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Digital agriculture

Towards sustainable food security

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Table 1 : List of abbreviations

AI	Artificial intelligence
AMS	Automatic milking system
CAGR	Compound annual growth rate
GNSS	Global navigation satellite system
IPF	International patent families
EPO	European Patent Convention
EPO	European Patent Office
PCT	Patent Cooperation Treaty
IoT	Internet of Things
R&D	Research and development
RTA	Revealed technology advantage
SDG	Sustainable Development Goals
WTO	World Trade Organization
UAV	Uncrewed aerial vehicle
UNCTAD	UN Trade and Development
UNEP	United Nations Environment Programme

Table 2 : List of countries and world regions

AT	Austria
AU	Australia
BE	Belgium
BR	Brazil
CA	Canada
CH	Switzerland
CL	Chile
CN	China
CO	Colombia
CZ	Czech Republic
DE	Germany
DK	Denmark
EP	European Patent Office (EPO)
ES	Spain
FI	Finland
FR	France
GB	United Kingdom
IE	Ireland
IL	Israel
IN	India
IT	Italy
JP	Japan
KR	Republic of Korea
MX	Mexico
NL	Netherlands (Kingdom of the)
NO	Norway
NZ	New Zealand
PE	Peru
PL	Poland
RU	Russian Federation
SA	Saudi Arabia
SE	Sweden
SK	Slovakia
TW	Taiwan province of China
UA	Ukraine
US	United States of America

Member states of the European Patent Organisation
Albania, Austria, Belgium, Bulgaria, Switzerland, Cyprus, Czechia, Germany, Denmark, Estonia, Spain, Finland, France, United Kingdom, Greece, Croatia, Hungary, Ireland, Iceland, Italy, Liechtenstein, Lithuania, Luxembourg, Latvia, Monaco, Montenegro, North Macedonia, Malta, Netherlands (Kingdom of the), Norway, Poland, Portugal, Romania, Serbia, Sweden, Slovenia, Slovakia, San Marino, Türkiye

Latin America
For ease of reference, for the purposes of this report, Latin America includes Mexico, Central America, South America and the islands of the Caribbean

The EPO technology insight report on digital agriculture in brief

This report highlights the rapid transformation of digital agriculture, crucial for addressing global food security, sustainability and climate challenges.

Since 2012, innovation in this sector has grown at a 9.4% CAGR, three times faster than other fields, driven largely by corporate R&D, with companies' patent share rising to 88% in 2022. Europe remains the largest source of patents, but Asia and Latin America are growing fastest, each with an 11% CAGR, and Asia overtook North America by 2020. Plant agriculture leads innovation with a sevenfold increase in patents and a 13% CAGR from 2012 to 2022, supported by imaging, sensing, AI and drone technologies. Major machinery firms dominate innovation, reflecting the sector's shift toward data-driven, automated and sustainable farming to meet the needs of a projected 10 billion global population by 2050.

Executive summary

Digital agriculture (DA) uses information and communications technologies (ICT) and data systems to develop and deliver targeted information and services that make farming more profitable and sustainable while supplying safe, nutritious and affordable food. The availability of data is a key enabler for precision farming, where plants or animals get targeted treatment which is focused with great accuracy thanks to the latest technology. Digital agriculture thereby enables optimised production and increased yield whilst allowing more sustainable crop and livestock farming thanks to the reduced need for water, fertiliser and pesticides.
Patent filing statistics provide insightful indicators for measuring and examining innovation, commercialisation and knowledge transfer trends across international markets. They also provide meaningful information on changes in technology trends, and make it easier to identify new players and consolidation efforts. All in all, this report aims to shed light on how technological challenges are being addressed by way of innovation documented in patent filings. Using a proven EPO data analysis methodology, this report's findings consider information from roughly 270 000 patent families covering 400 000 different patent applications. These patent applications cover inventions related to smart farming based on the following key technology concept groupings: Soil working, Seeding and fertilising, Harvesting, Spoil reduction, Forestry, Greenhouses, Growth media, Animal Husbandry, Milking, Smart watering, Influencing weather conditions, and Pest control.

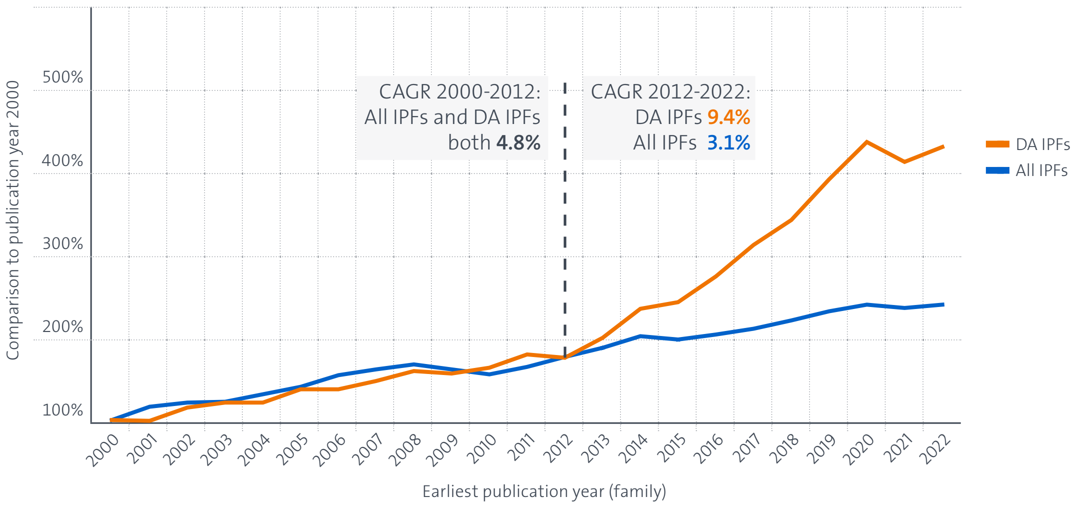
Key findings

1. Innovation in digital agriculture has entered a phase of acceleration since 2012

After an initial period during which digital agriculture did not grow any faster than the average of all technical fields, in 2012 innovation in this field began to advance at a much quicker pace. Over the past ten years, with a compound annual growth rate (CAGR) of 9.4%, digital agriculture has shown a growth rate higher than the average of all technical fields combined.

Figure E.1

IPFs in digital agriculture vs. all technology fields



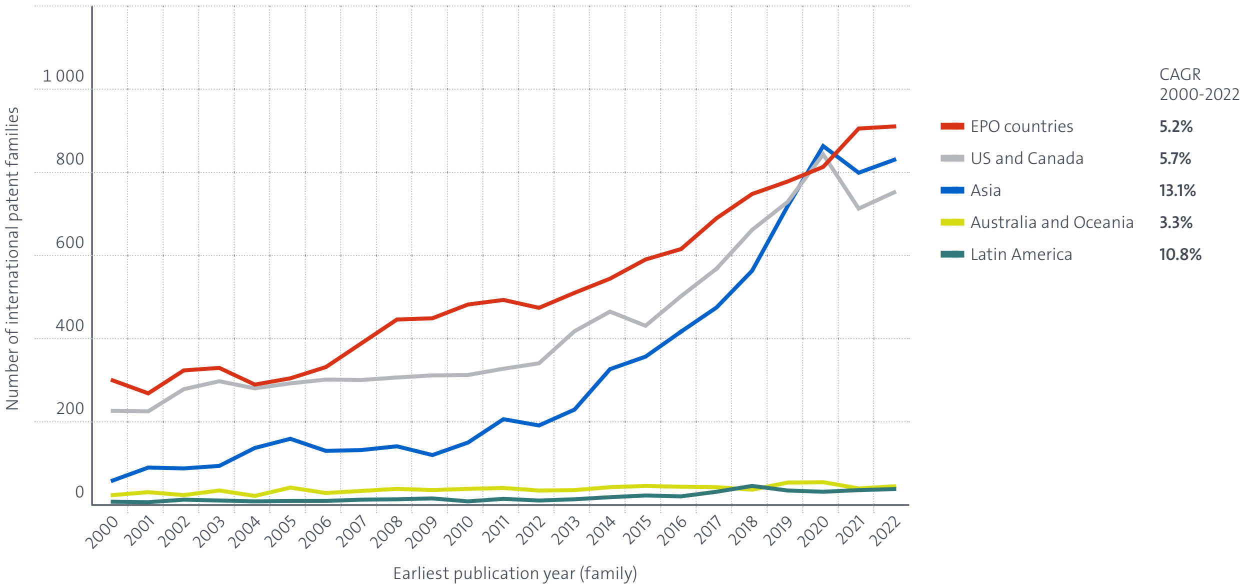
CAGR = compound annual growth rate

2. Strong position of Europe, with Asia and Latin America showing fastest growth

The leading innovative regions are Europe[1], North America and Asia. EPO member states have traditionally been strong in digital agriculture and have remained the largest area of origin of international patent families (IPFs) in digital agriculture throughout the period from 2000 to 2022. The largest growth comes from Asia with a CAGR of 13.1%, which, as of 2020, overtook North America followed by Latin American countries (10.8%), although starting from a more modest base rate. Next to hosting some of the giants in digital agriculture, Europe also is home to an innovation ecosystem with 125 universities and 194 start-ups with EP applications in digital agriculture.

Figure E.2

Trends in major regions



CAGR = compound annual growth rate

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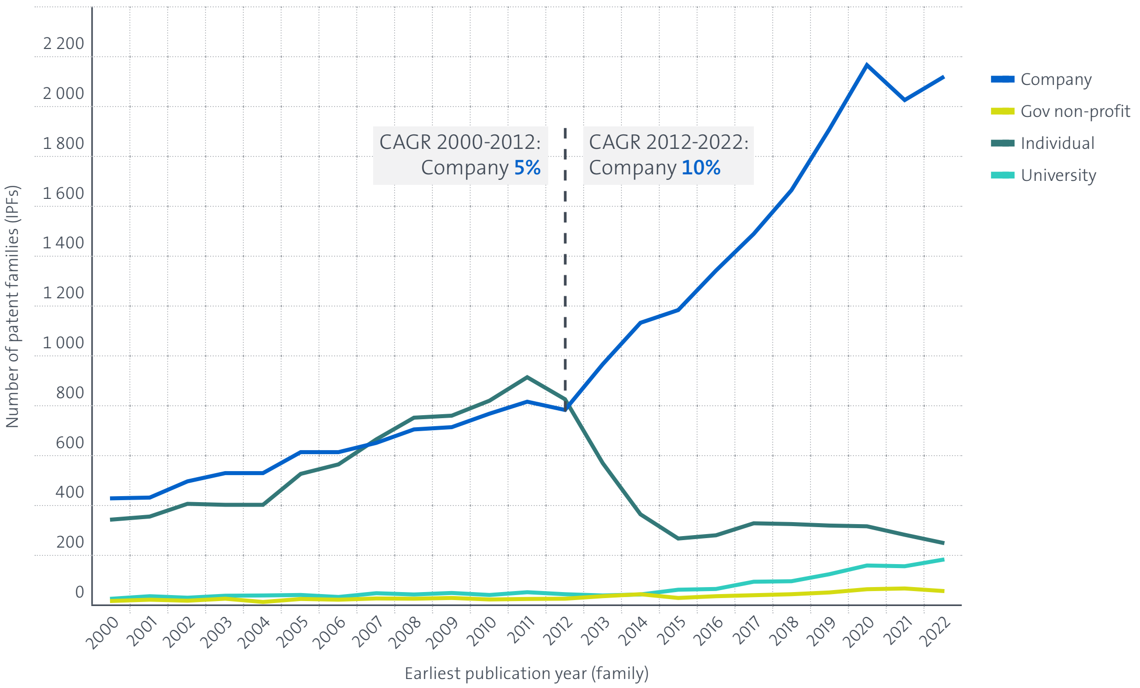
[1] In this context, we consider Europe to be the EPO member states.

3. Industry drives recent growth

The extensive growth that began in 2012 is entirely the result of activity from companies. By 2022 the portion of patent families from companies had risen to 88%. This finding is in line with available data that indicate R&D spending by companies in agricultural technologies increased dramatically after 2010, to the point of overtaking public spending, which had been dominant before that. While the CAGR of companies was 5% up until 2012, it has doubled to 10% over the past ten years.

Figure E.3

Trend of applicant sector distribution



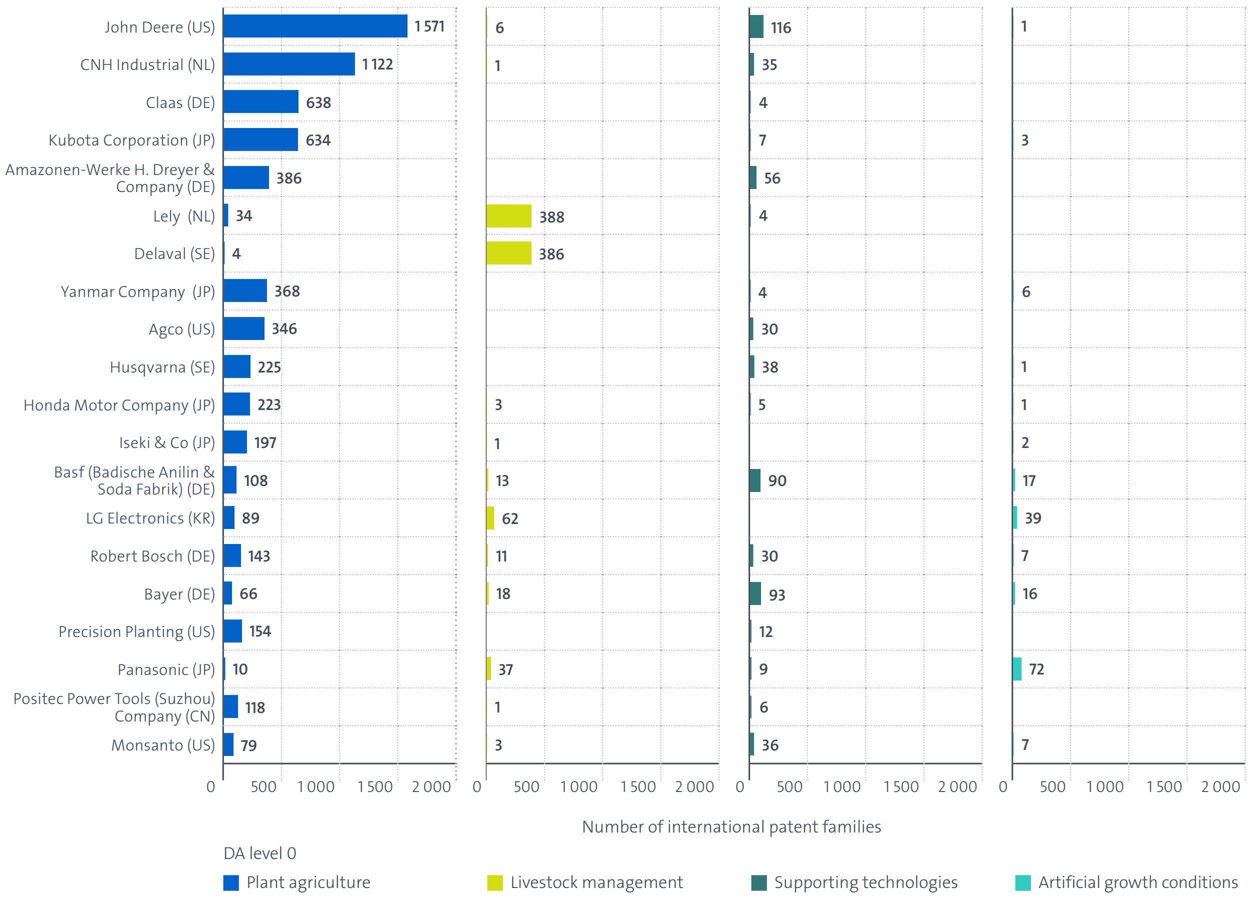
CAGR = compound annual growth rate

4. Agricultural machines are a key area of innovation in digital agriculture

The leading applicants in digital agriculture are the major producers of large agricultural machinery, such as John Deere, CNH International, Claas, Kubota and Amazonen Werke. Featuring among the top applicants include firms in animal husbandry such as Lely and Delaval, innovators in smart greenhouses such as electronics firms like LG and Panasonic, and firms in supporting technologies (e.g. pest control) such as BASF and Bayer.

Figure E.4

Top applicants by number of IPFs published from 2000 to 2022 per area cluster

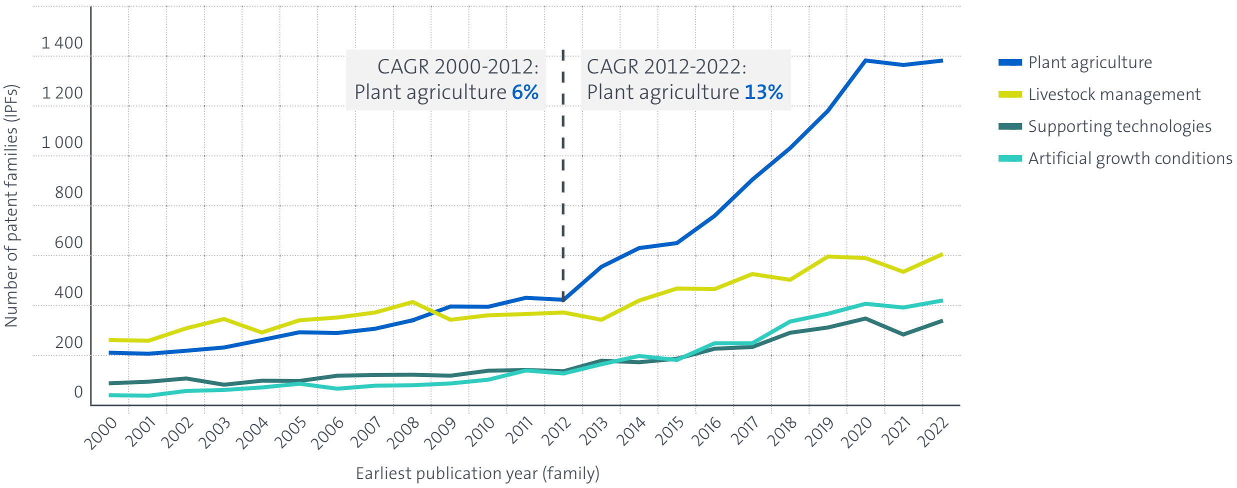


5. Highest innovation rate in plant agriculture

The area cluster that evidences most innovation in digital agriculture has been open-field plant agriculture, with a seven-fold increase in IPFs since 2000. This area cluster has been the source of a sharp increase in overall digital agriculture patenting growth since 2012, recording a CAGR of 13% from 2012 to 2022.

Figure E.5

Trend of IPFs per area cluster



CAGR 2000-2012: Plant agriculture **6%**

CAGR 2012-2022: Plant agriculture **13%**

CAGR = compound annual growth rate

Overall, the largest share of patents relates to digital imaging and sensing technologies. These enabling technologies are foundational to delivering the data needed to control treatment and automation, such as spraying and harvesting, which show parallel growth patterns. Since 2018, there has been a notable rise in data analysis and AI-related inventions, whilst drone-based technologies have gained increasing significance from 2019 onwards.

Table 3

Glossary

Cooperative Patent Classification (CPC)	The Cooperative Patent Classification (CPC) is an extension of the IPC and is jointly managed by the EPO and the US Patent and Trademark Office. It is divided into nine sections, A-H and Y, which in turn are sub-divided into classes, sub-classes, groups and sub-groups. There are approximately 250 000 classification entries.
DOCDB	The EPO's master documentation database with worldwide coverage. It contains bibliographic data, abstracts, citations and DOCDB simple patent family information.
DOCDB simple family	A set of patent documents relating to patent applications claiming priority over the same earlier applications. The technical content covered by the patent applications in a DOCDB simple patent family is considered to be identical.
European patent	The European patent system makes it possible to obtain European patents valid in up to 39 contracting states to the European Patent Convention (EPO) on the basis of a single application. A European patent has the same legal effects as a national patent in each country for which it is granted. As of 2023, it is also possible to request unitary effect for a granted European patent.
European Patent Convention (EPO)	International treaty signed by the member states of the European Patent Organisation. The EPO establishes a single application procedure for obtaining patent protection in Europe.
European Patent Office (EPO)	Executive arm of the European Patent Organisation. European patents are granted by the European Patent Office in a centralised, cost-effective and time-saving procedure conducted in one of the official languages of the EPO (English, French or German). Every European patent application undergoes substantive examination before a European patent is granted to make sure that inventions for which patent protection is sought meet all of the legal requirements set out in the European Patent Convention.
Espacenet	Free online patent searching service developed by the EPO. It includes information on over 150 million patent documents from more than 100 patent offices on all continents. Espacenet is available at worldwide.espacenet.com.
International patent application	Patent application filed under the Patent Cooperation Treaty (PCT). An international patent application may result in patent protection in more than 150 countries.
International Patent Classification (IPC)	The International Patent Classification system is a hierarchical patent classification system used by the EPO and more than 100 patent offices worldwide. It breaks technologies down into eight sections with several hierarchical sub-levels. The IPC system has approximately 75 000 subdivisions and is updated on an annual basis.
International patent family (IPF)	A set of applications for the same invention that includes a published international patent application, a published patent application at a regional patent office or published patent applications at two or more national patent offices.
Invention	A practical solution to a (technical) problem. The invention may be a new product, process or apparatus or any new use thereof. To be patentable under the European patent system, an invention must be technical, novel, involve an inventive step (i.e. it must not be obvious to those having ordinary skill in the technical area of the invention) and be considered as susceptible of industrial application.
Patent	Legal title giving the patent owner(s) the right, for a limited period of time (usually 20 years as of the date of filing the patent application), to exclude others from using the protected invention in a commercial context without permission in those countries for which the patent has been granted. The protected invention is defined by the claims of the patent, taking the description and drawings into account.
Patent application	Request for patent protection for an invention filed with the EPO or other patent office.

