emphasizing noticeable changes in compost chemical and microbial parameters. They found higher thermophilic microbial activity through the 8-weeks active composting period in the material with BD treatment. In the final ripening stage, the BD-treated piles respired CO_2 at a 10% lower rate and had a larger ratio of dehydrogenase enzyme activity to CO_2 production. Final samples of BD-treated compost also had 65% more nitrate than control. However the same authors, in another experiment to determine whether biodynamic preparations (compost preparations as well as field sprays) affect the soil biological community after one cropping season beyond effects of organic management did not found any significant difference between BD and non-BD treatments on parameters as: soil microbial biomass, respiration, dehydrogenase activity, soil C mineralized, earthworms population and metabolic quotient of respiration [44]. The effects of applications of traditionally vs. biodynamically composted FYM were studied over 9 years on soil chemical, biochemical and biological properties and yields in a 6 year crop rotation based on cereals, legumes and fodder crops. Results showed that the FYM with biodynamic preparations significantly decreased soil microbial basal respiration and metabolic quotient compared to non-prepared FYM. The prepared FYM however did not affect soil microbial biomass, dehydrogenase activity and crop yields [29, 45], in a long term field experiment comparing FYM in a crop rotation in two treatments with and without biodynamic preparations and inorganic fertilizer after 18 years found that (i) the organic C content was higher with manure than inorganic fertilization and (ii) the highest content was found in the treatment with biodynamic preparations. Therefore, applying the same quantity of manure, but without the preparations, led to higher decomposition of soil organic matter. To interpret such result the authors argued that (i) soil life was changed by the preparations with different effect on the soil organic matter decomposition, which is in accordance with the observed increase of dehydrogenase activity in the biodynamic treatment; or (ii) the quality, rather than the quantity, of manure made the difference as manure properties were possibly changed by the preparations; or (iii) both factors had an influence. The biodynamic treatment increased the potato yield, but no significant effect was recorded on the yields of the other crops in the rotation. Nevertheless when observing the yields of spring wheat over a period of 11 years, the effect of the preparations varied depending on the prevailing conditions of growth. Fig. 2 shows that when the yields of the treatment without the preparations (cow manure CM) increased under environmental favorable conditions, the treatment with the biodynamic preparations (CMBD) gave slightly lower yields; whereas, during the years with prevailing drought conditions with lower yields, CM yield was low and the CMBD yielded higher.

The same "regulatory" effect by biodynamic preparations on yield was described by Raupp and Konig [46] after a trial with cereals, carrots, beetroots and potatoes from 28 different field plot and pot experiments to determine the influence of the biodynamic preparations 500 and 501 on yields. The term "system adjustment" was suggested for this relationship of preparation’s effect and yield level. Fließbach et al. [47], in the long term "DOC trial" compared five farming systems, typical for Swiss agriculture: (i) livestock based bio-organic (BIOORG), (ii) biodynamic (BIODYN), (iii) integrated farming system (CONFYM), (iv) stockless integrated system (CONMIN) and (v) one control without any fertilization (NOFERT), in a 7 year crop rotation. In the third crop rotation period, soil organic carbon in the 0-20 cm layer of the BIODYN system remained constant, but in CONFYM as well as in

BIOORG it decreased of 7 and 9%, respectively, as compared to the starting value: according to the authors, this can be explained by the more stability of the organic matter in the biodynamic composted manure vs. the uncomposted dairy manure utilized in the other treatments. More drastic reduction of C_{org} occurred in CONMIN and NOFERT. After 21 years, the BIODYN and BIOORG systems showed the highest soil microbial biomass content among all the treatments. BIODYN showed the highest dehydrogenase activity and lower metabolic quotient for CO_2 with respect to CONFYM, meaning that micro-organisms in BIODYN need less energy to maintain their biomass than the ones of CONFYM.

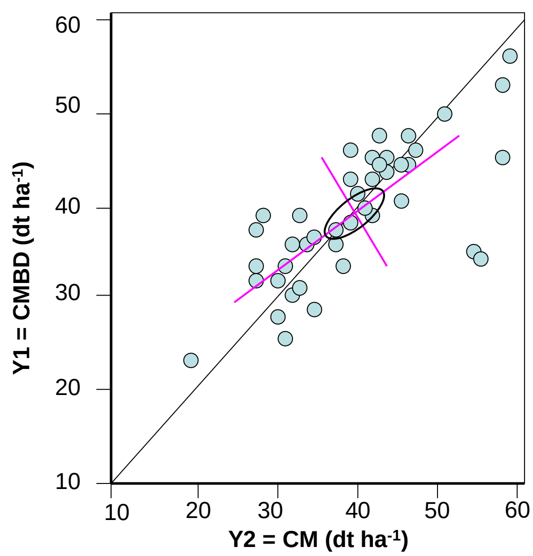

Fig. 2. Spring wheat yield (dt/ha) in 11 years after FYM (farm yard manure or cow manure CM) without (CM) and with biodynamic preparations (CMBD), each at the high rate in 4 replicates (n = 44). Ellipse shows the 95% confidence area of the mean value (redrawn from Raupp and Oltmanns, 2006)

5.3 The Relevance of Rudolf Steiner's Intuition to the Present Day

Despite the difficulty of providing objective evidence, at least with the state-of-the-art technology available for investigation, of the effects of many of the Steiner's "renewal forces" - this mostly stands for the more dogmatic statements about the supposed interactions between Cosmos and living organisms [48] - it has to be however acknowledged to Steiner the capacity to have, as first, emphasized the importance of the systemic approach when studying biological phenomena - in this case the activity of farming -, and this without considering the level of scale (single plant, cultivated field, cropping system, whole farm, etc.,), thus anticipating concepts that would have been addressed 30 years later by Cybernetics and Ecology. This approach would have led in subsequent years to the elaboration of complex concepts in science as "system thinking", holistic approach, and so on. In particular, it is topical the major emphasis Steiner puts on the "soil factor" as well as on the qualitative aspects of the organic matter cycling, so predicting - without the aid of modern and sophisticated analytical means - the strategic importance of maintaining a high soil biodiversity in the farm, which is in turn functional to the root growth, pests and disease control and more widely to the optimum operation of the entire farm "physiology" [35].

6. CONCLUSION

The organic and biodynamic agricultural methods share a unique holistic approach to sustainability.

Organic farming pre-dates all other approaches to “environmental friendly” agriculture and it is a rapidly developing sector for food production and processing in many countries. Biodynamic farming shares with organic farming the elimination of synthetic fertilizers and pesticides, and to control and address the organic matter cycle in the farm to improve and maintain soil fertility. But unlike organic farming, biodynamic farming uses, in addition, a series of fermented manure, plant, and mineral-based preparations which are added to the soil, crops, and compost. These substances are said to stimulate soil nutrient cycling, compost development, and photosynthesis. Biodynamic agriculture originally consisted of a mystical, and therefore unscientific, alternative approach to agriculture. Scientific testing of biodynamic preparations is limited and the evidence that addition of these preparations improves plant or soil quality in organically managed landscape is still in debate, but many organic practices, commonly used in organic and biodynamic farming systems, are scientifically testable and can result in improved soil and plant health parameters. The academic world needs to address the explosion of pseudoscientific beliefs and help non-academicians become more discerning learners, but at the same time it must be open to a more holistic approach in the study of agricultural systems.

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COMPETING INTERESTS

Authors declare that no competing interests exist.

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