The role of basic sciences in addressing global challenges to sustainable development: experiences from CIFOR-ICRAF

Eureka Emefa Ahadjie Adomako[1], Leigh Ann Winowiecki[2], Aster Gebrekirstos[2] and Ramni Jamnadass[2]

[1]Department of Plant and Environmental Biology, University of Ghana, P. O. Box LG 55, Legon, Accra, Ghana.

[2]Centre for International Forestry Research and World Agroforestry (CIFOR-ICRAF), Nairobi, Kenya.

* Corresponding author: eadomako@ug.edu.gh; +233 244 281821

Abstract

Human-induced global challenges, including climate change, biodiversity loss, land degradation and broken food systems, militate against the attainment of the United Nations' Sustainable Development Goals (SDGs). The Centre for International Forestry Research and World Agroforestry (CIFOR-ICRAF) has, for many decades, worked in support of research in development initiatives aimed at addressing these challenges. With reference to the functions of selected research units and laboratories located at CIFOR-ICRAF's Nairobi head office in Kenya, e.g., the Genetic Resources Unit, Germplasm Health Unit, Soil-Plant Spectral Diagnostics and Living Soils Laboratories, this paper highlights the application of the basic sciences in tackling the afore-mentioned challenges. Reference is also made to the Land Degradation Surveillance Framework (LDSF), designed for the collection of reliable soil, vegetation and land-use data to inform climate action such as landscape restoration. Based on the finding that knowledge generated from basic studies in plant and soil biology, as well as physics and chemistry, contribute to tree germplasm management, land and soil health assessment, forest restoration and other efforts aimed at meeting the SDGs, the paper makes recommendations to improve inclusion and funding of the basic sciences - particularly in African universities - in sustainability-focused research initiatives.

Keywords: climate resilience, biodiversity conservation, ecosystem restoration, food security, science education

1. Introduction

Many human activities aimed at development (e.g., agriculture and industrialization) have impacted on the environment at degrees of severity that threaten the sustainability of life on earth. There is evidence to show, for example, that periodic booms in cocoa production in countries like Ghana and Indonesia have been as a result of expansion into new forest frontiers; thus, causing extensive forest loss (Asare, 2019; Kelley, 2018). Reports indicate that West Africa – which provides about 70% of global cocoa production – no longer has any frontier forests to be exploited by future generations (Gockowski and Sonwa, 2011; Kroeger et al, 2017). Thus, going by the Brundtland Report's definition of sustainable development as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (WCED, 1987), the traditional method of cutting down forests for agriculture is no longer sustainable.

Since the publication of the Brundtland Report (WCED, 1987), sustainable development has been defined in many ways, but is generally conceived as development that balances economic, social and environmental sustainability. The seventeen sustainable development goals (SDGs), also referred to as the Global Goals, adopted by the United Nations (UN) in 2015, provide a framework for achieving this balance. However, human-induced global challenges (e.g., climate change, land degradation, deforestation and biodiversity loss) militate against the attainment of the goals. Forest loss, due to agricultural expansion, directly causes biodiversity loss and indirectly causes climate change as atmospheric carbon levels increase with the decrease in carbon sinks. Agriculture further contributes to climate change through the emission of greenhouse gases from agro-ecosystems, e.g., methane and nitrous oxide from rice paddy fields (Minami and Neue, 1994; Qin et al., 2010). Climate change in turn disrupts weather patterns, resulting in more severe droughts and floods, higher temperatures, increased incidence of pests and diseases; all of which affect biodiversity and ecosystem health.

Biodiversity is crucial to sustaining life on earth because it provides many ecological goods and services that support human livelihoods. These include provision of fuel, food and fibre, and maintenance of genetic resources as key inputs to agricultural crop varieties and livestock breeds, medicines and other natural products. While attention is often paid to the loss of individual animal species (e.g., elephants) and endangered plant species (e.g., mangroves), it is the fragmentation, degradation and outright loss of forests, wetlands, peatlands and other ecosystems that pose the gravest threats to biodiversity and, by extension, sustainable development. Biodiversity loss often destabilises and reduces the productivity of ecosystems and weakens their ability to deal with both natural disasters (e.g., floods, droughts, hurricanes) and human-induced stresses (e.g., pollution and climate change). This reduction in productivity and resilience of ecosystems undermines environmental sustainability and, invariably, leads to broken food systems and unsustainable value chains; thus, compromising economic and social sustainability.

