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Humusica: Soil biodiversity and global change

Augusto Zanella[1]*, Judith Ascher-Jenull[2], Jean-François Ponge[3], Cristian Bolzonella[1]*, Damien Banas[4], Maria De Nobili[5], Silvia Fusaro[6], Luca Sella[1], Raffaello Giannini[7]

[1] Università di Padova, Italy
[2] University of Innsbruck, Austria
[3] Muséum National d'Histoire Naturelle, France
[4] Université de Lorraine, France
[5] Università di Udine, Italy
[6] Università di Padova, Italy
[7] Academy of Forest Science, Italy

* **Correspondence:** Dipartimento Territorio e Sistemi Agro-Forestali (TESAF), Università di Padova, Italy.
E-mail: augusto.zanella@unipd.it, cristian.bolzonella@unipd.it

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Abstract. Born in Trento (Italy, 2003) for the purpose of standardising vocabulary and units of humus form classification, after publishing a first synthetic classification e-book (Zanella et al. 2011) they do not cover all site conditions in the European area. Although having basic concepts and general lines, the European (and North American, Canadian, the Humus group decided to use its classification for handling global change (Zanella and Ascher-Jenull 2018). The process is detailed in many scientific articles published in three Special Issues (Humusica 1, 2 and 3) of the journal Applied Soil Ecology. Conceptually, the whole of Humusica answers three crucial questions: A) What is soil? Soil is a biological ecosystem. It recycles dead structures and implements mineral material, furnishing more or less re-elaborated organic, mineral and organic-mineral elements to support living organisms. Article chapters: 1. Essential vocabulary; 2. Soil covers all the Earth's surfaces (soil as the seat of processes of organic matter storage and recycling); 3. Soil may be involved in the process of natural evolution (through organisms' process of recycling biomass after death). B) If soil has a biogenic essence, how should it be classified to serve such managerial purposes as landscape exploitation or protection? A useful classification of soil should consider and propose useful references to biologically discriminate soil features. Article chapters: 4. Soil corresponds to a biogenic structure; 5. TerrHum, an App for classifying forest humipedons worldwide (a first attempt to use a smartphone as a field manual for humus form classification). C) How can this soil classification be used for handling the current global change? Using the collected knowledge about the biodiversity and functioning of natural (or semi-natural) soil for reconstructing the lost biodiversity/functioning of heavily exploited or degraded soils. Article chapters: 6. Agricultural soils correspond to simplified natural soils (comparison between natural and agricultural soils); 7. Organic waste and agricultural soils; 8. Is traditional agriculture economically sustainable? Comparing past traditional farm practices (in 1947) and contemporary intensive farm practices in the Venice province of Italy.

Key words:
Humusica,
soil organic carbon,
soil structure,
soil biology,
soil organic matter,
agriculture,
organic agriculture,
global change,
humus,
forest humus forms,
TerrHum

Essential vocabulary

Since 2003, a group of soil scientists has been working on standardising the description and classification of humus forms (Zanella and Ascher-Jenull 2018). The humus form corresponds to the series of all organic and organic-mineral soil horizons lying superposed like in a sandwich at the top of the soil. Coined by Müller in 1889 (Feller and Boulaine 1987; Jabiol et al. 2005), the term is still in use, even if recently upgraded. The soil profile is now divided into three sections: Humipedon (organic and organic-mineral horizons), Copedon (mineral horizons) and Lithopedon (fragmented bedrock) (Zanella et al. 2018f). The Humipedon is studied as if composed of real objects, grouped according to central theoretical concepts. In the field, among the real objects, we may observe the humus profile corresponding to the side of a hole we open in the floor, itself subdivided in many organic and organic-mineral humus horizons (Fig. 1). There are many different kinds of humus horizons. For practical purposes, it has been necessary to gather the immense number of humus profiles into a few theoretical "humus systems" and the large number of humus horizons into a few theoretical "diagnostic horizons". Furthermore, a more detailed observation allows a few "humus forms" to be defined in each humus system. "Humus systems", "humus forms" and "diagnostic horizons" are useful concepts. They allow scientists to exchange data and other information about real soils grouped according to conceptual references.

Soil covers all the Earth's surfaces

Soil is not only limited to "garden earth". Soil is everywhere, on every surface of the Earth. It is responsible for an ongoing, structured process of recycling. Conceptually, it approximates to a fire without a flame, a burning machine controlled by living organisms. It may be looked upon as a process of respiration, confined to a cover that is on display all over our planet. Imagine an enormous mitochondrion covering the entire planet Earth like a glove, and able to digest and recycle any dead matter that touches it. This "living soil" changes here and there, adapting its functioning to climatic conditions. It directly responds to the permanent requests or needs of living organisms inhabiting it. These organisms mandatorily ask for food and water. They form a system and respond to climatic conditions, with-

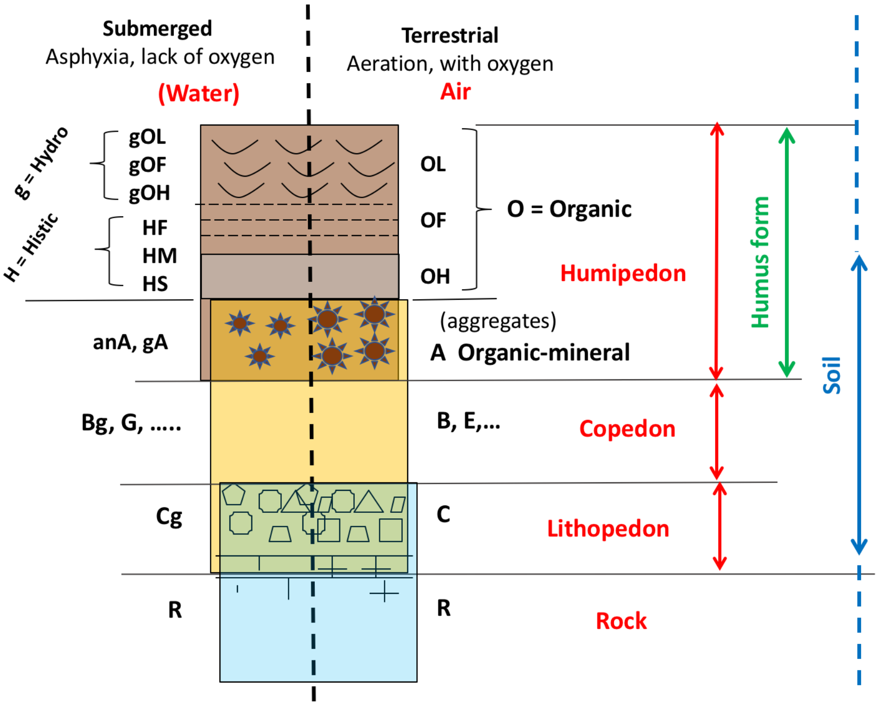


Fig. 1. Subdivision of the soil profile in main layers and in horizons, in submerged and terrestrial conditions, following Humusica indications (Zanella and Ascher-Jenull 2018)

in a matrix in which they are co-evolving in and with a commonly constructed niche (Odling-Smee et al. 2003; Ponge 2005; Bhatia 2008; Krogh (contributor) 2010; Ponge et al. 2013; Spurgeon et al. 2013). All these aspects have been treated in many articles of Humusica (Zanella et al. 2018a, 2018b, 2018f, 2018g, 2018j). Soil is transported by water and air, as particles of matter or as living organisms. Life was probably generated on Earth from organic particles from space. Even in present days, we receive on Earth a lot of particles from space (Fig. 2). Soil is a living thick cover that envelops our planet (under our feet, solid and hard: Humipedon, Copedon, Lithopedon; in the air: Aeropedon; in water: Hydropedon, which is very fluid and made of free particles and molecules and microorganisms; in the rock as fossil heritage: Geopedon; in living organisms, as symbiotic masses of microorganisms: Symbiopedon). It never stops evolving, embracing as in a cloud all other living organisms, influencing their evolution. Soil has been challenged as an ecosystem (Ponge 2015), embedded in larger ecosystems (e.g. forests, lakes, oceans) and in turn embedding smaller ecosystems (e.g. root tips, animal guts, aggregates) in a never-ending ladder of self-organised ecosystems. The absence of any frontiers between biotic and abiotic processes is at the heart of the Humusica project (Zanella and Ascher-Jenull 2018).

