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Editorial

Innovative Organic and Regenerative Agricultural Production

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Over the last 50 years, global agricultural food production has become increasingly dependent on the use of non-renewable and/or scarce resources, and, in particular, fossil fuel (e.g., for the production of mineral N-fertilizer and pesticides), mined minerals used as P and K fertilizers, and water used for irrigation. The costs of these inputs have increased more rapidly than farm gate prices, and this is thought to have a negative impact on farm incomes, crop yields, and food security [1–3]. There is also mounting evidence that the increased use of agrochemical inputs has had a negative impact on (i) soil and crop health; (ii) the nutritional quality of foods; and (iii) biodiversity, resource use efficiency, and the overall carbon footprint of food production [3–7].

Organic farming standards prohibit the use of all synthetic chemical N, P, and KCl fertilizers and pesticides because these inputs are thought to have negative side effects on soil, crop, and human health; biodiversity/natural resources; and the environment [3–7]. In contrast, non-organic, regenerative farming protocols aim to optimize and reduce the use of agrochemicals, but permit the use of most mineral NPK and synthetic chemical fertilizer products which are developed for and widely used in intensive conventional farming practices [8]. As a result, the inputs of mineral fertilizer and pesticides are thought to be substantially higher on farms using non-organic, regenerative farming protocols, while minimizing soil tillage is often a major challenge in organic farming systems due to the prohibition of the use of herbicides [3,8].

Both organic and non-organic regenerative farming systems prescribe or promote integrated soil, crop, and livestock management protocols that include: (i) the use of resistant and weed-competitive varieties, (ii) botanically diverse rotations that include N-fixing legume crops, (iii) regular inputs of animal manure and/or organic waste-based composts, (iv) the conservation and establishment of areas (green infrastructure) of biodiversity on farms, (v) minimum tillage, (vi) minimizing periods in which soil is not covered by vegetation (e.g., via the use of inter-, companion, and/or cover crops) and (vii) the integration of crop and outdoor grazing- or foraging-based livestock production systems [3,6–8]. However, it is important to highlight that organic farms have to be certified to legally binding farming standards (which includes regular farm visits/controls by licensed certification bodies/companies) to sell their products as organic, while there are currently no legally binding standards for regenerative farming systems [3,8].

Regenerative agriculture is, therefore, more difficult to define. For example, a recent report by Magistrali et al. [8] described that (i) "*there is currently no legal or regulatory definition of the term regenerative agriculture*", (ii) "*it* (= regenerative agriculture) *is commonly used as an umbrella term that includes a wide range of field operations and philosophical approaches which focus on two key deliverables: restoration of soil health (including the capture of carbon) and reversal of biodiversity loss*". Based on the perspective on regenerative agriculture published by Giller et al. [9], they, thus, defined regenerative agriculture as: *"farming systems and field operations that minimise soil disturbance, use diverse rotations and cover crops, and integrate*

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grazing livestock, to reduce GHG emissions, build soil C, improve soil health and biology, enhance farm-scale nutrient use efficiency (NUE) and promote biodiversity and the ecosystem services that flow from it" [8].

There is increasing evidence that organic farming systems deliver substantial environmental, biodiversity, and food quality and safety gains [3–5,7,10]. In addition, the soil quality, environmental, and biodiversity benefits of the core agronomic strategies/approaches promoted by both the organic and non-organic regenerative farming sectors (diverse rotations, cover crops, minimum tillage, integration of grazing livestock into crop production systems) are well documented [3,11–17]. The logical framework for regenerative, organic farming systems has recently been reviewed [3], and an updated graphical presentation is provided in Figure 1.