Patent classification system	The set of patent classification symbols assigned to categorise the technical subject-matter of a patent or utility model. There are various patent classification systems used today by national, regional and international patent offices.
Patent family	A set of patent documents covering the same or similar technical content and referring to the same priority filing(s).
PATSTAT	PATSTAT is a group of databases that contain bibliographical, procedural and other context information on millions of patents and utility models from numerous industrialised and developing countries. It is built from the EPO's databases of worldwide patent data.
Patent Cooperation Treaty (PCT)	An international treaty providing for a unified procedure for filing patent applications to protect inventions in its contracting states. Under the PCT, a single international application can be filed for patent protection in up to more than 150 countries. The PCT provides for a centralised procedure for filing the patent application whereby the substantive examination and the grant of the patent lies with the competent national or regional patent office(s).
Priority	Inventions can be protected by patents and utility models in more than one country. For a period of 12 months from the date of filing an application for a patent in a member state of the Paris Convention, the applicant or their successor can claim a right of priority from that application for any subsequently filed patent application that concerns the same invention. If the requirements are fulfilled, the date of the earlier application counts as the date of filing of the later application for the purposes of examining novelty and inventive step.

1. Introduction

1.1. Sustainable food security as we move towards a world of ten billion people

Food production, processing, preservation and distribution have had a fundamental impact on human society from the Neolithic period to the modern age. Feeding humanity remains a central pillar of the world economy and provides a concrete illustration of how knowledge and innovation are essential for our society to flourish.

The current pressures on agriculture are immense and come from many directions. Not least amongst those pressures are climate-related events such as water shortages, soil erosion, wildlife loss, biodiversity loss and landscape degradation, etc. Socio-economic factors such as demographic changes (e.g. population increase) and lifestyle dynamics also play a role.

Since 1800, the agricultural sector has managed to feed a world population that has grown by a factor of eight in the same period whilst delivering products that are increasingly abundant, diversified, certified and less expensive (in relation to other consumer expenses) (e.g. Federico, 2005).

Supporting a growing population and averting a Malthusian catastrophe in which population growth outpaces the earth's capacity to provide subsistence have been a tribute to human ingenuity (Smil, 2000). The long-term achievements have been astounding, with farm output and yields per acre increasing significantly, whilst real prices have declined due to sustained technical progress (Ferleger, 1990; Moser, 2020). Focusing on more recent times, agricultural production has increased 28% between 2010 and 2023 (FAO, 2024).

Looking ahead, major challenges still remain. In a world with a population that is projected to surpass ten billion in the not-so-distant future, the technological progress that underlies the food economy cannot stop here. Increasing global population and evolving food habits suggest that a doubling of agricultural output may be necessary by 2050 even whilst climate change accelerates faster than expected (Gladek et al., 2017). The United Nations has explicitly taken up food security as a Sustainable Development Goal (SDG) in the form of UN SDG 2: End hunger, achieve food security and improved nutrition and promote sustainable agriculture ("zero hunger"), to be achieved by 2030. Achieving zero hunger in a socially and environmentally sustainable manner is an unprecedented challenge.

About 85% of global crop output growth over the next ten years is expected to come from improvements resulting from more intensive input use, investments in production technology and improved cultivation practices. Further intensification of land use through multiple harvests per year is expected to deliver another 10%, whilst cropland area expansion is set to play a much smaller role than in the previous decade (OECD/FAO, 2020). **This all translates into an increased reliance on technological development to drive future agricultural output by gaining efficiency in a sustainable manner.**

In terms of available technology, agriculture has undergone a steady transformation, shifting from manual labour and purely human decision-making to increasing mechanisation and digitalisation, as shown in Table 4.

Table 4

Technological evolution in agriculture (source: FAO, 2022)

Development	Approx. time of start	Description
Manual tools	10 000 BC	Farmers take all decisions themselves, to the best of their abilities, and use only basic implements such as axes and hoes to carry out their work.
Animal traction	4 000 BC	Whilst humans still handle diagnosis and decision-making, animals provide the power to pull or operate equipment, such as ploughs, easing the physical labour.
Motorised mechanisation	Beginning of 20th century	Decision-making remains human-led, but engines powered by fuels or electricity drive the machinery. This represents a fundamental shift in energy, from biological sources (human or animal) to mechanical, requiring infrastructure to supply and maintain that energy.
Digital equipment	End of 20th century	A variety of electronic tools augment human judgment and machinery precision. This includes automating analytical tasks and fine-tuning mechanical operations.
AI-driven robotics	Beginning of 21st century	Fully integrated smart robotic systems take over the processes of diagnosis, decision-making, and execution. These range from stationary units (such as robotic milkers) to mobile harvesters, all overseen and maintained by people who monitor their sensors and upkeep. This stage embodies the cutting edge of automation, with many applications still emerging or not yet widely deployed.

Whilst the innovations of the past century have enabled agricultural production to keep pace with the rising demand for food and other agricultural commodities, the environmental costs of conventional agriculture have become more apparent. In some cases, intensive agriculture can be accompanied by substantial negative side effects as exemplified by the emergence of monocultures, pesticide use that threatens the insect life necessary for pollination, pollution of water through the over-use of fertiliser, excessive use of water for irrigation leading to aridity downstream, and overall increased pressure on biodiversity.

Against this backdrop, it is essential to develop and adopt methods that can satisfy future food needs without expanding – or, ideally, whilst shrinking – agriculture's ecological footprint. Cutting-edge tools such as geospatial mapping, the Internet of Things (IoT), big data analytics and artificial intelligence (AI) – i.e. the tools of digital agriculture – offer the promise of precision farming based on data-driven decision-making that can **boost crop yields whilst preserving environmental health** (Sishodia et al, 2020).

Digital agriculture is therefore a key topic in the context of providing enough food to feed the world whilst keeping the ecological footprint in check. It has the potential to contribute to UN SDG 2 (Zero hunger) whilst also contributing to UN SDG 11 (Sustainable cities and communities), UN SDG 12 (Responsible consumption and production), UN SDG 13 (Climate action), UN SDG 14 (Life below water) and UN SDG 15 (Life on land). Understanding the potential to provide food security for billions in a more sustainable manner is the key reason for providing this technology insight report.

WHAT IS DIGITAL AGRICULTURE?

Digital agriculture deals with the use of information and communications technologies (ICT) and data systems to develop and deliver targeted information and services aimed at making farming more profitable and sustainable whilst supplying safe, nutritious and affordable food (FAO, 2019). The availability of data is a key enabler of precision farming in which the latest technologies are focused with great accuracy to achieve targeted, high-precision management of plants and animals.

In short, digital agriculture allows production to be optimised and enables more sustainable crop and livestock farming.

The main distinction from classical agriculture is that, rather than determining the necessary action for each field or farm, digital agriculture has the potential to allow actions to be determined per square metre or even per individual plant or animal.

For the purposes of this report, we have excluded fisheries (pisciculture), aquaculture and aquafarming.

Patents are good indicators of R&D output, i.e. technical innovation at both company and country level (OECD, 2009). This report therefore identifies technological developments in agriculture through the lens of patent data. Despite being a "traditional" sector that has been in existence for millennia, as also evident from Table 4, agriculture is rapidly digitalising. This trend was recently confirmed in a study on patenting in agrifood carried out by the World Intellectual Property Organization (WIPO) which showed that digital agriculture has experienced significant growth, for instance through the use of predictive models or autonomous devices in precision agriculture. For example, autonomous devices in precision agriculture revealed a notable CAGR of +10.4% from 2017 to 2021 (WIPO, 2024).

This report offers a deep dive into innovation in digital agriculture, identifies technology trends and actors and provides illustrative examples of useful innovations.

1.2. Policy context

Smart agriculture is recognised by major policy actors as a way forward to increase agricultural output in a changing world (FAO, 2023; U.S. GAO, 2023; EC, 2025) leading to a number of (potential) benefits.

- **An increase of agricultural production**, in particular per square metre, thereby helping to achieve an overall increase in produce yield.
- **Improvements in animal welfare,** e.g. through more tailored food and earlier disease symptom detection, etc.
- **Improvements in farmers' quality of life,** e.g. through reduced levels of ungratifying work and earlier warning of issues affecting livestock or crops, etc.
- **Environmental benefits** through reduced usage of water, fertilisers and pesticides.
- **Improvements in transparency** for consumers through e.g. use of traceable logistics and blockchain.

At the same time, a number of barriers to widespread adoption of such measures have been identified, in particular the following.

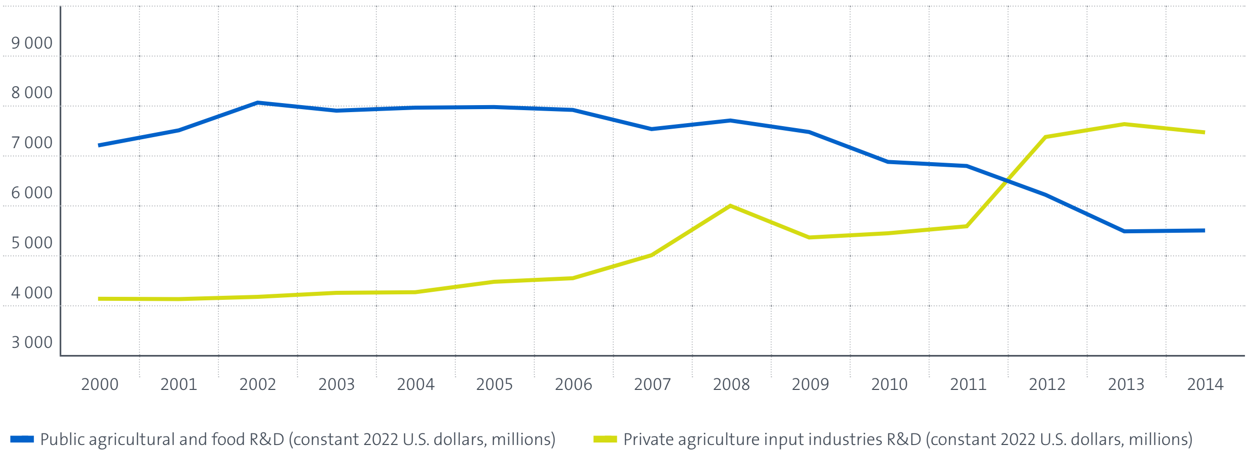
- **Cost:** larger farms with greater resources being able to support the necessary investments, whilst smaller farms are left behind (consistent with figures on current penetration of smart agriculture on farms (Lim et al, 2024)).
- **Digital divide, awareness and skills gap:** awareness of the available possibilities and access to well-functioning internet connectivity appear to be prerequisites.
- **Legislative and bureaucratic hurdles:** restrictions designed for traditional agriculture (e.g. designated time-windows for spreading fertiliser) and aerial regulations (restricting the use of unmanned aerial vehicles (UAVs)) may hamper precision farming in which far less fertiliser and pesticides are used, and spread out much more throughout the year as the individual plants may need.

- **Interoperability and standardisation:** necessary to enable full integration of diverse smart agriculture solutions and to avoid incompatibility between e.g. different manufacturers. This is especially critical for data which must be discoverable, interoperable and available for reuse.
- **Privacy and data-ownership concerns:** such issues an discourage farmers from exchanging critical information with partners or AI.

Clearly, the first two barriers (cost and the digital divide and awareness and skill gaps) can present a particular challenge in developing countries. In many cases, these barriers will be insurmountable in the absence of corresponding government policies or development programmes to remove or lower the hurdles. These barriers may also play a role in developed countries, where smaller farmers in more remote regions may struggle to implement data-driven agricultural solutions. The final two barriers gain significance when and where technology adoption levels increase and digitalisation of agriculture becomes more widespread. Legislative and bureaucratic hurdles are the ones that can be most directly addressed by government policy. Public institutions also have a direct influence on agricultural innovation by funding R&D programs and institutions, including efforts aimed at digital agriculture. The framework for agricultural R&D financing has evolved substantially over the past half-century. In the initial decades following the Green Revolution, **public institutions** supplied over 80% of global agricultural research funding, reflecting governments' commitment to innovations with broad societal benefits (Fuglie, Rada, 2013). From the 1980s onward, **private firms**, including major agribusinesses and equipment manufacturers, steadily increased their R&D investment such that, by 2010, private initiatives accounted for roughly half of total agricultural research spending worldwide. This was driven by private-sector on developing market-ready products and services to meet growing demands (Fuglie, Rada, 2013).

Figure 1

Public and private R&D spending in agriculture in the USA



Source: Fuglie, Nelson, 2022

In the United States, real public agricultural R&D investment fell by nearly 30 percent between 2003 and 2014, whilst private-sector R&D spending almost doubled over the same period. By 2010, private investment in agricultural inputs had already surpassed total public agricultural R&D spending. This trend continued through 2018, with private investment driving total agricultural R&D spending in the United States toward an estimated USD 15–20 billion by 2020 (Fuglie, Nelson, 2022).

The surge in private R&D has accelerated the delivery of precision-agriculture tools that address farmers' immediate needs. Private ventures often excel at scaling technologies through established distribution networks and providing end-user support. Yet, this pivot to a market-driven approach has resulted in research tending to focus on high-value commodities and large-scale farming systems. Staple crops and low-income regions receive comparatively less attention (OECD, 2013). In contrast, **public research** continues to underwrite foundational studies in crop physiology, soil health and agro-ecological resilience – areas in which social returns exceed what private actors typically capture. Indeed, meta-analyses show that public agricultural research delivers median benefit–cost ratios exceeding 10:1 and internal rates of return well above 50% per annum (Alston, Marra, Pardey, & Wyatt, 2000).

SOME NOTEWORTHY POLICY INITIATIVES RELATING TO DIGITAL AGRICULTURE

United Nations (UN):
The UN's Zero Hunger agenda (UN Sustainable Development Goal 2) recognises that investment in the agricultural sector is critical for reducing hunger and poverty, improving food security, creating employment and building resilience to disasters and shocks (Zero Hunger, 2023). A major UN stakeholder is the **Food and Agriculture Organization (FAO).**

The **FAO Strategic Framework 2022-31** seeks to support the 2030 Agenda for Sustainable Development through the transition to more efficient, inclusive, resilient and sustainable agrifood systems for better production, better nutrition, a better environment and a better life, leaving no one behind. The FAO launched 20 Programme Priority Areas (PPA) using four cross-cutting/cross-sectional accelerators for technology, innovation, data and complements (governance, human capital and institutions).

One of the programme priority areas under the better production initiatives is related to digital agriculture. This priority area aims to make digital technologies more accessible to enhance market opportunities, productivity and resilience integrated into agrifood systems policies and programmes, with particular focus on ensuring affordable and equitable access for poor and vulnerable rural communities (FAO, 2023).

CGIAR (formerly the Consultative Group for International Agricultural Research):
For over fifty years, the network of international agricultural research centres known today as **CGIAR** has carried out applied R&D aimed at improving food security for the world's poorest people. As a distinctive and remarkably effective model for co-ordinating and financing multinational agricultural research, CGIAR, founded in 1971, has invested the equivalent of roughly $60 billion (in present-value terms) into developing staple food crops for low-income populations. Evaluations of these efforts show an average benefit–cost ratio of about 10:1 across the CGIAR portfolio, with no sign that returns have diminished over time (Alston, Pardey, Rao, 2022).

European Union:
There are clear European efforts towards advancing the integration of digital technologies into the European agricultural sector. The European Commission has supported several research and innovation (R&I) projects (e.g. ATLAS[2], DEMETER[3]) as well as deployment initiatives, such as the Common European Agricultural Data Space, which shape digitalisation in EU agriculture.

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[2] Link to ATLAS project.

[3] Link to DEMETER project.

Furthermore, the Draghi report on EU competitiveness (Draghi, 2024) identifies agriculture as one of the ten strategic sectors for the launch of the EU Vertical AI Priorities Plan. Within these ten strategic sectors, the plan could provide funding for key vertical AI models across industrial sectors, built on EU data-sharing whilst safeguarded from anti-trust enforcement. This would encourage EU companies to participate in, and accelerate, European AI developments across the ten strategic industries where European know-how and value capture should be assured.

More concretely, The EU's digital-agriculture strategy is embedded in the common agricultural policy **CAP 2023–27,** which for the first time obliges every member state to include a digitalisation plan in its strategic plan. This is backed by up to EUR 8 billion from the European Agricultural Fund for Rural Development (EAFRD) to expand rural broadband, precision-farming tools, data platforms and advisory services. In 2024, EU member states have estimated that more than 20 000 farms have benefited from the support of digital technologies (EC, 2025-b). Alongside this, the **Digital Europe Programme** allocates EUR 7.6 billion to AI, cybersecurity and supercomputing, and funds **European Digital Innovation Hubs** through which farmers and SMEs can trial IoT devices and decision-support systems before investing (EC, 2025-c).

SmartAgriHubs, a Horizon 2020 flagship (GA 818182), has built a continent-wide network of innovation hubs and flagship experiments, piloting drone-monitoring, AI pest alerts and blockchain traceability to share best practices across regions (SmartAgriHubs, n.d.)

The Smart Villages initiative funded by ERDF and Cohesion Funds brought connectivity, digital-skills training and local innovation projects to Europe's most remote rural communities (European Commission, 2019).

Amongst more recent initiatives, **agrifoodTEF** (Horizon Europe GA 101100622) provides virtual and physical test-beds across seven agri-food subsectors to validate robotics and AI under real-world conditions (agrifoodTEF, n.d.), and **AgriDataSpace** (Digital Europe preparatory action) delivers a blueprint for a secure, interoperable Common European Agricultural Data Space (AgriDataSpace, n.d.).

In summary, **the benefits of digital agriculture are not automatic or uniformly achieved.** Outcomes depend on adoption rates and local conditions. To date, most of the dramatic productivity gains from precision agriculture have been in well-resourced, large-scale farming systems (e.g. in North America, EPO contracting states and parts of Brazil and China). Many smallholder farmers in Asia, Africa and Latin America are only beginning to adopt digital tools, often through pilot projects. As a result, the *global average impact* of smart agriculture for enhanced food output is still in the early stages. As the technology costs decrease and supporting policies take effect, we can expect the contribution of digital agriculture to world food production to grow steadily. It has been estimated that by 2050, Latin America could supply two to three out of every five fruit and vegetables (WEF, 2024), which makes this an interesting region to follow.

Rather than bringing immediate benefits in eradicating hunger in the poorest regions of the world, the broader benefits of digital agriculture may be longer term. On a shorter timescale, in more developed regions, digital agriculture may bring benefits in allowing increased precision in fertilisation, pest control and irrigation that serve to maintain or increase production whilst also reducing the environmental impact of agriculture. There clearly are substantial hurdles to overcome before adoption extends to both large-scale producers and smallholders, and there is much that needs to be done to overcome them. It is, however, a positive sign that, as shown above, digital farming is very much on the radar of policy makers world-wide.

1.3. About this report

In this report, we focus on key technologies that are driving the development of smart agriculture. Aimed at decision-makers in both the private and public sectors, it is a unique source of information on these technologies and the technical problems they aim to solve.

This publication draws on the latest available patent data and the expertise of EPO examiners to provide a comprehensive analysis of the innovation trends driving technical progress in digital agriculture. Patent information is leveraged to provide robust statistical evidence of technological progress. The data presented in this report show trends in high-value inventions for which patent protection has been sought in more than one country (IPFs). Further explanation of the methodology and sources is provided in Annex 1.

The statistical results are complemented by in-depth qualitative perspectives from case studies and individual patents. Although global in scope, the report has a focus on EPO contracting states (defined here as the 39 contracting states that are currently members of the EPO) complemented by a dedicated section on Latin America.

This report contributes to achieving the UN Sustainable Development Goals, namely SDG 2 (Zero hunger) while also contributing to, SDG 11 (Sustainable cities and communities), SDG 12 (Responsible consumption and production), SDG 13 (Climate action), SDG 14 (Life below water) and SDG 15 (Life on land).