Soil has been involved in the process of natural evolution

Over billions of years, all living organisms that have died on planet Earth have nourished the soil. Their DNA has been recycled. Part of it was recycled for building new organisms. This process of recycling is perpetually renewed and maintains a linear connection between all organisms living on Earth (Fig. 3). This connection corresponds to the genealogy revealed by current systems of classification of living organisms, following the principles of natural evolution (Darwin 1859). In recent studies about the extracellular fraction of the total (soil) DNA pool (metagenome), extracellular DNA has been reported as a species-specific growth inhibitor in plants, and proposed as an explanation for negative plant–soil feedbacks (Levy-Booth et al. 2007; Pietramellara et al. 2009). DNA extraction from litter materials showed a substantial accumulation of extracellular DNA during the decomposition process (Incerti et al. 2011; Mazzoleni et al. 2015; Cartenì et al. 2016). Even if further studies are necessary to unravel the exact role of soil organic matter biodegradation and recycling in the process of natural evolution (Drosos et al. 2018; Nardi et al. 2018; Olaetxea et al. 2018), it is not difficult to see that a

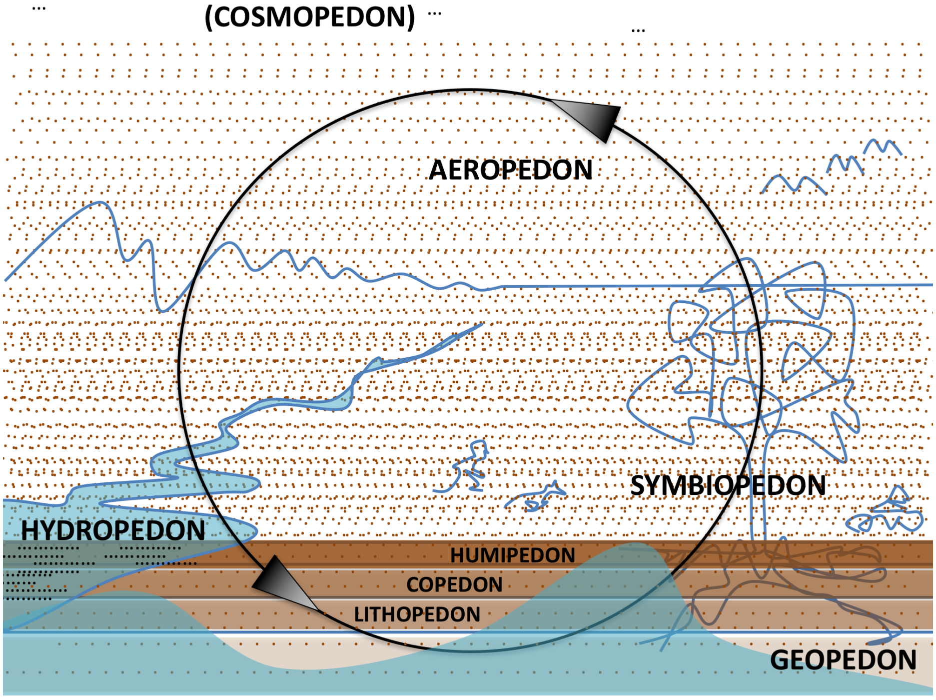


Fig. 2. Soil is not only under our feet. A larger concept is necessary to cover the whole of planet Earth and to understand its natural origin. From Zanella et al. (2018e)

large part of new organisms' genomes corresponds to a combination of pieces of DNA from dead organisms.

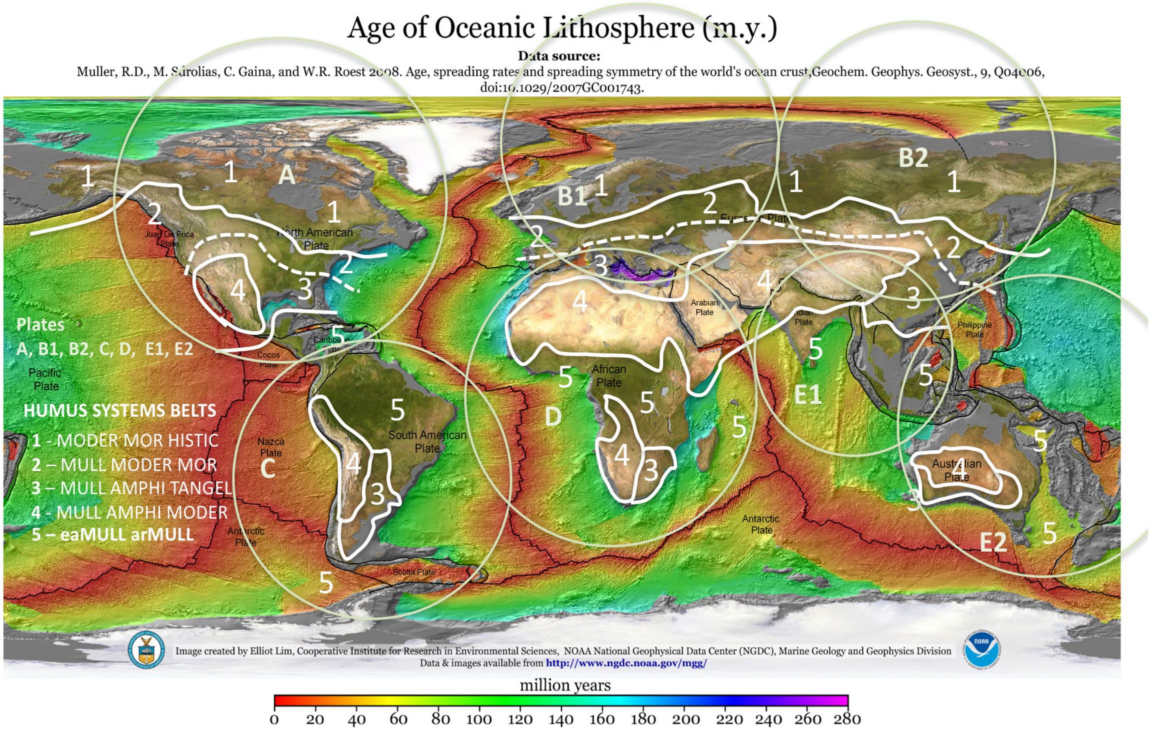
It is well known that the foundation for sustainable forest management is eco-biological knowledge of forest ecosystems, as well as an understanding of the relationships between functionality, productivity and stability. In this triangle a high diversity has been shown to enhance ecological efficiency on the spatial scale and over various time intervals (Giannini 2008; Aubert and Bureau 2018).

More generally, the functionality of the forest ecosystem depends on a) the characteristics and properties of components, b) the collective properties that derive from the organisation of these, and c) the result of the interrelations that are created at the level of biocenoses. In the system, the hereditary component transmitted at the molecular level is genetic variability. This represents the sum of the information contained in the genes of the organisms present in different ecosystems (Giannini and Susmel 2006).

Studies at the genetic level allow us to know the genetic diversity. The study of the variations or similarities in the primary sequence of nucleic acids of single organisms or groups of organisms allows the allelic distribution or the degrees of genetic diversity between and within populations to be estimated.

Each organism is the bearer of species-specific characteristics that can change over generations in response to the effect of abiotic interactions taking place at various moments of life. The ecological genetic component assumes great importance in the various phases of the functionality of ecosystems. Also referring to differentiated models, ecosystems will always have as their engine the genetic component that confers perpetuity on them. This indicates that the loss of organisms has a direct effect on genetic variability, with partial (erosion) or total (extinction) effects (Hirschhorn and Daly 2005; Puga-Freitas and Blouin 2015; Blouin 2018).

The forest ecosystem is dominated by the presence of trees, which are the very drivers and keystones of the system itself (Wohlleben 2016;


Age of Oceanic Lithosphere (m.y.)

Data source:
Muller, R.D., M. Sdrolias, C. Gaina, and W.R. Roest 2008. Age, spreading rates and spreading symmetry of the world's ocean crust, Geochem. Geophys. Geosyst., 9, Q04006, doi:10.1029/2007GC001743.

Image created by Elliot Lim, Cooperative Institute for Research in Environmental Sciences, NOAA National Geophysical Data Center (NGDC), Marine Geology and Geophysics Division
Data & images available from http://www.ngdc.noaa.gov/mgg/

Fig. 3. Planet Earth's plates and humus systems. From Zanella et al. (2018g). Source of plate map: http://www.ngdc.noaa.gov/mgg/ocean_age/data/2008/ngdc-generated_images/whole_world/2008_age_of_oceans_plates.jpg, Public domain, https://commons.wikimedia.org/w/index.php?curid=6972903). Data in Müller et al. (2008), reproduced with kind permission

Centenaro et al. 2018; Habashi and Waez-Mousavi 2018). In harmony with biotic and abiotic components of the local eco-environment, these long-lived organisms interpenetrate and participate in the formation of a pedogenetic substrate; the diversity of forest soils is very variable, but intrinsically still little-known.

Soils are indeed the location of processes of great importance: we remember their role in the development of eco-geopedological cycles that are a vital source for human survival. The role played as seed banks is also of interest (Tiebel and Tiebel 2018). In the soil, buried seed represents a reserve of diversity which will be viable and able to germinate under changing environmental conditions and it represents a strategy to prevent germination under unfavourable conditions.

The soil corresponds to a biogenic structure

It is well known that soil has a "biotic" essence (Ponge 2005; Lavelle 2012; Gruber 2015; Zanella et al. 2016; Sechi et al. 2017; Bernier 2018), meaning that its functionality depends on living organisms. What is still not known is that the whole soil is a biogenic structure. When we observe a rock exposed to the air, we are looking at a soil. Each surface is colonised by microorganisms which immediately start forming a soil (Zanella et al. 2018e). Then, this very thin film of soil grows. It structures itself in different layers. Soil scientists know them very well. Why do living organisms generate soil layers? Because organisms inhabiting the soil respond to climatic conditions and mandatorily utilise the mineral stock they found in place at their arrival as a food source.

