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One health

considerations in the International Year of Plant Health

Una sola salud

consideraciones en el Año Internacional de la Salud Vegetal

Uma só saúde

considerações no Ano Internacional da Saúde Vegetal

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Abstract

The concept of “one health” is gaining strength at a global scale. The term summarizes a notion that has been known for more than a century: human and animal health are interdependent and linked to the ecosystems in which they coexist. In the International Year of Plant Health (2020), it is crucial that the agricultural sciences call attention for the need to consider the health of plants and their microbiome as a whole within the “one health” concept, closely linked to the health of the soil, the environment, animals and humans. In the context of agroecological production based on the sustainable management of natural resources, integrated pest management has been promoted to reduce the use of pesticides and mitigate negative effects on human and environmental health. The combination of genetic resistance with cultural and biological control have contributed to achieving this goal. The management of the microbiome offers also the possibility of addressing plant nutritional issues and the continuum between environmental, plant, animal and human health. With its strategic plan and long-term vision, INIA plays an essential role in the generation of knowledge and technologies, acting in accordance to the one health approach.

Keywords: ecosystem health, food safety and security, human health, microbiome, soil health

Resumen

A nivel mundial, ha tomado fuerza el concepto de «una sola salud» (*one health*), que resume una noción conocida desde hace más de un siglo: la salud humana y animal son interdependientes y están vinculadas a los ecosistemas en los cuales coexisten. Desde las ciencias agrarias, en el Año Internacional de la Salud Vegetal, es importante señalar la necesidad de considerar la salud de las plantas y su microbioma dentro del concepto *one health*, íntimamente ligado a la salud del ambiente, el suelo, los animales y las personas. En el contexto de una producción agroecológica basada en la gestión sostenible de los recursos naturales, se ha promovido el manejo integrado de plagas para reducir el uso de plaguicidas y mitigar los efectos negativos en la salud humana y ambiental. La resistencia genética y el control cultural y biológico han contribuido a alcanzar esa meta. El manejo del microbioma permite igualmente abordar aspectos de la nutrición vegetal, contribuyendo a la salud ambiental, vegetal, animal y humana. Mediante su plan estratégico con visión de largo plazo, el INIA puede jugar un rol esencial en la generación de conocimiento y tecnologías, basando sus acciones en el enfoque de una sola salud.

Palabras clave: salud ambiental, seguridad e inocuidad alimentaria, salud humana, microbioma, salud del suelo

Resumo

O conceito de “uma só saúde” (*one health*) vem se fortalecendo globalmente. Ele resume uma noção conhecida há mais de um século: a saúde humana e a sanidade animal são interdependentes e estão vinculadas aos ecossistemas nos que coexistem. No Ano Internacional da Saúde Vegetal, é importante que as ciências agrárias salientem a necessidade de considerar a saúde das plantas e seu microbioma como parte do conceito *one Health*, intimamente ligada à saúde do solo, do ambiente, dos animais e das pessoas. No contexto de uma produção agroecológica baseada na gestão sustentável dos recursos naturais, promove-se uma abordagem integrada de pragas para reduzir o uso de praguicidas e reduzir os efeitos negativos na saúde humana e ambiental. A combinação entre a resistência genética e o controle cultural e biológico tem contribuído para alcançar esse objetivo. A gestão da microbioma também permite considerar aspectos da nutrição vegetal, contribuindo para a saúde ambiental, vegetal, animal e humana. Com seu plano estratégico e visão de longo prazo, o INIA

pode desempenhar um papel essencial na geração de conhecimento e tecnologias, com suas ações baseadas na abordagem de uma só saúde.