Several international bodies including the United Nations Environment Programme (UNEP), United Nations Food and Agricultural Organization (FAO) and the Consultative Group for International Agricultural Research (CGIAR) have, for many decades, conducted research aimed at ensuring sustainable development. This paper focuses on two CGIAR centres – the Centre for International Forestry Research (CIFOR) and World Agroforestry, also known as International Centre for Research in Agroforestry (ICRAF) – which merged to become CIFOR-ICRAF in 2019. It is important to note that CIFOR-ICRAF's work recognizes and holistically addresses the complexity of interactions between people and ecosystems and, therefore, entails more of applied research. Here, though, we highlight the contribution of the basic sciences to efforts aimed at tackling the global challenges by sharing experiences from selected laboratories and research units located at the organization's head office in Nairobi, Kenya. Mention is also made of the Land Degradation Surveillance Framework (LDSF), a field sampling method designed to collect reliable soil, vegetation and land-use data to inform ecosystem restoration activities and other forms of climate action. In the light of challenges faced by basic science departments in African universities to attract students and research funding, we conclude with recommendations to improve their inclusion in sustainability-focused research initiatives.

2. Brief profile of CIFOR-ICRAF

CIFOR-ICRAF works mostly in the Global South – Africa, Asia and Latin America – to spearhead research in development initiatives that aim at finding evidence-based solutions to the interconnected issues of climate change, deforestation and biodiversity loss, broken food systems, land degradation, and unsustainable value chains. Much of the organization's work is hinged on the crucial role of forests, trees and agroforestry in the management and conservation of biodiversity. The term 'agroforestry' is broadly used at CIFOR-ICRAF to mean agro-ecological approaches that involve not just trees, but also farmers, livestock and forests at multiple scales. These include remnant trees on farms, deliberate tree-crop production as well as farming in forests or at forest margins – all of which leverage the ability of trees to sequester carbon, record climate history, cycle water and nutrients from soil, build soil organic matter and carbon, and shelter biodiversity including pollinators (CIFOR-ICRAF, 2022).

Conservation of biodiversity, tree and forest genetic resources is one of CIFOR-ICRAF's major research themes. Work undertaken under this theme aims at delivering, *inter alia*, evidence-based solutions to the environmental impacts of production of economically important tree crop commodities such as cocoa, coffee, oil palm, rubber and tea. Efforts have been made, especially in coffee and cocoa agroforestry landscapes, to boost productivity and safeguard diversity through domestication and delivery of suitable tree planting material, including food, fodder, timber and medicinal trees, to growers. Another major research theme pursued at CIFOR-ICRAF is the Soil and Land Health theme which focuses on providing rigorous science-based evidence for soil and land restoration with relevance for food and nutrition security, and national climate commitments. The other themes are 'sustainable value chains and investment', 'governance, equity and well-being' and 'climate change, energy and low-carbon development'. Realizing the need for partnerships to meet the global goals (SDG 17), CIFOR-ICRAF has established Transformative Partnership Platforms (TPPs) that serve as knowledge co-creation and delivery channels, each with a specific research focus. These partnerships include other international research organizations, government agencies/ministries, national research institutes, universities, civil society organizations, etc. (CIFOR-ICRAF, 2022).

A notable CIFOR-ICRAF managed project is the Regreening Africa Project (www.RegreeningAfrica.org) which aims to improve the livelihoods, food security and climate resilience of 500,000 households across 100 million hectares in eight Sub-Saharan African countries - Ethiopia, Ghana, Kenya, Mali, Niger, Rwanda, Senegal, Somalia - by reversing land degradation and restoring ecosystem services, mainly using agroforestry. Proven agroforestry technologies, including farmer-managed natural regeneration (FMNR), were adapted to suit farmer needs under different socio-ecological settings. According to Smith et al. (2019), restoring degraded land using agroforestry could increase food security for up to 1.3 billion people. The success of agroforestry technologies that involve tree planting is, however, dependent on the availability of good quality planting material and the ability to choose the right tree, for the right place, and for the right purpose. The next section throws light on how various research units and laboratories at CIFOR-ICRAF's Nairobi head office contribute not only to effective conservation and distribution of disease-free tree planting materials, but also to building the rigorous scientific evidence required to ensure that project targets (e.g., soil fertility improvement, food security, climate adaptation and resilience, poverty reduction, and sustainable value chains) are met.

