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Eco-Intensification of agroecosystems to realize the sustainable development goals of the United Nations

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ABSTRACT

The initiative of sustainable development by the United Nations started with the Earth Summit in Rio De Janeiro from 3-14 June 1992, and it is called the Agenda 21. This was followed by the Millennium Development Goals (MDGs) launched in 2000 and the Sustainable Development Goals (SDGs) in 2015. These development initiatives are based on four issues that emerged at the end of the 20th Century: peace, freedom, development and environment. Consequently, two common threads among these initiatives are 1) human wellbeing, and 2) nature conservation and restoration. Therefore, sustainable management of soils and agriculture must be integral to any agenda for achieving objectives of these initiatives. It is precisely in this context that the importance of eco-intensification of agriculture through adoption of regenerative agriculture cannot be over-emphasized. Thus, restoration and management of soil quality and functionality, through sequestration of soil organic carbon in the root zone and enhancement of activity and species diversity of biota, are integral to a successful transition to achieving sustainable food and agricultural systems. Restoration and sustainable management of soil health and adoption of the strategy of "producing more from less" are key to advancing SDGs of the United Nations along with achieving the target of zero net land degradation or Land Degradation Neutrality by 2030. However, the SDGs have been jeopardized and derailed by adverse impacts of the COVID-19 pandemic in both developed and developing economies.

Keywords: Sustainable Development, Eco-intensification, Regenerative Agriculture, Soil Health, Soil organic carbon sequestration, Conservation Agriculture, Land Degradation Neutrality, Sustainable Development Goals.

INTRODUCTION

The Anthropocene (Crutzen and Stoermer, 2000), driven by a growing and increasingly affluent human population with insatiable demands, has caused severe problems of land degradation (Bai *et al.,* 2008), loss and extinction of wildlife (Briggs, 2020), eutrophication of water and the problem of algal bloom (Anderson, 2009), drastic perturbation of the global carbon budget (Friedlingstein *et al.,* 2019) and the attendant change in atmospheric chemistry along with strong increase in concentration of greenhouse gases since the onset of Industrial Revolution (WMO 2019), soil erosion and transport of > 36 Pg of sediment per year (Walling, 2008, 2009) and increasing risks of soil salinity (Machado and Serralheiro, 2017). This so-called "development" has occurred at the expense of nature, often leading to conflict among people on the one hand (civil strife and political instability) and between people and nature on the other, as is exemplified by tragedy of the COVID-19 Pandemic (Lal, 2020a). Thus, four priority issues emerged at the end of the 20th century: peace, freedom, development and the environment (NRC, 1999, Robert *et al.*, 2005) (Fig.1). Sustainable development initiatives were launched by the United Nations (U.N.) at its conference in Rio de Janeiro, Brazil, in 1992 to address these four issues. It started with the Agenda 21 (1992-2000) (UNCED, 1992), followed by the Millennium Development Goals, or MDGs,

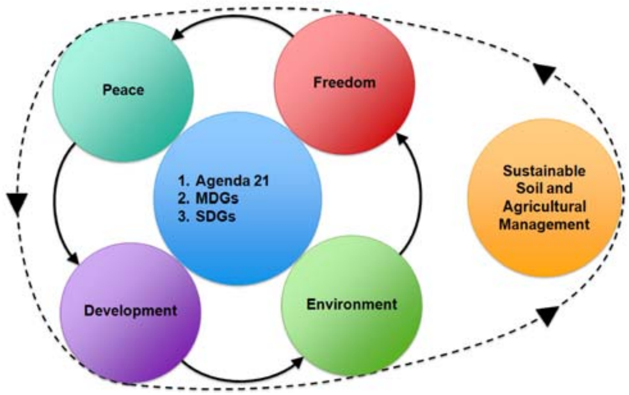

Figure 1. Addressing global issues through sustainable development

(2000-2015) (Sachs, 2012), and then the Sustainable Development Goals, or SDGs (2015-2030) (U.N., 2015). The Agenda 21 comprises a comprehensive plan of action adopted by > 178 governments at the UNCED in Rio de Janeiro (UNCED, 1992). It was a non-binding action plan, with the aim of achieving global sustainable development by urging each government to draw up its own development plan. This was followed by the Millennium Development Goals (U.N., 2000) and the Sustainable Development Goals (U.N., 2015). Major foci of three initiatives are outlined in Table 1. In addition to achieving sustainable development, there are two common goals among these three initiatives: 1) human wellbeing and 2) nature conservation and restoration. Griggs *et al.* (2013) proposed that the planetary stability must be the driving force to alleviate poverty and enhance human wellbeing. Indeed, alleviating the adverse ramifications of the Anthropocene (Crutzen and Stoermer, 2000, Steffen *et al.,* 2011) on planetary processes should be the pathway to achieving human wellbeing. In this context, triple goals of the SDGs are the following: i) managing land by respecting planetary boundaries, ii) achieving sustainable development by protecting nature, and iii) meeting the demands of the growing population while reversing degradation trends. These goals are in accord with the four issues that emerged at the end of the 20th century (Fig.1).

Similar to the Agenda 21 and MDGs, SDGs (Table 2) are also not on track to realization by 2030. This is especially the case with SDG #1 (End Poverty), #2 (Zero Hunger), #13 (Climate Action), and #15 (Life on Land and Land Degradation Neutrality), among others (U.N., 2019). Whereas the COVID-19 pandemic has been an important factor hindering this progress, the increasing risks of soil and environmental degradation are also important constraints. Over and above the adverse effects of land misuse and soil mismanagement, the risks of soil and environmental degradation are also exacerbated by the current and projected climate change, which may exacerbate the soil erosion hazard, drought, and salinization. Therefore, conversion to an appropriate land use and adoption of sustainable practices of soil/water/nutrient management are critical to putting SDGs on the right track. SDGs are also side-tracked by the adverse effects of the COVID-19 pandemic, in both developed and developing countries (Lal, 2020a, Lal *et al.*, 2020).

Sustainable management of soil and agriculture, along with restoration of degraded soils and ecosystems, must be integral to any agenda for addressing SDGs. In this context, farmers are the most important stockholders in stewardship of natural resources. Thus, farmers, both small-scale and large-scale, must be empowered and incentivized for adoption of scientifically proven technology. The

Table 1. Major focal points of these U.N. initiatives based on social, economic and environment issues.