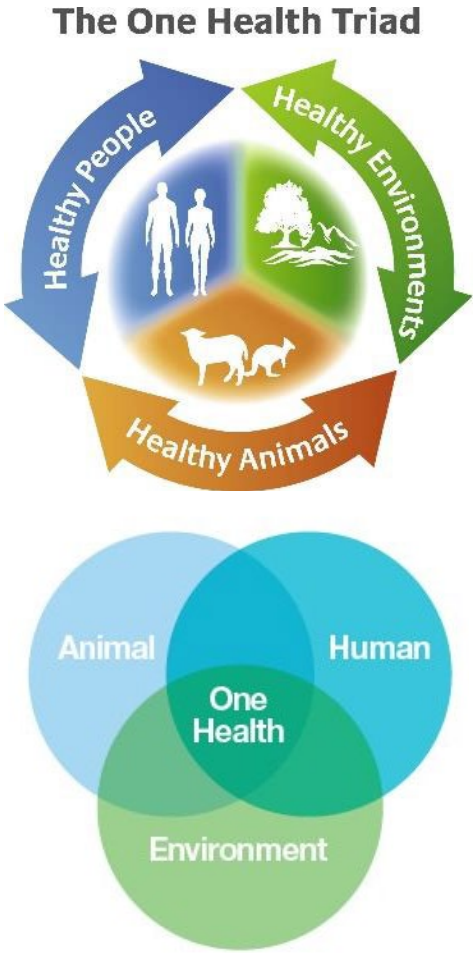
Palavras-chave: saúde ambiental, segurança e inocuidade alimentar, saúde humana, microbioma, saúde do solo

1. Introduction

The concept of "one health" is gaining strength around the world, and it has become more relevant since the emergence of Covid-19, acting as a reminder that many pandemics in human history originated from the transmission of animal pathogens to human hosts. The concept, introduced in the early 2000s, summarizes a century-old notion: human health and animal health are interdependent and bound to the health of the ecosystems in which they coexist[1][2]. The one-health approach is based on the design and implementation of programs, policies, legislation and research carried out coordinately by the different actors involved in human, animal and environmental health in order to achieve better outcomes in public health and address future challenges. It has been visually represented in different ways, always including human health, animal health, environmental health, and their interface[3] (Figure 1).

Several international organizations, including the United Nations and its various agencies —mainly the Food and Agriculture Organization (FAO), the World Health Organization (WHO), and the World Organization for Animal Health (OIE)—, have defined the concept and developed strategic plans through comprehensive approach initiatives[1][2][3]. In this context, the actions to evaluate and mitigate the risks that threaten public health established in the tripartite agreement between these organizations stand out[4][5]. This has allowed the development of global strategies and tools to ensure a harmonious and consistent approach, coordinating human, animal and environmental health policies at a global scale.

Figure 1. "One health", represented by the triad "Healthy People, Healthy Animals, Healthy Environments", is an approach in which multiple sectors work together to achieve better public health outcomes



Original source: Thompson[3]

2. International Year of Plant Health: protecting plants is protecting life

Plants and their microbiome —phytobiomes— are the basis of life on earth. Phytobiomes consist of plants, their environment, and their associated communities of organisms, which together influence plant health and productivity[6]. Plants produce the oxygen we breathe and provide the food we eat. We also use them to make clothes, shelter and medicine. Plants are a primary source of income for almost half of the Earth's population. Most countries trade plants and plant products to create wealth and support economic development. However, the importance of keeping them healthy is often not adequately addressed, which can lead to devastating results.

Plants are "custodians" of our air, our food and our environment. A threat to plant health is also a threat to the health, well-being and prosperity of people around the world, especially the most vulnerable ones. The United Nations General Assembly declared 2020 as the International Year of Plant Health[7]. This is a perfect opportunity to raise awareness on the key role of plant health care in fighting hunger, reducing poverty, contributing to health and well-being, protecting the environment and boosting economic development[8].