3. Functions and related research of selected CIFOR-ICRAF units/laboratories

3.1 Genetic Resources Unit

CIFOR-ICRAF's Genetic Resources Unit (GRU) houses a tree seed laboratory and a seed genebank. The core functions of the GRU are to collect, document, conserve, characterize and distribute high quality agroforestry tree genetic resources mainly for agricultural and ecosystem restoration purposes. The seed genebank holds over 6000 accessions from 190 tree species. The unit also has field genebanks for about 67 tree species with non-orthodox or recalcitrant seeds located in 42 sites in 17 countries. One of the field genebanks for *Allanblackia* is located in Ghana at the National Tree Seed Centre, which is managed by the Forestry Research Institute of Ghana (FORIG). Categories of use of the germplasm conserved at the GRU include food, fodder, timber, medicine, and soil fertility improvement.

Various types of germplasm – fruits, seeds and semi-extracted seeds (fruits mixed with pulp) – are received and processed by the GRU. Barcoding of all accessions in the seed genebank enhances tracking of each accession as it is taken through the various genebank processes; namely, material verification, seed extraction (when necessary), seed cleaning, seed purity analysis, seed drying, seed characterization, seed viability testing and storage. Information captured on seed storage packages include accession number, species name, provenance, country, weight and barcode number. Although data management of the seed genebank processes are all automated and standard operating procedures (SOPs) have been developed for each stage, a good understanding of plant biology still plays a role in the functions of the GRU.

Collection of tree germplasm for conservation requires accurate identification of the species. Plant morphological traits including leaf, fruit and seed parameters (e.g., shape, colour and texture) are used in species characterization (Nyarko et al., 2012; Odoi et al., 2020). Plant and seed physiology is also crucial to the work of the GRU as the viability and longevity of stored germplasm is affected by various physiological factors including seed moisture content and desiccation tolerance (Nya et al., 2000; Dickie and Pritchard, 2002). The SOPs used in the genebank processes have, no doubt, benefitted from basic science studies that have investigated the survival of tree seeds under different environmental conditions. Studies on seed dormancy breaking methods (e.g., Frederick et al., 2017; Noor Mohamed et al., 2021) also play a role since dormancy poses a challenge to germination, which is necessary for seed viability testing and the ultimate use of the seeds for their intended purpose. Investigation of varietal differences in seedling growth performance of important tree species such as shea (*Vitellaria paradoxa*) provide valuable information for the selection of suitable varieties for the establishment of field genebanks (Odoi et al., 2020).

3.2 Germplasm Health Unit

The Germplasm Health Unit (GHU) has an accompanying Tree Seed Long-term Storage Facility with capacity to store up to 8000 accessions. Plants and their seeds possess an inherent ability to serve as carriers of pests and diseases and, hence, pose a high risk of transboundary spread through germplasm distribution activities (Kumar et al., 2021). In Africa, for example, emerging native and invasive tree pests and diseases pose a threat to agroforestry-based strategies designed to enhance biodiversity, build climate resilience, and bridge gaps in food and nutrition security. Restoration efforts in Rwanda by the Regreening Africa Project have, reportedly, suffered setbacks in the adoption of agroforestry technologies due to pests and diseases (Cherotich, 2022).

The importance of biology to sustainable development is further demonstrated by the functions of the GHU which ensures the phytosanitary safety of tree seeds and other propagules that are received for processing and distribution by CIFOR-ICRAF's genebank. Through physical inspection and testing using standard plant pathology/microbiology procedures, the unit diagnoses and identifies microbial pathogens (e.g., fungi, bacteria and viruses) and uses curative measures, where applicable, to sanitize the germplasm before storage. Entomology and parasitology also come to play as insect pests and parasitic nematodes are identified using morphological characterization. The information gathered by the GHU is useful in devising appropriate strategies for effective management and control of tree pests and disease pathogens.

3.3 African Orphan Crops Consortium Genomics Laboratory

CIFOR-ICRAF is a member of the African Orphan Crops Consortium (AOCC) – a global partnership with the goal to mainstream 'orphan' crops (neglected, under-utilized and/or under-researched crops) into African food systems to tackle "hidden hunger" (micronutrient deficiencies) and improve nutrition. The objectives of the AOCC Genomics laboratory are to sequence, assemble and annotate the genomes of 101 traditional African orphan crops including 43 tree species, to facilitate their genetic improvement. An understanding of fundamental genetic principles taught in biology is integral to the objectives of the AOCC Genomics Lab.