Agenda SD-21	A Set of Eight Millennium Development Goals (MDGs)	A Set of Seventeen Sustainable Development Goals (SDGs)
Sustainable Development in the 21st Century (SD 21)	Poverty	Poverty Reduction
• Improving living standards	Hunger	Hunger Mitigation
• Better management and protection of the ecosystem	Diseases	Health and Wellness
• Bring about more prosperous future for all	Education	Nature Conservation
Gender Equality	Communication	
Environmental Degradation	Cooperation	
Climate Action	Governance	
	Anthropocene	

The common thread among all initiatives launched since 1992 is the four issues that emerged at the end of the 20th century: peace, freedom, development, and environment.

Table 2. Sustainable Development Goals by 2030 (Adapted from U.N. 2015)

SDG #	Common Pathways Roadmap	Specific Goals
1	Sustainable management of soil, water, atmosphere and other natural resources through "eco-intensification" of agroecosystems	No Poverty
2		End Hunger
3		Good Health and Wellbeing
4		Quality Education
5		Gender Equality
6		Clean Water and Sanitation
7		Affordable and Clean Energy
8		Promote Sustainable Economic Growth
9		Industry, Innovation, and Infrastructure
10		Reduced Inequalities
11		Sustainable Cities and Communities
12		Responsible Consumption and Production
13		Climate Action
14		Sustainably Use the Oceans
15		Life on Land
16		Peace, Justice, and Strong Institutions
17		Partnerships for the Goals

strategy is to optimize and sustain productivity rather than maximize it over a short period. Maximizing the productivity over a short period, while ignoring the natural resource base, can jeopardize the integrity and quality of soil and other natural resources. Therefore, the preferred strategy of optimization (rather than maximization) of productivity must be based on the concept of "producing more from less" through restoration and sustainable management of soil health by improvement of the eco-efficiency of agroecosystems.

ECO-INTENSIFICATION OF AGROECOSYSTEMS

The science of agroecology refers to the study of ecological processes under agroecosystems (YouMatter, 2020). In other words, agroecology comprises understanding of the relationships between ecological processes and agricultural production systems. Eco-intensification is a system of agricultural-production based restoration and sustainable management of soil quality and functionality (Lal, 2019a). Soil organic matter (SOM) content, a primary determinant of soil quality and functionality (Lal, 2020b), strongly impacts and is also impacted by both above and below-ground biodiversity. Thus, protection and restoration of biodiversity is of a critical importance to sustainability of agroecosystems (Power and Flecker, 2020). Furthermore, restoration and management of soil quality and functionality, along with that of biodiversity, are integral to a successful transition to sustainable food and agricultural systems. In this context, FAO (2018) outlined "The 10 Elements of Agroecology" (Fig. 2). The goal is to enhance resilience (sustainability) by improving synergies and efficiencies. The latter are achieved by strengthening biodiversity and recycling to achieve both a circular and solidarity economy. Eco-intensification is the most preferred and feasible option for bridging the

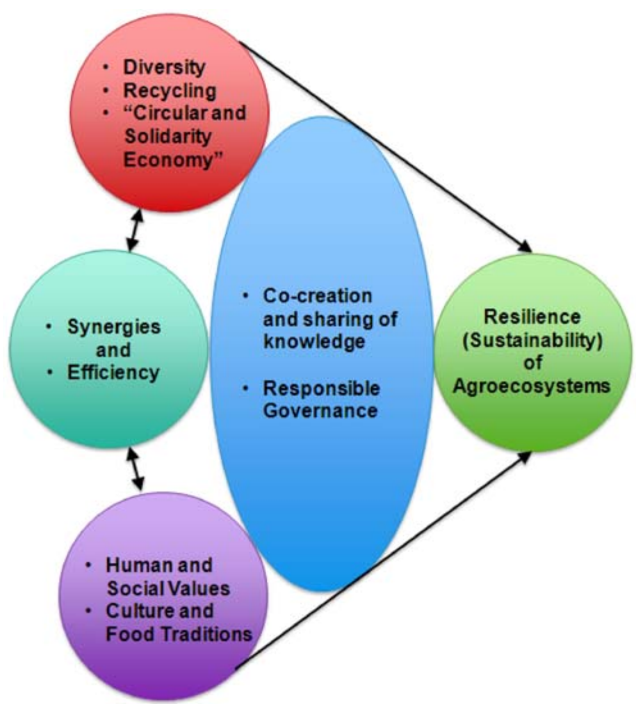

Figure 2. Achieving resilience and sustainability based on the ten elements of agroecology as outlined by FAO (2018)

gap between science and practice (Tittonell, 2014, Kleijn *et al.,* 2019) through creation and management of a safe operating space for humanity (Rockström *et al.,* 2009). Therefore, the human dimensions, social values, culture, and food traditions also play a critical role. These concepts are implemented under local, site-specific conditions through co-creation and sharing of knowledge by responsible and prudent governance. Political willpower and prudent governance are pertinent to translating the science of eco-intensification into action.

Environmental degradation, decline in soil quality, and the attendant global warming, are major threats to global food production (Wood *et al.,* 2000). The daunting challenge of agriculture in the 21st century—increasing quantity and quality of food production while reducing inputs of agrochemicals and energy (i.e., "producing more from less")—can only be met by a paradigm shift. The latter involves adoption of eco-intensification of agroecosystems, which creates numerous new possibilities. It is, indeed, the much-needed paradigm shift (Gaba *et al.,* 2014) and the need of the hour when the world is facing this pandemic crisis. However, implementation of the principles of eco-intensification involves prudent governance and strong participation of the farming community. This would comprise identification and implementation of innovative agricultural policies based on an eco-evolutionary framework to ensure long-term sustainability (Gaba *et al.,* 2014).

TRANSLATING SCIENCE INTO ACTION

There is a need for a strong communication between scientists and policy makers so that the scientific data can be translated into action. The scientific community is faced with a serious dilemma. On the one hand, scientists are frustrated because the results of their research are not being utilized. On the other hand, policymakers are seeking input and guidance from the scientific community for effectively addressing global issues, and this input is not forthcoming. Therefore, the dialogue between scientists and policy makers must be strengthened. Soil scientists must seize the moment and support policy makers in implementing issues such as "4 per Thousand" (Lal, 2020b). Critical global issues are the same as those outlined under the SDG platform (Tables 2 and 3). Policymakers from around the world have shown interest since 2010 in soil science and what it has to offer for addressing several SDGs (e.g., No Poverty, End hunger, Clean Water and Sanitation, Climate Action, Life on Land, etc.). Integration among these goals, through appropriate policy and prudent governance, are part of SDG #16 (Peace, Justice, and Strong Institutions) and SDG #17 (Partnerships for the Goals). This is the opportunity that soil scientists cannot afford to miss.