As a consequence, the soil structures itself into three main layers, Lithopedon, Copedon and Humipedon. These three layers function relatively independently, as compartments of a larger structure (Zanella 2018; Zanella et al. 2018b). Each of them is functionally very important and can, according to climatic conditions, dominate the others. No Copedon occurs in cold regions, where the Humipedon dominates. Rather, the Copedon dominates in equatorial regions and may reach metres in thickness. Humipedon, Copedon and Lithopedon co-dominate in temperate regions. The soil is made of biological aggregates, i.e. mineral and organic lumps (Fig. 4). No aggregation, no soil. On the Moon there is no living soil, because there are no living organisms generating new functional aggregates. On the Moon, only a fossil heritage could possibly ever be found, which could be classified as a Geopedon, made of now-fossilised (or disappeared) organisms.

Microorganisms, and in particular fungi, constitute an important part of the soil biomass and are considered the most efficient degraders of humic substances (Grinhut et al. 2007; Geisen and Bonkowski 2018). Fungi play major environmental roles by acting as decomposer organisms (saprophytes) and symbionts (mycorrhizas).

Saprophytes decompose dead organic matter, contributing to organic and inorganic nutrient recycling, and thus maintaining soil nutrient availability (Gadd 2004, 2007; Gadd and Sariaslani 2017). Mycorrhizas are a mutualistic association between fungi and plant roots that originated over 450 million years ago during the process of colonisation of the terrestrial environment. Currently, about 95% of vascular plant species are likely associated with mycorrhizal fungi, which solubilise and redistribute insoluble mineral salts (especially phosphates and ammonium ions) and metal ions (such as potassium, calcium, copper, zinc and iron) present in the soils that plant roots cannot easily uptake (Heijden and Horton 2009; Bardgett and Van der Putten 2014; Bender et al. 2016). In turn, mycorrhizal fungi usually depend on the plant host for carbon sources since few are able to utilise cellulose and lignin as saprotrophs. Fungi, particularly those forming mycorrhizal symbioses, affect the physical structure

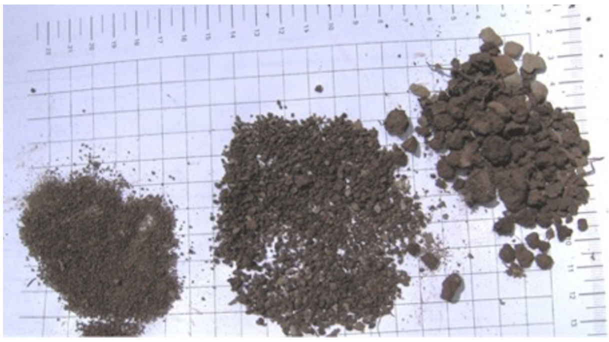


Fig. 4. Micro (<1 mm), meso (1–4 mm) and macro (>4 mm) soil aggregates. From Zanella et al. (2018d)

of soils, contributing to its formation and modification and influencing the key ecosystem process of soil aggregation at the macro- and probably also micro-aggregate level (Rillig and Mummey 2006; Maaß et al. 2015; Eisenhauer et al. 2017; Balestrini and Lumini 2018). Indeed, they maintain the soil structure due to their habit of filamentous branching growth (Ritz and Young 2004; Gadd 2004, 2007; Lavelle 2012) and secrete large quantities of exopolymers such as polysaccharides (Caesar-Tonthat 2002) and hydrophobic compounds that affect soil aggregation and the water infiltration properties of soils (Ritz and Young 2004; Brussard 2012).

TerrHum: an iPhone app for classifying forest humipedons

The name TerrHum is an abbreviation of the words “Terrestrial” (not hydromorphic, not submerged) and “Humipedon” (organic and organic-mineral humus horizons). With this application it will be possible, for the first time, to classify all non-submerged forest topsoils of our planet. The app is built on the indications about humus diagnostic horizons, forms and systems reported and illustrated in Zanella et al. (2018h, 2018i, Fig. 5). Freely available in the App Store, TerrHum makes use of many figures that are stored in the cloud and downloaded in the iPhone the first time the user recalls them. Once all figures (141) have been opened, the iPhone does not need to be connected to the Internet to run the application, allowing it also to be used in the absence of a network connection.

Let us consider a user faced with a soil profile to be classified. A cubic volume of 50×50×50 cm is generally sufficient for studying humus systems and forms in a forest environment, while a larger hole or many well-distributed small holes are necessary for surveying a heterogeneous area (Zanella et al. 2018j).

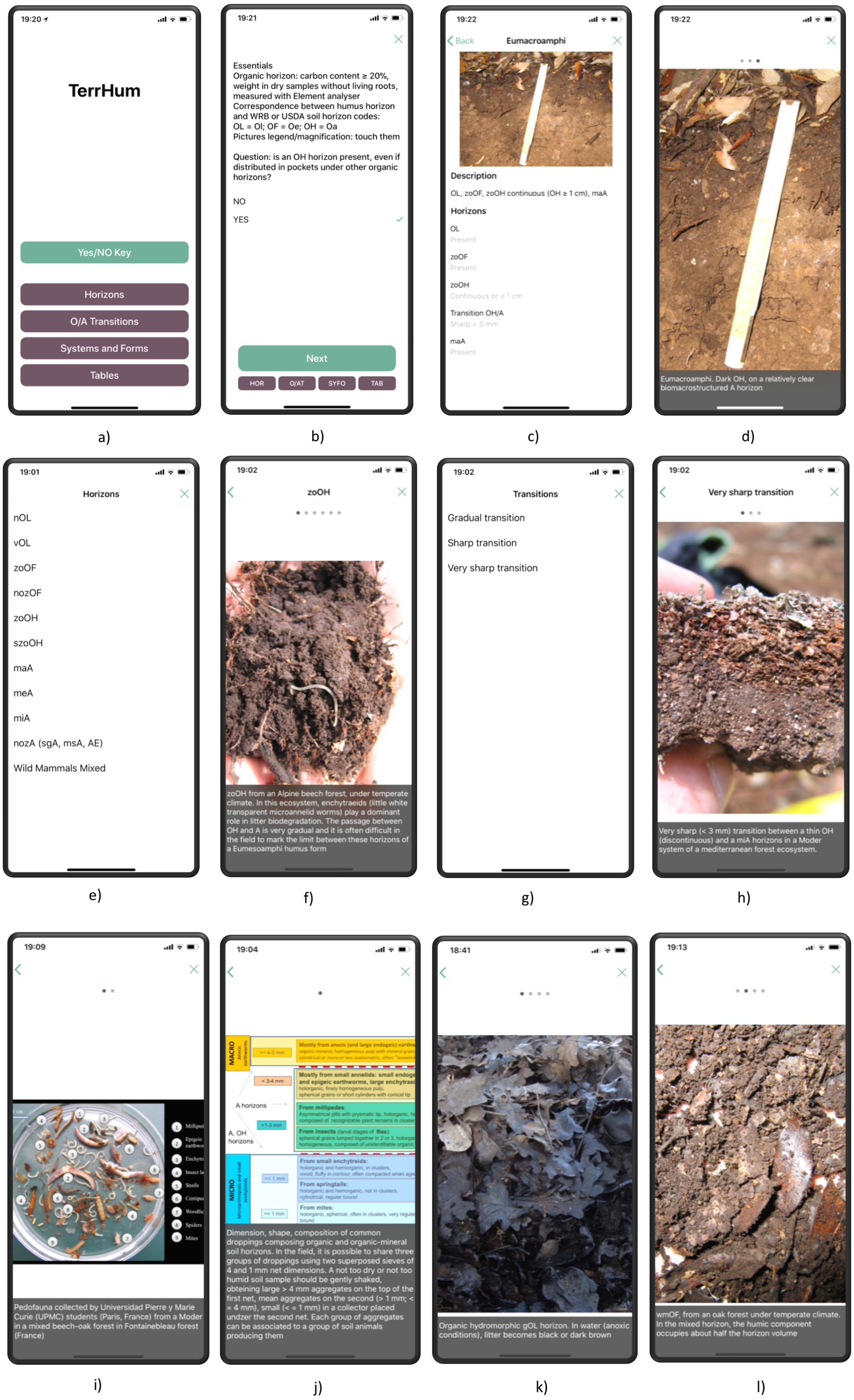
As a humus form is made of superposed humus horizons, the app asks the user to indicate one-by-one which types of humus horizons are present in the observed profile. The user is asked to answer a series of YES/NO questions (Fig. 5a-d). He can use the brown touch-buttons for help and display examples of horizons, types of transition (Figs 5e-h) or humus systems, as well as forms and tables of composition/classification of humus horizons, or groups of animals and droppings. At the end of the survey, a photograph of the target humus form appears, along with a list of the chosen horizons.

By clicking/touching on the screen, each photograph may be magnified (Figs 5d, 5f, 5h). A caption that appears at the bottom of the picture provides access to the morpho-functional features of the soil profile that lead to the result: the final classification of the humus system.

TerrHum is a University of Padua app that allows the main content of the Humusica 1 field guide (Zanella and Ascher-Jenull 2018) to be stored on a cell phone. Images, diagrams and useful tables of classification may be recalled with a few taps on the screen. The app is freely downloadable and in continuous evolution (automatic update). To contribute to its improvement, simply send your suggestions, photographs, schemes, etc. to augusto.zanella@unipd.it. Your name will be reported alongside a photograph or a relevant improvement, as in an open source app.