Whole genome sequencing has been made possible due to tremendous improvement in the DNA sequencing methods developed in the 1970s to determine the order of the four nucleotide bases (adenine, thymine, cytosine, and guanine) that make up a single strand of the DNA molecule. The complementary base-pairing of adenine with thymine (A-T) and cytosine with guanine (C-G) in the DNA double helix underlies most DNA sequencing methods and is also the basis for the mechanism by which DNA molecules are copied, transcribed and translated (Mardis, 2017). The whole genome of an organism contains millions of base pairs containing a vast amount of important genetic information that regulates the development and maintenance of the form and functions of the organism. Thus, DNA sequencing of the orphan crops would enhance determination of the genes involved in various plant functions, e.g., nutrient uptake, translocation and storage, yield, pest and disease resistance, shelf-life and climate adaptation. This information can then be used in breeding technologies for crop improvement. So far, about 8 crops on the AOCC list have been fully sequenced. These include *Vitellaria paradoxa* (shea tree), *Artocarpus heterophyllus* (jack tree), *Artocarpus altilis* (breadfruit tree), *Moringa oleifera* (horseradish or drumstick tree) and *Slerocarya birrea* (marula).

The AOCC works in collaboration with the African Plant Breeding Academy (AfPBA) to equip practicing African plant breeders with advanced genetic technologies to harness the diversity of neglected crops to meet the needs of producers, processors and consumers (Jamnadass et al., 2020).

3.4 Dendrochronology Laboratory

Though trees and forests are important for climate change adaptation and mitigation, trees themselves are vulnerable to climate change. Extreme weather events such as floods, droughts, and increased frequency and intensity of dry spells are impacting on the vitality, productivity, and quality of ecosystems and ecosystem services. To ensure progress toward attaining the SDGs, it is crucial that the negative impacts of climate change on trees and forests, and forest-dependent communities be addressed. In Africa, knowledge of tree growth and population dynamics, the range of natural climate variability and the range of tree species tolerance to climatic extremes is scarce. This information is crucial for sustainable natural forest management and to support decisions in agroforestry and reforestation efforts (Gebrekirstos et al., 2014). The Dendrochronology Laboratory at ICRAF was, therefore, established in 2013 to conduct studies aimed at generating the requisite information to address climate change challenges.

Dendrochronology is the discipline of dating tree rings to the year of their formation and using exactly dated tree rings to detect environmental signals that are common for a population of trees. Methods/tools including tree-ring analysis, wood anatomy, stable isotopes and dendrometers are applied to decode minutes, decades to multi-centuries of information stored in trees, to address spatio-temporal changes across scales. The results provide insight into past climate and environmental variability at annual resolution, and from local to regional scales. Dendrochronology, therefore, elucidates climate change impacts on tree growth and provides evidence and data to address a broad variety of questions (e.g., which species is productive, which species is resilient, when is the optimal period to cut, which species sequester more carbon, which species is drought tolerant, which one is competitive with crops, which one is beneficial for crops) and to understand long-term ecological processes.

Studies have demonstrated the large potential of dendroecological techniques in different climatic zones of Africa. A high number of tree species show datable annual tree rings and reach a considerable age. Thus, using tree rings as precisely dated high-resolution climate proxies, the dendrochronology lab has helped to put the existing short-term and sparse instrumental climate records in Africa into a longer perspective. On the basis of tree-ring widths in *Juniperus procera* in Ethiopia, Gebrekirstos et al. (2008) and Mokria et al. (2017) developed a climate reconstruction spanning 350 years. Gebrekirstos et al. (2008) also characterized co-occurring savanna species in Ethiopia into opportunist and resilient species based on their response to rainfall variability. Ecological studies have shown a strong association between tree growth rings and temperature and precipitation data (Boakye et al., 2016; Upadhyay and Tripathi, 2019). Some study findings also show trade-offs between stomatal conductance, water use efficiency and carbon sequestration (Gebrekirstos et al., 2011). Stomatal closure due to higher atmospheric carbon dioxide levels causes a decrease in transpiration rates and, therefore, improved water use; but also implies less carbon dioxide uptake and, hence, reduced carbon sequestration (Palandrani et al., 2021). The findings of such eco-physiological studies underpin the application of dendrochronology in assessing population dynamics (Abiyu et al. 2018), carbon sequestration, and trends of biomass production (Mokria et al., 2015; Sanogo et al., 2022). This could enhance the simulation of tree/forest growth trajectory models and, hence, minimize the high transaction costs of monitoring long-term research plots.