Resolution A/RES/73/252[7] reads: "*Noting* that healthy plants constitute the foundation for all life on Earth, as well as ecosystem functions and food security, and are key to sustaining life on Earth;
Recognizing that plant health is key to the sustainable development of agriculture to feed the growing global population by 2050;
Recognizing also that sustaining plant health protects the environment, forests and biodiversity from plant pests, addresses the effects of climate change, and supports efforts to end hunger, malnutrition and poverty and boosts economic development, and that the protection of plant health from pests is a key factor in strategies to eliminate hunger and rural poverty;
Stressing the urgent need to raise awareness of and to promote and facilitate actions towards the management of plant health in order to contribute to the implementation of the 2030 Agenda;
Trusting that the celebration of an international year would encourage actions to promote and implement activities in favour of preserving and sustaining global plant resources and raise awareness of the importance of plant health in addressing issues of global concern, including hunger, poverty and threats to the environment; […]
Decides to declare 2020 the International Year of Plant Health; […]".

Plants produce more than 80% of the food we consume (67% human consumption, 24% animal consumption, 9% industry), and are responsible for 98% of the oxygen we breathe[9]. Food security involves a multidisciplinary approach to agricultural research, natural resources management and human resources training, among other factors.

Pests and plant pathogenic microorganisms are responsible for significant losses in major food crops (wheat, rice, corn, potato, soybean)[9][10]. Without healthy plants, humans do not have healthy foods to eat. If we do not take care of the sanitary and nutritional management of crops, we will not be able to produce and supply food in sufficient and sustainable quantity and quality to feed the growing world population, to ensure the health and welfare of animals and people, and to create a more sustainable planet.

3. One Health from the agricultural sciences perspective

It is crucial that the agricultural sciences call attention to the need to consider plant health as a fundamental pillar of the one health triad (Figure 1). Plant health is closely linked to soil health, and both are influenced by the microbial communities that inhabit and affect them: the microbiome. Microbiomes have a significant impact on agricultural productivity, and they are considered the "new frontier" for achieving the sustainable and sufficient production of food, feed, and fiber to meet a global population of 9 billion projected for the year 2050[11][12]. The health of plants and crops is what sustains global food production; plants, by being the primary producers, are at the base of the food web that feeds the world[8][13]. Protecting plant health means ensuring food safety and security, which are essential for promoting

human health and well-being[13]. Proofs of this can be found in historical events such as the epidemic of late blight in potato (caused by *Phytophthora infestans*), which triggered the Irish famine in 1845 and killed millions of people[14]; or the devastation of crops and pastures caused by locusts, biblical plagues that are re-emerging with increasing frequency and voracity[15][16].

In addition to crop loss and famine, the occurrence of mycotoxins in plant-based food is another global concern that poses a challenge to food safety[17]. Contaminated food and feed products represent a major threat to human and animal health[18]. Mycotoxins are toxic secondary metabolites produced by fungi belonging mostly to the genera *Fusarium*, *Aspergillus* and *Penicillium*. They can occur in a wide variety of agricultural products (grains such as wheat, barley, corn, rice, peanuts), milling products such as cocoa and coffee, alcoholic beverages and dairy products. Toxins can be mutagens and its ingestion can induce diseases such as cancer and estrogenic, gastrointestinal, urogenital, vascular, renal and nervous disorders. Most countries have implemented regulations to limit the concentration of mycotoxins in food and feed products due to their implications for commerce and public health. National information is reported for almost every agriculturally important mycotoxin, including deoxynivalenol, trichothecenes, zearalenone, fumonisin, aflatoxin, ochratoxin and alkaloids[19][20][21][22][23][24][25].

Finally, recent studies have reported that plants can be carriers of microorganisms harmful to humans, which points at the plant environment as a reservoir of opportunistic human pathogens[26][27].