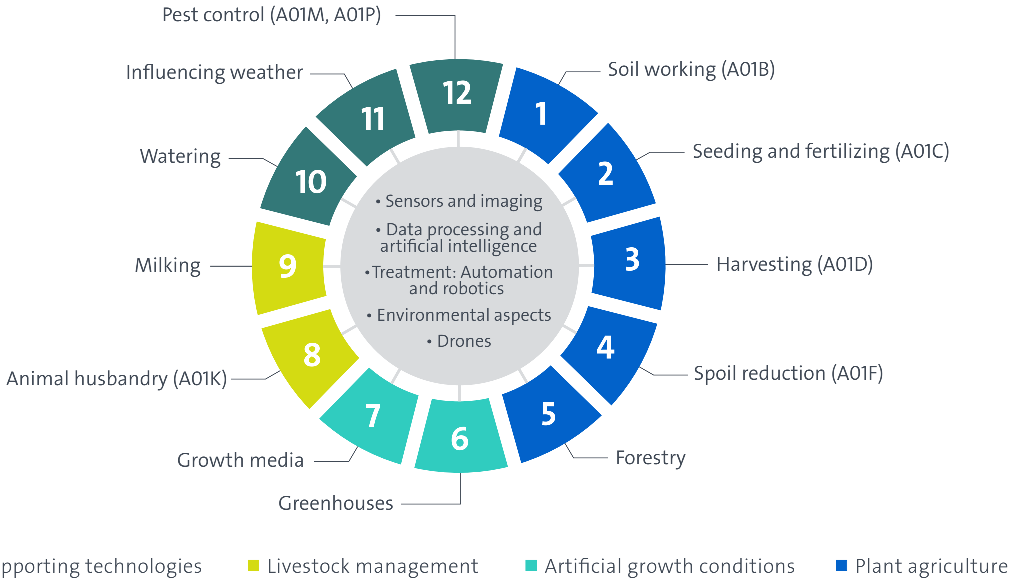
1.4. Technologies

For a comprehensive view of smart agriculture, a total of 117 search concepts were developed in a hierarchy comprising three levels. The detailed hierarchy with the search concepts can be found in the Annex to this report.

Figure 2 shows the twelve investigated technology areas that were grouped into four clusters: Plant agriculture, artificial growth conditions, livestock management and supporting technologies.

Figure 2

A simplified view on digital agriculture technologies used for this report



Plant agriculture comprises soil working (1), seeding and fertilising (2), harvesting (3), spoil reduction (4) and forestry (5). Greenhouses (6) and growth media (7) are clustered as **artificial growth conditions,** whereby **livestock management** comprises animal husbandry (8) and milking (9). **Supporting technologies** capture smart watering (10), influencing weather conditions (11) and pest control (12). A more detailed description of these technology areas can be found in chapter 6 of this report.

All of these areas benefit from the cross-cutting digital technologies.

Sensing and imaging: Soil and plant sensors measure moisture, pH and nutrient levels in real time, allowing site-specific irrigation and fertilisation that boost yields whilst conserving resources. In livestock settings, wearable sensors and automated cameras track animal behaviour, body temperature and feeding patterns, enabling early detection of disease or stress. Multispectral and thermal imaging performed from towers, fences, ground vehicles or hand-held devices identifies crop stress zones before symptoms are visible and locates heat-stressed animals, guiding targeted interventions and improving overall system health.

AI and data analytics: Machine-learning algorithms integrate data from sensors, weather stations and market trends to generate predictive models for yield forecasting, pest and disease risks and optimal feed rations. Decision-support platforms can recommend planting dates, crop rotations or vaccination schedules, turning complex datasets into actionable insights. In feedlots and dairy operations, AI analyses milk yield and weight data to optimise nutrition and breeding programs, enhancing productivity and animal welfare.

Automation and robotics: Autonomous tractors and harvesters perform tilling, seeding and picking with centimetre-level accuracy, reducing labour and compaction. In greenhouses and orchards, robotic arms prune, thin and pack produce. As for the livestock sector, robotic milking stations and feeders automate routine husbandry tasks, allowing farmers to monitor animal health more closely and redeploy labour to higher-value activities.

Unmanned aerial vehicles (drones): High-resolution drone surveys generate normalised difference vegetation index (NDVI) maps for crop vigour assessment, enabling farmers to apply inputs precisely where needed. Drones fitted with thermal sensors conduct nighttime counts of grazing herds and detect injured or missing animals. In both contexts, rapid aerial inspections accelerate decision-making loops, improving both agronomic outcomes and animal management.

By integrating these technologies, digital agriculture drives efficiency, sustainability and resilience across plant and livestock systems, aiming to secure food supplies and rural livelihoods.

Environmental aspects: When used to foster precision agriculture, digitalisation benefits the environment by increasing production whilst reducing water, fertiliser and pesticide input. This report also considers other environmental aspects for comparison purposes, such as the following.

- In **seeding and fertilising:** treating the crop residue, for improving soil nutrient content and water retention, including mechanical (cutting and burying) and inoculation.
- In **greenhouses:** vertical farming (note that there may be overlap with digital technologies because vertical farming, apart from being vertical, is often also well monitored and controlled) and (solar) energy optimisation.
- In **growth media:** symbiotic soilless cultivation, e.g. hydroponics combined with rearing animals, such as fish and prawns, high-density soilless cultivation, e.g. vertical hydroponics, reduced soil substrate, i.e. biodegradable/compostable substrates, and reduced water substrates, e.g. water absorbing polymers as substrate.
- In **pest control:** biological pest control, i.e. use of beneficial insects and microbes in agriculture.

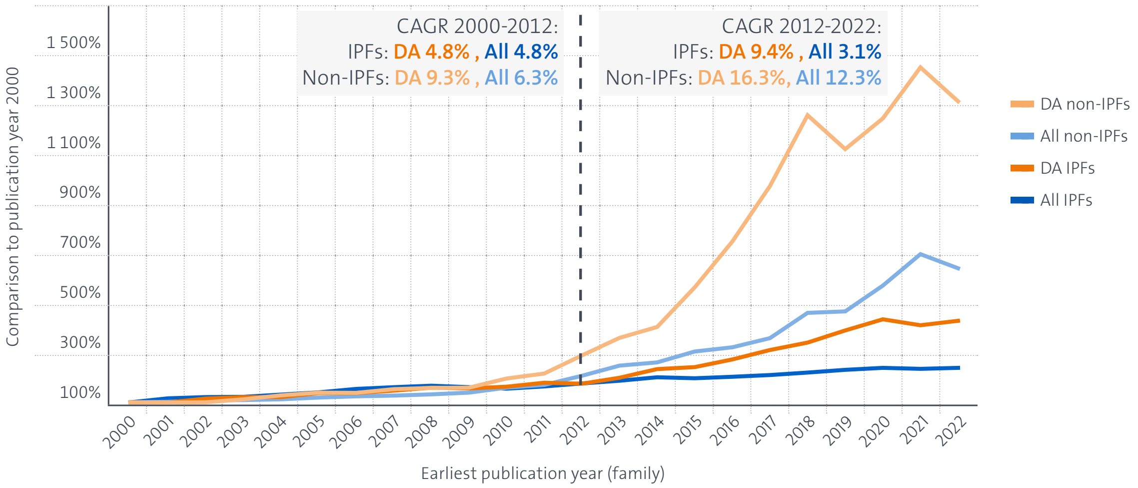
2. Technology trends in digital agriculture

This section outlines important trends in digital agriculture.

2.1. General technology trends

Figure 3

Normalised trends for IPFs and non-IPFs in digital agriculture and for all technology



CAGR = compound annual growth rate

Digital agriculture has demonstrated remarkable growth in recent years. Relative to the benchmark year 2000, publications in 2022 for IPFs showed a four-fold increase, while non-IPF publications showed a greater than 13-fold increase.

Up to 2012, digital agriculture patent application rates did not deviate significantly from all other technologies. Starting in 2012, however, a marked increase in patent publications in digital agriculture can be observed.

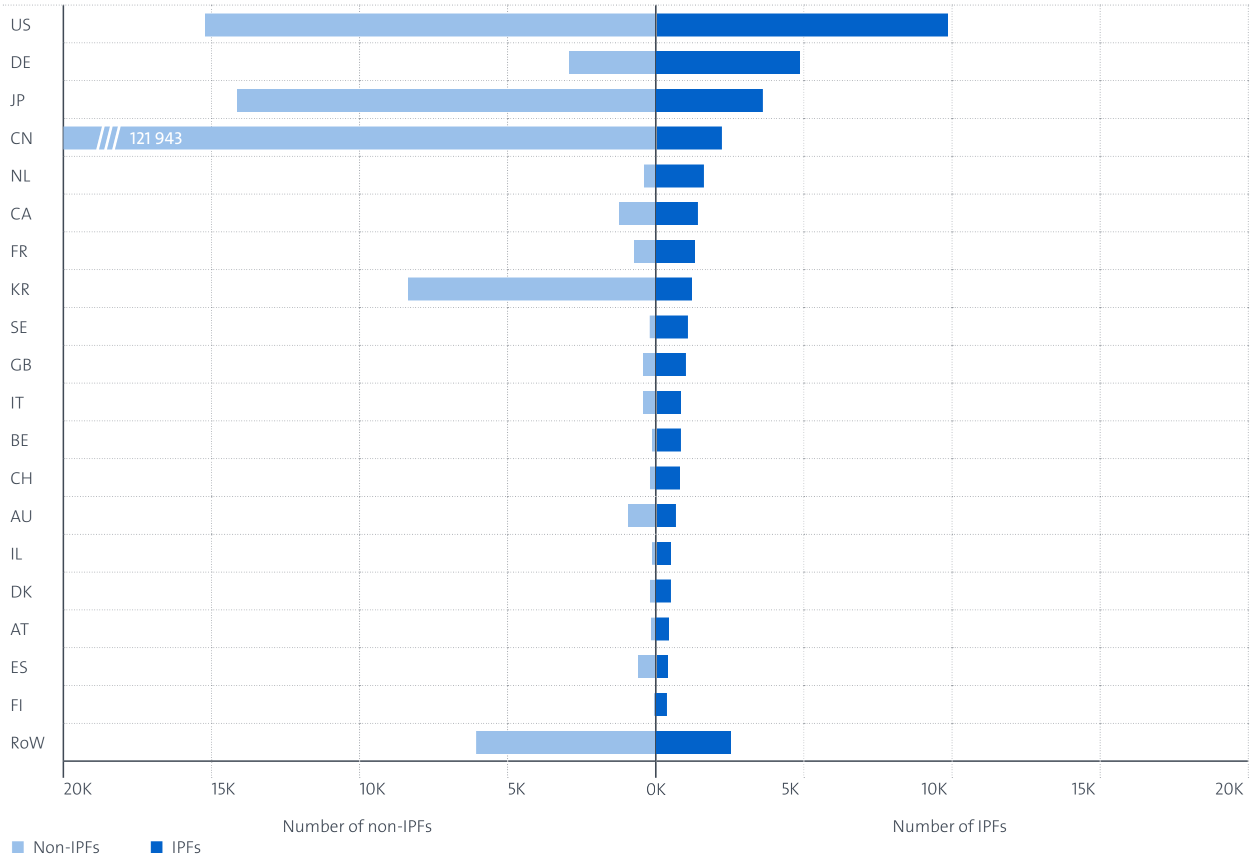
The publications in digital agriculture growing by more than a factor of two for IPFs and a factor of six for non-IPFs, with CAGRs of 4.0% and 8.8% respectively. This is significantly higher than the growth rates for all technologies in general.

2.2. Internationalisation and filings per intellectual property right (IPR) type

Figure 4 shows the number of patent filings in leading applicant countries in descending order in terms of IPF filings. While Chinese applicants are ranked only in fourth place in terms of IPFs, their number of national filings is almost 10 times higher than the second highest national filers from the US.

Figure 4

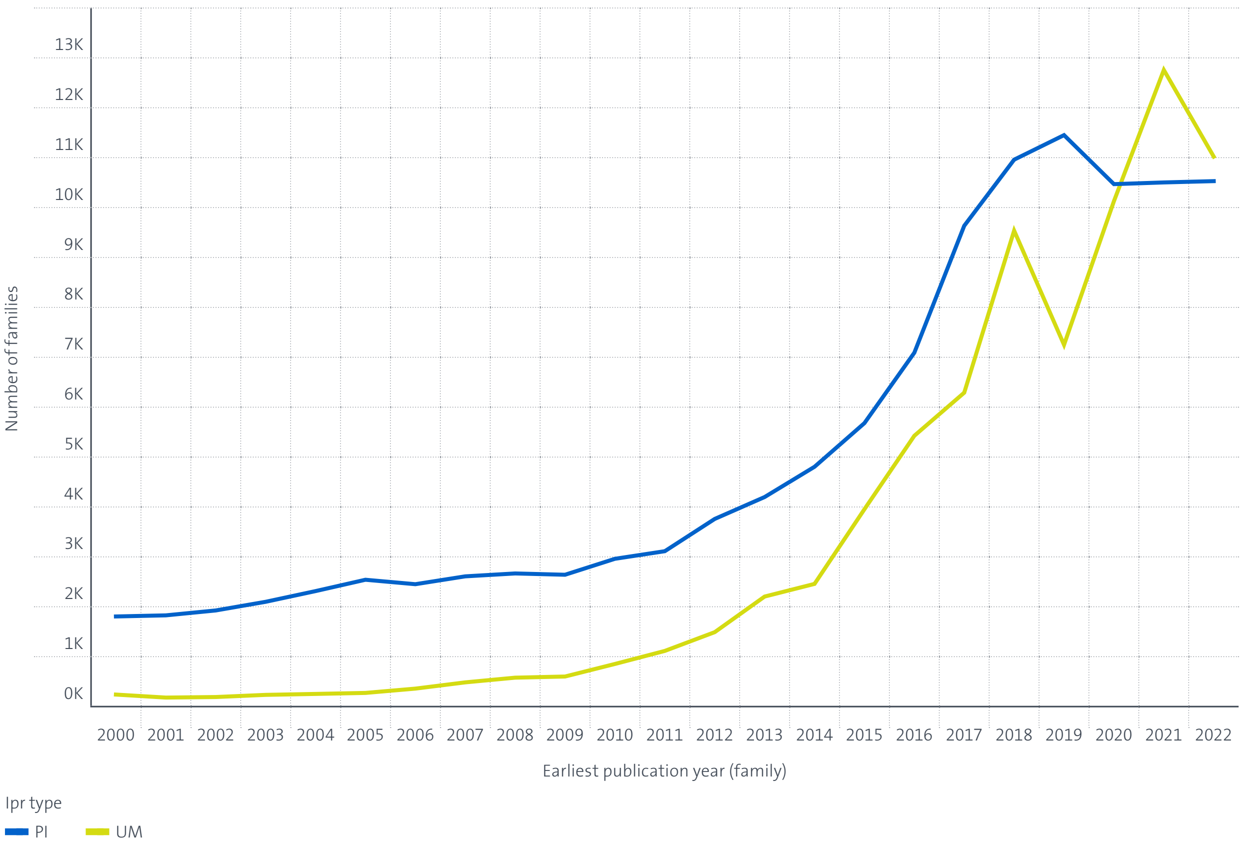
IPFs and non-IPFs per country of applicant (published 2000-2022)



Utility models play an important role in innovation in digital agriculture, as can be seen in Figure 5. They are mostly of Chinese origin (89%).

Figure 5

Overview of type of filings: patents of invention (PI) and utility models (UM)



A substantial dip in UM publications can be identified in 2019, which could be related to policy changes such as the introduction of more substantive examination of utility models in China in 2018 and a change in the allocation of funds to public research institutions. The distribution from then onwards depends on the number of granted patents, and not on the number of filed patent applications, as before. This change caused a considerable number of "accelerated grants", which has statistical implications.

3. Origins of innovation

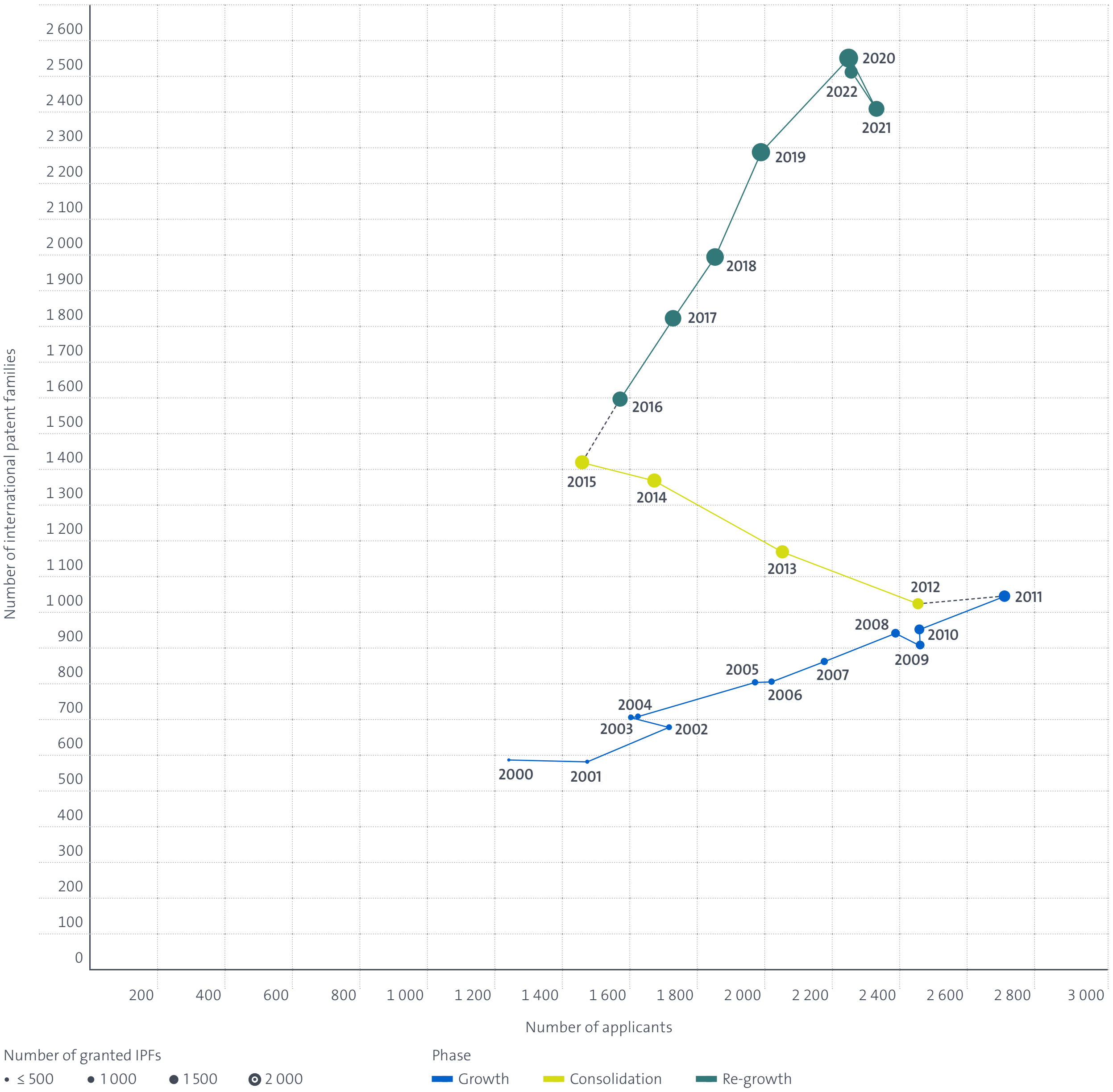
This section investigates the number of applicants, their sector and their region or country in order to better understand where and by whom inventions are created.

3.1. Maturity map

The maturity map in Figure 6 sheds light on the life cycle in this technology. It uses the number of published patent families (vertical axis), the number of patent applicants (horizontal axis) and the number of granted patents (size of bubbles) to illustrate the overall patent evolution in digital agriculture technologies.

Figure 6

Maturity map for digital agriculture



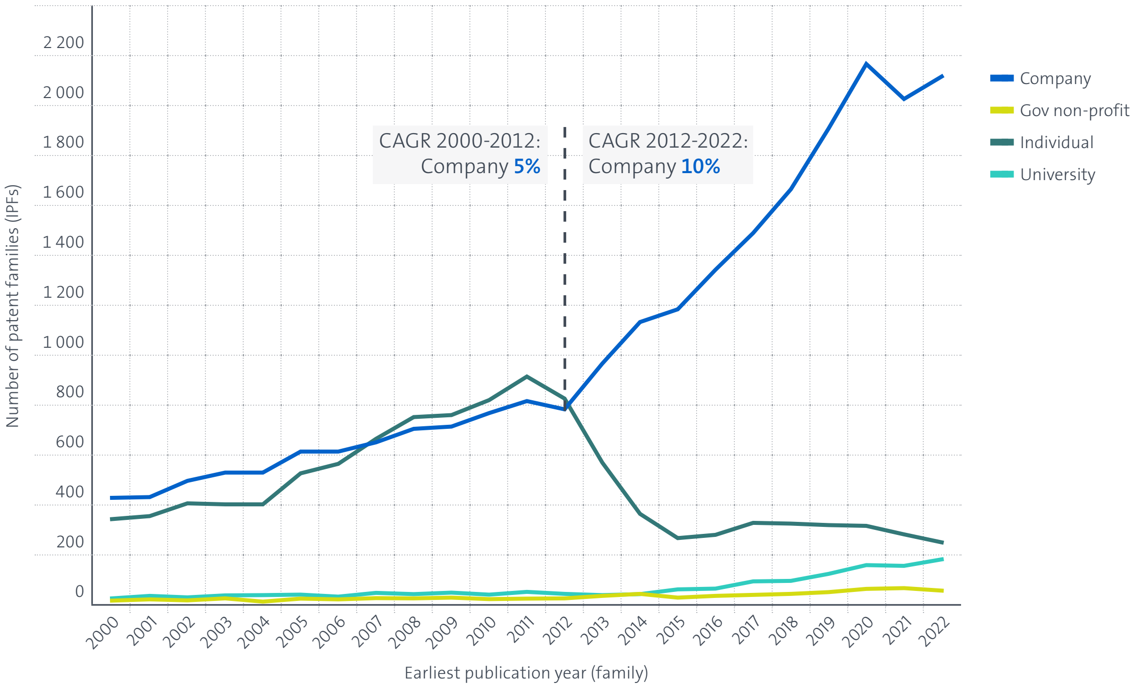
In an initial growth phase from 2000 to 2011, the number of applicants showed a modest growth rate. After 2015, the number of applicants rose again, coupled with sharp increases in the number of patent filings. The steeper slope seen post-2015 indicates that more applications were filed per applicant than in the pre-2012 period. No conclusions can be directly drawn with regard to the intermediate period 2012-2015, as it coincides with the introduction of the America Invents Act (AIA)[4]. The number of grants in recent years is expected to rise once the procedure is finalised with patent offices.

