Roadmap of research activities of CIRAD over 10 years in the sector of HORTICULTURE

Filière Horticulture

cirad

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Summary

Foreword

CIRAD has decided to prepare '10-year commodity chain roadmaps' for the main commodity chains on which it works. The aim of this exercise in collective reflection and foresight is to formulate a 10-year vision of CIRAD's research on these commodities. The roadmap is an internal institutional document. It is prepared in a participatory manner and is ultimately discussed and validated by the Codir (CIRAD Management Board). Once validated, the roadmap will be implemented in successive 3-year action plans, with progress assessed at the end of each period. This document was submitted to the Management Committee for approval on 31 May 2023.

The Expert Group

The Expert Group is made up of around twenty people. Four belong to a close-knit group and the others to a group that has been enlarged as the challenges and ambitions have been considered and the document has been drafted.

- ✓ The close-knit group is made up of the two industry correspondents, **Cica Urbino** (Phim) and **Rémi Kahane** (Hortsys) and **Hélène Delatte** (PVBMT) and **Mathieu Weil** (Qualisud).
- ✓ The extended group is made up of **Didier Bazile** (UMR Sens and CTS Biodiversité), **Matthieu Bravin** (Recyclage & Risque), **Christophe Bugaud** (QualiSud), **Fabrice Le Bellec** and **Pascal Danthu** (HortSys), **Caroline Lejars** and **Koladé Akakpo** (G-eau), **Raphaël Morillon** and **Fabienne Micheli** (AGAP), **Paule Moustier** and **Marie-Jo Amiot-Carlin** (MoISA), **Stéphanie Rabaud** (Dims), **Jérémy Salinier** (PVBMT), **Hervé Sanguin** (Phim), **Jean-Michel Sourisseau** (Art-Dev) and **Ludovic Temple** and **Nicolas Paget** (Innovation).

The preparation of this FdR also benefited from the support of:

- ✓ Sandrine Dury (Dir. Rég. Méditerranée) as scientific advisor to the Department Environments and Societies (ES)
- ✓ François X. Côte as Delegate for Tropical Commodity Chains

Dashboard 2021-23

- ✓ Concept note presented to the RPSS at the end of 2020 following proposals made at the Codep
- ✓ Appointment of horticulture industry correspondents on 1 May 2021
- ✓ Redefinition of priorities for the horticulture roadmap: Klaxoon workshop on 11 May 2022 (by videoconference)
- ✓ Bibliometric and human resources analyses in horticulture at CIRAD (June-July 2022)
- ✓ Participation in the International Congress of Horticulture (IHC2022) in Angers by 44 CIRAD researchers (August 2022)
- ✓ Validation and structuring of CIRAD's ambitions in horticulture: Lauret workshop on 11 October 2022 (face-to-face)
- ✓ Detailed drafting of each ambition by multi-department teams according to the model proposed by the Sectors Delegation: Dec 2022 - Feb 2023
- ✓ Harmonisation of the ambitions and validation by the DUs concerned: workshop on 14 February 2023
- ✓ Regular interaction with the Scientific Advisor and the Programme Delegate
- ✓ Presentation and discussion of the Horticulture roadmap at the Codir: 31 May 2023

I- History of horticulture worldwide and current context

In terms of volume, fresh horticultural food products have grown steadily over the last 50 years (Figure 1), and represent the world's largest market in terms of value, well ahead of cereals and animal products.

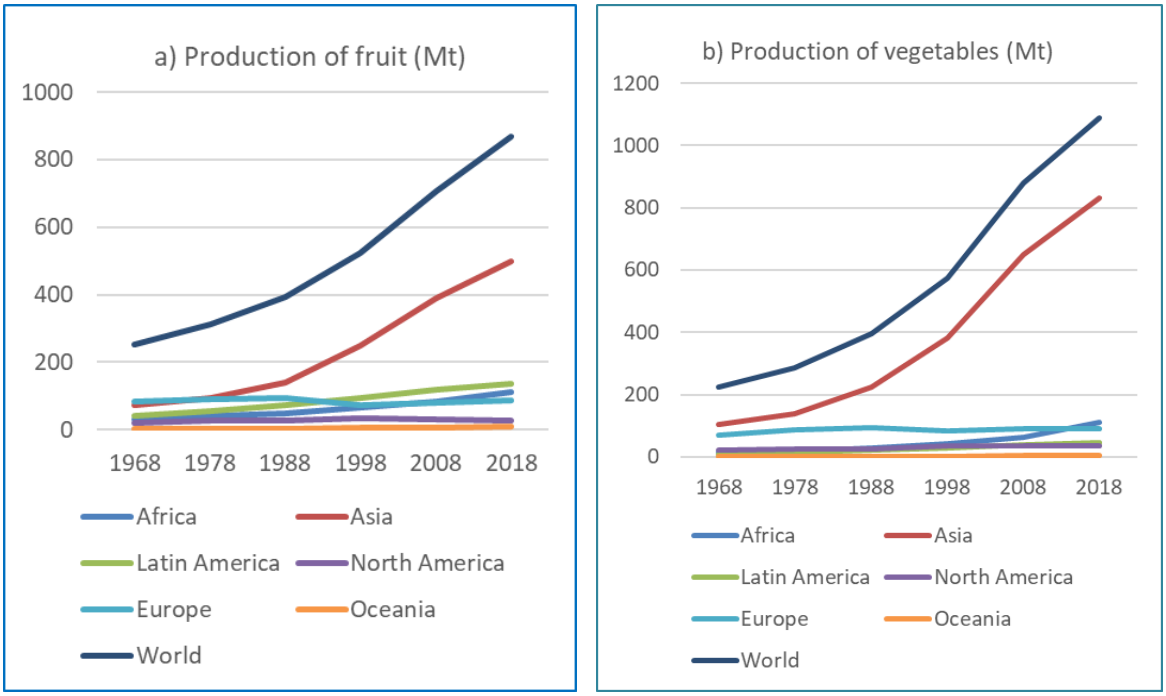

Figure 1 - World production of fruit (a) and vegetables (b) between 1968 and 2018 in million tonnes (Mt) (Source: FAOSTAT, 2020)

In addition to these global statistics, it is essential to distinguish between horticultural value chains in developed and emerging countries, which dominate these statistics and world trade, and value chains in less developed countries. In these low-income tropical countries, where CIRAD's priority is to work, many production and commercial transactions are informal and local. These value chains operate in a variety of production and processing systems, often dominated by family, rural and poorly organised structures with little capital (Figure 2). Because of their statistical invisibility, these value chains make little contribution to the balance of national trade balances, even though they are of crucial importance in terms of activity and income systems, territorial development, and food and nutritional security. The following comments from the FAO illustrate this point (Tropical fruits | FAO | Food and Agriculture Organization of the United Nations): (Tropical fruits | FAO | Food and Agriculture Organization of the United Nations) :

- In the absence of reliable statistics, the FAO estimates that 99% of tropical fruit production comes from developing countries, mainly in Asia and Latin America, and a smaller proportion from Africa (Figure 3).
- In most producing areas, tropical fruit and vegetables continue to follow marketing routes that are poorly integrated with markets.
- Combined exports of the four main tropical fruit species - bananas, mangoes, pineapple and papaya - represent only around 5% of total production volume, with the remainder destined for domestic markets.
- The global supply of tropical fruit and vegetables and the livelihoods of small-scale farmers are increasingly threatened by the impact of global crises, whether climatic or health-related.

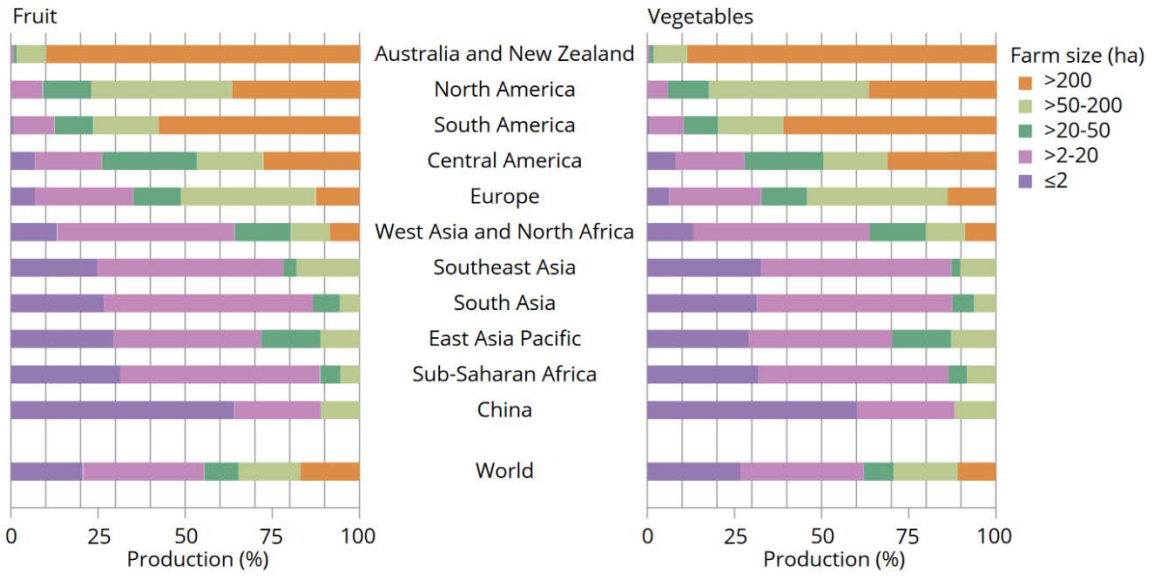

Figure 2 - Fruit and vegetable production by farm size and region (adapted from Herrero et al., 2017).