On the other hand, agricultural practices that base crop health on the exclusive use of agrochemicals imply a risk to human health from the direct or indirect exposure to residues in food [28][29][30][31]. Agrochemicals can also have a negative impact on the environment. When they affect non-target organisms or compromise the quality of watercourses and soils, they can "sicken" the agroecosystems[32][33][34][35][36][37]. This concern has led to the search for alternative strategies, based once again on the concept of one health. In the context of agroecological production based on the sustainable management of natural resources (soil, water, air, biodiversity), Integrated Pest Management (IPM) has been promoted to reduce the use of pesticides and mitigate the negative effects on human and environmental health[38][39][40][41][42]. The genetic resistance of crops to biotic and abiotic stresses[43][44][45][46] used in combination with cultural control[47][48][49] and biological control[50][51] have largely contributed to achieve this goal. However, large-scale agriculture still relies heavily on agrochemicals.

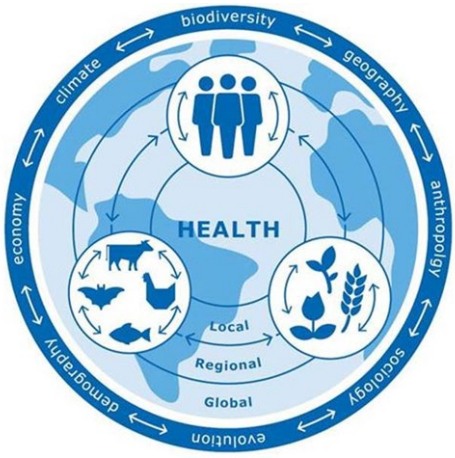
Demonstrating the effectiveness and reliability of alternative techniques to chemical pest control is one of the major challenges in the drive to increase the quality and quantity of food production, while simultaneously ensuring a sustainable ecosystem and a reasonable income for growers[52]. Recently, the concept of Agroecological Crop Protection (ACP) has gained strength, promoting the development of technologies for agroecological transitions with an ecosystemic approach at landscape and regional levels[52][53][54].

Plant health is explicitly mentioned in the definition of one health provided by the One Health Commission[55], which refers to a collaborative, multisectoral, and trans-disciplinary approach —working at local, regional, national, and global levels— to achieve optimal health and well-being outcomes, recognizing the interconnections between people, animals, plants, and their shared environment. Education and networking are promoted to improve human, animal and plant health, and support environmental resilience, through a holistic approach[55].

Wageningen University and Research (WUR) proposes the "A Global One Health" approach (Figure 2), reflecting the interconnectivity and global nature of healthcare for humans, animals, plants and the environment[56][57]. The different components of an ecosystem are connected through nutrient cycles, and the energy flows that make up the food web determine the interactions between organisms, and those organisms and the environment. This systemic approach is considered essential to preserve food security, public health and biodiversity, while mitigating the negative impact of climate change. WUR focuses on four major topics: 1. Health and infectious diseases; 2. health and the environment; 3. health and society; 4. health and food[56]. Many of humanity's health risks can be minimized

through effective interventions that provide an adequate and varied supply of food, medicines and vaccines, ensure hygiene and vector control, and promote plant protection.

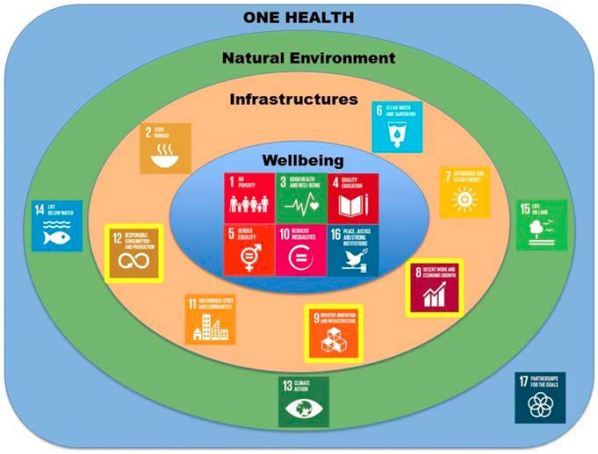
Figure 2. Representation of "Global One Health" as defined by Fresco and others[57]: the combined effort of multiple disciplines to improve the health of humans, animals and plants, within globally sustainable ecosystems, through an integrated systemic approach resulting in global and transnational policies, research and practices