3.2. Applicant sector analysis

Figure 7 offers a more detailed overview of the trends outlined in section 3.1. Companies have taken the lead and their filing rate has increased steadily, both during the period from 2012 to 2015 and afterwards, reflecting greater commercial interest in patents. In recent years, the number of patents filed by universities has been increasing.

Figure 7

Timeline per sector of applicant



CAGR = compound annual growth rate

It can be observed that the growth since 2012, even when taking into account the AIA effect (see section 3.1) and that was seen earlier as an overall trend in patenting digital agriculture, is caused by companies: While the CAGR of companies was 5% till 2012 it doubled to 10% in the 10 recent years. Since 2012, the share of companies increased to 88% in 2022. Since 2016, whilst the number of IPFs filed by companies continued to increase, the number of IPFs filed by private inventors stayed more or less constant, resulting in a decrease of their overall share to about 8% in 2022.

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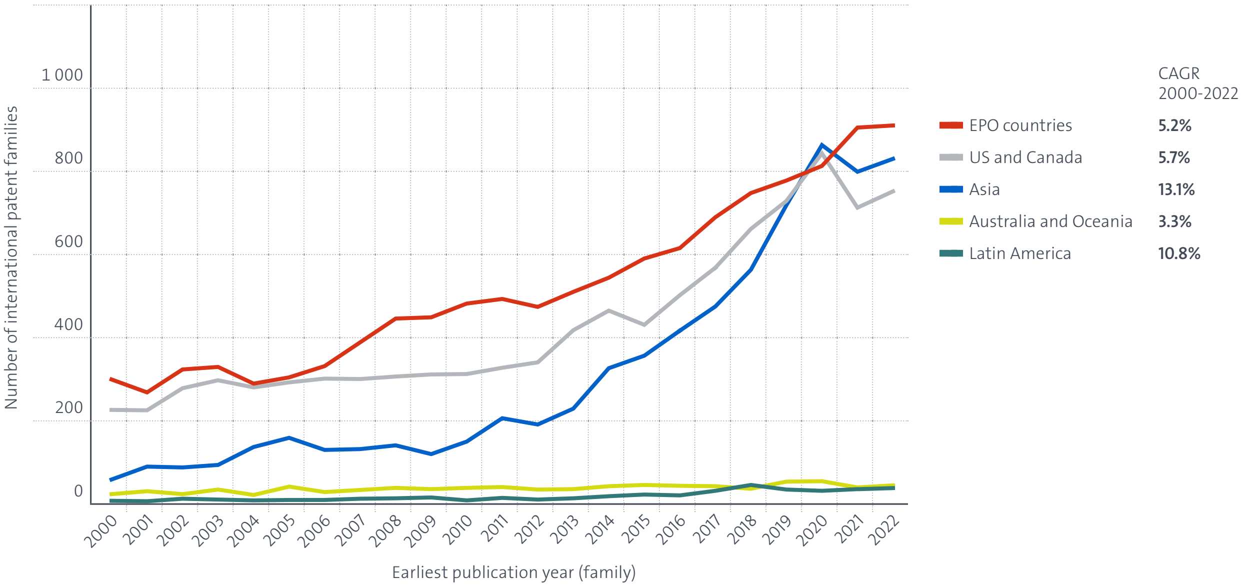
[4] The "consolidation" in Figure 6 is not necessarily specific to digital agriculture, but coincides with the introduction of the America Invents Act, which allowed companies to be applicants on US patents (and PCT-applications), rather than individual inventors. As US applications are often part of IPFs, and PCT applications are always considered as part of an IPF, this results in a replacement of (often multiple) inventors by (mostly a single) company as applicant in the period 2012-2015. This means that data concerning individuals and companies pre-2012 and post-2015 are not directly comparable either.

3.3. Regional trends (IPFs)

Digital agriculture patenting is dominated by EPO member states, North America and Asia. EPO member states have traditionally been strong in digital agriculture, and remained the largest area of origin of IPFs in digital agriculture throughout the period from 2000 to 2022. The largest growth has been seen in Asian countries, which overtook North America, although the pace of growth seems to have slowed somewhat in the most recent years. Latin America, although starting from a modest base rate, has shown high growth with a CAGR of 10.8%.

Figure 8

Tends in major regions

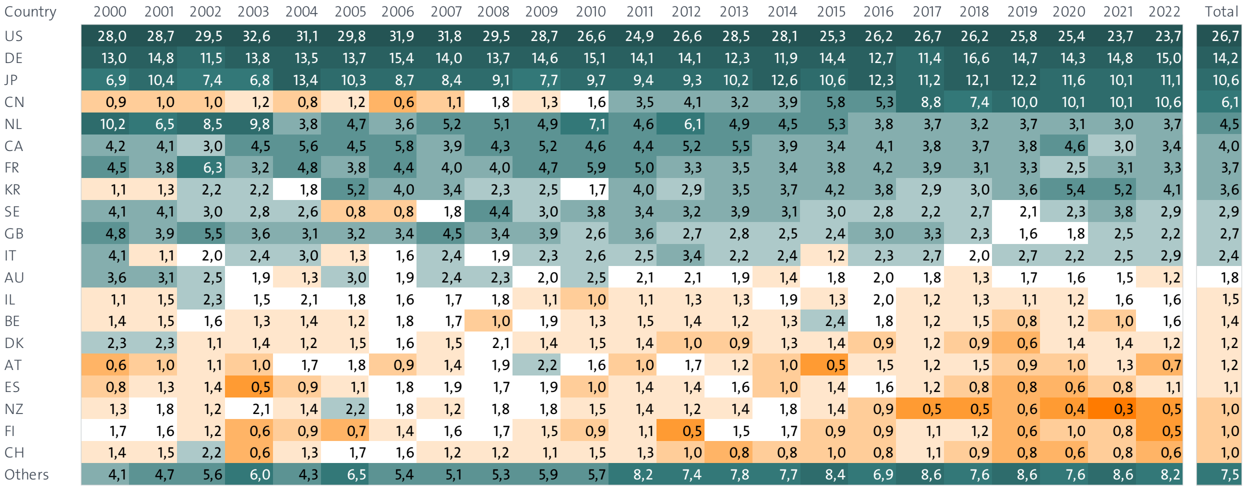


CAGR = compound annual growth rate

Distribution of inventor countries over time (the figures represent the percentage of international patent families in the respective year).

Figure 9

Distribution of the inventor country over time (in % of total)



Country	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	Total
US	28,0	28,7	29,5	32,6	31,1	29,8	31,9	31,8	29,5	28,7	26,6	24,9	26,6	28,5	28,1	25,3	26,2	26,7	26,2	25,8	25,4	23,7	23,7	26,7
DE	13,0	14,8	11,5	13,8	13,5	13,7	15,4	14,0	13,7	14,6	15,1	14,1	14,1	12,3	11,9	14,4	12,7	11,4	16,6	14,7	14,3	14,8	15,0	14,2
JP	6,9	10,4	7,4	6,8	13,4	10,3	8,7	8,4	9,1	7,7	9,7	9,4	9,3	10,2	12,6	10,6	12,3	11,2	12,1	12,2	11,6	10,1	11,1	10,6
CN	0,9	1,0	1,0	1,2	0,8	1,2	0,6	1,1	1,8	1,3	1,6	3,5	4,1	3,2	3,9	5,8	5,3	8,8	7,4	10,0	10,1	10,1	10,6	6,1
NL	10,2	6,5	8,5	9,8	3,8	4,7	3,6	5,2	5,1	4,9	7,1	4,6	6,1	4,9	4,5	5,3	3,8	3,7	3,2	3,7	3,1	3,0	3,7	4,5
CA	4,2	4,1	3,0	4,5	5,6	4,5	5,8	3,9	4,3	5,2	4,6	4,4	5,2	5,5	3,9	3,4	4,1	3,8	3,7	3,8	4,6	3,0	3,4	4,0
FR	4,5	3,8	6,3	3,2	4,8	3,8	4,4	4,0	4,0	4,7	5,9	5,0	3,3	3,5	3,4	3,8	4,2	3,9	3,1	3,3	2,5	3,1	3,3	3,7
KR	1,1	1,3	2,2	2,2	1,8	5,2	4,0	3,4	2,3	2,5	1,7	4,0	2,9	3,5	3,7	4,2	3,8	2,9	3,0	3,6	5,4	5,2	4,1	3,6
SE	4,1	4,1	3,0	2,8	2,6	0,8	0,8	1,8	4,4	3,0	3,8	3,4	3,2	3,9	3,1	3,0	2,8	2,2	2,7	2,1	2,3	3,8	2,9	2,9
GB	4,8	3,9	5,5	3,6	3,1	3,2	3,4	4,5	3,4	3,9	2,6	3,6	2,7	2,8	2,5	2,4	3,0	3,3	2,3	1,6	1,8	2,5	2,2	2,7
IT	4,1	1,1	2,0	2,4	3,0	1,3	1,6	2,4	1,9	2,3	2,6	2,5	3,4	2,2	2,4	1,2	2,3	2,7	2,0	2,7	2,2	2,5	2,9	2,4
AU	3,6	3,1	2,5	1,9	1,3	3,0	1,9	2,4	2,3	2,0	2,5	2,1	2,1	1,9	1,4	1,8	2,0	1,8	1,3	1,7	1,6	1,5	1,2	1,8
IL	1,1	1,5	2,3	1,5	2,1	1,8	1,6	1,7	1,8	1,1	1,0	1,1	1,3	1,3	1,9	1,3	2,0	1,2	1,3	1,1	1,2	1,6	1,6	1,5
BE	1,4	1,5	1,6	1,3	1,4	1,2	1,8	1,7	1,0	1,9	1,3	1,5	1,4	1,2	1,3	2,4	1,8	1,2	1,5	0,8	1,2	1,0	1,6	1,4
DK	2,3	2,3	1,1	1,4	1,2	1,5	1,6	1,5	2,1	1,4	1,5	1,4	1,0	0,9	1,3	1,4	0,9	1,2	0,9	0,6	1,4	1,4	1,2	1,2
AT	0,6	1,0	1,1	1,0	1,7	1,8	0,9	1,4	1,9	2,2	1,6	1,0	1,7	1,2	1,0	0,5	1,5	1,2	1,5	0,9	1,0	1,3	0,7	1,2
ES	0,8	1,3	1,4	0,5	0,9	1,1	1,8	1,9	1,7	1,9	1,0	1,4	1,4	1,6	1,0	1,4	1,6	1,2	0,8	0,8	0,6	0,8	1,1	1,1
NZ	1,3	1,8	1,2	2,1	1,4	2,2	1,8	1,2	1,8	1,8	1,5	1,4	1,2	1,4	1,8	1,4	0,9	0,5	0,5	0,6	0,4	0,3	0,5	1,0
FI	1,7	1,6	1,2	0,6	0,9	0,7	1,4	1,6	1,7	1,5	0,9	1,1	0,5	1,5	1,7	0,9	0,9	1,1	1,2	0,6	1,0	0,8	0,5	1,0
CH	1,4	1,5	2,2	0,6	1,3	1,7	1,6	1,2	1,2	1,1	1,5	1,3	1,0	0,8	0,8	1,0	0,8	1,1	0,9	0,8	0,6	0,8	0,6	1,0
Others	4,1	4,7	5,6	6,0	4,3	6,5	5,4	5,1	5,3	5,9	5,7	8,2	7,4	7,8	7,7	8,4	6,9	8,6	7,6	8,6	7,6	8,6	8,2	7,5

The colours in the chart show the percentage distribution from high percentages shown in green to low percentages in red. Two inventors from different countries would create a count for each country. Inventor countries like China and Korea have seen a remarkable increase in their share of international patent families, while others like the United Kingdom, Australia, New Zealand, Finland and Switzerland have lost share in digital agriculture.

Revealed technology advantage (RTA)

The revealed technology advantage (RTA) index indicates a country's specialisation in terms of technological innovation relative to its overall innovation output. It is defined as a country's share of IPFs in a particular field of technology divided by the country's share of IPFs in all fields of technology. An RTA above one reflects a country's specialisation in a given technology[5].

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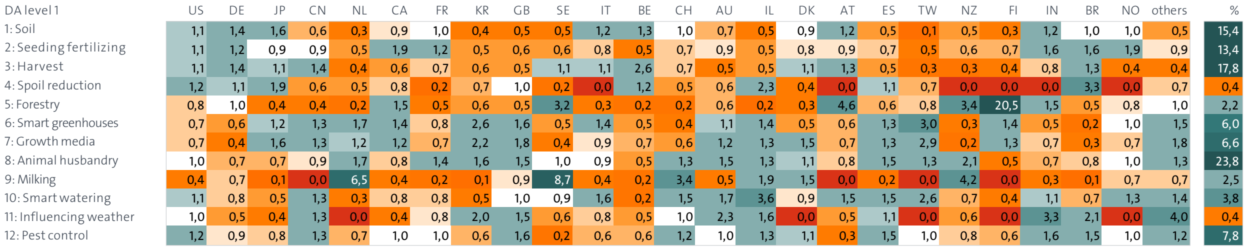
[5] Both the country of the applicants and of the inventors have been considered for the calculation of the RTA.

Figure 10

Revealed technology advantage (RTA) per country in digital agriculture (IPF)



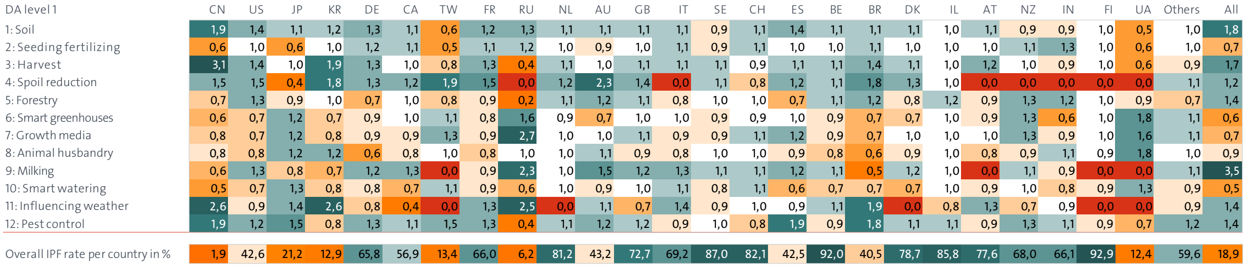
DA level 1	US	DE	JP	CN	NL	CA	FR	KR	GB	SE	IT	BE	CH	AU	IL	DK	AT	ES	TW	NZ	FI	IN	BR	NO	others	%
1: Soil	1,1	1,4	1,6	0,6	0,3	0,9	1,0	0,4	0,5	0,5	1,2	1,3	1,0	0,7	0,5	0,9	1,2	0,5	0,1	0,5	0,3	1,2	1,0	1,0	0,5	15,4
2: Seeding fertilizing	1,1	1,2	0,9	0,9	0,5	1,9	1,2	0,5	0,6	0,6	0,8	0,5	0,7	0,9	0,5	0,8	0,9	0,7	0,5	0,6	0,7	1,6	1,6	1,9	0,9	13,4
3: Harvest	1,1	1,4	1,1	1,4	0,4	0,6	0,7	0,6	0,5	1,1	1,1	2,6	0,7	0,5	0,5	1,1	1,3	0,5	0,3	0,3	0,4	0,8	1,3	0,4	0,4	17,8
4: Spoil reduction	1,2	1,1	1,9	0,6	0,5	0,8	0,2	0,7	1,0	0,2	0,0	1,2	0,5	0,6	2,3	0,4	0,0	1,1	0,7	0,0	0,0	0,0	3,3	0,0	0,7	0,4
5: Forestry	0,8	1,0	0,4	0,4	0,2	1,5	0,5	0,6	0,5	3,2	0,3	0,2	0,2	0,6	0,2	0,3	4,6	0,6	0,8	3,4	20,5	1,5	0,5	0,8	1,0	2,2
6: Smart greenhouses	0,7	0,6	1,2	1,3	1,7	1,4	0,8	2,6	1,6	0,5	1,4	0,5	0,4	1,1	1,4	0,5	0,6	1,3	3,0	0,3	1,4	0,5	0,2	1,0	1,5	6,0
7: Growth media	0,7	0,4	1,6	1,3	1,2	1,2	0,7	2,2	1,8	0,4	0,9	0,7	0,6	1,2	1,3	1,5	0,7	1,3	2,9	0,2	1,3	0,7	0,3	0,7	1,8	6,6
8: Animal husbandry	1,0	0,7	0,7	0,9	1,7	0,8	1,4	1,6	1,5	1,0	0,9	0,5	1,3	1,5	1,3	1,1	0,8	1,5	1,3	2,1	0,5	0,7	0,8	1,0	1,3	23,8
9: Milking	0,4	0,7	0,1	0,0	6,5	0,4	0,2	0,1	0,9	8,7	0,4	0,2	3,4	0,5	1,9	1,5	0,0	0,2	0,0	4,2	0,0	0,3	0,1	0,7	0,7	2,5
10: Smart watering	1,1	0,8	0,5	1,3	0,3	0,8	0,8	0,5	1,0	0,9	1,6	0,2	1,5	1,7	3,6	0,9	1,5	1,5	2,6	0,7	0,4	1,1	0,7	1,3	1,4	3,8
11: Influencing weather	1,0	0,5	0,4	1,3	0,0	0,4	0,8	2,0	1,5	0,6	0,8	0,5	1,0	2,3	1,6	0,0	0,5	1,1	0,0	0,6	0,0	3,3	2,1	0,0	4,0	0,4
12: Pest control	1,2	0,9	0,8	1,3	0,7	1,0	1,0	0,6	1,6	0,2	0,6	0,6	1,2	1,0	1,3	1,1	0,3	1,5	1,0	0,8	0,6	1,6	1,5	1,0	1,2	7,8

In the last column, the percentage distribution of the respective technologies for all countries is added in this table. It shows a high rate of IPF filings in animal husbandry, harvesting, soil, and seeding and fertilising.

US applicants file a comparatively lower number of IPFs in milking, growth media and smart greenhouses, which also have low intensity among German applicants, who focus more on open-space plant agriculture. The data for Japan reveal enhanced activity in spoil reduction and growth media, whereas the data from China show high IPF filing in harvesting, greenhouses and growth media. The Netherlands and New Zealand data indicate strong efforts in animal husbandry and milking innovation. Sweden's data are concentrated in milking and forestry.