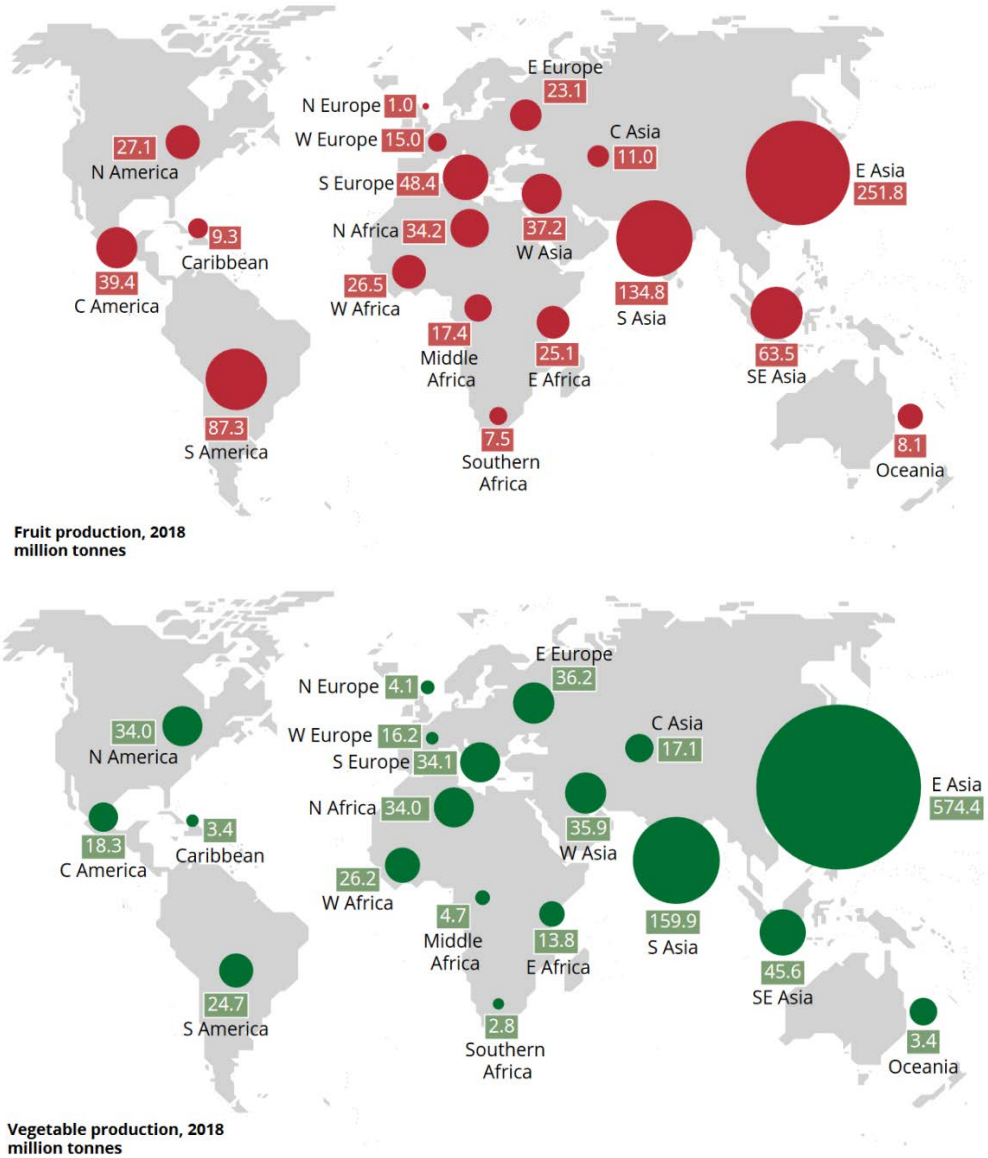

Figure 3 - World fruit and vegetable production in 2018, by region (in Mt) (Source: FAOSTAT).

Despite its economic importance and its role in food systems, horticulture is the sector that has received the least economic and political support, forgotten by the Consultative Group on International Agricultural Research (CGIAR) centers and the terms of the Green Revolution. This is undoubtedly due to one of its specific features: the great diversity of its species (Figure 4) and production systems, which scatters forces, escapes statistics, and gives the sector little political influence in the face of international industrial development strategies. Yet this diversity represents an asset in a context of agroecological transition (see definition in the box after Figure 5): fruit and vegetables, as well as all kinds of so-called orphan plants (aromatic, medicinal or ecosystem service plants), offer the opportunity to improve the lives of people in towns and the countryside while generating income and jobs (Roothaert, 2022) in a multitude of environmental contexts. This diversity also contributes to the resilience of production systems in the face of global change, and climate and health crises in particular.

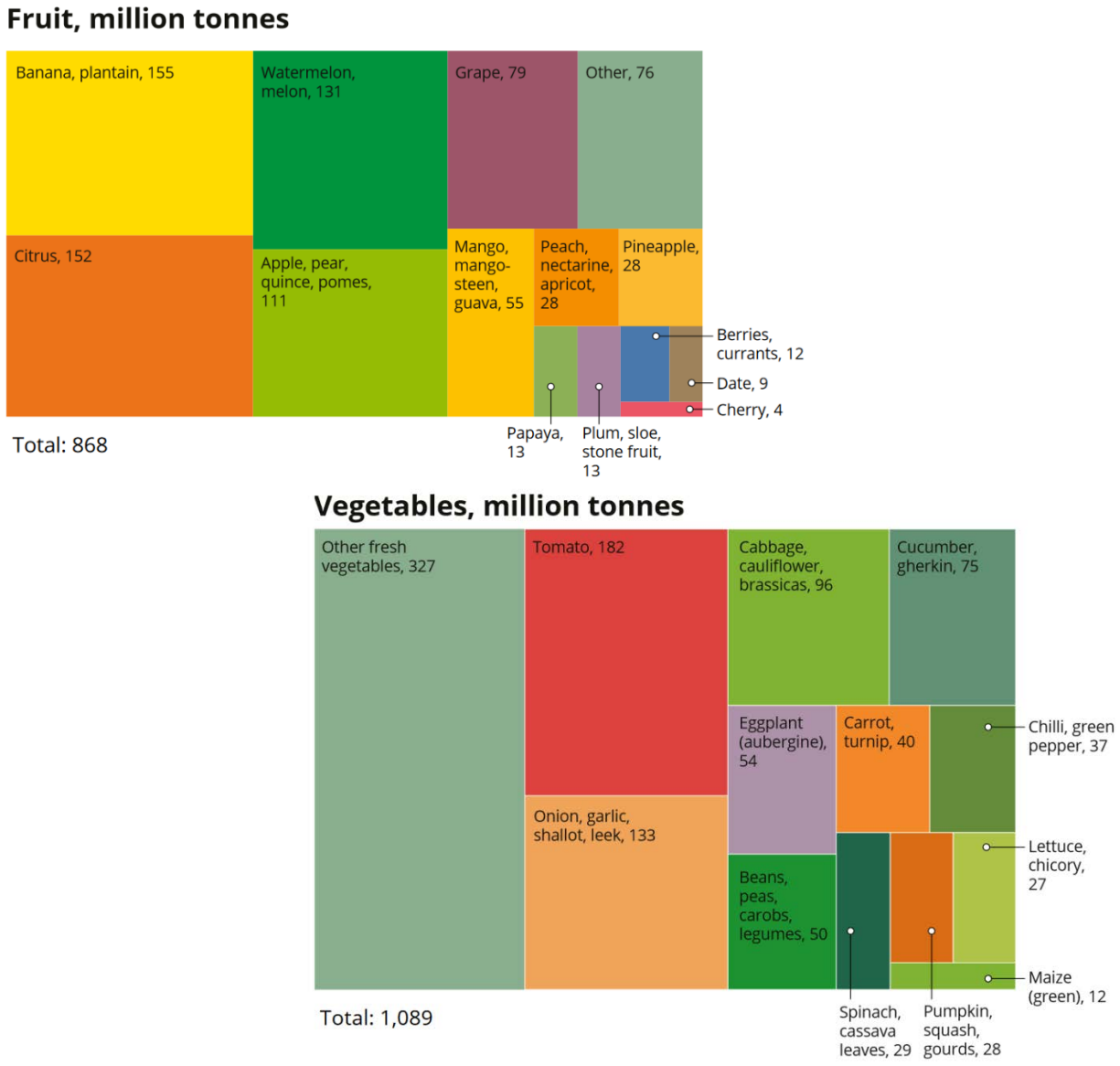

Figure 4 - World production of fruit and vegetables in 2018, by product (Mt) (FAO, 2021)**.**

The nutritional importance of horticultural produce, especially fruit and vegetables (Wang et al., 2021), has been emphasized for many years by public health officials in both North and South (WHO, 2002), who promote their consumption to combat both malnutrition linked to micronutrient deficiencies (minerals and vitamins) and malnutrition linked to over-consumption of fatty, sugary and ultra-processed products.

The challenge of global food and nutritional security is regularly highlighted in the light of climate change: by 2050, the most complicated issue will be providing balanced diets rather than sufficient calories. "Research priorities and policies must focus on nutritional quality by increasing the availability and affordability of nutrient-rich foods and improving dietary diversity" (Nelson et al., 2018).

Fruit, vegetables, aromatic plants, etc. are nevertheless highly sensitive to health pressures, and the quality and appearance criteria linked to their freshness lead to significant use of pesticides, both natural and synthetic. The horticultural sector is therefore one of the biggest consumers of chemical pesticides, generating hidden environmental costs (ecotoxicology) as well as increasingly significant health costs (negative externalities borne by the community as a whole, farm workers, consumers, etc.).

Production is also heavily dependent on water supply. In many parts of the world, the depletion of water resources and the pollution of water and soil that accompanies intensive horticultural production (fruit plantations, peri-urban market gardening) are the subject of much controversy. The agro-ecological transition represents an essential challenge for producing more and better, without forgetting to reduce losses and wastage, estimated at between 30 and 50% of the world's fruit and vegetable production (FAO-Cirad, 2021).

Several types of players are involved in the horticultural sector, from nurserymen and seedlings, family or external growers and workers, intermediaries (transporters, processors, traders) to consumers. The working conditions and pay of many people in these sectors are relatively unknown and certainly quite poor (exposure to pesticides, unregulated seasonal work, etc.). Avenues for improvement need to be explored, including analyzing the effects of technical support, particularly on the most vulnerable groups - young people, women and migrants.

II- Specific features of the horticulture sector

Horticulture covers plants grown for the production of fruit, vegetables, leaves, ornamental plants, aromatic plants and medicinal plants. In preparing this CIRAD Horticulture roadmap, we are including small-seeded legumes or green vegetables (pigeon peas or cowpeas, for example) but excluding large-seeded legumes or pulses (groundnuts), which are not considered horticultural species, and ornamental plants.

For reasons of non-duplication with the Banana and Plantain or Roots and Tubers sectors, these species (with the exception of potatoes) are not included in the Horticulture sector strategy. Horticultural farms are often better characterized by the type of work involved in production practices than by the surface area used. Production systems are highly varied, with levels of intensification more or less well covered by mechanization or technology (Figure 5). Family farms are distinct from corporate agriculture (of the plantation type) in which the domestic sphere is absent and production depends exclusively on permanent and temporary paid employees. Family farms may also be run by families and employ both family workers and permanent paid workers, implying a partial separation between the farm and the family (Bélières et al., 2015). While these three categories make it possible to set ideotypes for horticultural farms, the reality is a continuum of forms and organizations, ranging from strictly family-run farms to corporate-type farms (Table 1).