The agricultural soils correspond to simplified natural soils

Agricultural soils are natural soils used by man for producing food. Many of them originated from forest soils (Greenpeace/Global Forest Watch: https://www.greenpeace.org/archive-international/en/campaigns/forests/europe/map-of-europe-s-last-ancient-f/). As a consequence, the original features of present-day agricultural soils should have been similar to those of present-day forest soils. The comparison of present day agricultural and forest soils may provide us the “distance”, in terms of morpho-functional features, between natural and anthropic soils. These agricultural practices, renewed over years, differentiated present-day soils from original natural soils. In recent decades, the intensification of agricultural practices (mechanisation, the use of phytosanitary products, etc.) amplified the described forced evolution even more.



Essentials
Organic horizon: carbon content ≥ 20%, weight in dry samples without living roots, measured with Element analyser
Correspondence between humus horizon and WRB or USDA soil horizon codes:
OL = Ol; OF = Oe; OH = Oa
Pictures legend/magnification: touch them

Question: is an OH horizon present, even if distributed in pockets under other organic horizons?

Description

OL, zoOF, zoOH continuous (OH ≥ 1 cm), maA

Horizons

OL: Present
zoOF: Present
zoOH: Continuous or ≥ 1 cm
Transition OH/A: Sharp < 5 mm
maA: Present

Eumacroamphi. Dark OH, on a relatively clear biomacrostructured A horizon

zoOH from an Alpine beech forest, under temperate climate. In this ecosystem, enchytraeids (little white transparent microannelid worms) play a dominant role in litter biodegradation. The passage between OH and A is very gradual and it is often difficult in the field to mark the limit between these horizons of a Eumesoamphi humus form

Very sharp (< 3 mm) transition between a thin OH (discontinuous) and a miA horizons in a Moder system of a mediterranean forest ecosystem.

Pedofauna collected by Universidad Pierre y Marie Curie (UPMC) students (Paris, France) from a Moder in a mixed beech-oak forest in Fontainebleau forest (France)

Mostly from anecic (and large endogeic) earthw… organic-mineral, homogeneous pulp with mineral grain… cylindrical or more or less isodiametric, often "boweled…

Mostly from small annelids: small endoge… and epigeic earthworms, large enchytraei… holorganic, finely homogeneous pulp, spherical grains or short cylinders with conical tip

From millipedes: Asymmetrical pills with prysmatic tip, holorganic, he… composed of recognizable plant remains in cluster…

From insects (larval stages of flies): spherical grains lumped together in 2 or 3, holorgar… homogeneous, composed of unidentifiable organic…

From small enchytreids: holorganic and hemiorganic, in clusters, ovoid, fluffy in contour, often compacted when age…

From springtails: holorganic and hemorganic, not in clusters, cylindrical, regular bound

From mites: holorganic, spherical, often in clusters, very regula… bound

Dimension, shape, composition of common droppings composing organic and organic-mineral soil horizons. In the field, it is possible to share three groups of droppings using two superposed sieves of 4 and 1 mm net dimensions. A not too dry or not too humid soil sample should be gently shaked, obteining large > 4 mm aggregates on the top of the first net, mean aggregates on the second (> 1 mm; < = 4 mm), small (< = 1 mm) in a collector placed undzer the second net. Each group of aggregates can be associated to a group of soil animals producing them

Organic hydromorphic gOL horizon. In water (anoxic conditions), litter becomes black or dark brown

wmOF, from an oak forest under temperate climate. In the mixed horizon, the humic component occupies about half the horizon volume

Fig. 5. TerrHum screens: a) Initial screen. Main key of classification highlighted in green. Below the main classification key, three options allow access to illustrations of humus horizons, forms, systems and types of transition between organic and organic-mineral horizons. A final option opens particular tables containing helpful specific information for the classification (example % recognisable remains in different diagnostic horizons). Tapping on the "Yes/No Key green touch-button" opens a new window, where; b) a Yes/No question is displayed. On answering, tapping "Next" activates a series of other Yes/No questions, and at the end a humus form is proposed as the solution; c) The solution is accompanied by a list of the horizons chosen during the process. It is possible to magnify the picture and to see other examples of the same humus form, in different environments; d) The first brown touch-button "Horizons" opens screen e; e) Touching zoOH horizon opens screen f; f) Tapping on the second brown touch-button named "O/A transitions" displays screen g; g) Examples of passages between O and A horizons are displayed; h) An example of the last "Very sharp transition". Tapping on the third brown touch-button, "Systems and Forms", displays many examples of Humus systems and forms (a shortcut, when it is not necessary to follow a step-by-step classification). Tapping on the fourth brown touch-button, "Tables", a user may obtain: i) examples of soil animals; j) a table of animal droppings classification; and examples of: k) Hydro; or l) Wild mammal-mixed horizons

By definition, the biocides spread on and into the soil by humans had the objective of killing living organisms. Therefore, the risk of killing the soil ecosystem or at least significantly disturbing its functioning is real and demands that periods of rest be implemented (Polverigiani et al. 2017; Fusaro et al. 2018; Gavinelli et al. 2018; Menta et al. 2018; Pelosi and Römbke 2018; Ripple et al. 2018; Stellin et al. 2018). These treatment products are incorporated into the soil and are often transported by water. They join streams and/or lakes (Gaillard et al. 2016). As they become integrated into sediments, aquatic animal communities, which feed largely on dead organic matter of terrestrial origin, are then modified. All soil communities (terrestrial and aquatic) have been simplified in agricultural catchments in comparison to more natural forest catchments (Weigelhofer et al. 2012; Four et al. 2017).

These agricultural practices, renewed over years, have changed soils. These are differentiated from original natural soils. In recent decades, the intensification of agricultural practices (e.g. mechanisation, use of inputs such as phytosanitary products) has amplified this forced evolution.

In agricultural soils, particularly those of warm temperate climates, soil organic matter content strongly decreased due to the adoption of modern agricultural practices, such as intensive tillage and exclusive use of mineral fertilisers. In Italy, agricultural soils contain on average only 1.4% OC (Jones et al. 2005; Chiti et al. 2012; Lugato et al. 2014; Pergola et al. 2018), corresponding to 2.5% organic matter: this is apparently a very minor component as compared to minerals. Yet, in these OC-depleted soils, the actual contribution of even this tiny fraction becomes manifest if we consider the composition of soil on a volumetric or solid-surface base (Fig. 6). The essential roles of organic matter and the biogenic structure of soil are obvious even in these anthropically impoverished "mineral" soils.

By looking at natural soils it is possible to gain insights into the impact of agricultural practices on soil properties. Eighteen years ago, by observing the structure of an agricultural soil under a microscope, Topoliantz et al. (2000) noticed that the original structure made by large earthworms had gone. In different cultures around the world we find a rough discrimination between very different soil structures: crumby (macro-aggregated), micro-aggregated and massive. In a recent publication (Zanella et al. 2018k), these soil structures were better understood, comparing them to a larger arrow of natural structures corresponding to those assigned to main natural diagnostic horizons of common forest humus forms. It was possible to improve the former model, displaying four types of structures to be associated with the A horizon of cultivated soils (Fig. 7):

1. Anthropogenic poorly zoogenic massive A horizon (amsA);
2. Anthropogenic bio-micro-structured A horizon (amiA);
3. Anthropogenic bio-meso-structured A horizon (ameA);
4. Anthropogenic bio-macro-structured A horizon (amaA).

By comparing anthropogenic to corresponding natural structures it was possible to define how agricultural soils were dynamically related to natural ones:

a) Anthropogenic biomacro and biomeso structures are very similar to those found in the A horizon of Mull and Amphi natural humus systems; the pH of these horizons is generally higher than 5. These soils are relatively fertile and rich in pedofauna. Their functional physical and chemical structure

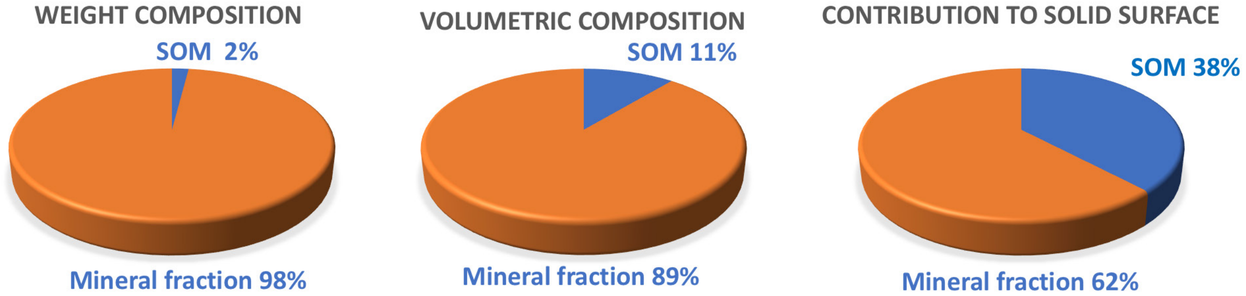


Fig. 6. Contribution of soil organic matter to the composition of an agricultural soil with an organic C content of 14 mg kg-1. From Zanella et al. (2018k), modified

is created by large anecic and endogeic earthworms. These soils are not threatened by compaction and erosion.