Figure 11

Relative technical internationalisation (RTI) per country in digital agriculture



DA level 1	CN	US	JP	KR	DE	CA	TW	FR	RU	NL	AU	GB	IT	SE	CH	ES	BE	BR	DK	IL	AT	NZ	IN	FI	UA	Others	All
1: Soil	1,9	1,4	1,1	1,2	1,3	1,1	0,6	1,2	1,3	1,1	1,1	1,1	1,1	0,9	1,1	1,4	1,1	1,1	1,1	1,0	1,1	0,9	0,9	1,0	0,5	1,0	1,8
2: Seeding fertilizing	0,6	1,0	0,6	1,0	1,2	1,1	0,5	1,1	1,2	1,0	0,9	1,0	1,1	0,9	1,1	1,0	1,0	1,1	1,0	1,0	1,0	1,1	1,3	1,0	0,6	1,0	0,7
3: Harvest	3,1	1,4	1,0	1,9	1,3	1,0	0,8	1,3	0,4	1,1	1,0	1,1	1,1	1,1	0,9	1,1	1,1	1,4	1,1	1,0	1,2	1,0	0,9	1,0	0,6	0,9	1,7
4: Spoil reduction	1,5	1,5	0,4	1,8	1,3	1,2	1,9	1,5	0,0	1,2	2,3	1,4	0,0	1,1	0,8	1,2	1,1	1,8	1,3	1,0	0,0	0,0	0,0	0,0	0,0	1,1	1,2
5: Forestry	0,7	1,3	0,9	1,0	0,7	1,0	0,8	0,9	0,2	1,1	1,2	1,1	0,8	1,0	1,0	0,7	1,1	1,2	0,8	1,2	0,9	1,3	1,2	1,0	0,9	0,7	1,4
6: Smart greenhouses	0,6	0,7	1,2	0,7	0,9	1,0	1,1	0,8	1,6	0,9	0,7	1,0	1,0	0,9	0,9	1,0	0,9	0,7	0,7	1,0	0,9	1,3	0,6	1,0	1,8	1,1	0,6
7: Growth media	0,8	0,7	1,2	0,8	0,9	0,9	1,3	0,9	2,7	1,0	1,0	1,1	0,9	0,9	1,1	1,2	0,9	0,7	1,0	1,0	1,0	1,3	0,9	1,0	1,6	1,1	0,7
8: Animal husbandry	0,8	0,8	1,2	1,2	0,6	0,8	1,0	0,8	1,0	1,0	1,1	0,9	0,8	1,0	1,0	0,9	0,8	0,6	0,9	1,0	0,8	0,9	1,1	0,9	1,8	1,0	0,9
9: Milking	0,6	1,3	0,8	0,7	1,2	1,3	0,0	0,9	2,3	1,0	1,5	1,2	1,3	1,1	1,1	1,2	1,1	0,5	1,2	1,0	0,0	1,1	0,9	0,0	0,0	1,1	3,5
10: Smart watering	0,5	0,7	1,3	0,8	0,8	0,7	1,1	0,9	0,6	1,0	0,9	1,0	1,1	0,8	1,1	0,6	0,7	0,7	0,7	1,0	0,9	1,0	0,8	0,9	1,3	0,9	0,5
11: Influencing weather	2,6	0,9	1,4	2,6	0,8	0,4	0,0	1,3	2,5	0,0	1,1	0,7	1,4	0,9	1,0	0,9	1,1	1,9	0,0	0,8	1,3	0,7	0,9	0,0	0,0	0,9	1,4
12: Pest control	1,9	1,2	1,5	0,8	1,3	1,1	1,5	1,3	0,4	1,1	1,2	1,2	0,9	1,0	0,8	1,9	0,9	1,8	1,1	1,1	0,9	1,3	1,1	0,9	0,7	1,2	1,4
Overall IPF rate per country in %	1,9	42,6	21,2	12,9	65,8	56,9	13,4	66,0	6,2	81,2	43,2	72,7	69,2	87,0	82,1	42,5	92,0	40,5	78,7	85,8	77,6	68,0	66,1	92,9	12,4	59,6	18,9

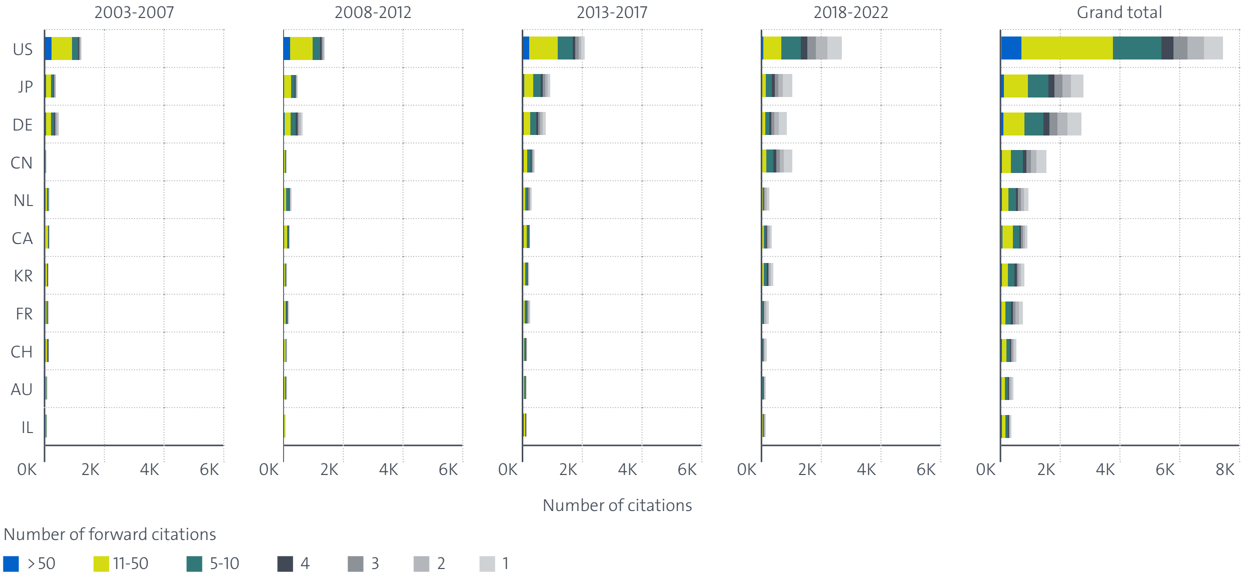
The percentage of IPF filings in all technologies compared to all filings per country is also shown in the last row of this table. The values suggest a relatively lower importance for the role of international patent filings in Asian countries when compared to EPO member states and the US. The countries are ordered in descending number of patent filings (IPFs and non-IPFs). Only 1.9% of patents from China are IPFs, whereas a relatively higher internationalisation is visible for harvesting, influencing weather, soil and pest control. Internationalisation of patents is higher in plant agriculture, milking and pest control from the US and Germany, and in pest control, influencing weather and smart watering from Japan.

Forward citations

Forward citations are commonly regarded to be an indicator of the importance of inventions.

Figure 12

Development in the number of forward citations over time (all patent families)



In this bar graph, we examine how many inventions are forward-cited and how many times this occurs. They may be cited either by the applicant or by examiners who have cited them as relevant state of the art. Hence, they may restrict the scope of follow-up inventions or prevent them from being granted. Receiving many forward citations has consistently been used as evidence of technology spilling over to other market participants or technology fields (Jaffe, Trajtenberg, Henderson, 1993).

Whilst the most-cited patents are from the US, Chinese patents are becoming more cited in recent years, i.e. which is a sign of them being more and more important.

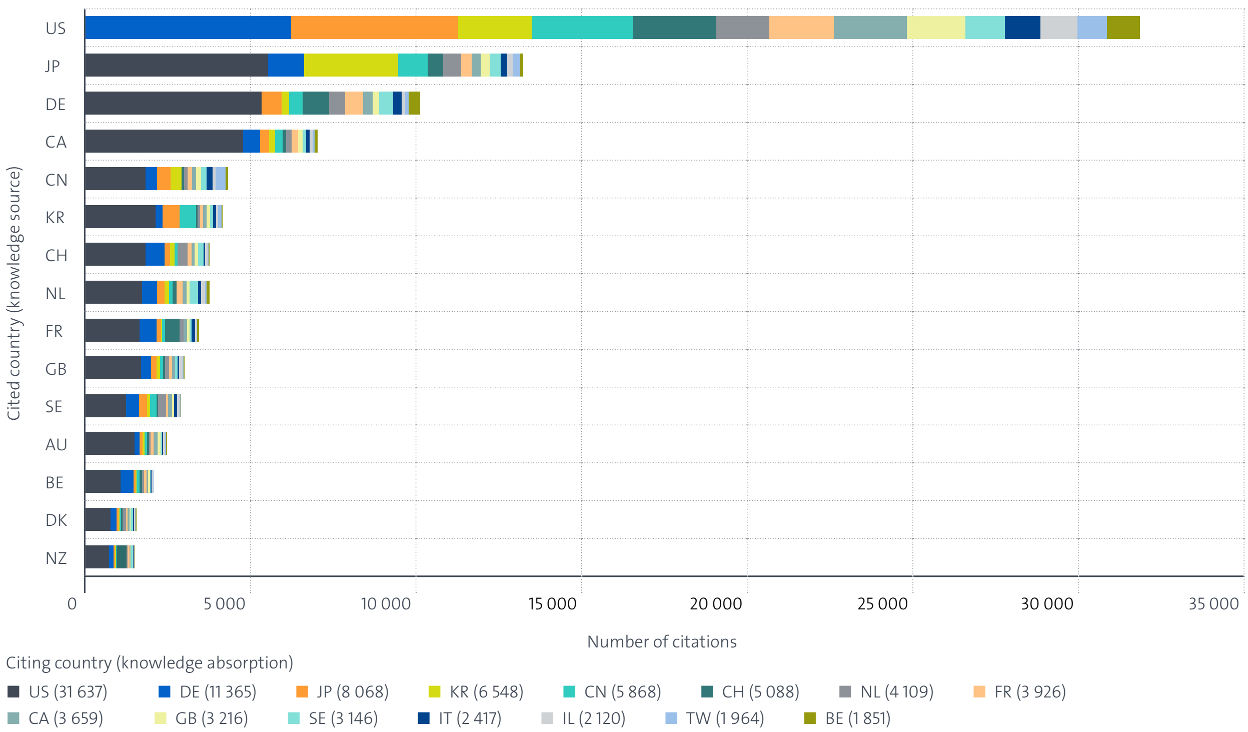
This simple forward-citation analysis has some drawbacks, such as the following.

1. National legislation has a strong influence (US citing largely due to legislative rules).
2. National citing-pattern ecosystems may exist that are less relevant globally.

Studying cross-national citation flows helps avoid these biases and limitations, and shows which countries are technology givers to other countries and which are technology receivers (see Figure 13).

Figure 13

Cross-national citation flows of applications published from 2000–2022



Note: All application in DA are used for this chart, only citations by the top citing countries are shown. Applicant country being cited by applicants in other countries.

While US applicants are highest on knowledge source and absorption, when analysing citation patterns, JP, CA and AU are ranked higher as a knowledge source. DE applicants are ranked higher in knowledge absorption than in knowledge source.

4. Top applicants

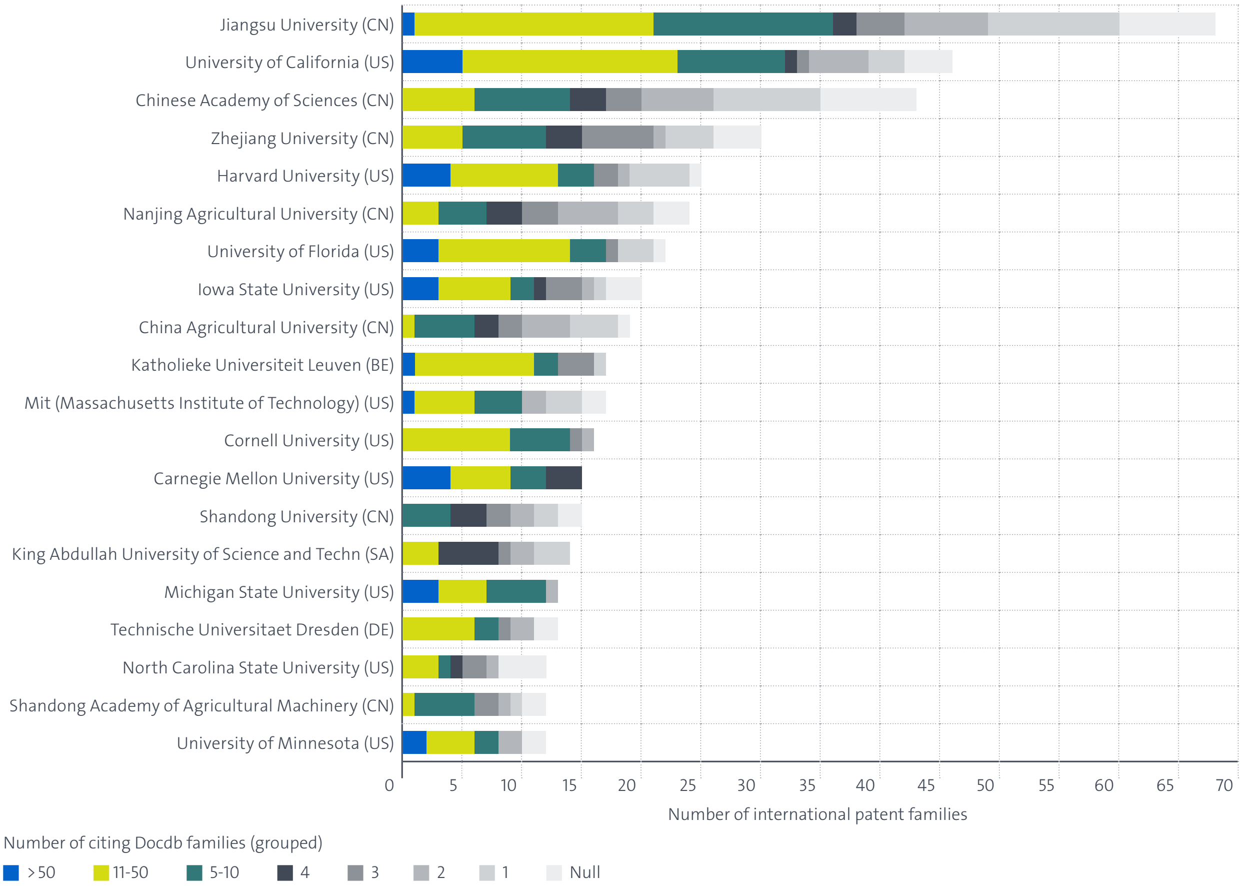
The top applicant lists present the main university and company players.

4.1. Universities

Universities in China are involved in the filing of over 38 000 patent families when non-IPFs are included, followed by Korea with more than 1 400 and the US over 900 patent families. The top-ranked universities' IPF filings can be seen in Figure 14 which includes their collaborations with industries and governmental institutions.

Figure 14

Top universities worldwide in IPFs and forward citations (2000-2022)



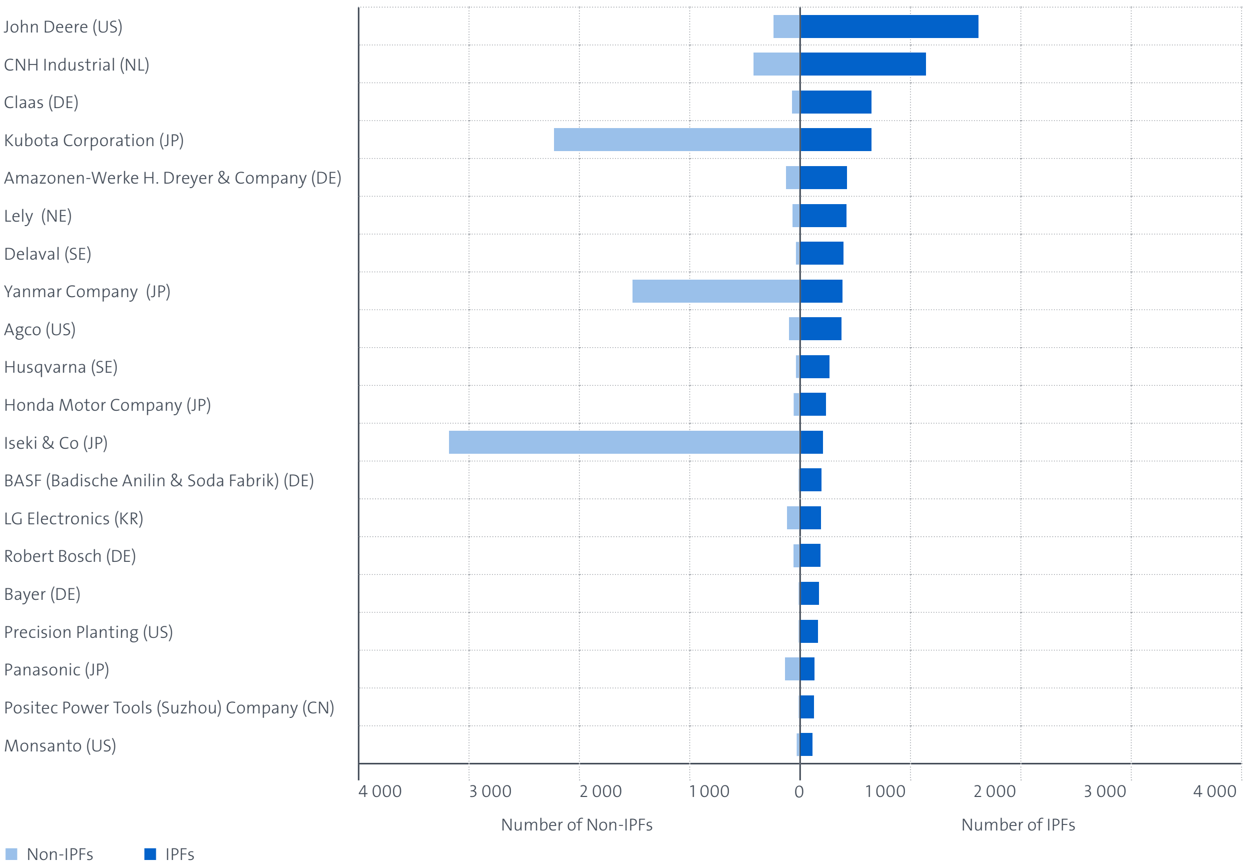
The top university in IPFs in digital agriculture is the Jiangsu University in China, followed by the University of California and many other US universities. The share of high forward citations (>10) is higher for US universities and the Katholieke University of Leuven in Belgium than for Chinese universities. In addition, the King Abdullah University of Science and Technology in Saudia Arabia and the Technische Universität Dresden in Germany made it into the top 20 list.

4.2. Companies

Figure 15 shows the top companies filing IPFs in digital agriculture, their headquarter location and their number of non-IPF filings.

Figure 15

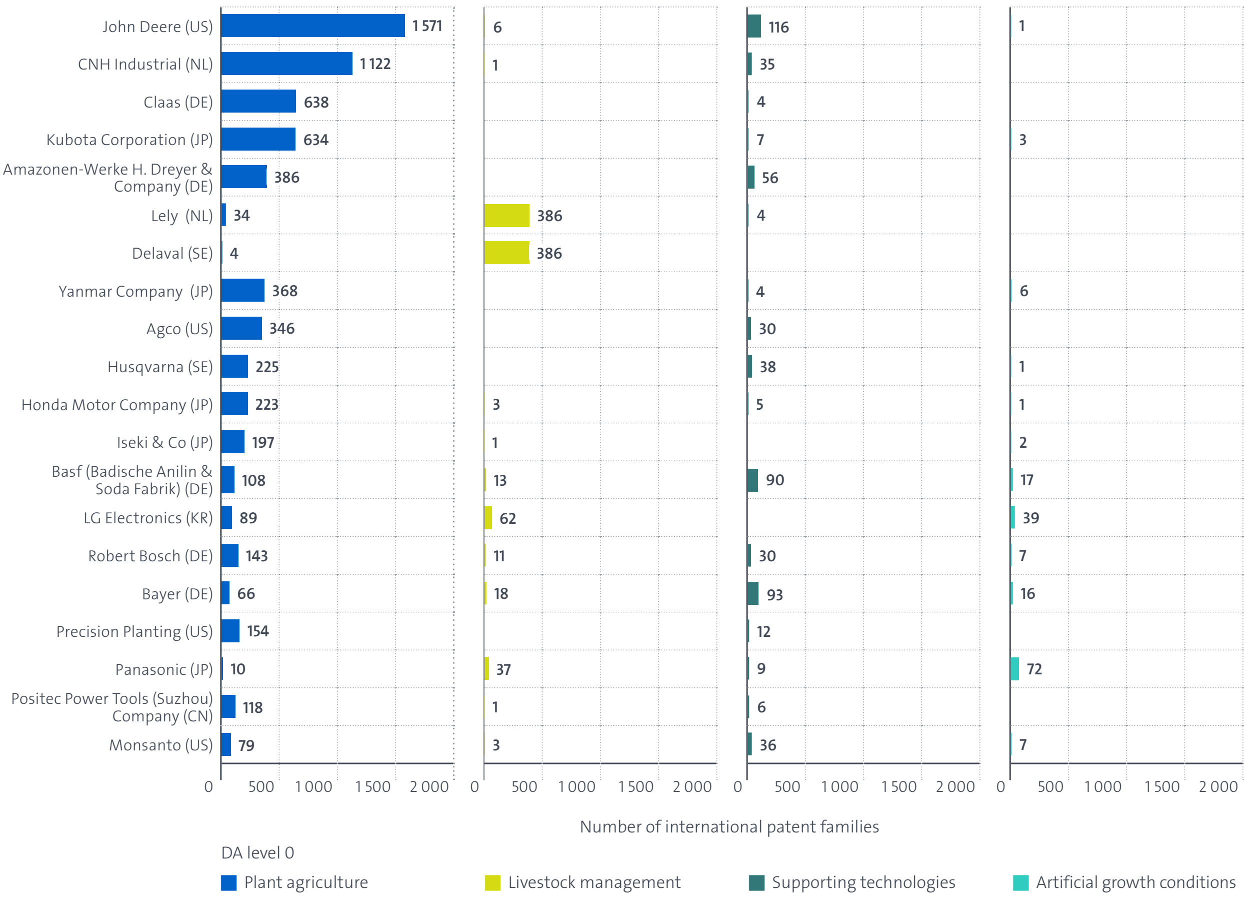
Top companies worldwide ranked according to IPFs (2000-2022)



The list of top corporate players shows that the traditional large agri-equipment producers dominate. A further point of note is that, with the exception of Honda, Asian companies tend to focus much more on filing one single national patent application. For US and European companies, in contrast, IPFs represent a much larger share of their patent portfolio.