3.5 Soil and Land Health Unit's Land Degradation Surveillance Framework (LDSF)

Estimates by the UN Food and Agricultural Organization (FAO) indicate that each year 12 million hectares of land are degraded, and 24 billion tonnes of fertile soils are lost due to soil erosion (FAO, 2023). The resulting decline in soil and land health affects agricultural productivity, food security, human livelihoods and climate resilience. The LDSF is a robust monitoring tool designed by CIFOR-ICRAF scientists to assess and monitor soil and land health at farm, landscape and global levels. It uses a consistent set of indicators and field sampling methods to assess vegetation cover and structure, current and historic land use, tree, shrub and grass species diversity, land degradation status, soil infiltration capacity and other soil characteristics.

An important contribution of biology to the LDSF is the reliable identification of plant species encountered during field surveys. For example, three different species of *Acacia* – *Acacia nubica*, *Acacia tortilis* and *Acacia thomasii* – were encountered during an LDSF survey of a rangeland in the Kajiado County of Kenya. This knowledge on diversification of species is attributable to plant taxonomy and systematics. Different taxonomic characters (e.g., morphological, physiological, molecular) are used in plant identification. At Kajiado, the different species of *Acacia* were identified based on their unique morphological traits including tree architecture and presence or absence of special structures (e.g., thorns). It is worth noting that studies on ecological characters such as plant adaptation to specific habitats have also informed current knowledge on the role of plants as biological indicators of environmental stressors. The frequency of encounter with *Acacia n*ubica and *Salvadora persica* during the Kajiado field survey, for example, was an indication of soil salinity.

3.6 Soil-Plant Spectral Diagnostics Laboratory

The Soil-Plant Spectral Diagnostics Laboratory – also called the Infrared Spectroscopy Lab – is a state-of-the-art laboratory that serves as a reference lab for more than 20 regional spectroscopy labs around the world. Spectroscopy is the measurement and interpretation of the electromagnetic spectra produced by matter due to absorption and emission of light (or more precisely electromagnetic radiation) into its constituent wavelengths. Since different types of matter interact differently with different types of radiation (e.g., visible light, infrared, and ultra-violet rays), spectroscopy is a valuable tool for elucidating the chemical composition of different substances. CIFOR-ICRAF's Spectral Diagnostics Lab provides cost-efficient, reliable and rapid analysis of soil, plants and agricultural inputs (e.g., fertilizers and manure) using mainly infrared diffuse reflectance spectroscopy (simply, infrared spectroscopy) and x-ray fluorescence.

With the infrared spectroscopy method, dry samples are illuminated and the emitted electromagnetic radiation is measured in narrow wavebands over the mid-infrared (MIR) range (4,000 – 400 cm-1) and near infrared (NIR) range (12,500 – 4,000 cm-1). When illuminated, the molecules in the samples rotate and vibrate at specific frequencies corresponding to discrete energy levels (vibrational modes). The vibrations occur either due to changes in bond angle (bending) or bond length (stretching). Analysis of the resulting spectral signature – a summary of the energy absorption features at each wavelength - reveals details about the composition and molecular structure of the sample, e.g., organic matter quality. Infrared spectroscopy, however, only allows prediction of soil properties (e.g., pH, particle size distribution, electrical conductivity, nitrogen, carbon) and plant properties (e.g., available nitrogen, phosphorus, and other nutrient elements). The x-ray fluorescence method is used for determination and quantification of total concentrations of nutrient elements as well as heavy metals (e.g., titanium, chromium, arsenic, cadmium and lead) in soil, plant and fertilizer samples. This is because x-rays enable more in-depth investigation of the chemical bonds, structure and orientation of molecules in space.