b) The anthropogenic biomicro structure is very similar to that found in some Amphi A horizons lying over a biomeso-structured A horizon in Mediterranean forest ecosystems; the pH (in water) of the A horizon is generally higher than 5. This type of soil may even be rich in organic matter and pedofauna and fertile, fertility being due to a combined pedofauna rich in enchytraeids and arthropods at the top and in endogeic and anecic earthworms at the bottom of the humus profile. Sensitive to superficial erosion, these soil types should be protected with a continuous vegetation cover.

c) The anthropogenic biomicro structure can be found in Moder humus systems, in very thin A horizons (3–7 cm); the pH (in water) of the A horizon is generally lower than 5. In this soil type, only the top part of the soil profile is fertile. The aggregates are small and not very stable. The lack of earthworms, which might otherwise generate larger stable aggregates, makes these soils very vulnerable to erosion.

d) A soil structure similar to that of anthropogenic massive A horizons is found in the A horizon of Moder or, even more so, of Mor natural humus systems. Poorly influenced by soil fauna, the A horizon of these humus systems tends to become massive, breaking into pieces like dried clay in the case of a Moder (for instance under a coniferous artificial plantation occupying a deciduous forest site), or like dried sugar in the case of the sandy A horizon of a Mor on sandy substrates (Podzol). Annual tillage and fertilisation are necessary to give these soils an artificial labile structure able to sustain a productive crop annually. Recovering a more natural structure is a challenge in the long run. If the soil is not contaminated with pesticides, the amendment/incorporation of high quality compost may be a promising strategy to give life back to these soils.

Organic waste and agricultural soils

The use of organic waste in agriculture is as old as agriculture itself. Even before becoming farmers, early humans, while gathering food, must have observed that seeds and edible plants thrived much better on animal or human waste. So the practice of adding organic manure, whenever available, was probably adopted right from the beginning and lasted through the millennia until the second half

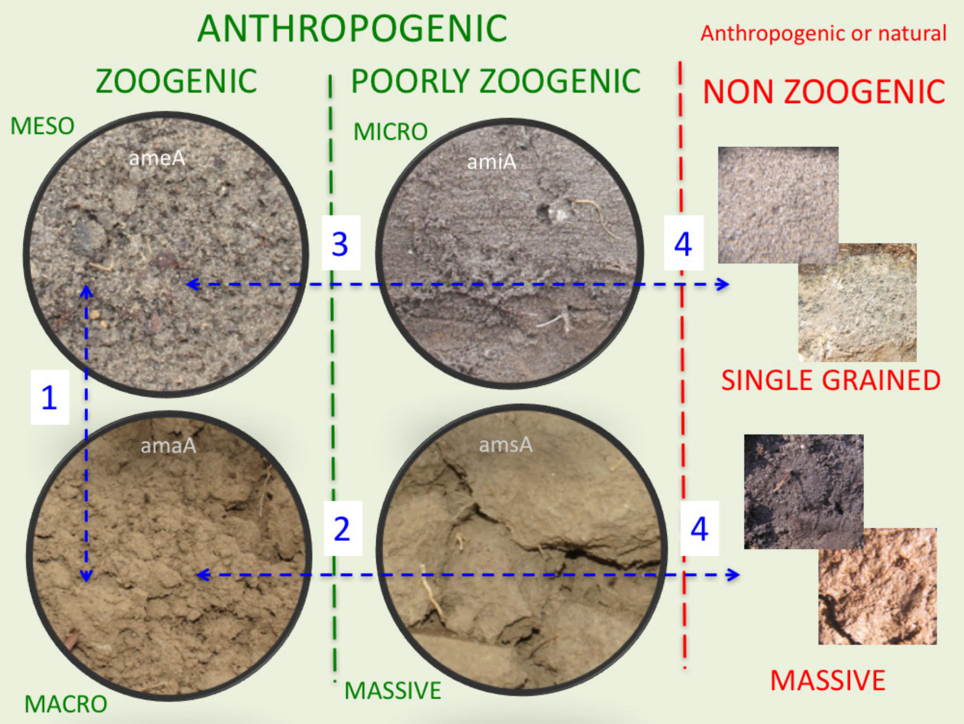


Fig. 7. Anthropogenic soil structures. From Zanella et al. (2018k). Hypothetical lines of structure evolution (in blue); from left to right, from more natural functional biological soil structures to non-zoogenic poorly functional soil structures

of the past century, when synthetic fertilisers became available worldwide. It was at that time that the great carbon and nitrogen biogeochemical cycles were disrupted and valuable resources were disposed of, most often improperly, polluting waters or consuming energy to carry them over long distances and dump them into landfills. We have now reached a point at which the unsustainability of all this has become evident and can hardly be denied. The case of phosphorus is emblematic. Even without considering the much-debated but likely possibility that economically profitable resources of phosphate rocks may soon run out on a planetary scale (Cordell et al. 2009), P fertiliser availability is a potential time bomb that may undermine food security, not only in areas where agricultural production is problematic, but also in Europe itself (Elser and Bennett 2011). In fact, most of the P fertilisers employed in Europe come from phosphate rock mines in southern Morocco, a politically unstable area, constantly maintained under military control. At the same time, huge amounts of organic P are discharged by rivers into oceans and are feeding the spread of dead zones where eutrophication has reached its utmost stage, consuming all dissolved oxygen and turning the sea into a barren space deprived of all life forms but anaerobic bacteria. Most of this P derives from livestock effluents poorly disposed of on agricultural land. At the base of the problem is high intensity livestock farming systems that have uncoupled animal husbandry from land cultivation.

How can we correctly use organic wastes in agriculture? Involving all the Humus group in a discussion, we answered three crucial questions (Zanella et al. 2018c):

1. Why is organic food better (tastes better, is healthier and richer in nutrients, contains less pesticide, etc.) than food produced with hydroponic or intensive farming techniques?

2. In a humipedon, are soil functioning, biodiversity and carbon content three interdependent and intersected aspects of a single ecosystem? In other words, can we treat these aspects as if they were inseparable in a humipedon?

3. Are agriculture and civilisation (society, culture, and way of life) interconnected?

In short (The answer was more complex, but its final essence may be summarised as follows.):

1) Organic food (food produced “without pesticide, or as little as possible”) is better because plants react to parasite attacks, producing molecules which give flavour to fruits and vegetables. So, we have to choose: attacked plants that produce flavourful food, or plants free of pests which produce flavourless food;

2) Yes, soil functioning, biodiversity and carbon content are interdependent and intersected aspects of a soil ecosystem. The soil hides an ecological pyramid of living organisms: the higher the carbon content, the higher the energy content, the taller the pyramid, the higher the soil biodiversity, the higher the soil productivity;

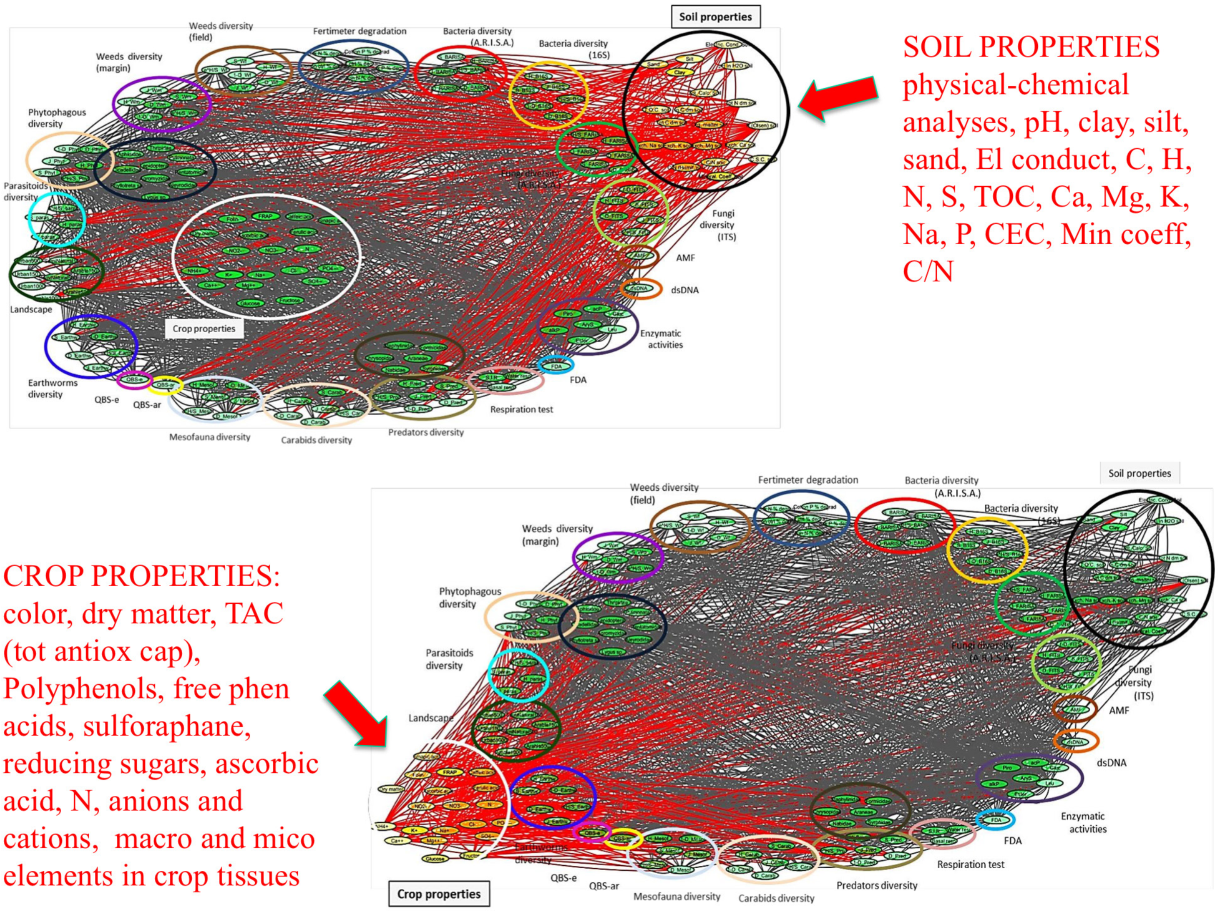
3) Yes, agriculture and civilisation are strongly interconnected. Humans began to do something other than searching for food for a living after they invented agriculture. If we eat healthy food, we stay and grow healthy; otherwise we die.