Figure 16

Top applicants by number of IPFs published from 2000 to 2022 per area cluster



Most top players focus on plant argirculture with the exceptions of Lely and Delaval, who focus on livestock managmeent, and Bayer, BASF and Monsanto, who have a stronger presence in supporting technologies (pest control).

5. Regional focus

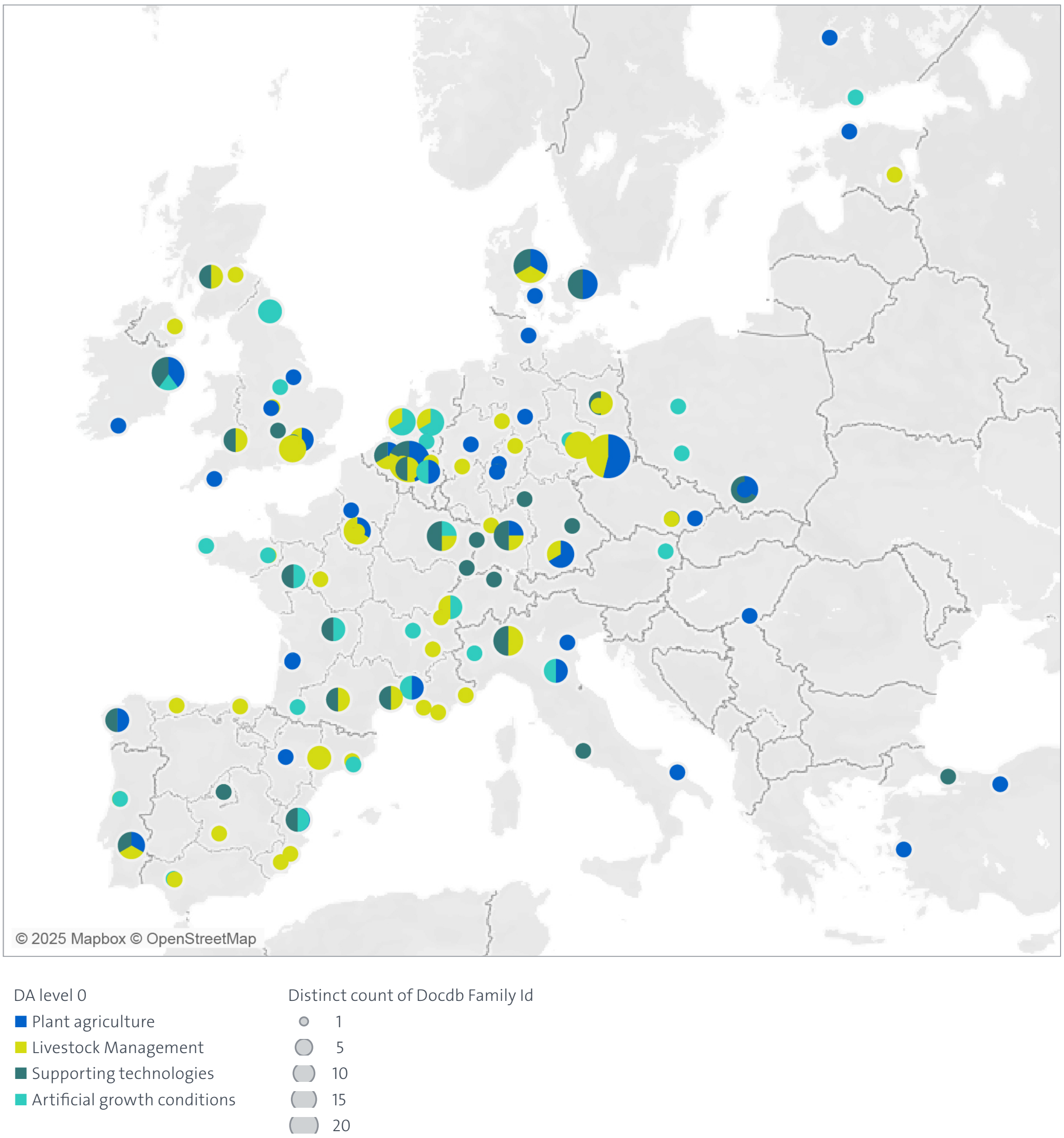
5.1. Focus on EPO countries

5.1.1. Universities

The following map shows the patenting of EPO universities in the area clusters.

Figure 17

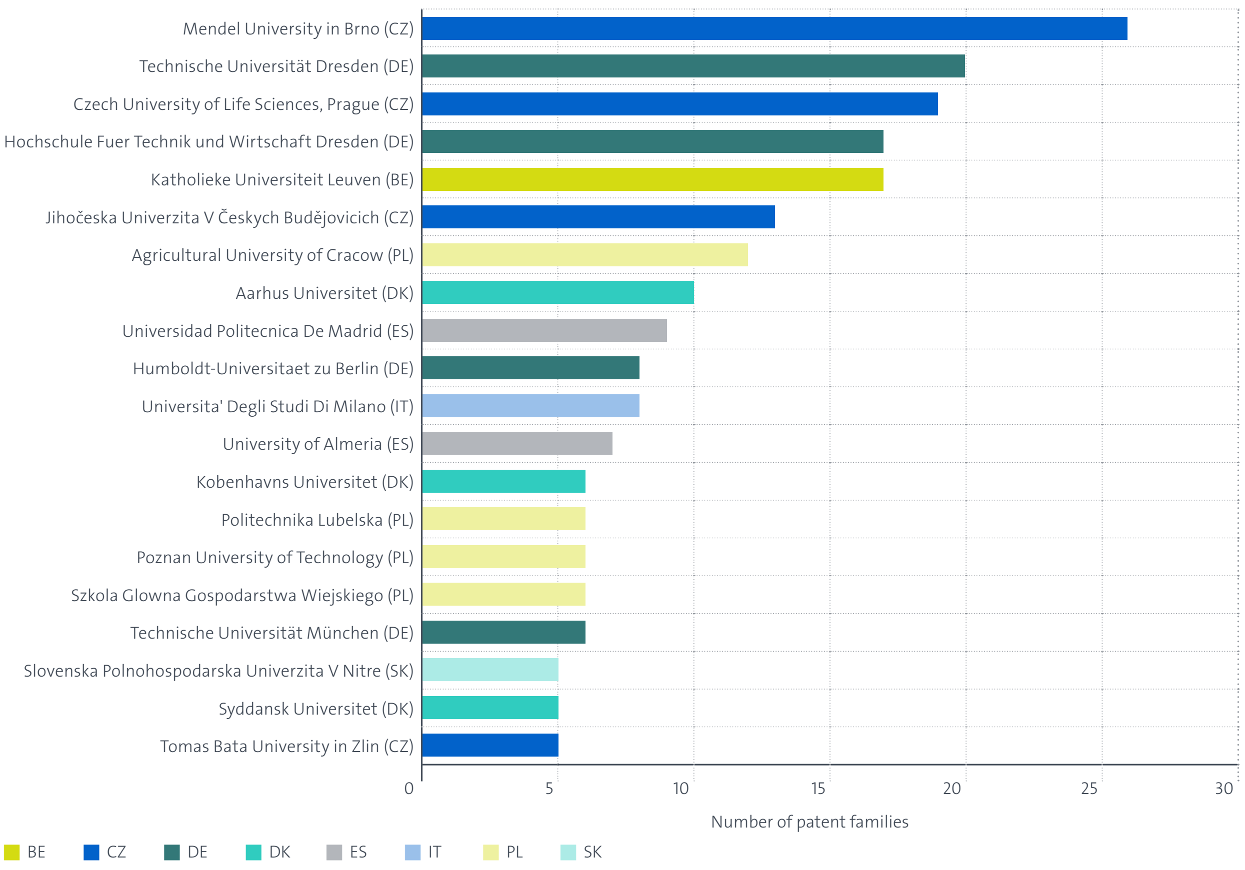
Universities in EPO member states with EP patent applications



Overall, 125 universities were identified that have filed a total of 184 EP applications in digital agriculture. All technology areas are well represented. Universities that file five or more EP applications tend to do so in multiple technological areas. Of the EPO member states, German universities have filed the highest number of EP patents in digital agriculture, followed by France, the United Kingdom and Spain. The leading universities are in Dresden, Leuven, Milano, Aarhus, Stuttgart and Paris.

Figure 18

Universities in EPO member states (all patent applications, not restricted to IPFs)



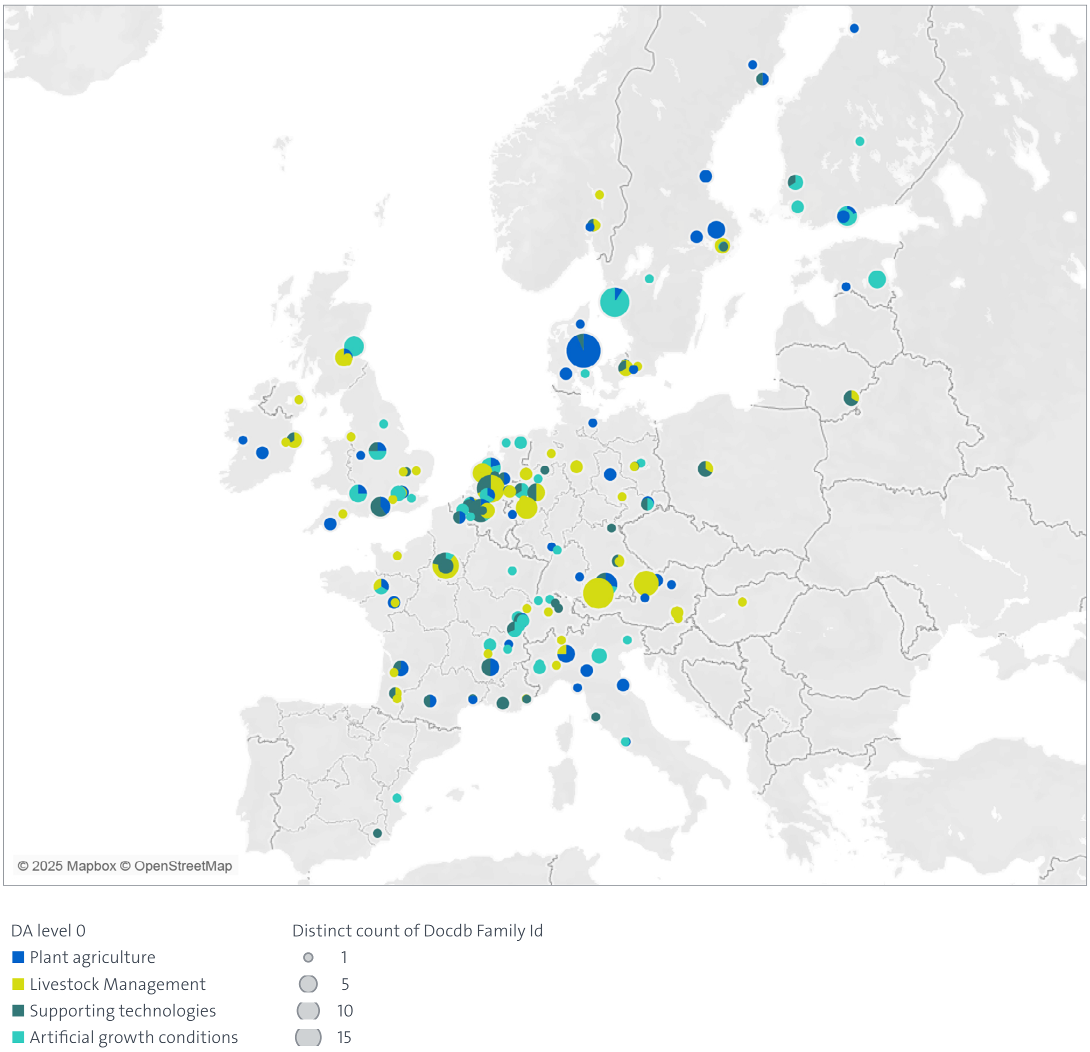
When including national filings, universities in the Czech Republic, Germany, Spain and Poland excel.

5.1.2. Startups

Data from the EPO's Deep Tech Finder provide further insight into the contribution of startups in EPO member states per area cluster.

Figure 19

Startups from EPO member states with European patent applications



The map shows the location of the startups in EPO member states having at least one published EP application and their number of European patents. In total, 194 start-ups were identified, which have filed 348 EP applications related to digital agriculture. Although start-ups tend to focus more on one core technology area, there is specific technology area that stands out as dominating the European start-up landscape here too.

5.2. Focus on Latin America

Latin America is one of the main grain, fruit and protein producers in the world and accounts for approximately 10% of the world's agricultural product exports (FAO, 2021). The region possesses the highest agricultural land and water availability per capita: with just 15% of the world's land area, Latin America receives 29% of global precipitation and holds 33% of globally available renewable resources. It stores 40% of the world's fresh water. **By 2050, Latin America could supply two to three out of every five fruits and vegetables globally** (based on data for Latin America and the world's historic production and export performance in the period 2010-2020) (WEF, 2024). As mentioned earlier in this report, although starting from a relatively modest number of IPFs, Latin America has shown some of the strongest growth in digital agriculture patenting over the last 20 years. This underlines the importance of agriculture in this region and validates the previously mentioned production potential from a strong commitment to innovation.

Against this backdrop, various Latin American patent offices have contributed to this report by highlighting some examples and initiatives relating to digital agriculture in their respective countries.

DIGITAL AGRICULTURAL AS A PATHWAY TO GREEN TRANSITION IN BRAZIL

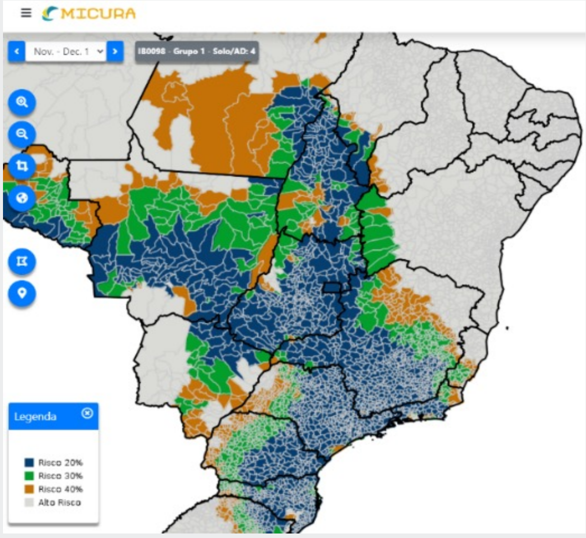
National Institute of Industrial Property – INPI Brazil

Brazil is one of the largest agricultural powerhouses in the world, currently producing enough food to supply 11% of the global population and therefore has enormous potential to be a protagonist in the green transition. Adopting digital technologies in agriculture such as drones, sensors and data management systems can increase crop efficiency, allowing a more sustainable use of natural resources. This is essential for the implementation of a bioeconomy model, mitigating climate change effects and ensuring global food security. These measures align with the United Nations Sustainable Development Goals, such as SDG 2 (Zero hunger and sustainable agriculture) and SDG 13 (Action against global climate change).

Among the top innovative institutions in Brazil, **Embrapa** is the main applicant of sustainable agriculture technologies. Embrapa *(Empresa Brasileira de Pesquisa Agropecuária)* is a public company, created in 1973, that operates under the Ministry of Agriculture and Livestock. It has an organisational unit dedicated exclusively to digital agriculture – Embrapa Digital Agriculture – tasked with developing innovative digital technological solutions aimed at assisting decision-making, management and monitoring of agriculture through systems, software, applications, databases and other technologies. For example, Embrapa developed the Agricultural Climate Risk Zoning (ZARC) app-based on an agrometeorological study that delimits production regions and planting seasons according to their probabilities of production loss caused by meteorological events (Figure 20) – an important tool for rural producers.

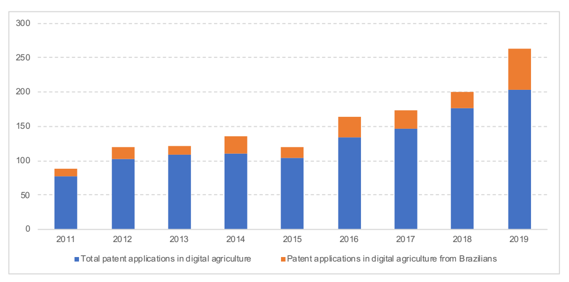
Figure 20

Agricultural Climate Risk Zoning (ZARC) application



Brazil is a lead-market for sustainable technologies. It is also a relevant developer of innovation, ranking ninth worldwide as an origin of patents for sustainable agriculture, as revealed in a study published by INPI Brazil. The study indicated that digital agriculture technologies accounted for 13.4% of inventions in sustainable agriculture in the world, while in Brazil this percentage was 15.7%, highlighting the role of potential users in this market. About one out of every five inventions related to digital agriculture are filed by Brazilians at INPI Brazil. This share doubled during the 2010s (Graph 1). These technologies help to reduce the use of chemical inputs and promote soil and water conservation, driving the green transition.

Graph 1 - Patent applications in digital agriculture filed in Brazil



INPI Brazil plays a strategic role in encouraging innovation. Since 2012, it offers a priority processing program for sustainable technologies, where about 18% are related to agriculture, including several digital innovations. The technological information from these patent applications are made available to society through the Observatory of Green Technologies, which facilitates access to these data, collaborating with the development of projects in the sector, revealing the Brazilian innovation scenario, its know-how, opportunities and bottlenecks.

Another relevant project to foster innovation in sustainable agriculture is the matchmaking initiative led by INPI Brazil with support from the European Union. In 2023, the project connected providers and users of sustainable technologies in Latin America and Europe, involving more than 500 participants from 20 countries and resulting in 96 successful connections, highlighting the area of digital agriculture.

CHILE: INNOVATION FOR SUSTAINABLE AGRICULTURE

National Institute Of Industrial Property – Inapi Chile

Wiseconn: Chilean innovation in intelligent water management

Wiseconn represents a flagship example of Chilean agricultural innovation, demonstrating how local entrepreneurship can create globally impactful solutions. Founded in 2006 by Chilean entrepreneurs with angel capital backing, the company developed DropControl – a groundbreaking technology for efficient agricultural water management.

The DropControl system delivers a comprehensive solution based on an advanced technological architecture comprising wireless sensors and controllers, rural communication networks, local processing nodes, cloud management and a mobile interface. Its core innovation lies in the autonomous local control system that dynamically adjusts irrigation parameters according to environmental conditions.

Protected by patents in the United States and Australia as well as through a European patent, Wiseconn operates throughout North and South America with over 20 000 installations monitoring and controlling 300 000 hectares.

Source: WISECCON website

Innovative climate solutions for cherry production

Chile's fruit industry faces mounting climate challenges threatening production quality and economic viability. Through the WIPOGREEN Latin American acceleration program – of which INAPI has been a member since 2019 – a connection was established between Prosecor SPA, a cherry producer in Osorno, and Germany's Voen Covering Systems. Southern Chile's cherry orchards endure severe weather – unpredictable hail, extreme winds and excessive rainfall – causing fruit splitting, flower loss and plant diseases. Traditional coverings prove inadequate against increasingly destructive winds that damage export-quality cherries.

Voen's premium covering systems feature self-venting technology adapted to Chilean orchard infrastructure, providing wind-resistant solutions that maximise yield and quality potential. This technology match is featured in the catalogue "Dealing with the negative effects of climate change in the Chilean Fruit Sector" available in the LAC Database Collection.

Knowledge transfer and diversity promotion

Recognising the critical role of sustainable agricultural innovation for Chile's future, INAPI has implemented other strategic initiatives to foster technological advancement and knowledge transfer in this sector. INAPI has published 42 technological surveillance reports since 2020, promoting industrial property protection and disseminating technological knowledge. Key agricultural reports include "Agriculture 4.0 and robotisation for agroindustry", "Technologies for agricultural irrigation" and "Technologies for wine production", providing essential patent landscape analysis for Chilean agricultural innovation.

Additionally, understanding diversity's importance in innovation, INAPI and the Chilean Network of Technology Managers (Red GT) established the Women Leaders in Technological Innovation award, which is celebrating its third edition in 2025. This initiative increases the visibility of female talent in Chile's science, technology and innovation ecosystem, addressing persistent gender gaps.

One notable participant was Camila Elibeth Beltrán Stuardo, CEO and co-founder of Permacultura Tech SPA, who competed with her innovative work in agricultural technology. Her company develops IoT sensors and AI-powered platforms for environmental monitoring and efficient water management in agricultural and forestry operations, promoting digitalisation and sustainability in these sectors.