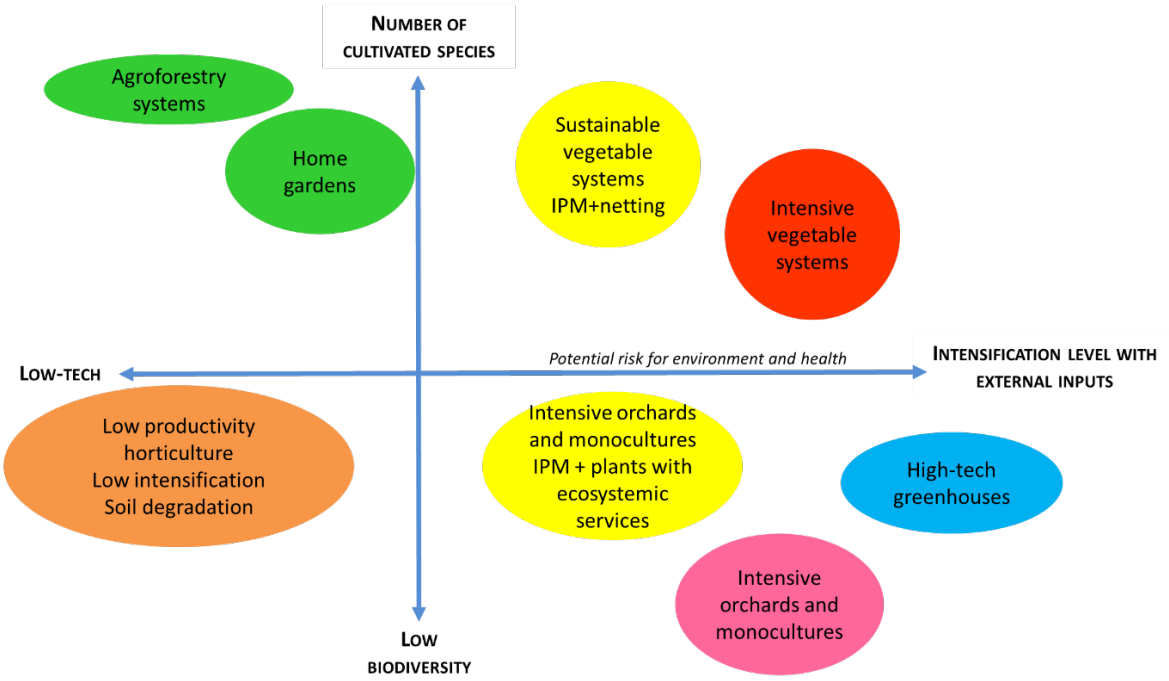

Figure 5 - Attempted typology of horticultural production systems according to the degree of intensification and biodiversity cultivated on the farm (FAO-CIRAD, 2021 from Malézieux et al., 2009).

Definition of agro-ecological transition (AET) adopted for this roadmap (after Côte et al., 2019).

The aim of the agro-ecological transition of horticultural production systems is to design agronomic, political, economic and social practices at different scales (plots, farms, production basins, territories) that promote biodiversity, in order to respond to climate change while strengthening the resilience of agrosystems and family farms.

Table 1 - Criteria for distinguishing between the different forms of agriculture, making it possible to identify the horticultural production units targeted by CIRAD's supply chain (Bélières et al., 2015).

	Capital-intensive farming <----------> Family farming		
	Industrial types	Business types	Family types
Work force >>>	Staff only	Mixed, with permanent staff	Family dominantly
Capital in the hands of	Shareholders	Family or family association	Family or family ownership
Management mode	Technical	Technical/Family	Family
Consumption	Not concerned	Residual	Partly on-farm
Legal status	Public limited company or any other form of company	Farmer status, forms of association	Not formalized or farmer
Land tenure status	Formal ownership or indirect occupation	Ownership or formal or informal indirect occupation	

The specific features of the Horticulture sector are as follows:

- **Diversity** of species and biologies (seeds or seedlings, annual or perennial) within fruit and vegetables (fruiting vegetables, leafy vegetables, root vegetables, etc.).

- Such diversity leads to a **cross-sectoral approach** to the sector, both in terms of products and systems: growing systems (open field, gardening, sheltered cultivation, soilless cultivation, etc.) and food systems (short distribution channels, storage and processing methods, integrated industrial sector, etc.).

- Paradoxically, fruit and vegetables are the only foodstuffs whose **human consumption**, even when encouraged by the public authorities, remains below the recommendations for public health.

- **Perishability** of fresh horticultural produce makes analysis of this sector unique, given the economic, commercial, health and nutritional issues involved, in relation to post-harvest management (preservation, transport, processing), human health and consumption.

- Local and regional activities are **often informal**, and above all multi-site and multi-stakeholder (often very small-scale), largely beyond the reach of statistical data, regulations and political decisions, both upstream (e.g. seed and plant management) and downstream (e.g. cross-border trade).

- While the need for knowledge linked to the environmental impact of this sector (transfer of pesticides, massive use of chemical fertilizers, irrigation management, etc.) gives it the status of **knowledge intensive**, it is losing ground in academic and technical teaching, both in the South and the North.

Because of its characteristics (high added value, risks linked to the perishability of products), this sector can be avant-garde in terms of innovation (adoption of new digital technologies, rapid response to market demand). Hence the need to set up training, knowledge-sharing and information systems that are accessible to industry players and updated on a regular basis (Bellon et al., 2022).

III- A long-standing international partnership

CIRAD has historically played a role in promoting horticulture for development in tropical countries (projects in West Africa on fruit flies from La Réunion, the SUSPER project in Southeast Asia), collaborating in global international initiatives (Global Horticulture Initiative – GlobalHort (2006-13) with ISHS, World Vegetable Center and FAO), focusing on nutritional quality (PROFEL/PROFAV with FAO and WHO), urban and peri-urban agriculture (Orsini et al. , 2013) and family farming (Sourisseau et al., 2014). All these areas of research in international partnership are reflected in most of the United Nations' sustainable development goals (Figure 6). It is worth highlighting the convergence of the two transitions, food and agroecology, supported by the United Nations, which are based on a larger share of fruit and vegetables in diets, responsible for fewer greenhouse gas emissions than sectors linked to animal production (Agribalyse 2020 data).

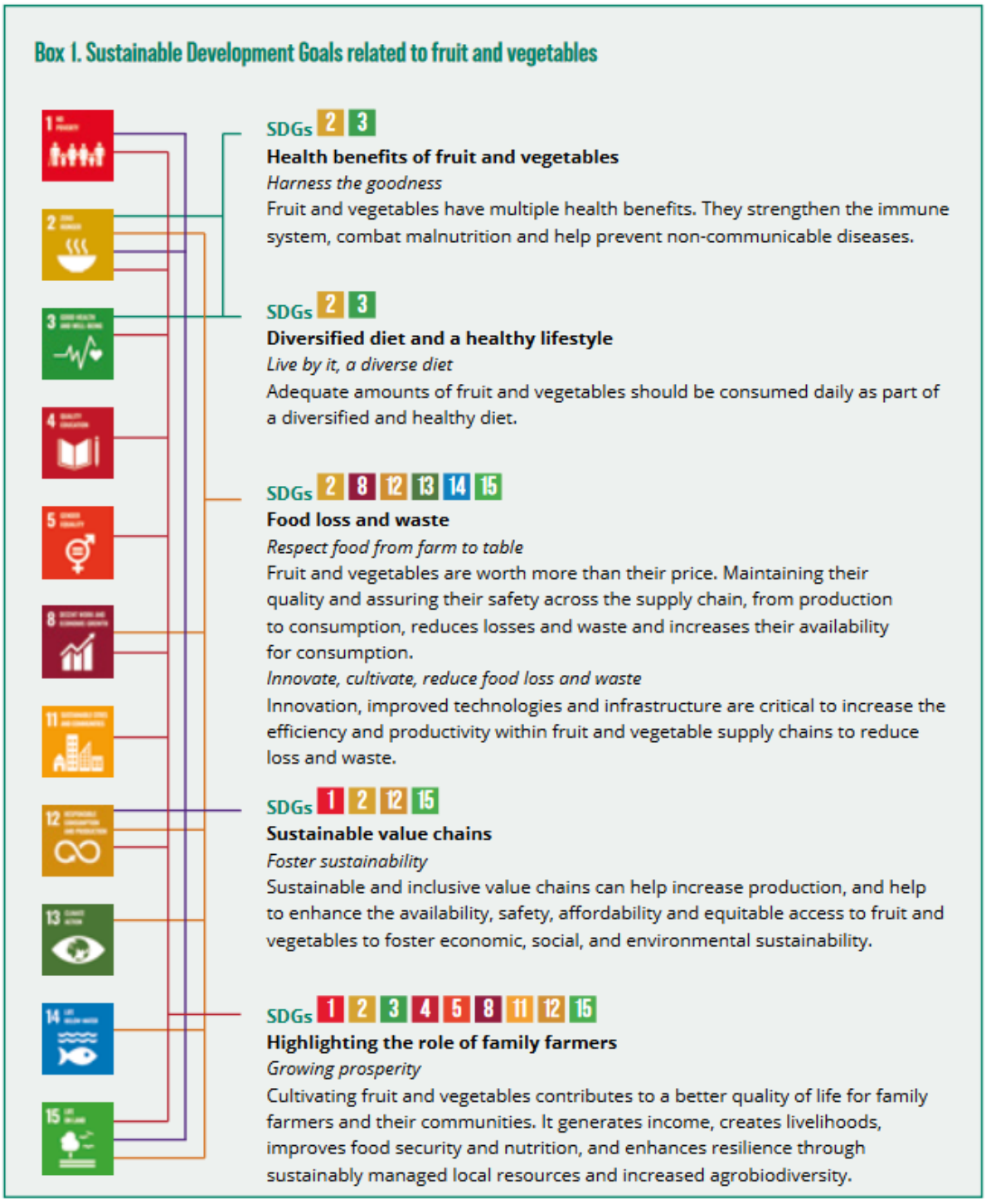

Figure 6 - Sustainable development objectives in relation to the FAO's strategic priorities for fruit and vegetables (FAO, 2021).