A means for using organic waste to increase the potential of a soil resource has been presented in Zanella et al. (2018c). This is a consequence of the answers presented immediately above and may be summarised in the following phrase of Jeff Lowenfels and Wayne Lewis: “If you want to feed your garden plants, feed all the organisms living in the soil under your plants” (Lowenfels and Lewis 2010).

Some scientific evidence of this new “law of agriculture” have been presented in a doctoral thesis (Fig. 8) regarding the analysis of biotic and functional indicators in agroecosystems under different managements (organic and conventional) and the search for the existence of relationships among crop plants, soil and biodiversity (Fusaro 2015; Fusaro et al. 2018).

In a supposed simplified environment, like an agroecosystem, the nutritional properties of crops are strongly correlated with many biotic and functional indicators of the agroecosystem. This means that the crop is affected by its environment in a holistic way. It is thus advisable to define this environment not just as its climate and/or soil chemical-physical properties, but also as the complex of biodiversity – all the organisms living inside and outside the soil next to the crop, as highlighted by the red lines in Figure 8.

It is highly desirable to nourish and take care of all the soil biodiversity, which is obviously strictly linked to soil condition (red lines in Fig. 8 above),



SOIL PROPERTIES physical-chemical analyses, pH, clay, silt, sand, El conduct, C, H, N, S, TOC, Ca, Mg, K, Na, P, CEC, Min coeff, C/N

CROP PROPERTIES: color, dry matter, TAC (tot antiox cap), Polyphenols, free phen acids, sulforaphane, reducing sugars, ascorbic acid, N, anions and cations, macro and mico elements in crop tissues

Fig. 8. Plots of all the significant correlation relationships in horticultural agroecosystems. These correlations emerged from nutritional properties of crop plants, several bioindicators (soil bacteria and fungi, arbuscular mycorrhizal fungi [AMF], mesofauna, earthworms, predators, phytophages, parasitoids, weeds), many functional indicators (some key soil enzymatic activities, fertimetro [International patent PCT N. WO2012 140523 A1, Squartini, Concheri, Tiozzo, Padova University] degradation, soil respiration rate, Soil Biological Quality index based on earthworms [QBS-e], Soil Biological Quality index based on arthropods [QBS-ar]) and soil physical-chemical properties. Each line represents a significant correlation ($p<0.05$, Pearson's or Spearman's correlation). Figures elaborated with Cytoscape software. From Fusaro (2015) and Fusaro et al. (2018)

to produce a food that is more nutritive and complete for human consumption and that reflects the particularities of a given place in a "terroir conception" (Fusaro et al. 2018). In contrast to Quantity agriculture, Quality agriculture, like organic and biodynamic farming, adopts practices that are less impactful and more respectful both of the soil, which is considered as a superorganism of life cycles and seasonal rhythms and, therefore, also of the environment where humans live; it also takes care of soil biodiversity, a component not considered at all by Quantity agriculture.

Is traditional agriculture economically sustainable? Comparing past traditional farm practices (in 1947) and contemporary intensive farm practices in the Venice province of Italy.

In the northeast of Italy, between the cities of Venice, Padua and Treviso, the land was divided by the Romans into square areas (Fig. 9) devoted to agriculture and called Roman Centurations (Graticolato Romano in modern Italian). These areas were given to soldiers when on leave.

The orientation of the Centuration was purposely inclined East–West in order to follow the natural slope of the land and to accompany water flow. Even the shape of the fields was strictly regulated and characterised by a central ridge called a "baulatura". In such a way, the probability of production loss was lower: even in the driest years, the lower and more humid part of the field always guaranteed the minimum production necessary to sustain the family and livestock. The fields were bordered by wooded strips. The trees ensured wind protection and were necessary for the production of wood used daily for cooking and in winter for heating houses.

Obviously, the situation has changed over time. Considering a recent evolution, for instance, a huge displacement of human populations has occurred since the 1980s, from densely populated suburbs of Venice to rural areas where the quality of life was better. The Centuration area was heavily urbanised, but the Roman subdivision of the territory into Centuriations remained untouched and still forms a kind of chessboard well visible on satellite images.

Traditional houses were built in bricks produced by drying clay obtained directly from the fields. Houses were very simple, consisting of a part dedicated to people and another part dedicated to cows; usually each family had 2–3 cows. Houses were built as part of an economic exchange by villagers, who in turn helped each other to tackle any extraordinary works. At that time there were no safety laws and everything was simpler.

Livestock played a very important role in family life, allowing fresh milk and eggs to be obtained daily. The animals exploited were different from those we currently breed on intensive farms. The cows were triple-purpose: for work, milk and meat production. The average production per cow was around 7 litres of milk per day, compared to the current 25–30 litres and the life span of the cows was much longer – nearly 12 to 15 years compared to the current 3 to 4 years. Also, the human consumption of meat was different from today's requirements, meat being consumed only one or two times per week. In the simple rural life of the past, the priority was to provide food for all the family.

In recent interviews, elderly people declared that they were happy in those years after the Second World War, i.e. from 1947 to 1960; although life was difficult because agricultural activities re-

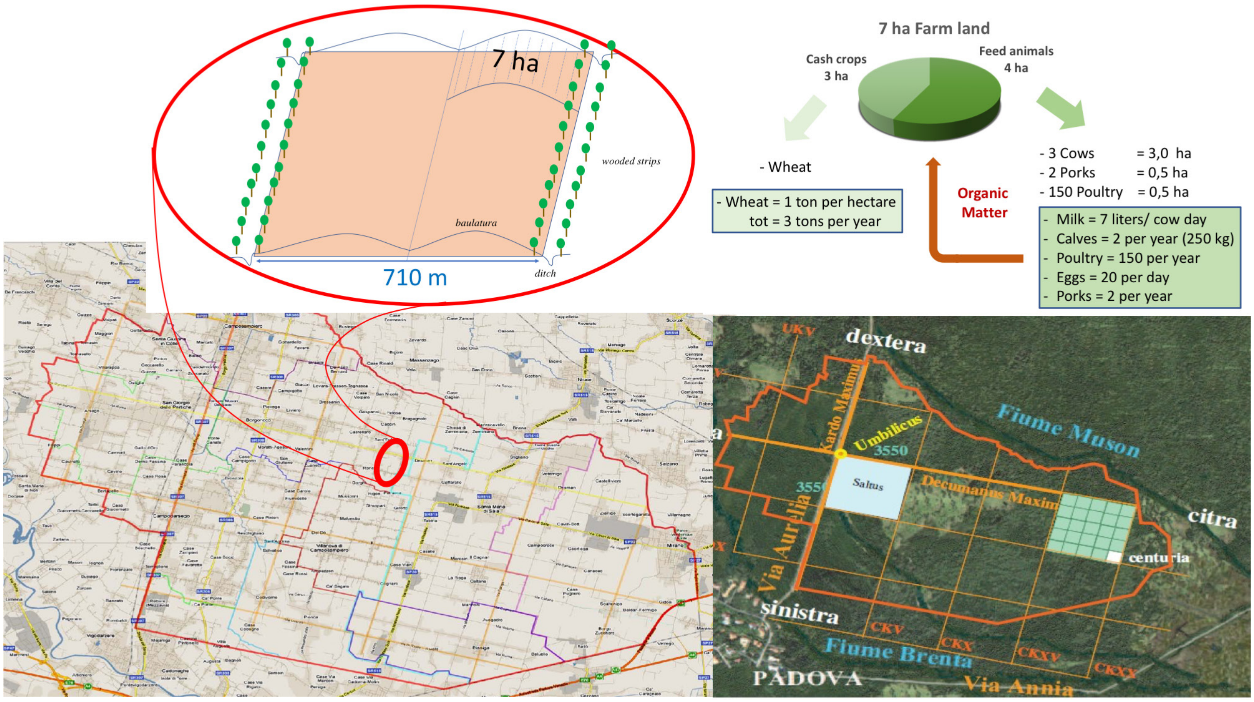


Fig. 9. Shape of the Roman Centuriation, with ridges (Baulatura) in each field, border channels and tree protection. The Graticolato romano (literally Roman broiler, grate) is visible even in present times with Google Earth. An example of a traditional (1947) farm system of 7 ha is reported at the top of the figure, alongside its production

quired a lot of manpower, it also provided satisfaction. Every family had its own land and took care of it as its only means of making a living. They took great care to maintain a good level of organic matter in the soil and to rotate uses in order to preserve soil fertility.