Some examples of the initiatives undertaken by policy makers include the following: i) Global Soil Week, launched by Dr. Klaus Toepfer (Germany) in 2012; ii) Global Soil Partnership, launched by FAO in 2012; iii) "4per1000," launched at COP21 in 2015 in Paris, France; iv) "Adapting African Agriculture" (AAA) initiated at COP22 in 2016 in Marrakech, Morocco; and v) the Platform for Climate Action in Agriculture (PLACA), launched in COP25 in Madrid/Santiago in 2019 (Lal, 2019b). The Land Degradation Neutrality (LDN) or zero net land degradation (Lal *et al.*, 2012) agreement launched by UNCCD (2013) is another example of the pertinent initiatives undertaken internationally (Cowie *et al.,* 2018).

Therefore, soil scientists must be proactive and reach out to policymakers for identifying and implementing appropriate policy interventions to facilitate translation of science into action towards the realization of SDGs. Targeted interventions from the scientific community are critical to alleviating poverty, ending hunger, improving water quality and renewability, adapting and mitigating climate change, and achieving LDN at the local, regional,

Table 3. The overlapping nature of Sustainable Development Goals of the United Nations (Adapted from U.N. 2015)

Category	Overlapping Sustainable Development Goals
Human Wellbeing	SDG # 1, 2, 3, 4, 5, 6, 7, 10, 11, 16
Environment Quality	SDG # 6, 13, 14, 15
Nature Conservation	SDG # 12, 13, 14, 15, 17
Education and Communication	SDG # 4, 5, 16, 17
Energy Security	SDG # 7, 9, 11, 12
Economic Development	SDG # 8, 9, 11, 12, 16, 17

national, and global scales. India has established the target of restoring 2.6 M ha of degraded lands by 2030 (UNCCD, 2019), and soil scientists must be proactive in realizing the target.

Scientists must also present their data and findings in a language that farmers can understand and relate to and policy maker find them in a politically correct composition. Promoting soil science and its application to address national and global issues (e.g., SDGs) is a high priority for soil scientists. Furthermore, soil scientists must also explore applications of pedological principles to alleviate constraints created by the COVID-19 pandemic (Lal, 2020b, Lal *et al.,* 2020). The adverse impacts of disruptions in food supply and demand chains can be mitigated through adoption of best management practices following the principles of soil science for sustainable management of pedological processes and properties. Sustainable management of soil health is important to world peace and prosperity, our common future (Lal, 2015). Being a living entity, soil also has rights to be restored, protected and managed judiciously (Lal, 2019c). Rights-of-soil or rights-of-nature must be respected.

CONCLUSIONS

Similar to the Agenda 21 and MDGs, SDGs of the U.N. are not on track to be accomplished by 2030. Disruptions in the food production and supply chains caused by the COVID-19 pandemic have also derailed the SDGs. Yet, adoption of the basic principles of soil science for improving agroecosystems can facilitate the realization of SDGs. Indeed, conversion to restorative land use and adoption of recommended management practices of soil management are critical to several SDGs, including #1 (No Poverty), #2 (End Hunger), #6 (Clean Water), #13 (Climate Action), and #15 (Life on Land). Application of soil science is critically important to achieving Land Degradation Neutrality. Similarly, SDG #16 (Peace, Justice, and Strong Institutions) and #17 (Partnerships for the Goals) necessitates understanding and application of soil science to advancing global peace and prosperity, for which soil health is important to our common future. Soil scientists must seize the moment and avail the opportunity to work with policymakers and help translate scientific knowledge into action for addressing the current and emerging global issues, and for providing a framework to protect soil so that it has a right to thrive and flourish and managed judiciously and prudently .

2020 World Food Prize laureate's answers to popular 45 questions on conservation of natural resources (*selected questions from the audience answered by Prof. Rattan Lal during the Plenary Session of the International Web-Conference on Resource Management and Biodiversity Conservation to Achieve Sustainable Development Goals, held during 11-12 September, 2020 and organized by Academy of Natural Resource Conservation and Management, Lucknow, India*)

Question/Query

1 *What are the options to retain soil C and nutrients in erosion prone soils on hilly tracts?*

Ans: The best option is to keep the ground covered by live vegetation (cover crop) or detritus material (mulch) and combine this with no-till farming. The so called "conservation agriculture" can also be done in combination with agroforestry (contour hedges of trees) and livestock (mixed farming). Together, this is called "regenerative agriculture."

2 *Can we fulfill food, fodder and fuel demands through organic farming as Government is promoting this?*

Ans: Yes, organic farming is desirable. However, long term experiments show that yield reduction of up to 20% may happen with organic farming especially during the transition period. The prudent option is judicious use of chemicals as supplements.

3 *What if we compel the farmers to convert their organic materials/manures to biochar and then apply?*

Ans: Biochar is considered as a "Negative Emission Technology" (NET). Like any other technology, it has its own pros and cons. Biochar is a feasible option when the feedstock used is biomass which does not have other uses (e.g., rice husk, coconut shells, oil palm kernels after oil extraction, byproduct of vegetable packing). Removing crop residues and leaving the ground bare is not a good option.

4 *Is microbial inoculation or use of biofertilizers at present required to enhance native microbial populations, and thereby improve efficiency of nutrients and improve soil carbon?*

Ans: Yes, microbial inoculation (e.g., Rhizobium, Mycorrhizae) are important options to enhance soil fertility. In combination with other components of integrated nutrient management (INM) options, these techniques are pertinent to reducing dependence on chemical fertilizers.

5 *Is natural farming promoting that which aims to utilize cow dung, urine, etc. for enhancing soil health?*

Ans: Mimicking nature is a useful strategy. Therefore, recycling animal waste is a good option. However, we must ensure adequate amount of nutrients available in soil to obtain an optimal crop yield. This is where INM strategy works well.

6 *How can the coastal ecosystem be managed for climate resilient agriculture?*

Ans: Vegetative buffers in coastal ecosystems are important barriers against hurricanes and oceanic intrusions. The destruction of natural barriers (e.g., Sundarban Delta) has caused problems in low lying lands.