In effect, fundamental principles of physics (e.g., optics, electromagnetism, quantum mechanics) and chemistry (e.g., chemical bonding, molecular structure, behaviour of atoms, properties of functional groups) underpin the science of spectroscopy. Thus, although much of the work conducted in the Soil-Plant Spectral Diagnostics Lab is automated, human knowledge of the underlying principles is irreplaceable for troubleshooting and interpretation of the data generated. Also worth noting is the fact that ecological studies on soil properties, plant mineral nutrition and plant-soil interactions in different landscapes have provided knowledge on the acceptable/permissible concentrations of various chemical elements in soil, plants, and other environmental media. This knowledge provides a basis for comparison and interpretation of the elemental concentrations in analysed samples and, hence, enables assessment of the success of agricultural interventions and restoration efforts undertaken in the landscapes from which the samples of soil, plants and/or agricultural inputs are obtained. The ability to match data from LDSF surveys with that generated by the Spectral Diagnostics Lab on such properties as soil organic carbon (SOC) is of significance as it provides opportunity to include soil carbon storage in the development of Nationally Determined Contributions (NDCs) to the Paris Agreement on Climate Change (Diwediga et al., 2022).

3.7 Living Soils Laboratory

Soil fertility is the ability of soils to sustain plant growth by providing essential plant nutrients and favourable chemical, physical and biological conditions. It is believed that microbiology drives most geochemical processes and, thus, soil function is influenced by the microorganisms present. Soil biodiversity is, therefore, important to ecosystem health (Pulleman et al., 2022). CIFOR-ICRAF's Living Soils Laboratory works mainly on the living component of soil with the aim of understanding the roles of soil biota in maintaining and improving soil fertility, particularly in agroforestry systems. Generally, a higher abundance of soil organisms (e.g., mycorrhizal fungi) is associated with the presence of trees across a range of agroforestry systems compared to adjacent monoculture systems.

Activities carried out in the Living Soils Lab include assessment of the diversity of arbuscular mycorrhizal fungi (AMF) and determination of fungal-to-bacterial (F:B) biomass ratios as an indication of soil health. The diversity of soil macrofauna (e.g., ants, termites, earthworms, millipedes, centipedes and beetles) whose activities affect soil physical and chemical properties, are also determined. Studies of AMF abundance and diversity, F:B ratio and status of other soil biota along gradients of climate, land use and degradation status provide an understanding of the interactions between soil organisms, soil processes, tree species and ecosystem services (e.g., decomposition, nutrient cycling and soil carbon storage). This then informs such decisions as the appropriate combination of trees to be selected for different sites and planting purposes.

4. Relevance to key initiatives for sustainable development

Recognition of the importance of biodiversity, tree and forest genetic resources as well as soil and land health to sustainable development underlies not only CIFOR-ICRAF's work, but many global and regional restoration initiatives. Notable among these are the Bonn Challenge, that aims to restore 350 million hectares of deforested and degraded land by 2030 (IUCN, 2020), Africa Union's Great Green Wall Restoration Initiative which has a target of restoring 10 million hectares of arid and semi-arid land around the Sahara every year until 2030 (FAO, 2023), and the African Forest Landscape Restoration Initiative (AFR100) – a country-led, community-focused effort that seeks to restore 100 million hectares of deforested and degraded land in Africa by 2030 (WRI, 2023). The areas earmarked for restoration include degraded tree cropping systems such the cocoa production landscapes in West Africa. It is envisaged that restoring these landscapes with carefully selected combinations of trees (e.g., fruits, nuts, legumes, fodder, medicines) and other agro-ecological components would address the issue of land scarcity while enhancing biodiversity, soil health, land productivity, food security and climate resilience.

Landscape restoration contributes to achieving SDG1 - no poverty, SDG2 - zero hunger, SDG3 – Good health and well-being, SDG6 - clean water and sanitation, SDG13 - climate action and, especially, SDG15 - life on land, which aims to "protect, restore and promote the sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss". Incidentally, one of the 23 targets listed for achievement by 2030 in the Kunming-Montreal Global Biodiversity Framework (GBF) is to have restoration completed or underway on at least 30% of degraded terrestrial, inland waters, and coastal and marine ecosystems. It is noteworthy that the UN Decade of Action to deliver the Sustainable Development Goals (2021 – 2030) is also earmarked as the UN Decade on Ecosystem Restoration.