In 1947 every family owned an average area of 5–7 ha (50,000–70,000 m^2). The average family consisted of two parents with four or five children. Each family owned two or three cows, one or two pigs, and poultry such as chickens, geese and ducks, and rabbits (Fig. 9).

Of the seven hectares, four were used to feed the animals and three were planted with wheat to be sold on the market. There were no chemical fertilisers, so all the organic matter produced was used for field fertilisation. The three cows produced an average of seven litres of milk per cow per day and two calves per year. Of two pigs, one would be for domestic consumption, and one sold, increasing the family income. There were about 20 chickens producing 20 eggs per day – five for domestic consumption and 15 sold on the market or exchanged against other food. Of the 150 poultry and rabbits, 50 were annually sold. The main customers were Venice citizens.

Using the tables proposed by Moscufo and De Martinis (2017), we calculated the annual gross domestic product (GDP) of a traditional farm, adjusting the 1947 prices for inflation, change of currency and goods value (Table 1). It is interesting to note that the adjusted prices of the various raw products paid to the farmer are similar to the prices of currently processed organic products paid by consumers. For instance, the price of wheat paid to the producer in 1947 is similar to the price of organic flour for the modern consumer, or the 1947 price of a live chicken to the farmer is the price of a processed organic chicken for today's consumer. The data on current prices were collected from a sample of organic food shops.

In those years the skills to process the products were probably widespread among the population; everyone knew how to slaughter a pig or a chicken; furthermore, there were not the sanitary restrictions so the difference between the producer price and the consumer final price was minimal.

The simulation shows an annual GDP of €18,600, equal to €2,650 per hectare.

In a traditional farm there were no exogenous explicit costs, only family labour. Other inputs, such as wheat seeds and organic matter, were self-produced.

Table 2 reports a comparison between the inflation-adjusted price of farm products in 1947 and the current price of products of present-day organic farms.

These prices are astonishingly similar, but 1947 prices refer to raw material at producer level, while present-days prices refer to products processed at consumer level. For instance, wheat seeds cost 0.89 €/kg in 1947; meanwhile, today's organic wheat flour costs 1.30 €/kg, but the price of flour has to also cover processing costs.

Currently, in a farm of 7 hectares, assuming it is intensely cultivated with a double harvest of corn and wheat (an improbable situation), the annual GDP would be about 9,300 €/year, equal to 1,300 €/hectare (Table 3). Adding a Common Agricultural Policy (CAP) contribution of 600 €/ha, with a GDP of 13,500 €/ha corresponding to 1,900 €/ha, the current farm is less competitive than the traditional one.

We calculated how much area a current farm should add to reach the economic performance of a traditional farm. Without CAP subsidies, to reach an equivalent income a current farm needs two times the past surface (+104%); with subsidies, an increase of 40% of cultivated area is sufficient. However, there is no more land available in the area and the only way to match the economic performance of the traditional farm is to increase product prices. Without CAP subsidies and maintaining the current yields, the prices of wheat and corn should increase by 44% and 57%, respectively.

Currently, the prices are 18 €/100 kg for wheat and 14 €/100 kg for corn. The same economic performance is obtained by a present-day organic farm with prices of 26 €/100 kg for wheat and of 22 €/100 kg for corn. Taking into account CAP subsidies, an equal economic performance is obtained with a price 22% higher for wheat and 29% higher for corn.

Also, assuming the current farm is rented, to gain the same GDP of the traditional farm the rent should be 1,850 €/ha, which is €1,000 higher than the average rent paid currently in the area of 800 €/ha.

Table 1. A simulation of the annual gross domestic product (GDP), which is a monetary measure of the market value of all final goods and services produced by a traditional family farm with 7 hectares of arable land in 1947

Product	Total quantity	Domestic consumption	Sold products	1947 Price*	Actualized Price**	Value
Wheat	3000 kg	0	3000 kg	4500 £/100 kg	89 €/100 kg	2600 €/year
Milk	7560 liters	1440 liters	6120 liters	40 £/liter	0,79 €/liter	4800 €/year
Calves	2	0	2 (500 kg)	600 £/kg	11,90 €/kg	5900 €/year
Poultry	150	100	50 (75 kg)	500 £/kg	9,90 €/kg	700 €/year
Eggs	15	5	10	35 £/egg	0,69 €/egg	2400 €/year
Pork	2	1	1 (150 kg)	750 £/kg	14,90 €/kg	2200 €/year
Corn	0	0	0	0	0	0
Total						18.600 €/year
GDP/ha						2.650 €/ha

*Istat 1953

**Moscufo and De Martinis 2017

Table 2. Comparison between adjusted price to producer and current organic product price to consumer

Product	Actualized price (1947)*	Organic price products (2017)	Product
Wheat	0,89 €/kg	1,30 €/kg	Organic wheat flour
Milk	0,79 €/liter	1,20 €/liter	Organic milk
Calve	11,90 €/kg	16 €/kg	Organic beef
Chicken	9,90 €/kg	10,50 €/kg	Organic Chicken
Eggs	0,69 €/egg	0,60 €/egg	Organic Egg

*Moscufo and De Martinis 2017

Table 3. Annual GDP produced currently by a farm of the same surface of 7 hectares

Product	Total quantity	Domestic consumption	Sold products	Current Price	Value	Direct Costs	Gross Margin
Wheat	49.000 kg	0	49.000 kg	18 €/100 kg	8800 €/year	3500 €/year	5.300 €/year
Corn	70.000 kg	0	70.000 kg	14 €/100 kg	9800 €/year	5800 €/year	4.000 €/year
Total							9.300 €/year
GDP/ha							1.300 €/ha
Cap subsides					600 €/ha		4.200 €/year
Total							**13.500 €/year**
GDP/ha							**1.900 €/ha**

Note: When speaking of sustainable development, things are not so simple. Economic balance sheets are one thing, but sustainable development should also be ascertained from a demographic point of view (Dahan and Tsiddon 1998). Can the population of a farm, a village or a region be sustained over successive generations? If some members of a family are forced to leave the farm, the village or the region to live, whether themselves or their family, can we speak of "sustainable development"? Clearly, when the number of children is in excess of three [the number currently known to ensure the maintenance of a population after the advent of mass vaccination and infancy protection at the end of the Second World War (Mclanahan 2004), it means that emigration (not only overseas but just out of the "terroir") is mandatory to ensure the maintenance of a family. The reproduction ratio is not a regional problem, because human development has from the beginning been based on demographic expansion. Now that we know that resources will be lacking worldwide in the near future if nothing is done (Pinstrup-Andersen and Pandya-Lorch 1998), we have to follow a new model of development, no longer based on continuous demographic expansion. This aspect is neglected by economists when they consider only revenues and expenses of farmland.

Another aspect is that children are the only resource for poor people wanting to survive in a region where new genetic resources are mandatory for the survival of the population. A low reproduction rate is not suitable for communities living in harsh conditions. The correct solution is not to prevent poor people from having numerous children but to equitably spread out resources. The reproduction rate imbalances between social groups is not a cause but a consequence of poverty. If we were able to understand that natural resources are a common inheritance it would mean that all of us had become more civilised and cultivated.

What destroyed the "traditional agriculture" is the new model of life which came after World War Two and was diffused via television. When people see that other humans live better than they do, that other people have well-made houses with a bath and a kitchen, that other people have money to spend on clothes and even holidays, that children can go to school and have enough to eat, the only thing they want is to imitate these people. If they do not have money, they will migrate. If they have money, they will buy things and become like those people who live well. This is exactly what is going on even in the present day. The primary source of the force that moves people is now the information spread all over the world by the Internet.

Conclusions

On one side, conclusions are related to a new concept of soil; on the other they depend on a new and more sustainable organisation of the relationships between the producers and consumers of essential goods.

A new concept of soil

Soil is not a substrate or a source of nutrients. It is a living matrix that sustains the functioning of every ecosystem. It works like an efficient bank. It capitalises energy and nutrients to be delivered for building and sustaining more complex and efficient ecosystems. It is a source of new materials, continuously generated from biodegradation and re-elaboration of dead structures. Here are some points that may support this new concept of soil:

- The prebiotic soup (with the meaning given by Bada and Lazcano 2002; Cleaves et al. 2008) was a primordial soil. Even further: the primordial soup (at least the intergalactic part of it) is still influencing the today soil and life evolution on planet Earth.

- We are living in a cloud of microorganisms. They are connected to the soil. We evolve with them. Global change is occurring/acting at all spatial and time scales, even at the level of microorganisms.

- Soil has properties related more to its physical structure than to its chemical composition. Soil structure is made by living organisms. Successfully and sustainably managing the soil for furnishing healthy food and water to an increasing human population presupposes preserving its biodiversity and physical structure.