Original source: Fresco and others[57]

Queenan and others[58] add an interesting insight to the Global One Health ecosystem approach proposed by WUR, arguing that human development and intervention have generated negative externalities for ecosystems, while the loss of biodiversity and ecosystem services, air and water pollution, and climate change threaten to reverse public health gains. There is a need for a change of paradigm, where it is fundamental to consider an integrated approach to the study of human, animal, plant and ecosystem health, with a socio-ecological focus[58][59]. Queenan and others[58] propose that the 17 Sustainable Development Goals of the United Nations Development Program[60] offer a unique opportunity to work on the concept of one health, analyzing and reframing its integration and interdependence[58] (Figure 3). Recognizing the interconnections between people, animals, plants and the environment, this approach promotes actions for the achievement of public health and welfare, with a long-term vision[58].

Figure 3. Reframing the Sustainable Development Goals, based on their intended outcomes[58]



Original source Queenan and others[58]

4. Research challenges in the plant health area

Each year, diseases and pests are responsible for average losses of up to 40% in global food production, costing the economy more than 220 billion dollars annually[9]. The health of forests and forested areas must also be directly addressed, as these resources provide more than 63 billion dollars in ecosystem services, such as climate regulation, waste treatment, food production and recreation[9].

With land scarcity, crop production intensification rather than area expansion becomes the primary option available to feed the world. Well-managed ecosystems are essential for ensuring a healthy resource base on which to intensify sustainably to warrant that enough food is produced.

There is a need for increased investment in research and communication capacities that focus on plant health to mitigate the damage caused by pests and diseases, and to promote the health of the soil as a source of nutrients[8][11]. It is also necessary to strengthen the training of human resources in the area of plant health, incorporating the concept of one health to the new generations.

The various actors involved —including governments, industrial sectors, civil organizations, academia, scientists and society as a whole— need to take coordinated actions. Scientific innovation should be encouraged in order to address pest threats and promote responsible practices that reduce their spread. Increased support from the public and private sectors is essential to implement more sustainable plant protection and nutrition strategies. Production systems based on genetic strategies and cultural and ecological practices for health and nutritional management should be promoted in order to mitigate the risks to human and ecosystem health associated with the use of pesticides and fertilizers[52].

Climate change, human activities, and their consequences on ecosystems directly affect plant health, reducing biodiversity and contributing to the occurrence of new or re-emerging pests. This requires a continuous effort to develop new technologies in the service of health management. Examples of successful national and regional technologies (molecular marker assisted selection, transgenesis and genome editing, simulation models, early warning systems, smart apps) are reported by Arruabarrena and others[61], Blanco and others[62], Boschi and others[63], Feingold and others[64], Leoni and others[65], Stewart and others[66], and Simeto and others[67].

Modern tools and disciplines (genetic engineering and gene editing, genomics, transcriptomics, bioinformatics, biostatistics) can be used to improve traits in crops and to select beneficial microorganisms to act as plant growth promoters or biological control agents[68][69][70][71]. The application of these tools contributes to developing cultivars resistant to diseases, pests and environmental stress, improving the quality and nutritional content of crops, increasing the efficiency of soil nutrient uptake, and enhancing sustainable crop production.

International trade and the increased movement of people also pose a threat, favoring the spread of pests and increasing the need to develop rapid diagnostic methods for their identification, and genotyping techniques for phytopathogenic strains[8][72]. As in human and animal health, prevention is much more effective than dealing with epidemics.

In Uruguay, the disciplines associated with plant health, such as phytopathology, entomology, weed science and bird pest management, have contributed significantly to prevent losses in food and feed yield, quality and safety, as well as in other areas such as forestry. Microbiology, soil biology and other disciplines associated with soil sciences and crop nutrition also contribute to the preservation of plant health and must be prioritized within the one health framework.