7 *Soil tolerance limit of 5 tonnes is being considered – can this be a definite one?*

Ans: The so-called A value of 5 ton /acre per year, established in 1950-60 for the U.S. cropland in the Midwest is too high for soils of NW India. It is important that the A value is established for divergent soils, climate and farming system, and should also be based on the rate of new soil formation.

8 *Should technology and policy go hand-in-hand to stop burning of rice residues as summer rice cultivation has been reduced?*

Ans: In-field burning of crop residues must be stopped. It has adverse impacts on soil, environment, and people. Provisions must be made to provide machinery rental facilities for harvester of crop residues (close to ground level), baler, no-till seeders, and other modern equipment that can rapidly seed wheat through the wet and heavy residues of rice without burning or ploughing under the precious residues.

9 *Does neem coated and poly coated urea help in improving efficiency of nitrogenous fertilizers?*

Ans: Yes, slow-release formulations of urea and other soluble fertilizers is a good option to reduce losses of fertilizers by leaching and volatilization. Fertilizer industry must develop innovative type of fertilizers which are mostly absorbed by plants and do not volatilize nor leach out into the ground water.

10 *Whether we will be able to offset the effect to permafrost melting with regenerating vegetation or cultivation?*

Ans: Soils of the permafrost zone contain large amount of soil organic (and inorganic) carbon reserves (1500 to 1700 Pg to 3-m depth). Thawing of permafrost by global warming can aggravate risks of release of this carbon as methane and carbon dioxide along with nitrous oxide. Thus, we must do whatever we can do not to reach the tipping point (i.e., limit global warming to 2 C). Thus, finding no-C fuel sources is an urgency.

11 *In some parts of world, farmers tend to abandon agriculture and move to cities for labour and in some countries large corporate are managing agriculture. How would this influence agroecological regions.*

Ans: We must adopt agriculture which produces more from less. The objective is to save land and water for nature. Rather than 700 M ha under cereal production, we must limit the area under cereal cultivation to no more than 500 M Ha by the year 2100.The goal is to adopt recommended management practices especially by small land holders to narrow the yield gap and saving land and water for nature. Rather than horizontal expansion of land area to meet the growing demands, we must increase agronomic productivity from existing lands, and save land and water for nature.

12 *Soil and water conservation research is different in different areas of globe, and so can we have adaptive approaches for specific regions?*

Ans: Basic principles of soil and water conservation are the same (i.e., eliminate plowing, keep the soil covered, grow a cover crop during the off season, use complex cropping systems, establish vegetative contour hedges). However, the practices based on different combinations of these components differ among ecoregions and social/economic factors. Site-specific adaptation of the basic concepts is very critical. There is no one size fits all.

13 *In areas with soil sodicity, particularly in the Indo-Gangetic region, farmers prefer to sell their unproductive topsoil to brick kilns. What options do we have for checking this and how to convince the farmers against it?*

Ans: Soil is a finite and a precious resource. It has taken hundreds of thousands to millions of years for formation of the top 20 tot 30 cm layer of soil. Further, agriculture is not the only use of soil. It is a source of multiple services and functions. Removing soil for brick making must be discouraged, and alternative material to make bricks must be identified. Even if a sodic soil at present is not productive, it may be so in future with development of innovative options.

14 *What is your suggestion about future research areas for students of Masters and Doctorate degrees?*

Ans: Graduate students must be taught how to identify pertinent research themes which address the current and future issues facing humanity and the Planet Earth. The education must be "relevant to addressing societal needs." Science must serve humanity and nature. Science without humanity is a sin, so said Mahatma Gandhi. Technology without wisdom is also a sin. We must prepare graduate students to differentiate between what is relevant vs. interesting, and important vs. urgent.

15 *Does a rice-wheat system provide the scope for recharge especially in the central part of Punjab and Haryana in India?*

Ans: Northwestern states of Punjab, Haryana, Rajasthan and other are parts of desert and semi-desert ecosystems. Growing flooded rice in such a climate of high evaporative demand is a wasteful use of the finite and limited water resources. It is important to find viable alternatives to rice (pulses, millet, sorghum, corn, cotton, fruits) and rice be grown under humid climates in Northeast and Central India. If rice must be grown in Northwestern regions, it must be aerobic direct seeded and non-flooded rice. This type of cultivation may reduce rice production by 5 -10 % or more, but it will save the scarce water resources.

16 *How can India achieve sustainable development goals effectively? What are the most important measures India should include in its programmes?*

Ans: Sustainable management of soil and improved agriculture are critical to achieving several goals, such as: #1 (No Poverty), #2 (Zero Hunger), #13 (Climate Action), and #15 (Life on Land). Sustainable management of natural resources is also critical to achieving SDG # 6 (Clean Water), #8 (Sustainable Economic Growth), #10 (Reduced Inequalities) and #16 (Peace and Justice). India has a commitment to restore 2.6 M ha of degraded land by 2030, which is a part of SDG3 (15). Thus, improving agriculture is the best option to realize SDGs.

17 *How can carbon status be managed in tropical countries?*

Ans: With favorable climate for growing vegetation throughout the year, India has a vast potential to sequester atmospheric carbon dioxide as organic carbon in terrestrial biosphere (soil, trees, wetlands, degraded lands, urban lands). With a vast region under semiarid and arid region, India also has potential to sequester inorganic carbon in arid ecosystems by both biotic and abiotic processes. India must adopt policies that lead to "farming carbon "so that carbon becomes a farm commodity that can be traded as any other farm produce.

18 *How to eradicate poverty and generate employment among poor by making sustainable horticulture practices?*

Ans: India has a vast potential to improve fruit and vegetable production, flowers and ornamental plants.All of these are high value cash crops. It is important to diversify farming. Our farmers are used to growing food crops. Now that India is food self-sufficient, it is important to diversify farming and promote horticulture. However, storage, transport, packaging and industry for value addition must be developed to prolong the shelf life. This is the right time to focus on a "Horticulture Revolution."

19 *Now due to outbreak of pandemic are we able to achieve sustainability in agriculture that too with changing climatic scenario? If yes How?*

Ans: Yes, the Pandemic is a tragedy, and the attendant disruptions of transport and non-availability of labor have necessitated the need for strengthening the local food production systems. It means strengthening of urban and peri-urban agriculture based on recycling of water and nutrients brought into the cities. In addition to conventional systems, modern agriculture in green houses, glass skyscrapers and use of soil less agriculture (aquaponics, aeroponics, hydroponics, aquaculture, cyanobacteria for biomass) must be promoted. This kind of agriculture (in glass houses) is neither subject to climate change nor to insects and pathogens. This is indeed a climate smart and futuristic agriculture which does not involve soil or uses synthetic soil.