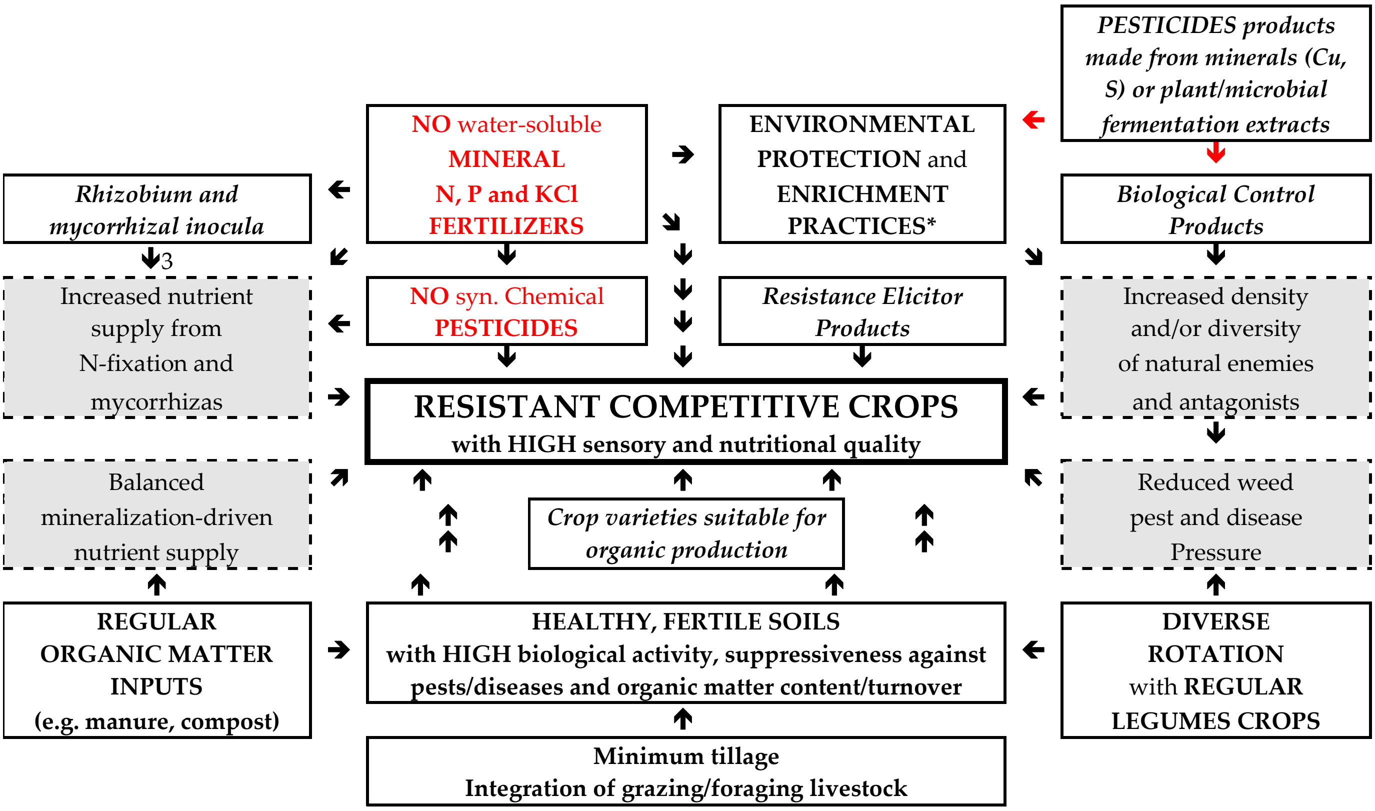

Figure 1. Logical framework for regenerative, organic crop production systems (revised from Rempelos et al. [3]). Black text on a white background describes inputs and practices permitted in organic farming; black text in boxes with grey backgrounds surrounded by dotted lines indicate an agronomically desirable effect of permitted inputs and practices or the non-use of agrochemicals; black text in boxes with white backgrounds surrounded by solid lines describes agronomic practices permitted and/or recommended in organic farming; and red text in boxes with white backgrounds surrounded by solid black lines describes inputs that are prohibited in organic farming, but are permitted and widely used in non-organic, regenerative crop production systems. Black arrows indicate desirable impacts; red arrows indicate undesirable impacts. * This includes non-cropped field margins, beetle banks, hedges, ground cover/inter-crops, and agroforestry methods.

Major "milestone" studies which have demonstrated the soil health benefits of regenerative, organic/biodynamic production protocols are listed in Table 1. It important to note that our current estimates of soil health and environmental benefits from regenerative, organic management practices are based on data from a relatively small number of long-term field experiments [3] (Table 1).

Table 1. Milestone studies which have demonstrated the soil health benefits of regenerative organic/biodynamic production protocols.

Study Type (Trial Name)	Main Agronomic Parameter(s) Studied • Soil Health Parameters Studied	References
Farm survey	**Long term biodynamic farming** • soil physical, biological, and chemical soil properties • loss of top soil	[18]
Field trial (Rodale trial)	**Long term organic farming** **Rotation design, tillage, regular manure inputs** • weed–crop competition • soil fertility indicators and organic matter content • microbial biomass and biological activity biomass	[19,20]
Field trial (DOK-trial)	**Long-term organic farming** **Regular manure/composted manure inputs** • soil fertility and biodiversity • soil organic matter; biological soil quality indicators • nutrient use efficiency; mycorrhizal root colonization • soil-derived greenhouse gas emissions	[21–24]
Field trial	**Reduced tillage** • soil microbial biomass and dehydrogenase activity • earthworm density and biomass • soil organic carbon and nutrient budgets	[25,26]
Field trial (NFSC-trial)	**Long-term organic farming** **Rotation design, crop protection, fertilization, tillage** • Diversity of total and N-fixing bacteria in soil • Soil invertebrate and natural enemy activity and biodiversity • Weed competition; soil pests and disease pressure • Greenhouse gas emissions (life cycle analysis)	[27–35]
Field trial	**Rotational grazing; rotation design** • Soil fertility parameters and enzymatic activity	[36]
Literature review	**Reduced tillage** • soil organic carbon stocks • climate change mitigation potential	[37]
Modeling study	**Organic farming** • greenhouse gas emissions from food production	[38]