- Soil changes according to the main biomes of our planet. We suggest looking at the soil in relationship with the main geological plates (Fig. 10), because it evolved on each plate with the supported ecosystems. For a better idea, 1) living organisms are determined by their intracellular functional DNA (the functional DNA of each single cell interacts with its intra- and extracellular environment); 2) organisms evolving in a cloud of organic particles under degradation, composed of parts of dead organisms (even DNA), lying in litter or circulating in the air and water pushed by physical and biological vectors; 3) like a language, organic matter (even DNA) under degradation represents a code diffused all over planet Earth in "particles". We still do not know how far this "organic matter" is interfering with the process of evolution; we still do not know the exact role of these particles within the process of speciation: are better adapted organisms those that better integrate this universal language in their DNA?

- Agricultural soils are simplified (degenerated) natural soil systems. To recover their lost functionality, we have to look at and learn from equivalent natural soils that have still not lost their biological, physical and chemical attributes.

- For discriminating natural humipedons, and making reference to standardised units, we suggest using TerrHum, an iPhone application freely avail-

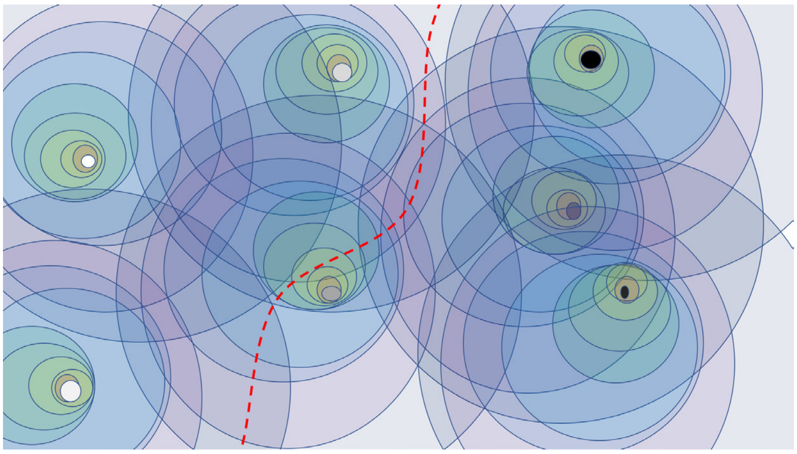


Fig. 10. Brainstorming: Soil as particles of organic matter (even DNA) wandering among living organisms. A red dashed line dividing two geological plates, individuals as black dots gradually changing into white dots (as a response to an ecological continuum between different environments), evolving in waves of DNA under degradation

able in the Apple Store, in order to standardise topsoil classification on a worldwide scale.

- For a detailed description of these concepts and for a helpful practical guide to field investigations, see: Special Issues Humusica, volume 1 (https://www.sciencedirect.com/journal/applied-soil-ecology/vol/122/part/P1), e.g. articles 1 to 8 (forest non-submerged humipedons) and volume 2 (https://www.sciencedirect.com/journal/applied-soil-ecology/vol/122/part/P2), e.g. articles 9 to 12 (submerged humipedons); article 13 (less common humipedons); and articles 14 to 19 (urban and agricultural humipedons).
- Special Issue Humusica, volume 3: more than 70 articles (reviews, applied field research articles, and short communications) about soil functioning and field experiments with a living soil. This volume is in press.

Essential goods

The consumer plays a fundamental role in promoting the diffusion of sustainable agriculture. However, it is not enough to consume organic products to be a reasonable “sustainable consumer”. For example, eating only breast of organic chicken (which is usually the case in a modern society), can lead to a system that is less sustainable than consuming all parts of a conventionally produced chicken.

Organic chicken production requires a longer cycle – at least 90–100 days, compared to 50–60 days for a conventional chicken, and requires more natural resources, such as water, cereals, etc. To produce organic chickens and sell only the breast at a higher price (€18–20 per kg) is a very inefficient process from an ecological point of view. The same reasoning applies to the consumption of beef, which is not made only of Florentine steaks.

To make the process more sustainable, all parts of the animals should be consumed, and sold at a fairer averaged price. In this work, we tried to quantify this “fairer price” by adjusting the historical price of agriculture from 1947, which ultimately looked more “organic and sustainable” than present-day organic farming practices. Currently, to try to replicate that “old but efficient” model, we have to follow two paths:

a) increasing the cultivated surface per farm, and technologically-new vertical farms could be a solution, even if not in the short term, or

b) raising the prices of products all over the world in a coordinated economy. Can consumers accept paying a higher price for food, water, and other necessities in order to provide adequate incomes to farmers/producers and preserve the environment?

Building a better life for humans on planet Earth means being able to change humans’ way of life. Consumers have to become aware of the real costs of food and water and the means of spreading a human experience that is sustainable (i.e., in a healthy environment). It is necessary to act consciously as human beings who belong to one humanity and are exploiting the limited resources of a shared planet. It is never feasible to impose such projects. In fact,

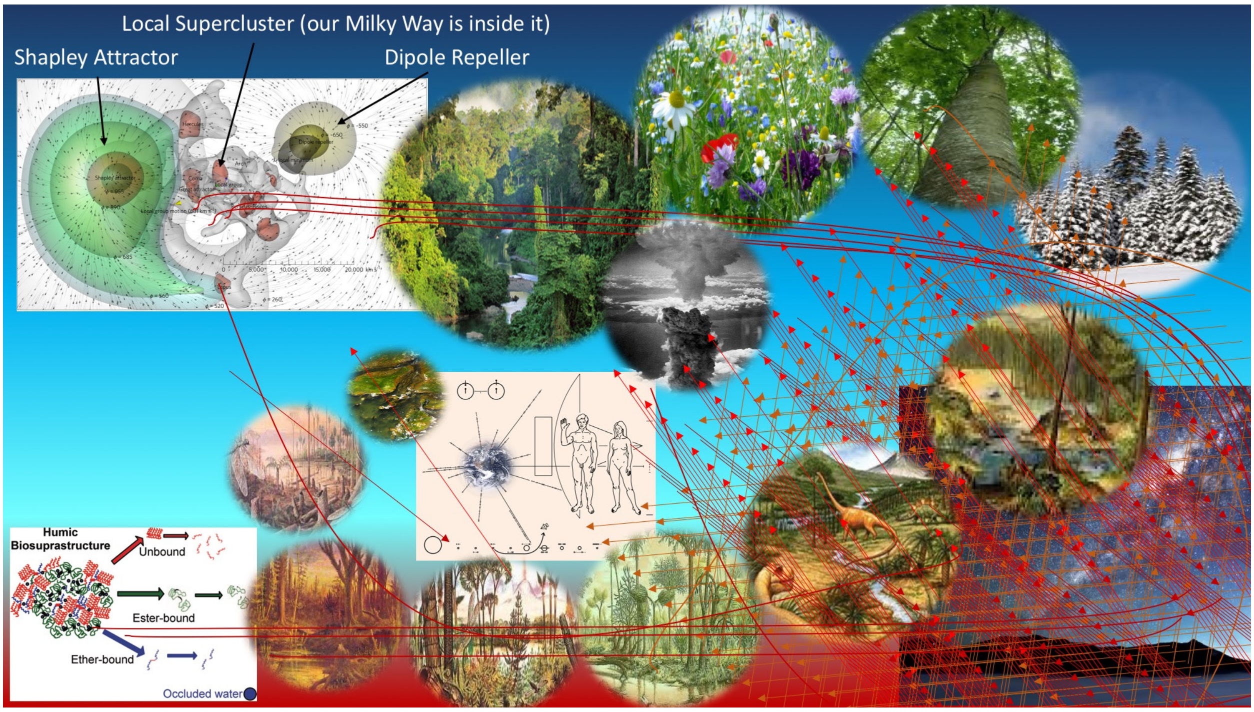


Fig. 11. Planet Earth evolution. From Zanella (2018), background modified. Bottom left, a humic molecule made of smaller organic molecules following confirmed discoveries about the structure of soil organic matter (Nannipieri et al. 1996; Piccolo and Mbagwu 1999; Piccolo and Stevenson 1982; Stevenson 1983); top left, the Dipole Repeller which is involved in the evolution of our galaxy (Hoffman et al. 2017); the central part of the figure is made of pictures representing the evolution of planet Earth from a starting point on the left (top-left corner of the panel that NASA sent into space in 1972: we wanted to speak with extra-terrestrial life, giving our position in the Milky Way and in the solar system). In the centre of the picture the Hiroshima atomic bomb, as a warning. Many figures have been rooted out from the Internet. This figure is used in the first of the petitions listed above

in a well-organised democratic society, the move should start from the bottom as a cultural phenomenon, as a sign of having reached a high level of civilisation. Three original petitions are promoting such a long-term effort with the help of the Internet (Fig. 11):

a) ask world citizens to agree to stop climate warming:

https://secure.avaaz.org/it/petition/Toshiro_Muto_Tokyo_Organising_Committee_of_the_Olympic_Games_2020_As_planet_Earth_citizens_will_you_stop_the_climate_fro

b) in search of additional resources, ask world citizens to agree to abandon at least the building of atomic bombs:

https://secure.avaaz.org/en/petition/Tony_Estanguet_President_of_the_Organizing_Committee_of_the_Olympic_Games_Ban_nuclear_weapons_from_the_planet_Earth/

c) and finally begin to build new globally valid civil and penal codes:

https://secure.avaaz.org/en/petition/All_humans_Should_we_act_as_members_of_a_real_single_Humanity/edit/

Notice that at a cursory glance, the three campaigns do not appear to be connected to one another.

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