20 *To what does diet trends like veganism, keto diet, etc. effect the sustainability approach? How to deal with resource management in disaster prone areas?*

Ans: Choice of an appropriate diet is an important part of sustainability. First of all, we must reduce waste, which is estimated at 34 % for grains and as much as 50% for fruits and vegetable. Food waste is a crime against nature. Secondly, we must maintain a focus on plant-based diet. Vegetarian diet, properly balanced, is good for the health of human and that of the Planet Earth. Animal-based food can be used sparingly and prudently, with focus on fish and poultry. India should maintain its ancient diet habits and not copy western diet.

21 *How to change the mindset so that scientists start thinking for broadening knowledge base, not only for paper work*?

Ans: It goes back to the education curricula at school college and post graduate level. We must train the next generation to address the current and future issues by being original thinkers and innovators. Whatever one may choose to study, it is important to do the best you can in the same subject. I have focused on soil science all my life, and it has been very rewarding. I cannot think of anything better for my way of thinking. That goes back to upbringing and education. I was fortunate to have excellent mentors and role models.

22 *How can carbon-based nutrient management for research study be planned?*

Ans: You may recall I emphasized the need for CNPK rather than NPK. By increasing soil organic carbon in degraded and depleted soils, the rate of fertilizer needed to obtain optimal crop yield can be substantially decreased. Similarly, increasing soil organic carbon content can also reduce the need for supplemental irrigation. Therefore, increasing soil organic carbon content in the root zone is the highest priority for adopting a soil-centric strategy for agriculture in India. Farmers must be incentivized to adopt this approach through payments for ecosystem services. Some of the bad subsidies must be replaced by compensation through payments for ecosystem services (carbon sequestration, saving water, eliminating in-field burning of residues).

23 *How can land use policy in India be refined to promote sustainable agriculture?*

Ans: We must identify and implement policies which are pro-nature and pro-farmer. Policies must encourage use of soil-centric strategies (conservation agriculture, precision farming, direct seeded aerobic rice, retention of crop residue mulch, integrated nutrient management etc.). Similarly, policies must discourage in-field burning of crop residues, flood-based paddy rice, removal of topsoil for brick making etc. To do this, there must be a strong dialogue between scientists and policy makers.

24 *Whether achieving 100% organicity in Agriculture will have positive effect on food security in coming years, seeing the rising trends in population. If not, what alternatives are there to manage the natural resources efficiently at the same time without undermining the food security of the nation?*

Ans: Having access to adequate amount of a healthy food is the most basic right of all humanity. Therefore, achieving food and nutritional security for all is among the highest priorities of India and all nations of the world. With India's population of ~1.4 billion and that of the world at 7.8 billion, and growing, we must ensure food and nutritional security for all, while also restoring and sustaining environment quality. Whereas organicity of agriculture is the most ideal situation, it may not be the best fit under all biophysical and socioeconomic conditions. Yet, we must aim at producing more food from less input of chemicals and adopt the strategy of "integrated nutrient management" (INM). The latter is based on a judicious combination of organic and inorganic sources of nutrients. When used discriminately and based on scientific concepts, supplemental use of chemicals can help accomplish the targeted yield without jeopardizing the environment. With declining trends in global population from the end of the 21st century, organicity of agriculture may become a universal reality. Let us hope that would be the case.

25 *What source of manures or any other material supply high organic matter to soil?*

Ans: The so called "farmyard manure" based on integration of livestock with crops has traditionally been the best source. In addition, compost from diverse sources of byproducts (or waste) is another source of recycling organic matter and nutrients back to the soil. The term manure must also include green manure and use of cover crops to catch nutrients, recycle from sub-soil, and also improve N through biological nitrogen fixation and P by mycorrhizae association must be important. It is important to recognize the N fixation occurs by both legumes and grasses (especially tropical grasses).

26 *What differences/ gaps do you see between organic management in India and other countries?*

Ans: Countries in Asia (India, China, Japan, Korea, etc.) have long history of using organic materials to enhance soil fertility. Chankya (Kautalya) recommends its use in his classical "Arth Sharstra," and its use is also mentioned in Vedas and books in Tamil and other languages. The modern concept of organic farming is commercialized more in the western countries (USA, Europe, Australia etc.) than it is in India. There are more laws and certification procedures in western countries than in India.

27 *In the current world, natural resources are getting contaminated. Then, how would we get access to pure food?*

Ans: Yes, contamination of soil, water and air is a major issue that must be addressed. Contamination (by agricultural chemicals and land application of industrial effluents) is caused by indiscriminate and inappropriate use of inputs (e.g., fertilizers, pesticides, sludge, and irrigation with poor quality water). This is where education and communication with farmers and land managers is important. It is important to remember that "dose is the difference between remedy and poison". Using precision agriculture (soil-specific farming) is critical. Application of fertilizers, pesticides, irrigation, and tillage by soil test and on the basis of expected crop yield is an essential step to minimize contamination. Wasteful use of inputs must be avoided, and we must learn to "produce more from less "by reducing losses and increasing the use efficiency of inputs.

28 *Suggest any feasible measures to improve soil health under Indian conditions!*

Ans: Soil organic matter (SOM) content is the major determinant of soil health. The critical range of SOM content, depending on biophysical factors and land use along with the human dimensions factor, is 2.5% to 3.5 % for soils of the tropics. The SOM content in most cropland soils of India is less than 0.5% in the root zone, and some soils have as low as 0.1%. The severe depletion of SOM is caused by long term use of extractive farming practices (removal of crop residues for other uses, none or minimal input of manure, in-field burning of crop residues, removal of topsoil for brick making, uncontrolled grazing, negative nutrient budget, unbalanced application of nutrients). Such extractive practices must be discouraged. Soil health is also adversely affected by degradation processes such as erosion by water and wind, destruction of soil structure by excessive and inappropriate tillage, flood-based irrigation, use of brackish water for irrigation.Soil health can be restored by input of biomass carbon into the soil and creation of a positive soil carbon budget. India must have a plan to assess and publish national soil health report once every five year.

29 *What can be the options for crop residue management in salt affected soils especially in Vertisols?*

Ans: Leaving crop residues on the surface (as mulch with no-till) is the best option. The goal is to keep the surface covered so that it is no over-heated in summer and is protected from raindrop impact with the onset of rains. I worked on Vertisols in NSW, Australia, and found that heat of wetting is the major cause of slaking that reduces the rate of water infiltration in soil. Therefore, mulch cover is important to reduce the risks of slaking and break down of aggregates. In addition to residue retention, application of FYM and compost is also useful.