Among the 159 338 publications (articles, conferences) in Horticulture recorded in the Web of Science Core Collection over the period 2012-2021 ([1]), 700 are authored from at least one CIRAD's staff ([2]). Although it ranks behind many universities and research centers in terms of publications (Figure 7), CIRAD occupies a unique position in the tropical and Mediterranean horticulture sector, particularly for

[1] https://www.webofscience.com/wos/woscc/summary/0b519d74-38f7-4fcf-a158-77a5a550f352-443d84f5/relevance/1

[2] https://www.webofscience.com/wos/woscc/summary/c7c0f559-2302-419b-acf8-22115517ef73-44b9f459/relevance/1

its systems approaches to cropping systems, production systems and food systems. No CGIAR center occupies a significant place in terms of publications in this sector: Bioversity and CIAT focus more on cultivated fruit agrobiodiversity (botany and biochemistry of under-utilized species; links with human nutrition), CIP on Andean tubers, and ICRAF-World Agroforestry Center does not include horticultural forms of agroforestry. Some AIRCA centers occupy scientific niches: the World Vegetable Center (WorldVeg) is building its network of donors and partners on its genetic resources (characterization, selection, seed systems and health benefits); Icipe specializes in insect-human-environment interactions, mainly in Africa. CIRAD is also a key player when it comes to an integrated commodity chain approach (providing expert advice to the AFD, COLEACP and the FAO), although its visibility has become less clear since it was reorganized into three scientific departments. International centers have very little interest in horticulture.

According to our partners in the South, and based on an analysis of international organizations publishing on horticultural species over the past 10 years (Figure 7), members of national agricultural research systems (NARS) find CIRAD a reliable research partner for tackling the major issues of food and nutritional security, climate change and biodiversity management (see Table 4). Many NGOs (Agrisud International, CARI, GRET, ENDA) and farmers' organizations (in Africa and the French overseas departments and territories in particular) expect CIRAD to provide support for domestic and sub-regional horticultural sectors, which have until now been underestimated in relation to export markets. The countries that publish the most on fruit and vegetables are concentrated on the American continent (USA, Canada, Brazil, Argentina), Asia (China, India) and Australia (Figure 8). Europe and the countries of North Africa and the Middle East contribute 20% and 10% of these publications respectively. CIRAD does not appear in the top 25 organizations, with 700 articles over the period 2012-2021, 9% of which were co-published with INRAE (over the period 2010-19). It should be noted that most of these organizations are either digital archive banks (EXB) or universities in the North whose publications take little account of food systems in the South.

Figure 7 - Affiliation of the 25 largest contributors among the 159,338 publications (articles and conferences) in horticulture registered in the Web of Science Core Collection over 2012-2021.

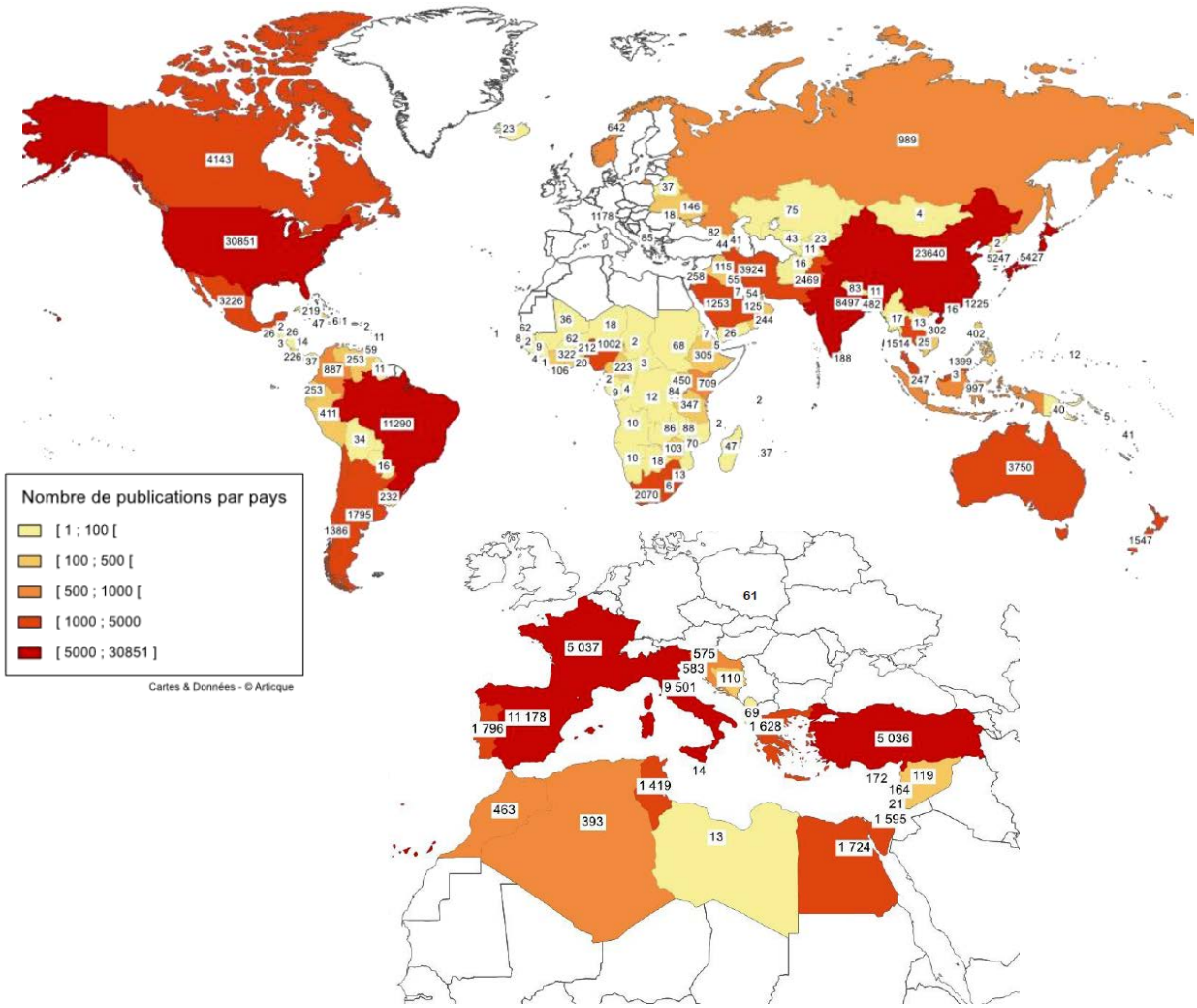

Figure 8 - World map of countries that published on fruit and vegetables during the 2010-19 period (Savajol et al., 2021)**.**

Several CIRAD partnerships (dPs) have horticulture-related projects: Divecosys (www.divecosys.org) and IAVAO in West Africa, Forêt & biodiversité (www.forets-biodiv.org) in Madagascar, Malica (www.malica.org) in Southeast Asia, the new dP Biocontrol in the Indian Ocean (www.dp-biocontrole-oi.org), and Sirma (www.rcp-sirma.org) in North Africa. These dPs focus on the sustainable management of the environment (rural or urban) and agrosystems, with the aim of meeting the needs of local populations (such as water resources and wood energy). They contribute to the development of the horticulture sector only indirectly, for example through the development of crops that improve people's incomes and food and nutritional security (e.g. cloves and lychees for Forest & Biodiversity).

However, compared with a corpus of CIRAD impact-factor journal articles between 2018 and 2021 on Horticulture, the links to the strategic thematic fields (CTS in French) are not all as strong (Figure 9). One Health (170) and Agroecological Transitions (142) are clearly in the lead, followed by Biodiversity (83) and Sustainable Food Systems (67). Territorial approaches (36) comes last, while Climate Change (16) is virtually absent.

By mid-2022, CIRAD was contributing to 85 projects involving horticultural species (Figure 10). These projects were of the collaboration and research or partnership and development type, with private (20% of cases) or public (European Union for 39% of cases, other institutions for 31%, and DROM funding for 10%) backers. Nearly half the projects were in the "Improvement and production" theme (37/85), or

concerned pests and diseases (15/85) and product quality (10/85). The majority of these projects were carried out in the French overseas departments and territories and mainland France (56/85, mainly in plant production and plant health), Latin America (14) and the Indian Ocean islands (12).

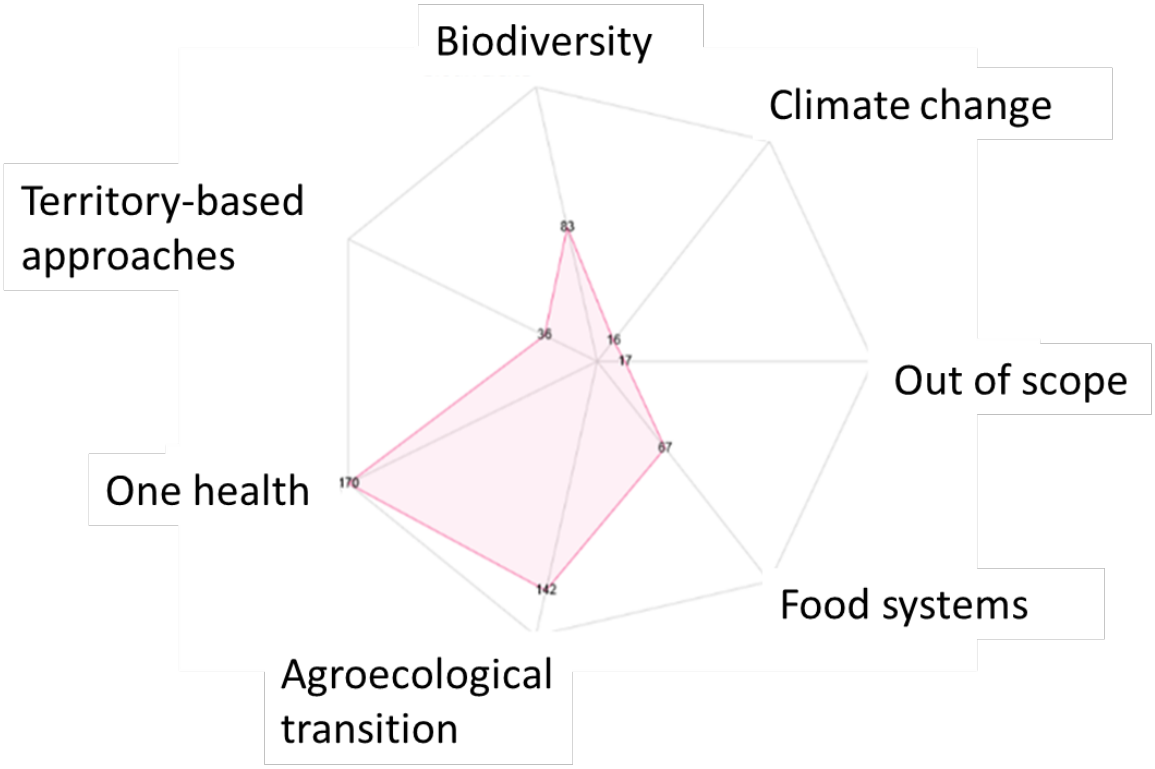

Figure 9 - Breakdown of the 531 CIRAD horticultural publications (2018-2021) by CIRAD Strategic Thematic Fields (CTS).