Although many of the desirable impacts of specific agronomic practices shown in Figure 1 are well documented (see Table 1), Rempelos et al. [3] describe that there are few studies in which the relative effects of (and interactions between) different agronomic parameters (e.g., rotation, tillage, fertilization, and crop protection) used in organic and regenerative farming were investigated. In addition, there are very few studies in which the relative importance of (and interactions between) environmental, crop genetic, and agronomic factors was investigated [3,35,39–41]. However, such data are thought to be essential for the development of strategies that can mitigate the negative impacts of global climate change [18,19,37,38].

Regenerative and organic production methods generate very different soil physical, chemical, and biological background conditions compared with intensive farming systems [39,40]. As a result, there is an urgent need to develop/select crop genotypes that are suitable for regenerative, low-input, and organic production systems [39,40]. This need has been or is currently being addressed by a range of European Union-funded projects, including Blight-MOP, ECOBREED, HealthyMinorCereals, LIVESEEDS/LIVESEEDLING, NUE-crops, and QLIF; see Table 2 for the website addresses, reference lists, and selected key publications for these projects.

The first EU projects focused on breeding/selecting varieties suitable for organic and regenerative farming systems targeted at the broad-acre arable crops, including potato (Blight-MOP, NUE-crops, ECOBREED), cereals (QLIF, NUE-crops, HealthyMinorCereals), and oil seed rape (NUE-crops) (Table 2). For example, studies carried out in the QLIF, NUE-crops, and HealthyMinorCereals projects showed that modern short-straw wheat varieties lack (i) the weed competitiveness, (ii) the disease resistance, (iii) the resource use efficiency, and (iv) the processing and nutritional quality traits required for optimum performance in regenerative/organic systems [39]. In contrast, older/traditional wheat species (e.g., spelt) or varieties and cultivars/populations developed and selected for the organic sectors were reported to outperform modern wheat varieties when grown in regenerative, organic farming systems [3,39–41]. Similarly, the Blight-MOP, NUE-crops, and QLIF projects demonstrated that the breeding/selection of more late-blight resistant and nutrient-use-efficient cultivars should be a major target for the regenerative, low-input, and organic farming sector [3,35,42–44].

The more recent BRESOV, ECOBREED, and HARNESSTOM projects focused on the development of broccoli, snap bean, tomato, wheat, buckwheat, potato, and soybean varieties for the organic sector (Table 2), while the LIVESEEDS and LIVESEEDING projects provide a platform focused on supporting and expanding crop breeding, variety selection, and seed production for the organic, low-input, and regenerative farming sector in Europe. Deliverables from these projects are expected to greatly improve the performance and competitiveness of regenerative and organic farming systems (Table 2).

It is important to note that the European Union has also supported research focused on breeding livestock for outdoor grazing/foraging-based regenerative, low-input, and organic production systems. This includes the R&D projects LowInputBreeds, (https://www.lowinputbreeds.org/home.html, accessed on 1 April 2023), GENTORE (https://www.gentore.eu/project.html, accessed on 1 April 2023), ERA-NETSUSAN (https://era-susan.eu/funded-projects, accessed on 1 April 2023), Animal Future, https://www.animalfuture.eu/, accessed on 1 April 2023), and the Farm Animal Breeding and Reproduction Technology Platform (https://www.fabretp.eu/eu-projects.html, (accessed on 1 April 2023). Since the (re-)integration of grazing livestock to support weed, pest, disease, and fertility management in crop production is a critical component of re-generative farming systems, the breeding/selection of robust livestock breeds suitable for such systems has gained renewed importance (e.g., https://www.lowinputbreeds.org/publications/lib-technical-notes.html, accessed on 1 April 2023; https://www.lowinputbreeds.org/publications/organic-eprints.html, (accessed on 1 April 2023)).

Table 2. EU-funded projects focused on breeding/selecting crop genotypes suitable for organic and regenerative production systems.