30 *Is organic farming farming the future, and is it a sustainable one?*

Ans: Refer to Question #24. Yes, organic farming is feasible under site-specific conditions. It has specific niches, which must be carefully identified and judiciously implemented. Education, certification, pricing and policy interventions are also pertinent to promoting organic farming.

31 *What are the alternatives to escape from drought in crop production and biodiversity?*

Ans: Drought is a manmade problem. It is caused by land misuse and soil mismanagement. Every drop of water must be preserved in the soil where it falls, especially under sub-humid, semi-arid and arid conditions. In these eco-regions, drought and flood are two sides of the same coin: the land that suffers from floods during the rainy season also suffers from drought during the dry season. Management of drought must be based on understanding of the type of drought (meteorological, climatological, pedological, agronomical, ecological, and sociological). Strategies to alleviate drought depend on the drought type. There are also different types of water for supplemental irrigation (blue, green, gray, black, and virtual). The type of water used/enhanced must be matched with the type of drought.

32 *What is more important, basic research or applied research? How to get better acceptance of research papers in the journals?*

Ans: We need both basic and applied research. Basic research is essential to understand processes and establish the cause-effect relationship. Applied research is needed to address specific issues. Basic research helps us in solving long-term problems and applied research is needed to solve immediate issues.However, quality of research data must be very high in both cases. Papers are often rejected because of the poor quality of data. Research must be based on sound rational (why), knowledge gaps (review of literature), specific objectives and hypotheses (what), sound and standardized methodology (how), discussion of data (cause-effect relationship), conclusion (were hypotheses proven or disproven and objectives obtained or not) and where do we go from here (policy, recommendations, additional research). Research done methodologically is not rejected as often.

33 *Do we have other options for agriculture growth in changing climate, other than mitigation?*

Ans: Of course, adaptation is another and a better option. On a short-term basis, we must try to adapt. That is what is called "climate-smart or climate-resilient agriculture." Adaptation involves choice of species, varieties, date of planting or harvesting, methods of seed bed preparation, storage and post- harvest processing and value addition. Adaptation must come before mitigation. That is why it is called "ADAM" — Adaptation and Mitigation.

34 *If organic farming is enough to change the degraded soils into productive soils; how many years it may take to make this country completely healthy with enough food under such scenarios?*

Ans: Soil restoration is a slow process. It occurs on a decadal or a generational scale. That is why "prevention of soil degradation is better than cure through restoration." However, many soils of India have been severely degraded because of historic land misuse and soil mismanagement. Therefore, restoration must not be delayed. In fact, the cost of no action on restoration of soil health is more expensive than cost involved in restoration.

35 *How to reduce farmers' affinity towards synthetic urea fertilizers in north India?*

Ans: There are four options: 1) eliminate wrong subsidies so that it is not made artificially cheaper, 2) educate and communicate about uses and misuses of urea and other chemicals, 3) legislate to prohibit its use, and provides incentive for the use of biofertilizers such as through carbon sequestration in soil, and 4) provide better alternatives. The last option is better in the long run, and it is based on the use of biofertilizers.Beginning with dialogue and communication is a good starting point. Remember, it is an addiction. And rehabilitation from any addiction takes patience, dialogue, and understanding.

36 *We are emphasizing on long term carbon storage i.e. Carbon sequestration. Which pool plays a role in carbon sequestration?*

Ans: Everything begins with the labile carbon pool. Through microbial processes over time, the labile pool is transformed into intermediate and eventually into a passive pool with a long mean residence time (MRT). With the exception of input of mature compost, all three pools outlined above are critical. However, formation of stable micro-aggregates which encapsulation labile material within aggregate leads to its protection against microbial processes, and it is an important mechanism of increasing MRT. There are several mechanisms of protection of SOM: physical, chemical, biological, and ecological.

37 *Can soil inorganic carbon be considered as C-sequestration? What is the cheapest way of carbon management for wetland rice ecology in Indian scenario?*

Ans: Yes, sequestration of soil inorganic carbon (SIC) is an important process of soil carbon sequestration. It is especially important in soils of arid and semi-arid regions. There are two types of SIC sequestration: formation of secondary carbonates (pedogenic carbonates) and leaching of bicarbonates in irrigated soils with good quality water. In rice-based systems, under humid and sub-humid climates, sequestration of soil organic carbon is predominant but SIC can also happen. More research is needed on SIC sequestration in India.

38 *Do you believe that soil organic C or total C is the only indicator of soil quality or soil health?*

Ans: There are many indicators of both soil quality and soil health. Soil organic carbon or total carbon content/stock is a prominent indicator. Other indicators include physical (texture, aggregation, available water capacity, bulk density), chemical (pH, CEC, nutrient reserve, acidity, salinity), biodiversity (MBC, respiration quotient, biodiversity), and ecological (erosion, leaching, nutrient cycling). However, most of these are also affected by SOC content.

39 *What are the best ways that can help in biodiversity conservation, carbon sequestration, and promoting rural livelihood?*

Ans: There is no one size fits all best option or a panacea for all conditions. However, there are some basic principles: replace whatever is removed, predict what changes may happen in soil from natural and management, and always create a positive soil carbon budget. Conservation agriculture (also called regenerative agriculture) based on 4 pillars is an option that must be adapted under site-specific conditions: no-till, residue retention as mulch, complex rotation, cover cropping/forages in rotation, and integrated nutrient management.

40 *To what extent can organic sources of nitrogen substitute the mineral fertilizer nitrogen for reducing the load of urea in the crop management?*

Ans: Refer to Q 24 and 30 above. Priority must be given to organic sources of N or the so-called bio-fertilizers, and these must be supplemented with judicious and discriminate use of chemical fertilizers.

41 *What are job prospects in soil science field in other countries?*

Ans: Job opportunities are getting better because soil science is being promoted by policy makers and the U.N. organizations. Soil scientists must also promote this subject and be pro-active. It is important to mention that potential of improved varieties can only be realized if grown under conditions of healthy soil.Importance of soil has not been given the emphasis that it deserves. But it is getting better.

42 *Can we achieve the production required to fulfill the demand of India by adopting "Organic Farming"!*

Ans: Restoration of degraded and depleted soils of agroecosystems may take one to two decades. Once the soil health is restored, organic farming can be a reality. Thus, restoration of soil health and improvement of soil organic matter must be a high priority on national agenda for organic farming to succeed. We must begin with transformation of traditional agriculture to "regenerative agriculture."