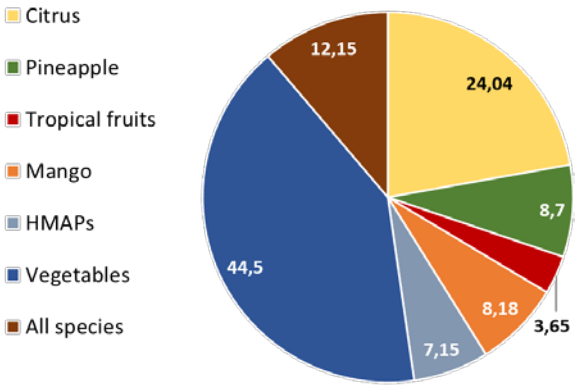

Figure 10 - Diversity of horticultural species studied in 85 CIRAD projects in 2022 (Source: Dims-CIRAD).

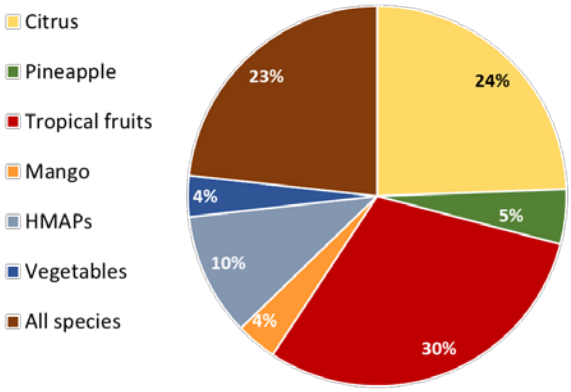

Figure 11 - Breakdown of FTEs by horticultural species studied at CIRAD (based on survey of unit researchers, March 2023)**.**

Market garden crops (including tomatoes and other Solanaceae, onions and other Alliaceae, zucchinis and other Cucurbitaceae, okra and other Malvaceae, cabbage and other crucifers) are the undifferentiated horticultural products involving more than 44 FTEs at CIRAD (Figure 11). Fruit crops (excluding bananas) are more often mentioned specifically (citrus, pineapple and mango) for the same total (44 FTEs with other fruit species such as lychee or cashew). It should be noted that more than 12 FTEs work on a range of horticultural species, reflecting a thematic approach close to agroforestry (market garden orchards or Creole gardens, for example).

IV- CIRAD's original scientific positioning

As well as representing a large number of cultivated species, horticulture is of scientific interest due to the originality of a sectoral approach encompassing several sectors:

- Horticultural systems are all the more complex in that they can involve special combinations of vegetable crops with short cycles, allowing several harvests in a year, and perennial plants (agronomy, agroecology, horticultural agroforestry, genetics, socio-economics).
- The sensitivity of horticultural plants and products to a wide range of pests and diseases means that they are highly prone to the use of pesticides (plant pathology, epidemio-surveillance, pest and disease management, biological control, ecology).
- Their high dependence on water means that they need to be well integrated into the landscape, in association with sustainable management of soil fertility (agronomy, hydrology, pedology).

In view of the number of horticultural species studied at CIRAD, the horticulture sector is ideal for producing knowledge on:

- Ecological intensification (making it easier to multiply breeding cycles and generations, study synergies between associated plants, soil/plant dynamics),
- Relationships with other sectors such as rice (for water and soil fertility management), banana (in agroforestry), perennials (association with coffee, cocoa), or roots and tubers, not forgetting livestock farming (poultry and fish farming in urban areas, pastoralism in rural areas) in situations where little biomass is available,
- Integration into landscapes and societies (family farming, urban farming, island farming).

This sectoral approach justifies the need for interdisciplinary approaches, between agrotechnical sciences and economic and social sciences, as well as a predisposition of horticultural sectors to interactions between species and between players within the same territory, to agroecology and to organic farming approaches (consumers close to producers, expression of strong environmental and social preferences).

CIRAD offers a combination of skills in contrasting situations such as the French overseas departments and territories (DROMs) and tropical, sub-tropical and Mediterranean countries. Horticulture research fields, whether territorial, systemic or by species, can benefit from this dual biotechnical and socio-economic approach, whether in the field or under cover, in rural or urban areas.

In the same way, the cross-disciplinary approach to fruit and vegetables naturally allows us to understand the spatial and temporal combination of different crops, the management of agroforestry and associated crops in their ecological and environmental dimensions, as well as their sociological, economic and cultural dimensions, to better understand the rationality of producers and the impacts of their activities on the environment.

The aim of structuring and promoting a horticulture supply chain approach at CIRAD is to increase the impact of research that is currently too often conducted in silos and to propose an organized vision for discussion with our various partners in national agricultural research centers, Universities and international organizations (such as FAO, IARCA and CGIAR). This new structure will stimulate inter-unit activities and an interdisciplinary approach to horticultural value chains, where there is still little interaction between the various teams. This commodity chain approach should lead to new and original research questions, which will be used to structure the projects of the research units concerned through new recruitments.

The aim of labelling the Horticulture field at CIRAD in 2021 is to highlight the major issues that meet CIRAD's ambitions for the field, taking in account what is being done and what is not being done elsewhere. It is also an opportunity to talk more particularly with our national partners, INRAE (GIS PIC-Leg and GIS Fruits), IRD and L'Institut Agro, so that we can work in complementarity rather than competition, given the global issues and the resources (human) available to CIRAD. The Horticulture sector should be a driving force behind the CIRAD-INRAE initiative in Africa (TSARA = Transforming Food Systems and Agriculture through Research in Partnership with Africa), in which both are involved in food security, the fight against global warming, the enhancement of biodiversity, the health of humans, animals and ecosystems, as well as youth employment and gender equity. In addition to the research that already exists within the UMRs, these partnerships could be developed to strengthen and complement CIRAD's skills.

V- Human resources, a strength in meeting the challenges of the horticultural sector

To analyze the human resources involved in horticulture, we asked each unit to list the staff working in the sector, excluding bananas and plantains as explained above. The units thus counted their staff in full-time equivalents (FTE), identified the species they were working on and the scientific themes concerned.

Research on horticultural plants involves at least 12 CIRAD research units (Figure 12). This represents 164 employees with 108 FTEs, mainly in the Bios and Persyst departments. A third of the staff (40% of FTEs) are agronomists, and another third (30% of FTEs) work in plant health, while only 5% work in economic and social sciences. This field has the most human resources of all CIRAD's fields. This can be explained by the historical importance of horticulture at CIRAD (Irfa, then the Flhor Department), and by the fact that research units such as HortSys, PVBMT, Agap and Qualisud are strongly dedicated to horticultural plants, particularly in the French overseas departments (Martinique and Réunion). Logically, the themes with the highest number of FTEs are those developed by these units (Figure 13). Managers over the age of 50 are predominantly men, but there has been a shift in the gender balance of managers under the age of 50, due to more recent recruitment (Figure 14).

In the French overseas departments and territories (>50% of FTEs in the sector), mainly in Réunion (40 FTEs) and Martinique (12 FTEs), the scientific themes most frequently studied are genetic resources (13.8 FTEs), agronomy and production systems (18.0 FTEs) and plant health (24.8 FTEs).

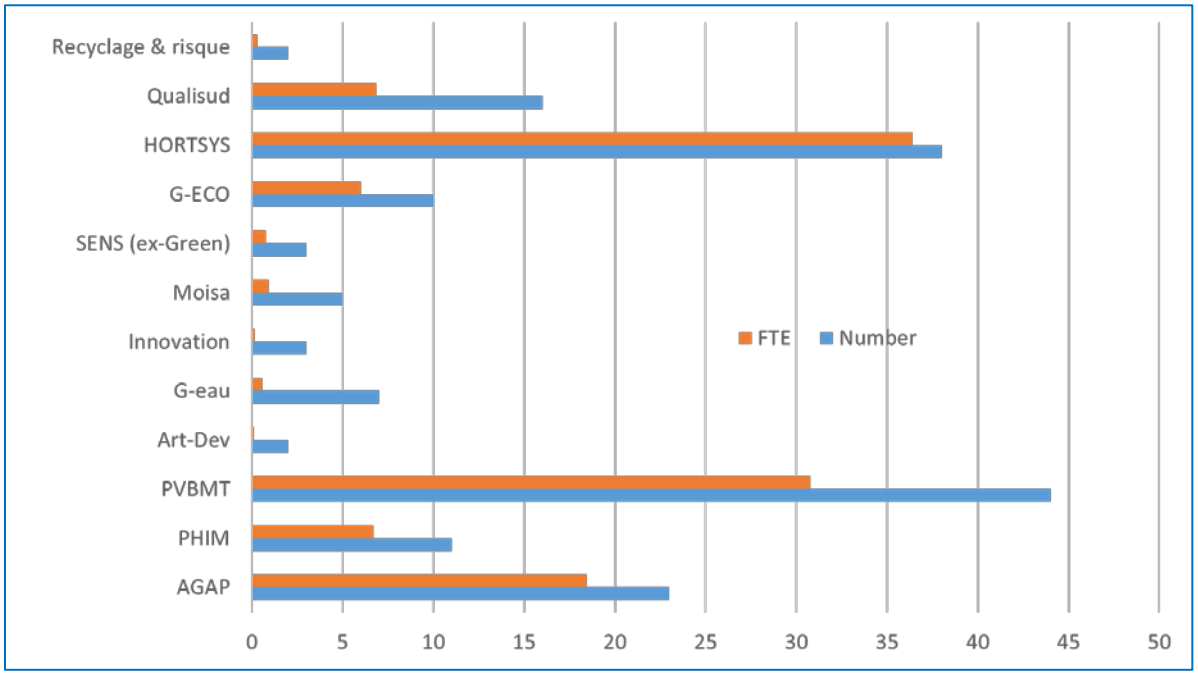

Figure 12 - Number of staff and FTEs dedicated to horticulture per CIRAD research unit (based on a survey of unit researchers, March 2023).