5. INIA's contributions to plant health and environmental health

With several national research programs, the National Institute for Agricultural Research (INIA) has made significant contributions to the study of plant and environmental health across the various disciplines in which it operates[73]. For over a century, INIA and its predecessor (Alberto Boerger Agricultural Research Center, CIAAB) have contributed to plant health by generating knowledge and providing innovative and integrated strategies and technologies that promote safe phytosanitary and nutritional management for human and animal health in an environmentally friendly manner[74]. INIA works with a multidisciplinary and inter-institutional approach to contribute to the design of resilient agricultural systems, favoring biological processes mediated by beneficial microorganisms and low external inputs[73]. This institute has made notable historical contributions by generating knowledge in the following areas[74]:

• Creation and release of cultivars with genetic resistance to diseases, pests and environmental stress in the different plant breeding programs of the institution;

• Integrated Pest Management with an ecosystemic approach, combining strategies and practices to produce healthy crops with the promotion of biological alternatives that minimize the use of pesticides and fertilizers;

• Identification of agronomic practices that minimize the incidence of diseases and pests, promoting the spatial and temporal diversity of crops and soil biodiversity through crop-pasture rotations and/or

green manure cover crops (e.g., long-term experiments);

• Strengthening disease and pest monitoring, through knowledge of predisposing conditions and risk assessment to provide early warning systems;

• Increased crop production in a sustainable manner.

INIA's National Research Programs of Rainfed Crops, Pastures and Forages, Rice, Citrus, Fruit, Horticultural and Forestry Production have developed capacities and strengths in each thematic area at regional and national levels[73]. The focal points of these programs include the genetic improvement of soybeans, wheat, barley, rice, vegetables, fruit trees, citrus, forage and forest species; the characterization of the nutraceutical potential of fruits and vegetables; the strategies for pest and disease monitoring and surveillance; the integrated pest management in extensive, intensive and forestry production systems; the biological control of pest and diseases in vegetable, fruit and forestry crops; the sanitation of varieties and rootstocks; the integrated management of weeds and their resistance to herbicides; the management of pest birds, and the nutrition of pastures and agricultural, horticultural, citrus and forestry crops.

Likewise, since the creation of the Production and Environmental Sustainability Program in 2006, INIA's research and innovation proposals have contributed to answer questions and solve problems related to sustained agricultural production and the health of natural resources —soil, water, atmosphere and biodiversity (animals, plants and microorganisms)— as the basis of our ecosystems[73]. The program has developed capacities and strengths in the following thematic areas: the design and assessment of new sustainable agricultural systems, promoting an efficient and responsible use of natural resources, soil, water, air and biodiversity; the development of biological products for agricultural use based on beneficial microorganisms; microbiome and soil health; mitigation strategies for greenhouse gas emissions and carbon footprint of production systems; water resources management, water quality and irrigation; long-term rotation platforms.

At the Bioinputs Platform (*Plataforma de Bioinsumos*), we work on the identification, characterization, bioproduction and formulation of microbial strains for their development as agricultural bioinputs, to be used in plant protection and plant nutrition. The resulting knowledge promotes more environmentally-friendly technologies that contribute to meeting the demands of world markets for safe, high-quality food with restricted use of agrochemicals. Likewise, the generation of knowledge favors agricultural interventions based on an ecological vision of the production systems[75]. The biotechnological developments contribute to biological control programs for insect pests and diseases, as well as to nutritional management programs for forestry, agricultural and forage crops[76]. The rhizosphere and soil microbial communities, as well as the endophyte microorganisms and plant symbionts, collectively called microbiome, play an essential role in maintaining soil and plant health, and therefore the health of the global ecosystem. This occurs because microorganisms play a fundamental role in the cycling of nutrients and soil fertility, and in the suppression and control of crop diseases and pests. For this reason, the focus of our work is on the microbiome, characterizing microbial diversity and the multiple functions it performs in agroecosystems (Figure 4).