43 *Is the inorganic C sequestration harmful to soil health in long run?*

Ans: The only problem that can be associated with SIC is soil salinity. But salinity is caused by buildup of salt from poor quality of irrigation water and inappropriate and excessive irrigation without adequate provisions for drainage. If it is a true SIC sequestration, the answer is no.

44 *Suggest methods of protecting natural resources from further exploitation!*

Ans: Education for not taking natural resources for granted is the basic first step. Each one of us must take personal responsibility of not wasting food, water and other finite but precious resources. It is important to live in harmony with nature rather than try to conquer it. Greed and cutting corners for quick economic gains (getting rich quick) has caused serious problems. Mahatma Gandhi said that "Mother nature has enough for everyone's need but not so for everyone's greed." Produce more from less, and return some land back to nature.

45 *Suggest methods for soil health management that can be adapted by the farmers easily?*

Ans: Reduce, reuse, and recycle. Reduce losses and inputs, reuse biowastes and other by-products, and recycle water, nutrients, organic matter etc. Treat soil as a living entity, which has rights to be restored, protected, thrive, flourish and be used properly. Take from it whatever is needed and no more. Follow the principle of "grains for people, and residues for the soil." This equity must be respected. If not, soil will eventually rebel. And remember, mother nature knows best and has no mercy for disobedient children. See what happened to all extinct civilizations which were once thriving and did not respect the Mother Nature.There are four Laws of Ecology (Barry Commoner, 1972): 1) There is no way to throw away, 2) Everything is connected to everything else, 3) Mother nature knows no mercy, and 4) There is no such thing as a free lunch. Everything has a price. The ecological price is the dearest, and it was paid by all the forgone and extinct civilizations.

CHECKED REFERENCES

Anderson, D. M. (2009). Approaches to monitoring, control and management of harmful algal blooms (HABs). *Ocean & coastal management*, *52*(7), 342. https://pubmed.ncbi.nlm.nih.gov/20161650.

Bai, Z. G., Dent, D. L., Olsson, L. and Schaepman, M. E. (2008). Proxy global assessment of land degradation. *Soil Use and Management, 24*(3), 223–234. https://doi.org/10.1111/j.1475-2743.2008.00169.x

Briggs, H. (2020). Wildlife in "catastrophic decline" due to human destruction, scientists warn. BBC News | *Science & Environment*, Online: https://www.bbc.com/news/science-environment-54091048.

Cowie, A. L., Orr, B. J., Castillo Sanchez, V. M., Chasek, P., Crossman, N. D., Erlewein, A., Louwagie, G., Maron, M., Metternicht, G. I., Minelli, S., Tengberg, A. E., Walter, S. and Welton, S. (2018). Land in balance: The scientific conceptual framework for Land Degradation Neutrality. *Environmental Science and Policy*,*79* (November 5, 2018) ,25–35.

Crutzen, P. J., and Stoermer, E. F. (2000). The Anthropocene, Global change. *International Geosphere–Biosphere Programme* (IGBP), *41*,17–18.

FAO. 2018. The 10 Elements of Agroecology: Guiding the Transition to Sustainable Food and Agricultural Systems. Rome, Italy: Food and Agricultural Organization of the United Nations (FAO). http://www.fao.org/3/i9037en/i9037en.pdf.

Friedlingstein, P., Jones, M. W., O'Sullivan, M., Andrew, R. M., Hauck, J., Peters, G. P., Peters, W., Pongratz, J., Sitch, S., Le Quéré, C., Bakker, D. C. E., Canadell, J. G., Ciais, P., Jackson, R. B., Anthoni, P., Barbero, L., Bastos, A., Bastrikov, V., Becker, M., Bopp, L., Buitenhuis ,E., Chandra, N., Chevallier, F., Chini, L. P., Currie, K. I., Feely, R. A., Gehlen, M., Gilfillan, D., Gkritzalis, T., Goll, D. S., Gruber, N., Gutekunst, S., Harris, I., Haverd, V., Houghton, R. A., Hurtt, G., Ilyina, T., Jain, A. K., Joetzjer, E., Kaplan, J. O., Kato, E., Klein Goldewijk, K., Korsbakken, J. I., Landschützer, P., Lauvset, S. K., Lefèvre, N., Lenton, A., Lienert, S., Lombardozzi ,D., Marland, G., McGuire, P. C., Melton, J. R., Metzl, N., Munro, D. R., Nabel, J. E. M. S., Nakaoka ,S.I., Neill, C., Omar, A. M., Ono, T., Peregon, A., Pierrot, D., Poulter, B., Rehder, G., Resplandy, L., Robertson, E., Rödenbeck, C., Séférian, R., Schwinger, J., Smith, N., Tans, P. P., Tian, H., Tilbrook, B., Tubiello, F.N., van der Werf, G. R., Wiltshire, A. J. and Zaehle, S. (2019). Global Carbon Budget 2019. *Earth Syst. Sci. Data, 11*(4),1783–1838. https://www.earth-syst-sci-data.net/11/1783/2019/

Gaba, S., Bretagnolle, F., Rigaud, T. and Philippot, L. (2014). Managing biotic interactions for ecological intensification of agroecosystems. *Frontiers in Ecology and Evolution, 2*, (30 June 2014)29. https://www.frontiersin.org/article/10.3389/fevo.2014.00029.

Griggs, D., Stafford-Smith, M., Gaffney, O., Rockström, J., Öhman, M. C., Shyamsundar, P., Steffen, W., Glaser, G., Kanie, N. and Noble, I. (2013). Policy: Sustainable development goals for people and planet. *Nature, 495*(7441), 305–307. https://doi.org/10.1038/495305a

Kleijn, D., Bommarco, R., Fijen, T. P. M., Garibaldi, L. A., Potts,S. G. and Van der Putten, W. H. (2019). Ecological Intensification: Bridging the Gap between Science and Practice. *Trends in Ecology & Evolution, 34*(2), 154–166. http://www.sciencedirect.com/science/article/pii/S0169534718302738

Lal, R. (2015). The soil–peace nexus: our common future. *Soil Science and Plant Nutrition, 61*(4), 566–578.

Lal, R. (2019a). Eco-intensification through soil carbon sequestration: Harnessing ecosystem services and advancing sustainable development goals. *Journal of Soil and Water Conservation, 74*(3),55A-61A.