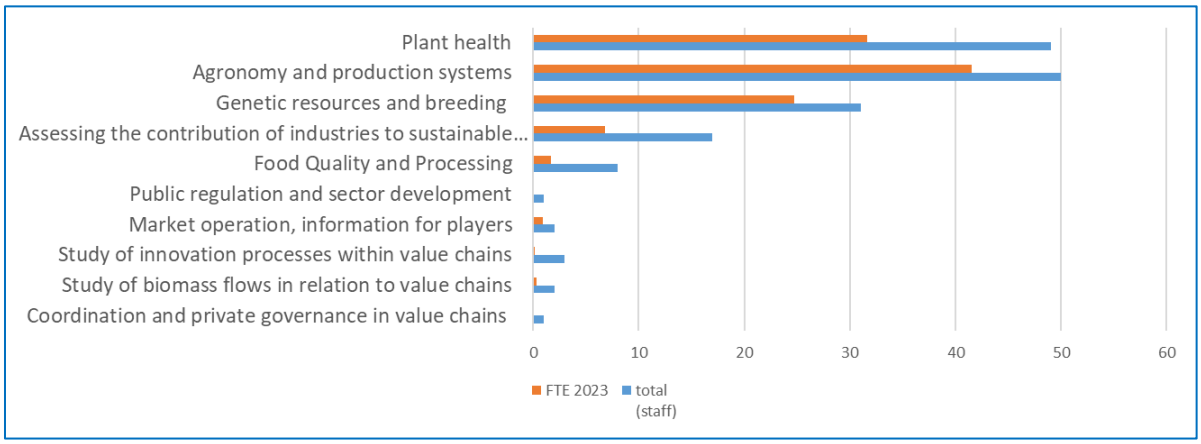

Figure 13 - Breakdown of staff and FTEs by scientific theme.

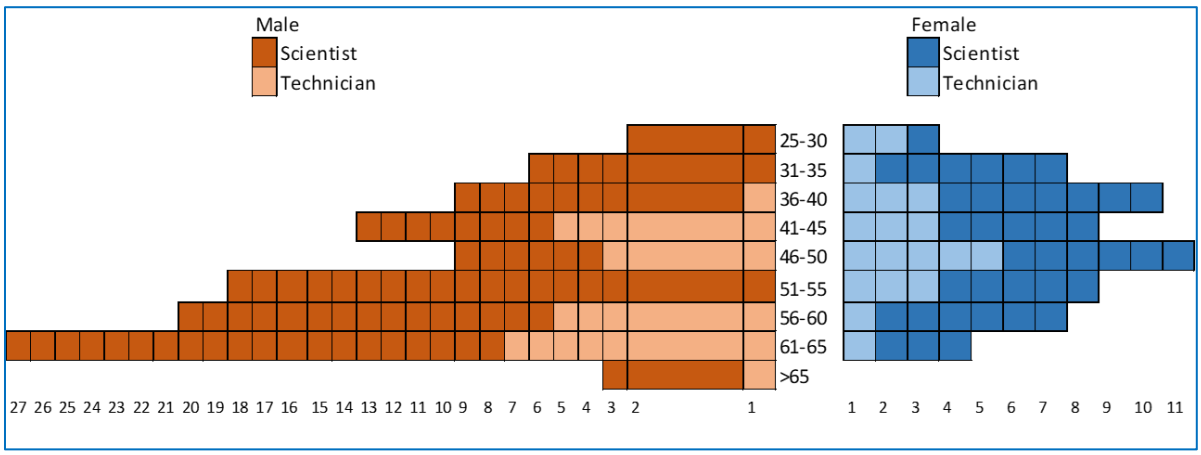

Figure 14 – Age pyramid for CIRAD researchers and technicians involved in horticulture.

Less than 10% of these human resources are expatriated to Africa, while 90% are based in France (Montpellier, Corsica) and particularly in the French overseas departments and regions (50% of staff, 60% of FTEs) where most field activities are carried out (Table 2). It is also worth noting the strong presence of technicians and engineers in the DROMs, in charge of experimental areas and laboratories, particularly in Réunion and Martinique (37 staff, 28.4 FTEs).

Table 2 – Geographic distribution of CIRAD's staff.

Geographic sites	Staff	FTEs
Asia (Vietnam)	1	0,20
Latin America	1	0,60
Africa (incl. Madagascar)	15	11,25
Montpellier and Corsica	67	35,24
DROMs	80	60,61
Total	**164**	**107,9**

Without taking in account new recruitments, the demographic evolution of the sector over 5 and 10 years (Table 3) leads to a loss of 27.8 and 40.0% of FTEs, respectively. The impact will be particularly significant in the fields of biology/ecology/agronomy, food science and economics/management science, which will have lost 28 to 100% of the FTEs currently available.

Table 3 - Five- and 10-year trends in the number of horticultural researchers and full time equivalent (ETP) by discipline from 2022 onwards.

	Agronomy and production systems	Construction, evaluation of industry qualification systems	Contribution of food chains to local food systems and regional exchanges	Coordination and private governance in value chains	Study of biomass flows in relation to value chains	Assessing the contribution of industries to sustainable development	Study of innovation processes within value chains	Market operation, information for players	Food quality and processing	Public regulation and sector development	Genetic resources and breeding	Plant health	Total
Staff number in 2023 (researchers + technicians)	37	8	1	1	2	2	3	3	17	4	30	56	164
FTE 2023	30,35	1,65	1	0,05	0,3	2	0,16	1,15	6,83	0,25	24,55	39,56	107,9
FTE loss over 5 years	-8,6	-0,05	-1	0	0	0	-0,05	0	-2,69	-0,1	-6,24	-10,11	-28,84
FTE loss over 10 years	-14,65	-0,95	-1	0	0	0	-0,1	-0,05	-3,48	-0,15	-6,24	-16,46	-43,08
5-year change (in %)	**-28,34**	**-3,03**	**-100,00**	**0,00**	**0,00**	**0,00**	**-31,25**	**0,00**	**-39,39**	**-40,00**	**-25,42**	**-25,56**	**-26,74**
10-year change (in %)	**-48,27**	**-57,58**	**-100,00**	**0,00**	**0,00**	**0,00**	**-62,50**	**-4,35**	**-50,95**	**-60,00**	**-25,42**	**-41,61**	**-39,94**

VI- From the challenges facing horticulture to defining ambitions for Cirad

The IHC2022 held in France last August provided an interesting snapshot of CIRAD's position in the concert of international horticultural sciences, even if the political and health context of the time inevitably distorted the absolute representativeness (absence of the People's Republic of China in particular) of themes and countries. Of the 477 French participants, 47 were CIRAD staffs, from 3 departments (the majority from Persyst) and 9 research units (the majority from research units Hortsys, Geco and Phim) (Figure 15).

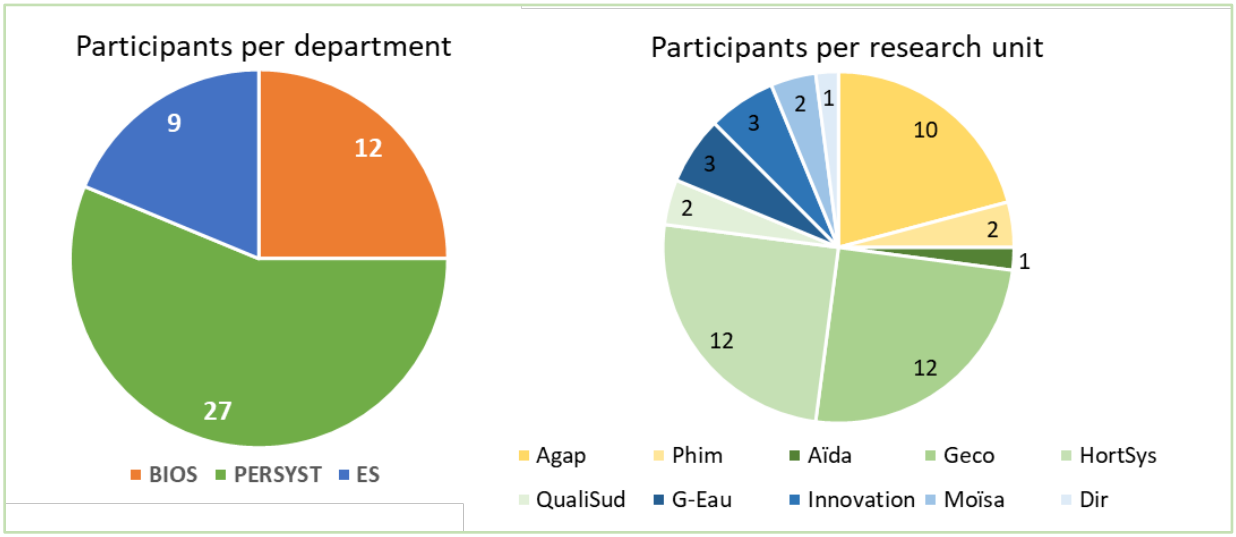

Figure 15 - Breakdown of CIRAD participants per department and per research unit at the International Horticultural Congress (IHC2022), Angers, August 2022.

Of the many scientific topics covered at the conference, four stood out because they were new to the ISHS. They will influence CIRAD in the development of its various roadmaps for the horticulture, banana and tuber sectors: water, agroecology, microbiota and the digitization of horticulture.

Water was the subject of an entire symposium, but also featured in every reference to climate change. Once again, water was chosen as the flagship theme to be presented to the French Minister of Agriculture to illustrate the crucial issues at stake and the scope of French and international research for the horticultural sector: irrigation efficiency in irrigated systems, and good water management practices to support the agroecological transition, with the reuse of waste water or the development of crops under cover.

Agroecology as a scientific theme made its first appearance at an ISHS congress. For some of the conference's 'north-western' scientific community, in a sector that is particularly intensive in the use of pesticides and whose environmental impact is increasingly questioned, this recognition and visibility of agroecology was in itself innovative. Faced with technological promises whose feasibility has not been the subject of scientific research, there was little presentation of the use of biodiversity to meet the challenges of reducing the use of chemical inputs.

The role of microbiota in improving seed germination, plant growth and protection, soil and substrate quality, and of course in human nutrition, was particularly highlighted by the research presented. It was surprising, however, to see that microbiota were already being used for highly applied biocontrol purposes, even though little is known about the interactions between the microorganisms that make them up and the consequences of their use in the environment. A few more generic works described the complexity of processing metadata, and even more so of analyzing them in a reasoned manner. Given the financial, IT and scientific resources needed to analyze molecular sequence data, there is a risk that this knowledge will be 'privatized' by those who have the means to exploit it. CIRAD and its partners must take action in this area to ensure fair access to knowledge and biological material.

The digitization of horticulture has mainly concerned market access and agribusiness, linked to the perishability of fresh produce. It is leading to a new technological paradigm shift that affects physical networks, information and knowledge media, computer terminals (computers and smartphones are ubiquitous) and robots (drones and others). This last technological trajectory holds great promise for development (less arduous work, appeal to young people), but is also highly intensive in terms of energy,

rare minerals, capital investment and information. Its sustainability in terms of environmental impact, and its globalization in terms of the social inclusion of farmers in developing countries who have little access to the necessary resources, have yet to be fully explored, and will undoubtedly require further research by CIRAD and its partners.