DIGITISING THE AGROINDUSTRY IN COLOMBIA

Superintendence of Industry and Commerce – SIC Colombia

In light of the challenges facing Colombia's agricultural sector – such as climate change, food security and productive sustainability – digital technologies have emerged as key tools for transforming rural development. Solutions such as artificial intelligence (AI), the Internet of Things (IoT), sensors, drones and robotics are revolutionising how crops are cultivated, monitored and managed. These technologies enable more informed decision-making, resource optimisation, improved productivity and reduced environmental impact. Their adoption in Colombia is already showing concrete results in several strategic crops, helping to strengthen a more efficient, resilient and innovative agroindustry.

Here are a number of examples.

- **Coffee:** In southeastern Colombia, drones and sensors are used to monitor crop health, improving bean quality and boosting production (more information here).
- **Sugarcane:** In Valle del Cauca, the Cenilogger – a soil moisture sensor connected to an IoT network –optimises smart irrigation, reducing water use by up to 50% (more information here).
- **Fruits and vegetables:** The AgroTIC project developed a mobile app powered by AI that allows farmers to monitor their crops and connect with experts and merchants (more information here).
- **Flowers:** In Antioquia, drones are used for precision spraying, improving crop quality and reducing environmental impact (more information here).
- **Hass Avocado:** Companies like Cartama have integrated AI and intelligent monitoring to meet export quality standards (more information here).

Recognising the importance of these developments, the Superintendence of Industry and Commerce (SIC Colombia) has published two technological bulletins focused on digital technologies in the agro-industrial sector.

- Coffee: A sector of opportunity for Industry 4.0 technologies
  This bulletin highlights how this agricultural sector represents a significant opportunity for integrating Industry 4.0 technologies. Among the key trends are the use of digital transformation tools for pest inspection via imaging, systems that estimate variables such as insect presence or oxygen levels in the soil, and automated coffee planting devices using motorised drilling rods. It also identifies smart storage systems for agricultural products that regulate internal conditions using sensors.


BOLETÍN TECNOLÓGICO
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SUPERINTENDENCIA
CAFÉ
UN SECTOR DE OPORTUNIDAD PARA LAS TECNOLOGÍAS DE LA INDUSTRIA 4.0.

- Artificial intelligence and robotics: The future of the countryside in Colombia
  This bulletin highlights the transformative role of AI and robotics in advancing the Colombian agricultural sector. The technological trends identified include agricultural robots, AI-based systems, geolocation tools and natural language processing technologies as key components of human-machine interaction. These solutions aim to enhance productivity, reduce costs and promote sustainability with a focus on strategic crops like potatoes, coffee, sugarcane, tropical fruits and flowers.


Industria y Comercio
SUPERINTENDENCIA
BOLETÍN TECNOLÓGICO
Inteligencia artificial y robótica, el futuro del campo en Colombia
SEPTIEMBRE 2021

Both documents highlight key opportunities in areas such as productivity, sustainability, added value and traceability while also identifying challenges such as the digital divide, regulatory frameworks, technical training and implementation costs.

For those working in agroindustry, these bulletins serve as key instruments for enhancing productivity, modernisation and rural development, especially in a country like Colombia which holds vast potential due to its biodiversity and social conditions. These technological bulletins are available on the website of SIC Colombia, and were developed by its Deputy for Industrial Property as part of its commitment to the country's technological advancement in agriculture.

MEXICO: ENHANCING AGRICULTURAL PRODUCTIVITY THROUGH DIGITAL IP-DRIVEN SOLUTIONS

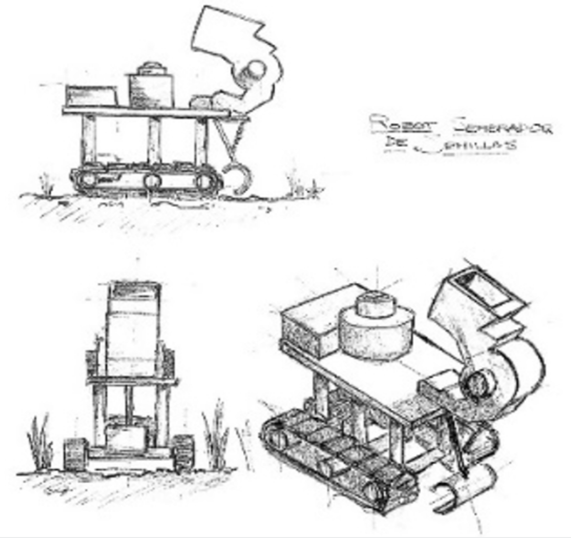
Mexican Institute of Industrial Property (IMPI)

Mexico has increasingly focused on fostering innovation in agriculture, particularly through the integration of digital technologies that enhance sustainability, productivity and resource management. Through patented inventions, Mexican researchers and institutions address challenges such as climate change, resource optimisation and food security.

One notable example is the **portable, non-contact device** for **monitoring vapour pressure deficit (VPD) and humidity deficit (HD)** in crops. Patented by the **Universidad Autónoma de Chapingo**, this device uses infrared sensors to measure leaf temperature and integrates various sensors for air temperature, humidity and atmospheric pressure. It helps optimise irrigation, reducing water waste and improving crop yield by ensuring favourable environmental conditions for plant growth.

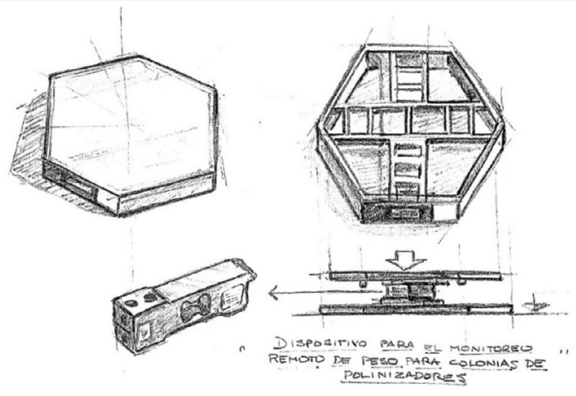
Another key innovation is the **system to determine the hydrologic condition of orchard trees**, also developed by the **Universidad Autónoma de Chapingo**. This patented technology allows even non-expert farmers to monitor water stress in fruit trees. By using a combination of dendrometers, infrared sensors and a Bluetooth-enabled mobile app, the system provides real-time data on tree health and helps manage irrigation schedules efficiently.

From the **Instituto Tecnológico de Xalapa**, a patent was granted for a **remotely controlled seed-sowing robot.** The robot is guided by mobile applications that program seed spacing, depth and sowing parameters. It communicates with the mobile device, reports positioning and error data in real time and detects obstacles, thereby increasing planting efficiency and reducing the dependency on manual labour.



Pollinator monitoring is another area of innovation. A team at the **Universidad Nacional Autónoma de México (UNAM)** patented a **remote beehive weighing system** using Internet of Things (IoT) technologies.

The system includes a load cell sensor to detect hive weight variations, Bluetooth and GSM modules for data transmission and a cloud-based server for real-time data analysis. This allows continuous monitoring of colony health, which is crucial for maintaining pollination services and ecosystem stability.



The **Mexican Institute of Industrial Property (IMPI)** plays a vital role in fostering innovation in the agrifood sector. From 2018 to April 2025, 3 680 patents were granted in the AgTech and FoodTech innovation domain. A total of 464 of these active patents are held by Mexican applicants, and a closer look reveals that a considerable proportion of these patents come from higher education institutions and research institutes. Leading Mexican universities with three or more active agri-food technology patents include national and regional institutions committed to agricultural research, biotechnology and environmental sustainability. These institutions are not only generating patentable technologies, but also contributing directly to Mexico's economy by transferring knowledge to industry and fostering public-private collaboration.

By mapping and promoting patenting activity in digital agriculture, IMPI not only ensures legal protection for national inventions, but also facilitates knowledge transfer and strengthens the innovation ecosystem. These efforts are aligned with Mexico's commitment to food security, sustainability and technological sovereignty. The country's efforts are a testament to the potential of digital agriculture to transform how food is produced, processed and managed in a rapidly changing world.

INNOVATION IN DIGITAL AGRICULTURE IN PERU

National Institute for the Defence of Competition and Protection of Intellectual Property – INDECOPI

Did you know that Peru is one of the main exporters of blueberries in the world?

Agriculture in Peru, like many sectors, is constantly changing, moulding itself based on the needs of the current and future reality, which is why innovative projects such as the "Unmanned vehicle with autonomous navigation and robotic arm" – which currently has two applications for registration of utility model patents under processing before the **Directorate of Inventions and New Technologies of Peru's National Institute for the Defence of Competition and the Protection of Intellectual Property (INDECOPI)** – is of great relevance. It combines automation with artificial vision technologies and convolutional neural networks. Applied to the blueberry agricultural sector, it is one of the innovations that has great potential for national agriculture, contributing to technological development with the protection of inventions through patent registration, and thus contributing to innovation and the development of Peruvian agriculture.

Technological-digital innovation: The integration of a vehicle with the capacity for moving over irregular terrain and for autonomous or remote-controlled handling, together with a robotic arm with the capacity to detect and evaluate the fruit in the field, directly contributes to solving the problem of the amount of manpower needed when harvesting blueberry fruit. By detecting, counting and evaluating the level of ripeness of the fruit in an efficient manner, it improves decision-making at the time of harvesting blueberries.

Innovation-University-Company: This technological innovation project of great impact on the agricultural development of the country has three main actors who form a synergetic circle: the Universidad Privada Antenor Orrego (UPAO) as the developer of this innovation, the Consejo Nacional de Ciencia, Tecnología e Innovación Tecnológica (CONCYTEC) as the state entity that provides financial support for innovation projects, and the Empresa Agroindustrial Danper as the private entity in which the real field tests were carried out.

Production of blueberries in Peru: The number of hectares planted with blueberries in Peru in the last 10 years has grown significantly, from 400 hectares in 2013 to 19 500 hectares in 2023, making blueberries one of the main Peruvian export products.

Plant varieties: The evolution of technological innovation in the blueberry sector teaches us that the cultivation of blueberries must go hand in hand with the continuous development of new blueberry varieties, which constitute an important pillar in the agricultural development of the sector, favouring the advancement of a more sustainable and efficient agriculture. As a result, during the years 2011 to 2024, 140 applications for new blueberry plant varieties have been filed with the Directorate of Inventions and New Technologies of INDECOPI.

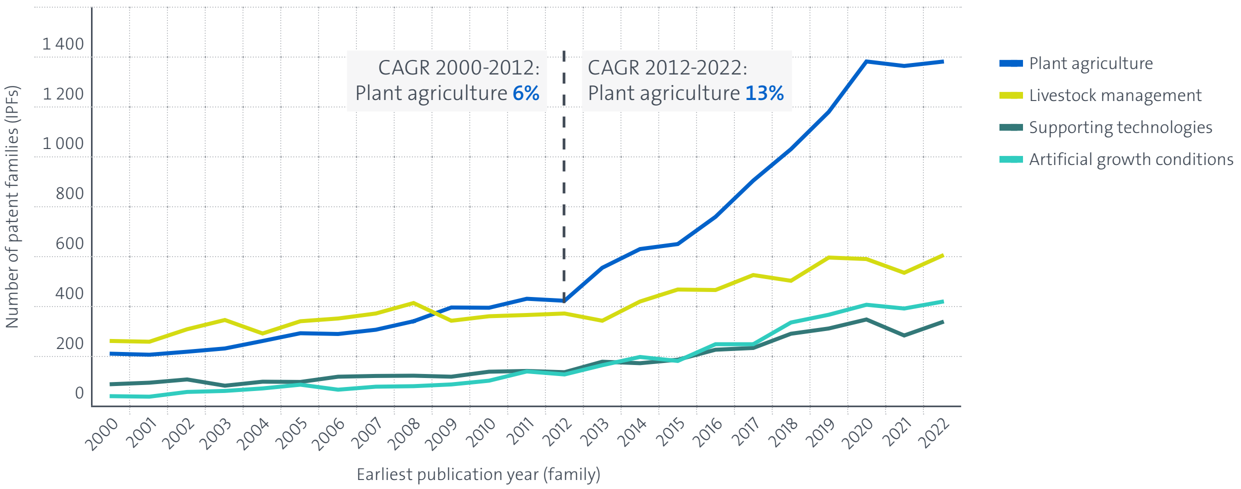
In this sense, INDECOPI is an institution essential to the economic and social development of Peru, which, through the **Directorate of Inventions and New Technologies**, plays a fundamental role in the ecosystem of innovation and national technological development, promoting the registration of inventions, utility models, designs, plant varieties and collective knowledge of indigenous peoples. It does so by promoting and strategically leveraging these assets, supporting inventors and entrepreneurs through technical advisory services and connecting them with universities, research centres and companies, thereby fostering the country's competitiveness and consolidating a culture of innovation that responds to the challenges of sustainable development in Peru.
To achieve more successful cases of technological innovation, INDECOPI is committed to digitalisation, greater access to information, the promotion of intellectual property tools and the development of public policies related to intellectual property to strengthen innovation and competitiveness in the country.

6. Technology area descriptions and statistics

Following a statistical overview, this section provides a deeper dive into the various technological fields and areas. Figure 21 gives an overview of IPF filings in digital technologies per area cluster.

Figure 21

Overview of IPF filings per area cluster



CAGR = compound annual growth rate

It shows that the main driver since 2012 is plant agriculture, with a compound annual growth rate that rose from 6% in the period of 2000–2012 to 13% in the period of 2012–2022.

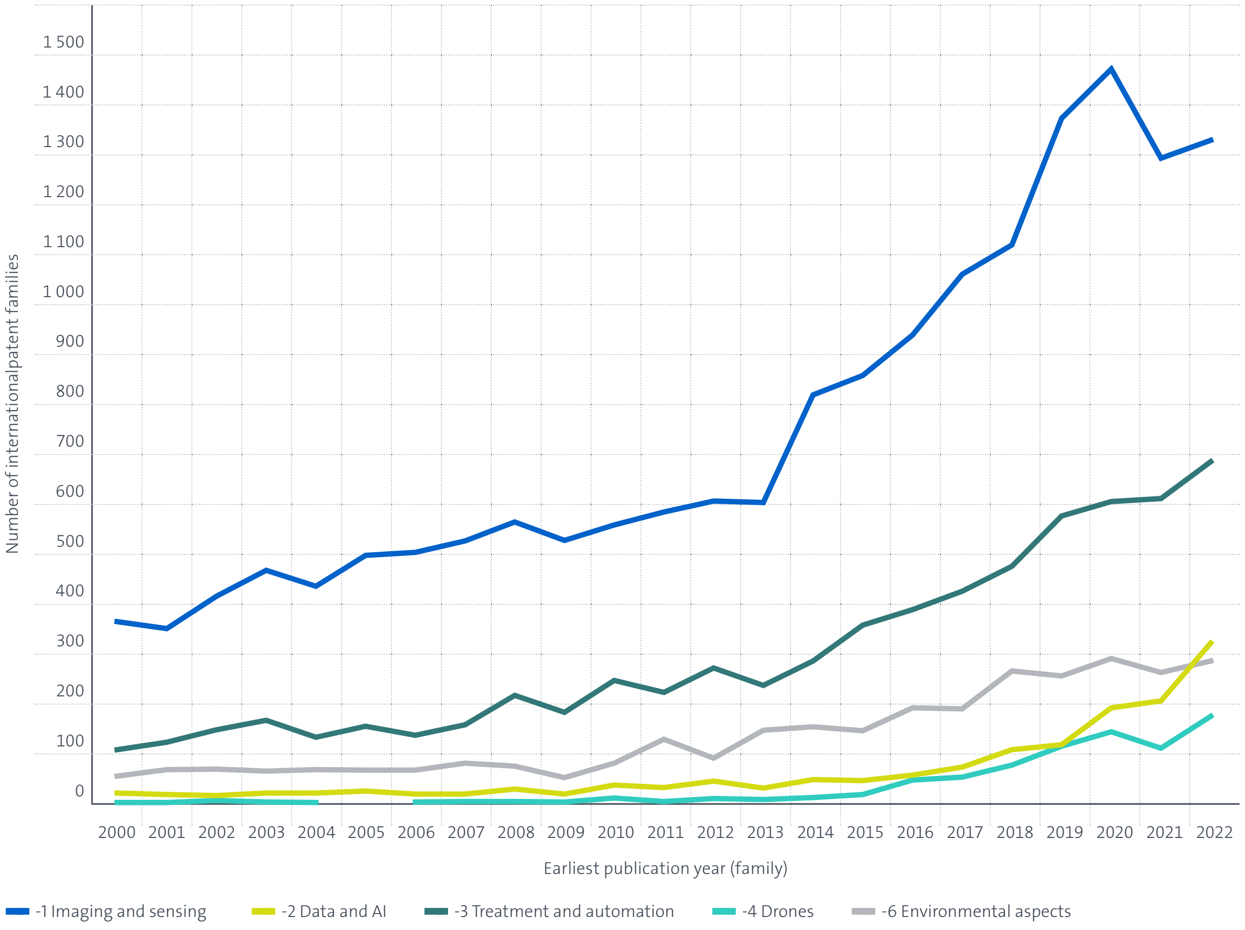
Chapter 9 features an overview of the IPF and non-IPF filings in all areas according to the technology cartography that was developed for this report (see Figure 37).

The digital technology is subdivided in each area into specific technologies from imaging and sensing, data analysis and AI, automation and treatment, drones and environmental aspects. It shows the importance of specific digital technologies in each of the 12 areas.

Analysing the data according to the cross-cutting digital technologies, Figure 22 shows that patents involving imaging and sensing play a pivotal role in digital agriculture.

Figure 22

Trends in digital technologies



Moreover, treatment and automation show considerable growth rates in inventive activity. While drones and, in particular, data and AI began their growth somewhat later, presently the strongest growth is in data and AI, which have now overtaken environmental aspects in the number of IPFs per year. The importance for each of these areas can be seen in Figure 23.

Figure 23

Breakdown of cross-digital technologies to agricultural areas (IPFs 2000–2022)

PLANT AGRICULTURE

Plant agriculture is the area cluster with the highest growth rates in the past 10 years in digital agriculture. The following sections provide an overview of these technologies and their digital development.

6.1. Soil working

Soil working aims to improve soil structure, enhance aeration and increase water infiltration, ultimately creating optimal conditions for seed germination and plant growth. Soil working covers all relevant details of tools, method, implements or parts of agricultural machinery which are used for an action that will result in furrowing, ploughing, tilling, moving, opening or smoothing, etc.
Historically, soil working is an ancient agricultural practice, with evidence of ploughing dating back to around 4 000 BC in Mesopotamia. Early ploughs were simple wooden tools pulled by humans or animals. Today, digital tools and technologies are transforming soil working practices, making them more sustainable and efficient, and helping farmers to optimise crop production whilst minimising environmental impact. Drones can be used to gather field or soil data during soil treatment, for example, to create field maps showing soil characteristics. AI algorithms can predict the impact of factors such as tillage depth and patterns on future yields by correlating soil data with historical crop performance.

6.2. Seeding and fertilising

Seeding involves planting seeds, seedlings, plants, bulbs and/or tubers in the soil to grow crops. Fertilising involves adding nutrients to the soil to enhance plant growth and yield. Fertilisers can be organic (e.g. compost or manure) or inorganic (e.g. chemical fertilisers). This report encompasses a wide range of technologies and methods related to planting, sowing and fertilising in agriculture, reflecting the diversity and complexity of these essential agricultural processes. This technology covers manual and mechanical devices for distributing seeds and plants as well as for treating seeds prior to planting or for potting plants. Methods and apparatus for fertilising soil or plants, either in conjunction with planting or sowing, or independently, are also part of this technology. High-precision autonomous seeding and fertilising, for example, can be based on AI and machine learning that can be used to analyse images of crops to establish their current state and then estimate fertilisation needs, or to estimate yield optimisation and recommend precise planting patterns. Precision fertilising can substantially reduce the total amount of fertiliser used by farmers. Nitrogen reductions of up to 75% have been reported, using variable-rate nitrogen application, without affecting product yield (Idier et al., 2024).

6.3. Harvesting

In agriculture, harvesting is the process of gathering mature crops from the fields. Harvesting covers a wide range of technologies and methods related to the harvesting of crops and mowing of grass or similar vegetation. It encompasses the general methods and apparatus for cutting, gathering and collecting crops, as well as specific machines for harvesting root crops, fruits and vegetables. It also covers mowing apparatus for grass, devices for handling and processing harvested crops such as binders and threshers, and auxiliary devices such as cutting mechanisms and conveyors, ensuring comprehensive coverage of the harvesting process.

The invention of the combine harvester in the 19th century revolutionised grain harvesting by combining reaping, threshing and winnowing into a single operation. Today, digital agriculture is transforming harvesting by utilising technologies such as GPS, sensors and data analytics involving AI to enable precision harvesting, optimise timing and improve efficiency and sustainability in crop collection.