Lal, R. (2019b). Promoting "4 Per Thousand" and "Adapting African Agriculture" by south-south cooperation: Conservation agriculture and sustainable intensification. *Soil and Tillage Research, 188*(2019), 27–34.

Lal, R. (2019c). Rights-of-Soil. *Journal of Soil and Water Conservation ,74*(4),81A-86A.

Lal, R. (2020a). Soil Science Beyond COVID-19. *Journal of Soil and Water Conservation, 75*(4),1–3.

Lal, R. (2020b). Food security impacts of the "4 per Thousand" initiative. *Geoderma*, *374*,114427. http://www.sciencedirect.com/science/article/pii/S0016706119321585

Lal, R., Brevik, E. C., Dawson, L., Field, D., Glaser, B., Hartemink, A. E., Hatano, R., Lascelles, B., Monger, C., Scholten, T., Singh, B. R., Spiegel, H., Terribile, F., Basile, A., Zhang, Y., Horn, R., Kosaki, T. and Sánchez, L. B. R. (2020). Managing Soils for Recovering from the COVID-19 Pandemic. *Soil Systems, 4*(3),46.

Lal, R., Safriel, U., and Boer, B. (2012). Zero Net Land Degradation: A New Sustainable Development Goal for Rio+ 20. UNCCD Position Paper for Rio+20, *30*. http://catalogue.unccd.int/991_Zero_Net_Land_Degradation_Report_UNCCD_May_2012.pdf.

Machado, R. and Serralheiro, R. (2017). Soil Salinity: Effect on Vegetable Crop Growth. Management Practices to Prevent and Mitigate Soil Salinization. *Horticulturae, 3*, 30.

NRC. (1999). Our Common Journey: A Transition Toward Sustainability. Washington, DC: The National Academies Press. pp 363. https://www.nap.edu/catalog/9690/our-common-journey-a-transition-toward-sustainability.

Power, A. G. and Flecker, A. S. (2020). Agroecosystems and Biodiversity. Smithsonian's National Zoo & Conservation Biology Institute. [No Publication Date: Accessed September 25, 2020]. Online: https://nationalzoo.si.edu/SCBI/MigratoryBirds/Research/Cacao/power.cfm.

Robert, K. W., Parris, T. M. and Leiserowitz, A. A. (2005). What is Sustainable Development? Goals, Indicators, Values, and Practice. Environment: *Science and Policy for Sustainable Development, 47*(3), 8–21.

Rockström, J., Steffen, W., Noone, K., Persson, Å., Chapin, F. S., Lambin, E. F., Lenton, T. M., Scheffer, M., Folke, C., Schellnhuber, H. J., Nykvist, B., de Wit, C. A., Hughes ,T., van der Leeuw, S., Rodhe, H., Sörlin, S., Snyder, P. K., Costanza, R., Svedin, U., Falkenmark, M., Karlberg, L., Corell, R. W., Fabry, V. J., Hansen, J., Walker, B., Liverman, D., Richardson, K., Crutzen, P. and Foley, J. A. (2009). A safe operating space for humanity. *Nature, 461*(7263),472–475.

Sachs, J.D. (2012). From Millennium Development Goals to Sustainable Development Goals. *The Lancet*, *379* (9832): 2206–2211. http://www.ncbi.nlm.nih.gov/pubmed/2268246

Steffen, W., Persson, A., Deutsch, L., Zalasiewicz, J., Williams, M., Richardson, K., Crumley, C., Crutzen, P., Folke, C., Gordon, L., Molina, M., Ramanathan,V., Rockström, J., Scheffer, M., Schellnhuber, H. J. and Svedin, U. (2011). The anthropocene: from global change to planetary stewardship. *Ambio, 40*(7),739–761.

Tittonell, P. (2014). Ecological intensification of agriculture—sustainable by nature. *Current Opinion in Environmental Sustainability,* 8, 53–61.

U.N. (2000). United Nations Millennium Declaration. Resolution 55/2. U.N. A/RES/55/2, 18 Sept. 2000. New York, USA. pp9. https://www.un.org/en/development/desa/population/migration/generalassembly/docs/globalcompact/A_RES_55_2.pdf

U.N. (2015). Sustainable Development Goals. Sustainable Development Goals Knowledge Platform. Online: https://sustainabledevelopment.un.org/?menu=1300.

U.N. (2019). Global Sustainable Development Report 2019: The Future is Now – Science for Achieving Sustainable Development. (Independent Group of Scientists appointed by the Secretary-General, Ed.). New York: United Nations. pp 252. https://sustainabledevelopment.un.org/content/documents/24797GSDR_report_2019.pdf

UNCCD. (2013). A Stronger UNCCD for a Land-Degradation Neutral World. Issue Brief. Bonn, Germany. Pp 20. https://catalogue.unccd.int/225_Stronger_UNCCD_LDNWorld_web.pdf

UNCCD. (2019). World leaders call for global action to restore degraded land. Online: https://www.unccd.int/news-events/world-leaders-call-global-action-restore-degraded-land.

UNCED. (1992). United Nations Conference on Environment and Development (UNCED), Earth Summit. Sustainable Development Goals Knowledge Platform. Online: https://sustainabledevelopment.un.org/milestones/unced.

Walling, D. E. (2008). The changing sediment loads of the world's rivers. Annals of Warsaw Univ. of Life Sci. – SGGW. *Land Reclamation, 39*(325),323–338.

Walling, D. E. (2009). The Impact of Global Change on Erosion and Sediment Transport by Rivers: Current Progress and Future Challenges. United Nations Educational, Scientific and Cultural Organization (UNESCO-IHP): The United Nations World Water Assessment Programme. Paris, France. pp 30. https://unesdoc.unesco.org/ark:/48223/pf0000185078

WMO. (2019). WMO Greenhouse Gas Bulletin #15: The state of greenhouse gases in the atmosphere based on global observations through 2018. WMO Greenhouse Gas Bulletin. Geneva, Switzerland. Pp 8.

Wood, S., Sebastian, K. and Sherr, S.J. (2000). *Pilot Analysis of Gobal Ecosystems: Agroecosystems*. Washington, D.C.: World Resources Institute. https://files.wri.org/s3fs-public/pdf/page_agroecosystems.pdf.

YouMatter. (2020). Agro-Ecology Definition: History And Examples. YouMatter. Online: https://youmatter.world/en/definition/definitions-agro-ecology/