The overall challenge for horticulture in the years to come is to contribute to food and nutritional security, while limiting the impact on the environment and ensuring the well-being of individuals within their communities. The agroecological transition of horticultural production (AET), as an alternative to sustainable intensification, is considered to be an approach of choice for meeting the nutritional needs of human societies in terms of both quality and quantity. It underpins a series of more specific challenges involving:

- overcoming the negative externalities caused by intensification. This means designing more diversified production systems based on ecosystem services that can be more resilient in the face of climatic, health and economic risks, and less dependent on external inputs and resources. "Faced with the current crisis and the characteristics of agriculture in the South, agricultural diversification appears to be one of the possible responses, often desired by a majority of stakeholders, which should enable better adaptation to consumer demand, socially accepted agricultural development and greater respect for the environment" (Malézieux and Moustier, 2005).
- manage soil fertility, water resources and the non-renewable natural resources (fossil fuels, mineral resources) required for the production and use of horticultural products over the long term (Fairhurst, 2015). The development of new production, management (more community-based, more integrative) and consumption practices will make it possible to optimize uses and make the most of the biomass produced (recycling, circular economies, ecological services). Making the most of the soil microbiome is also an avenue to be explored that is highly compatible with agroecology (Kendzior et al., 2022).
- designing and implementing strategies to limit losses during cultivation and post-harvest (Soethoudt et al., 2021), thereby guaranteeing that horticultural products have the health (without the use of pesticides and without biological or chemical contamination), organoleptic and nutritional qualities demanded by the market. "Protecting crops against pests other than by using pesticides alone is one of the major challenges posed by the need to produce more and better" (Deguine and Ratnadass, 2016). The challenge is to find solutions that limit the socio-economic risks for producers while ensuring that consumers have access to healthy, tasty and inexpensive products.
- designing and developing food systems that are resilient in the face of global change, which often poses constraints that are more socio-political, economic and cultural than technical or technological (population growth and urbanization, economic and employment crises, climate change and declining biodiversity). The challenge for horticulture is to succeed in reconciling low and high-technologies in order to adapt to multiple contexts and meet health, nutritional and sensory quality requirements.
- managing information and knowledge to support those involved in the sector, in order to produce, promote and generate decent, motivating jobs for young people and women, particularly in developing countries. The challenge is not only to make horticultural professions attractive at a time when the agricultural workforce is shrinking everywhere and horticultural needs are increasing, but also to strengthen the capacities and empower the players in the sector by taking advantage of the digital boom in the agricultural and agri-food sector.

As part of the preparation of this roadmap, we reworked these challenges to make them more specific and complementary, including in terms of geography and partnerships (Table 4).

Table 4 - Geographical location of current institutional partners involved in the challenges facing the horticulture sector.

Challenges	Countries/Regions of study for CIRAD	Partners of CIRAD
1- Improving the uses and quality of water in horticultural systems in a context of global changes (climate, agricultural intensification, dietary change, demographic pressure and urbanization), strong pressure of use and pollution	Martinique Guadeloupe La Réunion Madagascar North Africa Latin America (Brazil)	CAEC, RITA INRAE (CRB-PT) Universities, Armeflhor, RITA Fofifa, Univ. Tana, Essam ENA Meknes, IAVHII
2- Agroecological transition of horticultural production systems to face socio-economic and environmental challenges	Martinique La Réunion, Mayotte West Africa (Benin, Burkina Faso, Congo, Côte d'Ivoire, Senegal) East Africa (Kenya, Tanzania) + Madagascar Southern Africa North America (USA) Latin America (Brazil, Cuba) Asia (Vietnam) Mediterranean Europe	IRD, RITA RITA, SGAR CNRA and Universities, CORAF, IITA, Agrisud, IRD WorldVeg, Icipe, IITA, Universities Univ. Florida, Hawaii Embrapa, Univ. Ciego de Avila SOFRI, Bioversity & CIAT INRAEe, IVIA, Univ. Bologna
3- Improving access to diverse and healthy foods for vulnerable people	Martinique Guadeloupe La Réunion Mayotte West Africa Madagascar Latin America (Colombia) Asia (Thailand, Vietnam)	IRD, RITA INRAE, Chambers of Ag., RITA University, SGAR, RITA AFSA, FAO, IFPRI CTHT Corpoica, Bioversity & CIAT Univ. Kasetsart, Institut Polytechnic Institute Hanoi, FAVRI
4- Consideration of horticulture in agri-urban and rural territories	Martinique La Réunion Mayotte North Africa Latin America (Brazil, Colombia) Asia (Vietnam, Lao)	IRD, RITA University, RITA SGAR, RITA ENA Meknes Embrapa, Corpoica FAVRI, Univ. Nabong
5- Capacity building in the face of digitization of horticulture	La Réunion Afrique du Nord (Morocco, Tunisia) West Africa (Benin, Ghana, Senegal, Côte d'Ivoire) East Africa (Kenya)	 ENAM, IAVH II CORAF, FARA, IITA, Universities Cabi, Icipe, Ruforum

Sub-Saharan Africa is the international field with the most coverage, in partnership with national agricultural research systems rather than with international centers, which are less involved in this field. Given the importance of CIRAD's position in the French overseas departments and regions (DROMs) in horticulture, and the relevance of the two recent analyses carried out by CIRAD (Marzin et al., 2021) and IRD (Méjean et al., 2020), it seemed worthwhile to link the challenges identified in the Horticulture

roadmap to the specific needs of these DROMs (Table 5). Consultation with the regional directors involved in drawing up the strategic plans of the two main DROMs for horticulture, Martinique and Réunion, would seem to be particularly appropriate in the coming months.

Table 5 - Correspondence between the overall challenges of the Horticulture FdR and those of the DROMs (French overseas departments and regions).

Challenges for the Horticulture roadmap	Challenges for the DROMs
1- Improving the use and quality of water in horticultural systems in a context of global change, high pressure of use and pollution	The irregularity of rainfall and the intensity of climatic events in the Caribbean and the Indian Ocean have a major impact on agriculture in the French overseas departments and territories, and there are three levels of demand for research: - Analysis of regulatory instruments in contexts of strong competition between different water uses, - Support for producers in improving the management of water resources, in terms of both volume and quality, - Acquiring knowledge and practices that can be extrapolated to other tropical contexts.
2- Agroecological transition of horticultural production systems to meet socio-economic and environmental challenges	The people of the French West Indies have enormous expectations of alternatives to chemical pesticides, particularly in view of the continuing chlordecone crisis. Short-term solutions consist of importing fresh fruit and vegetables (from mainland France or neighboring countries), which is not economically, ecologically or socially sustainable. The DROMs therefore have a strong demand for agroecological solutions for themselves (well taken in account in MASA's F&V Sovereignty Plan for 2023), and are bridgeheads for research and experimentation in partnership and multi-sector interaction (active participation in the RITA networks). In Martinique and Réunion, the laboratories and stations (open-ground or sheltered) located in farming environments are largely dedicated to horticultural species in tropical contexts and regional networks (dP Biocontrol in the Western Indian Ocean).
3- Improving access to a variety of healthy foods for vulnerable people	The concept of food and nutritional security for populations in the French overseas departments and territories is paradoxical: the diversity and potential availability of fruit and vegetables is much the same as in mainland France. Yet the rates of obesity and associated diseases (type II diabetes) are higher, constituting a veritable epidemic among children. The issue of food consumption and food sovereignty is based on eating habits (excess sugar and fat) and behaviors (sedentary lifestyle, purchase of imported products) as well as accessibility (poverty rate of the population), with specificities depending on the DROM. Quality signs and procedures and short distribution channels are public policies that have already been explored, but which need to take in account the whole diet if they are to have a beneficial impact on health and the island economy.

4- Consideration of horticulture in agri-urban and rural territories	The multifunctional nature of horticulture is a key issue for the French overseas departments and territories (DROMs), given the anthropization of natural environments and the desire of populations for greater sovereignty, whether in terms of food, the economy or culture. In the management of island territories, landscape management clearly raises the issue of biodiversity endangered by human activities. Horticulture practiced by small family farms (forest gardens) has a potential for beneficial effects that have yet to be assessed, and negative impacts (waste, pollution, nuisance) that we must seek to limit. These methodological expectations (evaluation criteria, statistical models) are specific to each DROM, but also have more generic interests (inter-DROM and inter-sector, role of RITA).
5- Capacity building in the face of digitization of horticulture	The DROMs are dominated by digital innovations, via the Internet and smartphones, with no potential for innovation or internal development, as in West Africa (Manobi Africa[3]) or East Africa (M-Pesa). The role of digital technology in DROMs in general, and in horticulture in particular, should be particularly studied in relation to the potential and specific features of DROMs: attracting young people to the agricultural professions, running inter-DROM networks, the skills of local organizations to run information, service and capacity-building platforms to access and contribute to technical knowledge (robotics) and commercial, financial and partnership opportunities.

In order to contribute to and support this agronomic and food transition, the Expert Group has proposed 5 ambitions for CIRAD's Horticulture roadmap. The final title of these ambitions (Table 6) is the result of the group's reflections after 3 workshops and numerous exchanges with the DUs (G-Eau, HortSys, MoISA), the scientific referent for the Horticulture roadmap, and the Delegate for Tropical Sectors:

1- Co-designing innovative solutions for sustainable and equitable water management in tropical and Mediterranean horticulture,
2- To co-design attractive and sustainable solutions for managing bio-aggressors and soil fertility in horticultural production,
3- Identifying and understanding the drivers of diversified fruit and vegetable consumption in the South, and using socio-technical and organizational innovation to serve and support these drivers,
4- Understand, evaluate and strengthen the multifunctionality of horticulture in agri-urban and rural areas,
5- Exploring digital opportunities in the horticultural sector for the benefit of small farms and family businesses in the South.

[3] https://www.manobi.com/

Table 6 - Formulation of ambitions for the 10-year strategy of the CIRAD horticulture sector.