Project Acronym (Crops Targeted)	Website	Reference Lists and Selected Publications
Blight-MOP (potato)	https://cordis.europa.eu/project/id/QLK5-CT-2000-01065 (accessed on 1 April 2023)	Speiser et al. [41], Wilcockson et al. [42], Ghorbani et al. [45], Hospers-Brands et al. [46], Flier at al. [47]
BRESOV (broccoli, snap bean, tomato)	https://bresov.eu/ (accessed on 1 April 2023)	https://bresov.eu/publications/scientifc-publications;Tripodi et al. [48], Menga et al. [49], Treccarichi et al. [50], Ben Ammar et al. [51], Scuderi et al. [52]
ECOBREED (soybean, potato, wheat, buckwheat)	https://ecobreed.eu/ (accessed on 1 April 2023)	https://ecobreed.eu/outcomes/publications/;Vollmann et al. [53], Urbanavičiūtė et al. [54], Zhao et al. [55], Miljaković et al. [56], Praprotnik et al. [57]
HARNESSTOM (tomato)	http://harnesstom.eu/en/index.html (accessed on 1 April 2023)	https://cordis.europa.eu/project/id/101000716/results (accessed on 1 April 2023); Blanca et al. [58], Hu et al. [59], Gonzalo et al. [60,61], Bineau [62], Asins et al. [63]
HealthyMinorCerals (spelt, einkorn and emmer wheat, rye, oat)	https://healthyminorcereals.eu/ (accessed on 1 April 2023)	https://healthyminorcereals.eu/en/publications (accessed on 1 April 2023); Rempelos et al. [39], Magistrali et al. [64], Wang et al. [65,66], Tupits et al. [67]
LIVESEED **LIVESEEDING**	https://www.liveseed.eu/ (accessed on 1 April 2023) https://liveseeding.eu/ (accessed on 1 April 2023)	https://www.liveseed.eu/tools-for-practitioners/ (accessed on 1 April 2023) https://www.liveseed.eu/synthesis-of-the-projects-results/(accessed on 1 April 2023)
NUE-crops (maize, oil seed rape, barley, wheat, potato)	https://cordis.europa.eu/project/id/222645/reporting (accessed on 1 April 2023)	https://cordis.europa.eu/project/id/222645/results (accessed on 1 April 2023); Rempelos et al. [40,44], Miersch et al. [68], Li et al. [69], Qi et al. [70]
QLIF (wheat, potato)	https://cordis.europa.eu/project/id/506358/reporting (accessed on 1 April 2023)	https://orgprints.org/view/projects/eu-qlif.html (accessed on 1 April 2023); Rempelos et al. [3,39], Eyre et al. [27–29], Cooper et al. [30], Orr et al. [31,32], Wilkinson et al. [41], Palmer et al. [43]

Interestingly, both crop and livestock breeding/selection studies have identified significant nutrition–genotype interactions, not only for yield, but also for quality parameters relevant to human health, including (i) protein, phenolic, and mineral concentrations in wheat [3,39–41] and (ii) omega-3 concentrations in bovine milk [71]. It will be important to further explore crop/livestock management–genotype interactions, since optimizing the nutritional composition of foods from organic and regenerative production systems may allow farmers to achieve a price premium in the market [3].

However, there remain significant challenges which currently prevent the more widespread implementation of regenerative and organic farming practices. Challenges include (i) the lower yield and/or higher production costs in many organic, regenerative farming systems and (ii) reliance on agrochemical inputs in non-organic, regenerative systems [3,8–10,72]. In addition, most of the information on organic and regenerative production systems is from temperate regions in developed countries in Europe and North America, although some information from semi-arid regions in the Mediterranean, North America, and Australia is also available [3,72–76]. More recently, the failure to explore the critical role of water when investigating the benefits of regenerative agricultural practices has also been highlighted [76,77].

The topic collection on Innovative organic and regenerative agricultural production systems therefore aims to provide a platform for the dissemination of research into the design, development, improvement, optimization, and implementation of regenerative and organic farming systems. This will include studies aimed at:

- Assessing/comparing contrasting soil, crop, and farm management practices/systems;
- Further improving soil health, crop yields, yield stability, energy and resource use efficiency, biodiversity, food quality, and safety;
- Further reduce negative environmental impacts and, in particular, greenhouse gas emissions and carbon footprints, in organic and regenerative agriculture;
- Development of technologies/strategies for the efficient recycling and production of precision fertilizers from domestic, communal, food processing, and farm waste;
- Studying/modeling impacts of climate change on organic and regenerative farming systems;
- Integrating or reintegrating grazing livestock into annual and perennial cropping systems;
- Developing, evaluating, and/or studying barriers to the implementation of agroforestry systems;
- Evaluating the impact of contrasting government intervention strategies designed to increase the implementation of organic and/or regenerative agriculture.

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