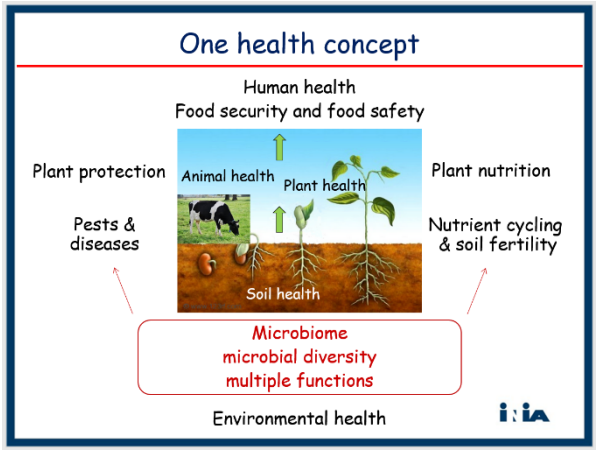
Particular emphasis has been placed on beneficial microorganisms that provide fundamental nutrients to plants, reducing the need for synthetic fertilizers. Such is the case of rhizobia that allow biological nitrogen fixation through symbiosis with leguminous plants, or bacteria that facilitate the absorption of assimilable forms of phosphorus[77][78]. In addition, work is underway to identify strains of antagonistic microorganisms and plant growth promoters (PGPR) for the development of biological pest and disease control agents, which will reduce the need for synthetic pesticides[79][80][81][82][83]. Research has determined the agricultural practices that shape soil microbiomes to optimize ecosystem services by reducing nutrient and agrochemical pollution in the environment[47][48][75].

Interactions within microbiomes have profound effects on soil, plant and agroecosystem health, which in turn impact soil fertility, crop yields, and food quality and safety[12][84]. Microbiome organisms form

complex networks that are regulated through nutrient cycling, competition, antagonism, and chemical communication mediated by a diverse array of signalling molecules[6]. An understanding of microbiome structure and functions will lead to new biological, chemical, and breeding strategies to improve crop health and productivity.

Rattan Lal, winner of the 2020 World Food Prize, has evidenced that soil health is intricately linked to human health and well-being, and thus, relates closely to the Sustainable Development Goals and is key to their achievement[84]. He clearly states that the health of soil, plants, animals, people and ecosystems is one and indivisible[84].

Figure 4. The concept of one health provides the framework for research at INIA's Bioinputs Platform (Production and Environmental Sustainability Program)



The concept of one health has been adopted at INIA as a conceptual framework in various research lines[85]. Some of the areas that benefit from working with this approach, at academic, governmental, industrial, public-policy and research levels, are: plant and microbial health; ecosystem health; microbiome and soil health; water resources health; climate change and its impacts on plant, animal, human and ecosystem health (carbon footprint, greenhouse gas emissions); natural resources management and conservation; biodiversity; food safety and security; animal health and welfare; mitigation of antibiotic resistance; education and training of new generations of one health professionals.

6. Conclusions

There is a clear and unquestionable continuum between the health of humans, animals, plants and their microbiome. The latter is a key and determining factor for environmental health and the health of the planet itself. A healthy soil with optimal ranges of physical, chemical and biological properties is a prerequisite for the production of healthy and safe food, feed, fiber, and bioenergy crops. Harvesting high-yield and high-quality crops improves farm profitability, the sustainability of production systems, the quality of life of communities and food security, thus fighting poverty and preserving public health and welfare. Demonstrating the effectiveness and reliability of alternative techniques to chemical pest control is one of the major research challenges which would greatly contribute to the health of plants and their microbiome, based on an agroecological approach at landscape and regional levels. With a strategic plan and long-term vision, INIA plays an essential role in the generation of knowledge and technologies, acting in accordance to the one health approach.

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Author contribution statement

Authors contributed equally to developing the ideas. NA wrote the manuscript, and EA revised it.

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