Ambition 1 **Co-designing innovative solutions for sustainable and equitable water management in tropical and Mediterranean horticulture**	Tropical and Mediterranean horticultural production systems are facing unfavorable conditions as a result of climate change. Responding to these constraints requires the development of innovations that contribute to a better management of water resources (groundwater, surface water and wastewater), and to preserving their quality. This will involve developing water-centered impact assessment methods (life cycle analysis, LCA-water) as well as multi-scale and multi-species improvement strategies for the use and distribution of water resources, in order to promote biodiversity at different scales (plant, field, farming system, catchment area, landscape). This ambition reflects a shift in CIRAD's research work, aimed at analyzing the role of water and irrigation in the agroecological transition of family horticultural production in the South.
Ambition 2 **Co-designing attractive, sustainable solutions for managing pests and soil fertility in horticultural production**	Horticultural production is very often treated with chemical products, endangering the health of producers and consumers, as well as the environment. This ambition will seek solutions for growing crops without synthetic inputs in order to guarantee the health of workers, the nutritional and sanitary quality of produce and the preservation of the environment. This involves identifying and assessing the agronomic, economic and ecological advantages, constraints and risks of farming practices. This knowledge will enable attractive and sustainable production systems to be designed and implemented with local stakeholders, taking in account the conditions for preserving and mobilizing biodiversity and the interactions between plants, soils and micro-organisms. This ambition is in line with CIRAD's agroecological approach, but with a new focus on the role of the microbiome in soil and plant health.
Ambition 3 **Identify and understand the drivers of diversified fruit and vegetable consumption in the South, and use socio-technical and organizational innovation to serve and support these drivers.**	Horticultural products are both fragile and of high nutritional and economic value. Their diversity in the diet makes them essential to consumers' health. Yet their consumption is threatened by the erosion of biodiversity and the standardization of food. Furthermore, the link between production volumes, accessibility and consumption levels is not always obvious. Processing, storage and transport to reach markets are all risks of loss of the products themselves and deterioration of their quality. With this in mind, the aim will be to understand the levers for consumption of horticultural products, especially fruit and vegetables, to contribute to the essential diversity of the diet of populations in the South, in both urban and rural areas. The specific objectives will then be to study, design and implement, with all involved stakeholders, socio-technical innovations (new varieties, growing practices, processing and preservation, small-scale mechanization) and organizational innovations (markets, quality labels, participatory certification, business start-ups) to serve and support these levers.
Ambition 4 **Understanding, assessing and strengthening the multifunctionality of horticulture in agri-urban and rural areas**	In addition to its food and nutrition functions, horticulture provides multiple social, economic, environmental and cultural (landscape, recreational) services, the impacts of which are poorly defined, whether positive or negative (unhealthiness, various types of pollution). The aim is here to define the criteria for measuring and assessing this multifunctionality in tropical and Mediterranean contexts. The aim will also be to document and activate the levers (technological innovations, public instruments) that enhance multifunctionality and limit the negative impacts of horticulture. A forward-looking approach to reconciling the need for food in the urban centers of the future and employment in horticulture is the turning point in this ambition.
Ambition 5 **Exploring digital opportunities in the horticultural sector for small farms and family businesses in the South**	The increasing digitization of industrial agriculture is having a major impact on the horticultural sector, with the need to manage a vast amount of information and the desire for more rewarding working conditions. Digitization is a key factor in the development of the horticultural sector, enabling real-time sharing of data and knowledge on products (market information), services and local horticultural resources (identification of diseases or pests, for example). In order to support players in the sector and in the regions, particularly small-scale family producers, in the agroecological transition, an analysis of existing opportunities will be carried out, both in the south and the north. This ambition will provide food for thought about CIRAD's digital positioning, particularly with regard to the attractiveness and creativity of horticulture-related professions. The aim will then be to strengthen the capacities of players in the sector so as to preserve their freedom of choice and autonomy. This ambition is an inflection that resonates with each of the other ambitions in this roadmap, and will be consolidated as we go along.

VII- Moving towards an action plan

CIRAD's strategy for the Horticulture field has been built around the specific features of this field:

- A large human potential (164 staff for 108 FTEs), spread across an equivalent number of research units in the 3 departments, but with a huge imbalance in FTEs between ES and the other two departments, and 3 units accounting for 80% of CIRAD's horticulture FTEs (Agap, HortSys and PVBMT), 60% of which are in the French overseas departments and territories.

- A large number of staffs work without any species specificity, what encourages multi-sector approaches based on shared ambitions such as water management (Rice), agroecological transition (Banana & Plantain, Roots & Tubers, Milk, small-scale livestock farming) and product quality (R&T, Milk, Rice, Oil palm). Within the Horticulture sector itself, it is easy to establish links between the ambitions of the different roadmaps. All these links are shown in Figure 16.

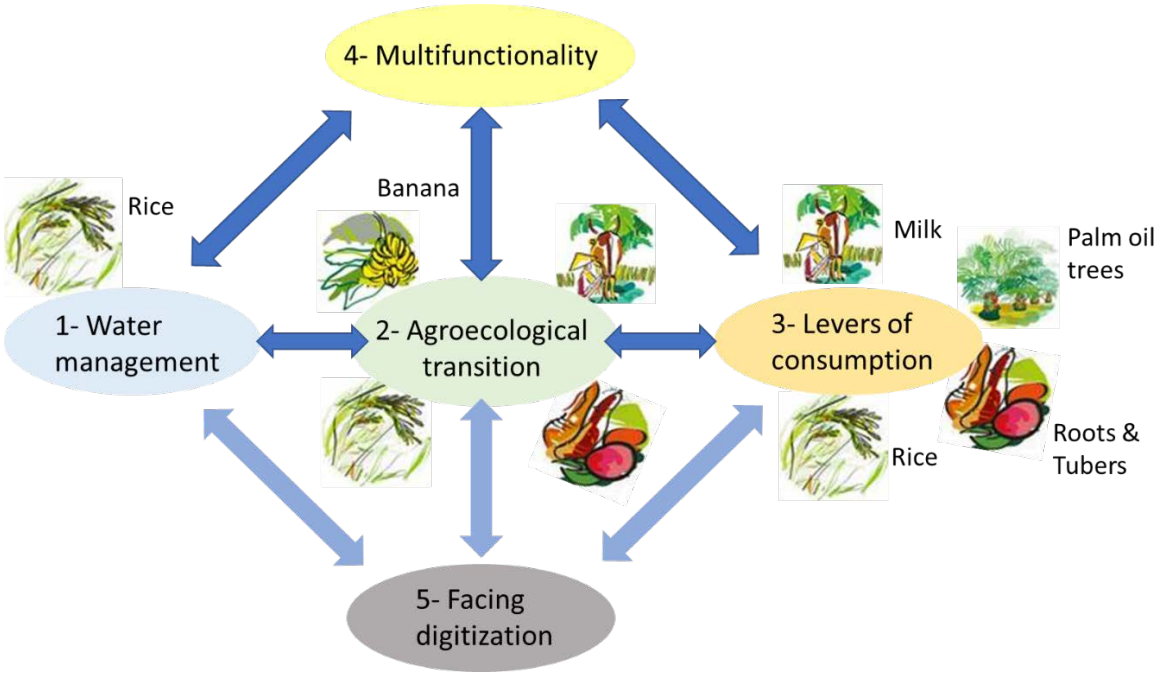

Figure 16 - Diagram showing the links between the horticulture sector ambitions and ambitions shared with other CIRAD sectors.

Overall (Table 7), Ambitions 1 and 2 rely on CIRAD expertise in separate research units (G-Eau on the one hand, PVBMT and HortSys on the other), to propose integrative approaches (multi-disciplinary work at scales and on common ground, new scientific approaches related to microbiota). Ambitions 3 and 4 correspond to exploratory approaches (the levers of consumption on the one hand, the multifunctionality of horticulture on the other) which should again lead to activities between research units and CIRAD departments. Ambition 5, still at the planning stage, seems essential to raise CIRAD's awareness of the challenges of the digitalization of agriculture.

The international partners with which it is planned to pursue CIRAD's strategy are historical partners (Bioversity & CIAT and WorldVeg, FAO and ISHS) and natural partners such as INRAE (GIS Fruits and GIS Pic-Leg through initiatives such as TSARA and PEPR Food system, microbiome and health) and the IRD (on water and health). Partnerships in the DROMs must be maintained and strengthened both as

experimental grounds and as a rear base for a regional scale-up (Caribbean, Indian Ocean, even West Africa).

The strong presence of the DROMs in this roadmap impacts the geostrategic orientation due to the socio-economic importance of horticultural production, and the issues they bring to these territories (see Table 5). West Africa and North Africa remain the priority areas, on which it will be necessary to share more skills and partnerships. Fields in Asia (real engine of horticultural production) and in Latin America (large fruit exporters) will be strengthened by multidisciplinary approaches, within the framework of existing partnerships (dP MALICA) or to be initiated (with Embrapa or with WorldVeg), favored by the dynamics of CIRAD in the ISHS.

This geographical dispersion, far from being an obstacle to the implementation of the Action Plan, could contribute to bringing together the multidisciplinary skills of CIRAD. At the same time, it will be necessary to reflect on the scientific themes to be reinforced (Table 8), in particular in view of the numerous retirements over the next ten years.

Table 7 – Degree of involvement of CIRAD research units in each of the ambitions of the Horticulture roadmap.

Ambitions of the Horticulture roadmap	CIRAD's research units		
	Leaders	Involved	To be mobilized
Ambition 1 **Co-designing innovative solutions for sustainable and equitable water management in tropical and Mediterranean horticulture**	**G-eau, Agap**	**Phim, Hortsys, Recyclage & Risque, Eco&Sols**	**PVBMT Absys, Aida Sens, Innovation Tetis**
Ambition 2 **Co-designing attractive, sustainable solutions for managing pests and soil fertility in horticultural production**	**Phim, Hortsys, Eco&Sols**	**Agap, PVBMT Recyclage & Risque Sens**	**Amap Geco Innovation**
Ambition 3 **Identify and understand the drivers of diversified fruit and vegetable consumption in the South, and use socio-technical and organizational innovation to serve and support these drivers.**	**PVBMT, Qualisud**	**Agap Hortsys, Recyclage & Risque Innovation, MoISA, G-eau**	**Geco Art- Dev, Tetis**
Ambition 4 **Understanding, assessing and strengthening the multifunctionality of horticulture in agri-urban and rural areas**	**Hortsys, MoISA**	**Astre Qualisud, Recyclage & Risque, BioWooEb, Selmet G-eau, Innovation, Art-Dev**	**Tetis, Sens**
Ambition 5 **Exploring digital opportunities in the horticultural sector for small farms and family businesses in the South**	**Innovation, Hortsys**	**Qualisud Tetis, G-eau**	**Phim Geco, AbSys, Aida**

Table 8 – Combination of disciplines involved for various flagship horticultural species at CIRAD.

Horticultural productions per broad groups of crops	Scientific disciplins				
	Agronomy agroecology	Genetics improvement	Plant health	Food sciences	Value chain economics
Citrus	X	X	X HLB		X
Olives	X	X		X	X
Mango	X		X	X	X
Tropical fruits (cashew, pineapple, litchi)				X Litchi	X Bioenergy
Fruit vegetables (tomato, peppers, melons, gourds)	X	X	X	X	X
Leafy vegetables (salads, spinaches, cabbage, greens)				X	X Consumption
Bulbs (garlic, onions, shallots)	X	X	X		
Small seed legumes (cowpea, mungbean)	X	X		X	X
HMAPs (vanilla, pepper, clove)		X	X		X

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