Although tree and forest genetic resources play a key role in tackling the global challenges, there are reports of declining interest in such fields of study as forestry (Shanahan et al., 2021) and botany/plant biology (Crisci et al., 2020; Stagg and Donkin, 2013). A CIFOR-ICRAF led survey by the Global Forest Education Project revealed that forest-related knowledge is often inadequately covered in school curricula in most regions of the world, particularly in the Global South (Taber and Decristofaro, 2021). A study undertaken in the United Kingdom revealed that out of approximately 104,895 students who graduated from general biology programmes between 2007 and 2019, less than 0.05% (n = 565) were enrolled in plant science or plant biology programmes (Stroud et al., 2022). Even for the plant biology programmes, Stroud et al. (2022) found that modules with a dedicated plant focus contributed only 22% of the taught content with plant identification accounting for only 1%. The growing threat to botanical education has been attributed to a misunderstanding of the broad spectrum of scientific skills that plant biologists/botanists draw upon which go beyond plant identification (Manzano, 2021).

The foregoing narrative on the functions of selected CIFOR-ICRAF units and laboratories has demonstrated the contributions of fundamental studies in various branches of plant biology (e.g., anatomy, ecology, genetics, pathology, physiology, taxonomy) as well as soil science, chemistry and physics to efforts aimed at addressing the global challenges to sustainable development. The world cannot preserve and enhance biodiversity, improve food and nutrition security, reverse and prevent soil and land degradation, meet carbon sequestration targets, and realise the global goals without the basic sciences. Ensuring continued capacity development in these fields of study is necessary for generating the site- and species-specific data that gets synthesised (e.g., via meta-analysis) to inform global policy decisions on ecosystem restoration and other sustainability-focused initiatives. To this end, the importance of statistics (a branch of mathematics) in data synthesis, analysis and interpretation cannot be overlooked.

5. Recommendations and conclusion

A key disincentive to the study of the basic sciences in African universities is dwindling financial support. In Ghana, for example, calls for grants like the World Bank's Teaching and Learning Innovation Fund (TALIF) - implemented in the early 2000s to support tertiary institutions to improve their academic programmes - are now few and far between. The last decade has seen a rise in research grant calls that are skewed towards the applied sciences (e.g., agriculture, food and nutrition, health) as the world races to meet the SDGs. Consequently, university departments, mandated to contribute to the training of competent basic science teachers and to conduct research that leads to the generation of new knowledge, tend to shift focus to applied research in order to attract funding. Those that stay focused on their mandate become financially handicapped, with run-down facilities and obsolete equipment that are not fit for teaching and learning. This situation undermines the very foundation on which solutions to the global challenges are built.

Thus, in line with research grant calls that request applicants to demonstrate compliance to gender equity/equality and a recent proposal by Carsan et al. (2022) for tree planting project proponents to indicate how tree seed sourcing will be done, we recommend that grant funders request university-based applicants - particularly in Africa - to identify and indicate the role of the basic sciences in meeting project targets. A percentage of the applying university's overhead costs (where applicable) can then be paid into a dedicated fund to support teaching, learning and research in the basic sciences. Such a fund would facilitate the acquisition of equipment and enhance fieldwork, student internships, and on-the-job training for technical staff.

Evidence from the composition of CIFOR-ICRAF's TPPs indicate the competitive advantage of national research institutes, such as those under Ghana's Council for Scientific and Industrial Research (CSIR), in partnering international research organizations on national/regional projects. The onus is, therefore, on them to facilitate the involvement of relevant university departments in research and training opportunities. Where distance is a barrier, a good start would be virtual participation in scientific colloquia held by such national research institutes to keep their academic counterparts abreast with on-going national projects and research needs. Within- and between-university research partnerships that integrate the basic and applied sciences should also be encouraged to enhance the creation of multidisciplinary/transdisciplinary research teams that are more likely to attract funding. Properly negotiated memoranda of understanding (MOU) would ensure long-term partnerships with effective outcomes.

Finally, while not losing the essence of the basic sciences, efforts must be made to incorporate emerging research topics in basic science textbooks used at all levels of the educational system, especially at the tertiary level. Tropical dendrochronology, for example, is a new research frontier which is still in its infancy in Africa. There is, however, a strong interest to develop and ensure a wider use of dendrochronology science in Africa, which will require collaborative efforts. Including new research frontiers in the curricula of African universities would enhance their capacity to contribute meaningfully to research initiatives that address the global challenges and promote attainment of the SDGs.

Acknowledgement

A nine-month research visit to CIFOR-ICRAF's Nairobi Head Office by the primary author was facilitated by a University of Ghana sabbatical leave grant. All CIFOR-ICRAF scientists and technical/laboratory staff associated with the work described herein are gratefully acknowledged.

Competing Interests

None.

Data and Code Availability Statement

Not applicable.

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