6.4. Spoil reduction

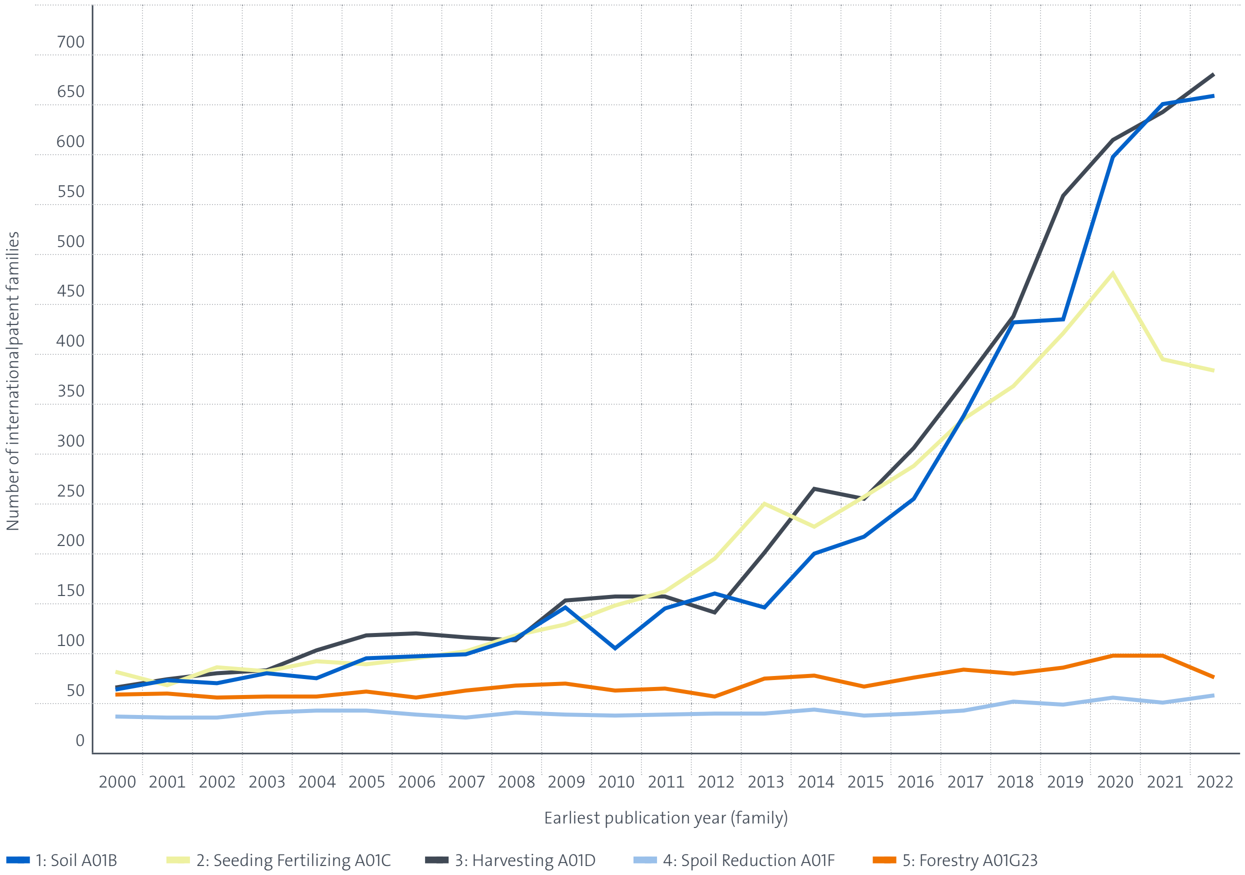
In agriculture, spoil reduction involves strategies and practices aimed at minimising the loss of crops and food products throughout the supply chain, from production to consumption. This includes improving harvesting techniques, enhancing storage conditions, optimizing transportation and implementing efficient processing and packaging methods to extend shelf life and maintain quality, thereby reducing waste and increasing food availability. This encompasses technical aspects such as machines and methods used to separate grains from their husks or straw, devices for handling harvested crops such as conveyors, elevators and other machinery, and logistics improvements to optimise storage and transportation. The use of AI algorithms can optimise storage and transportation routes to reduce delays and food waste, while cloud platforms track produce quantities and quality in real time, improving supply chain efficiency, and energy efficiency.

6.5. Forestry

Forests are home to over 80% of the world's terrestrial biodiversity. They provide habitats for countless species of plants, animals and microorganisms, many of which are not found anywhere else. Forestry in agriculture, often referred to as agroforestry, includes managing forest resources for timber, non-timber products and ecosystem services. It covers various aspects of forestry, including the cultivation, management and conservation of forests, technologies and methods for planting, maintaining and harvesting trees as well as managing forest ecosystems for timber production and environmental benefits. Forestry is a complex and multifaceted field that balances ecological, economic and social considerations, highlighting the need for sustainable management practices. Mapping and precision agroforestry are enhanced by the use of drones and AI algorithms.

Figure 24

Trends in digital plant agriculture



Statistics on digital technologies in plant agriculture
Figure 24 shows a high uptake of digital technologies is in soil working, seeding and fertilising, and harvesting. It is still in its infancy in spoil reduction and forestry.

Figure 24 shows the time development of the agriculture fields in the three most important areas of plant agriculture, namely 1) soil, 2) seeding and fertilizing, and 3) harvesting.

Figure 25

Detailed trends for plant agriculture

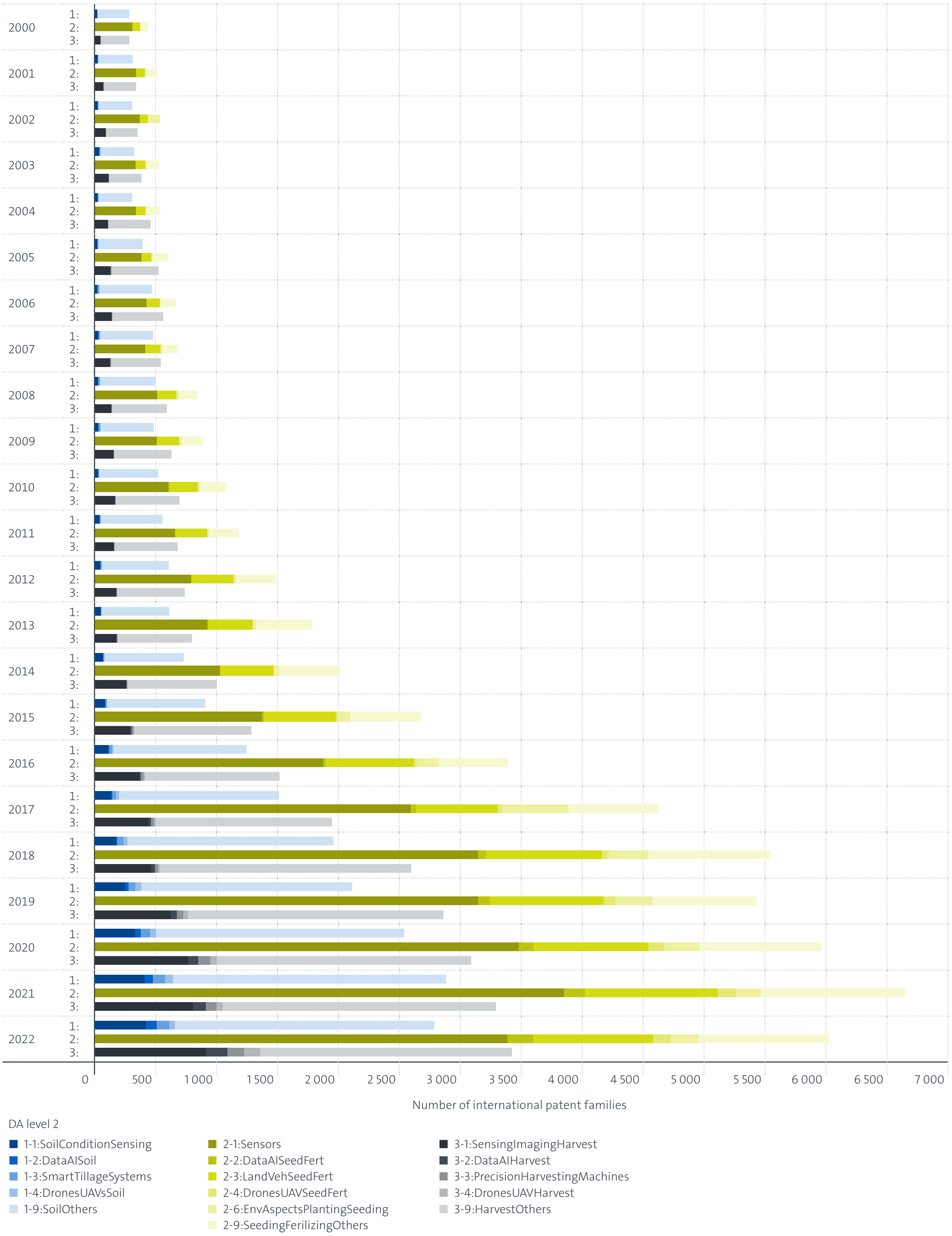
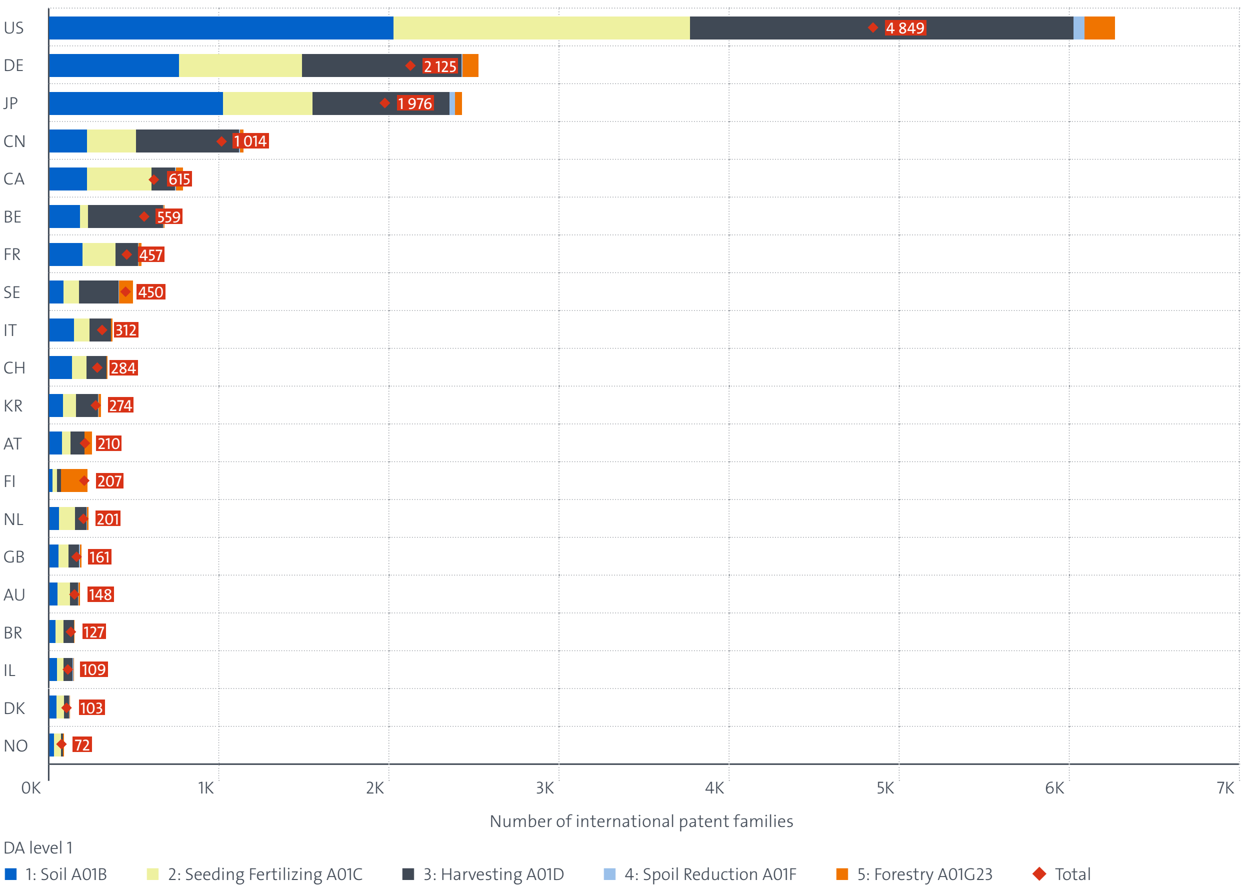


Figure 26

Top countries in plant agriculture by number of IPFs (2000–2002)



The most important applicant countries are the USA, Germany, Japan, China and Canada.

Figure 27

Top applicants in plant agriculture by number of IPFs (2000–2002)

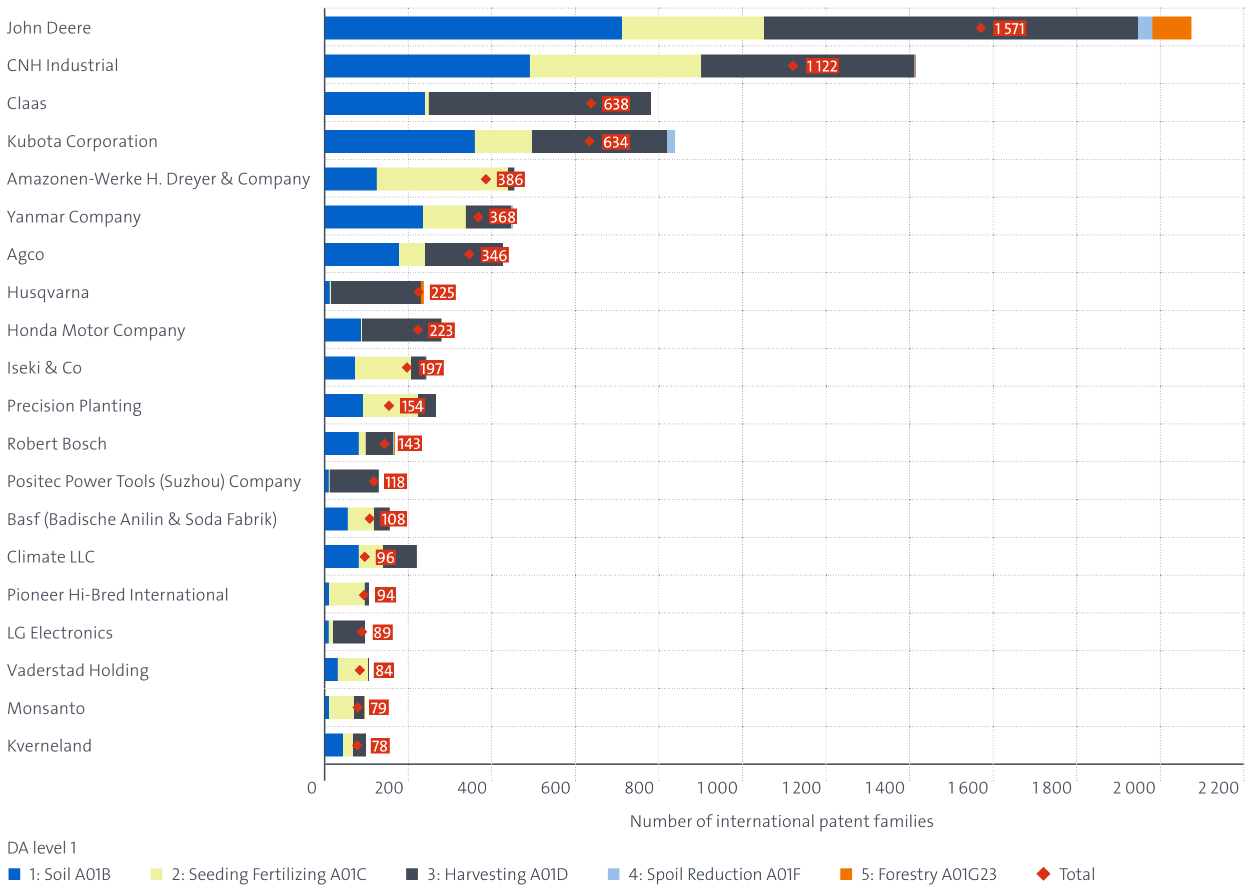


Figure 27 shows the harmonised top applicants and the portfolio of areas covered in their respective portfolios.

ARTIFICIAL GROWTH CONDITIONS

6.6. Greenhouses

Smart greenhouses are advanced agricultural systems that integrate technology to optimise the growing environment for plants. These greenhouses use sensors, automation and data analytics to monitor and control various environmental factors such as temperature, humidity, light and CO2 levels. By continuously collecting data, smart greenhouses can adjust these parameters in real time to create optimal conditions for plant growth. Devices or systems for heating, ventilating, regulating temperature, illuminating or watering and irrigation in greenhouses and the control of these systems allows for remote monitoring and management, enabling farmers to make informed decisions and respond quickly to any changes or issues.

6.7. Growth media

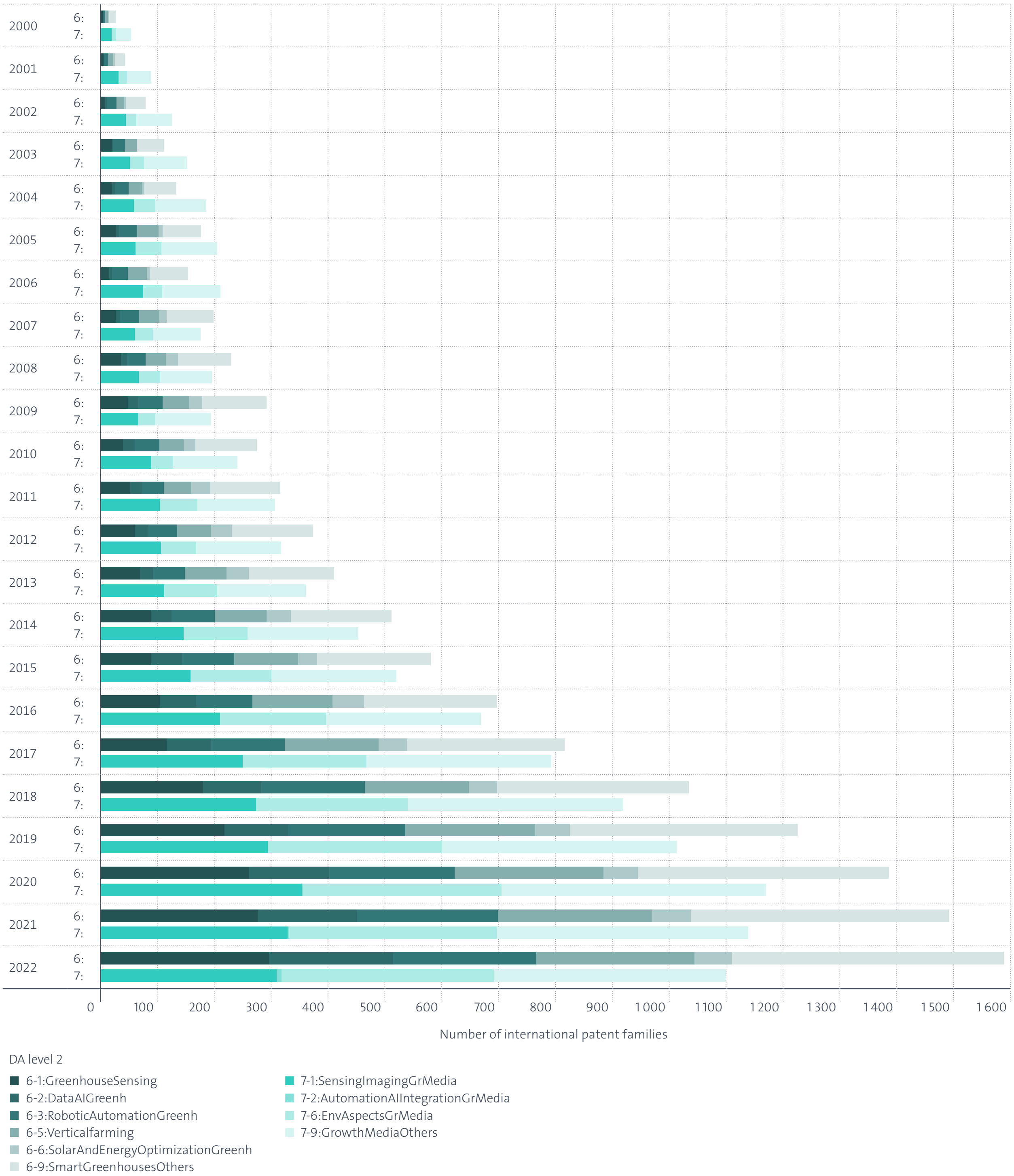
Growth media in agriculture refers to the various materials used to support plant growth, providing a stable environment for roots and supplying essential nutrients, water and air. Unlike natural soil, growth media can be tailored to specific plant needs and growing conditions, making them ideal for controlled environments such as greenhouses and hydroponic systems. Sensors and imaging technologies improve control of the plant environment, tailoring it to the plants' needs. Growth media can be reused and recycled, minimising waste and environmental impact. Additionally, growth media enable year-round cultivation and higher crop yields by optimising conditions for plant growth. In hydroponics and aquaponics, growth media play a crucial role in supporting plants whilst facilitating efficient nutrient and water use, contributing to the development of innovative agricultural systems that address the challenges of food security and resource conservation.

Statistics on digital technologies in artificial growth conditions

The timeline for specific innovations in greenhouses and growth media presented in Figure 28 shows a remarkable increase in digital technologies starting from a low level.

Figure 28

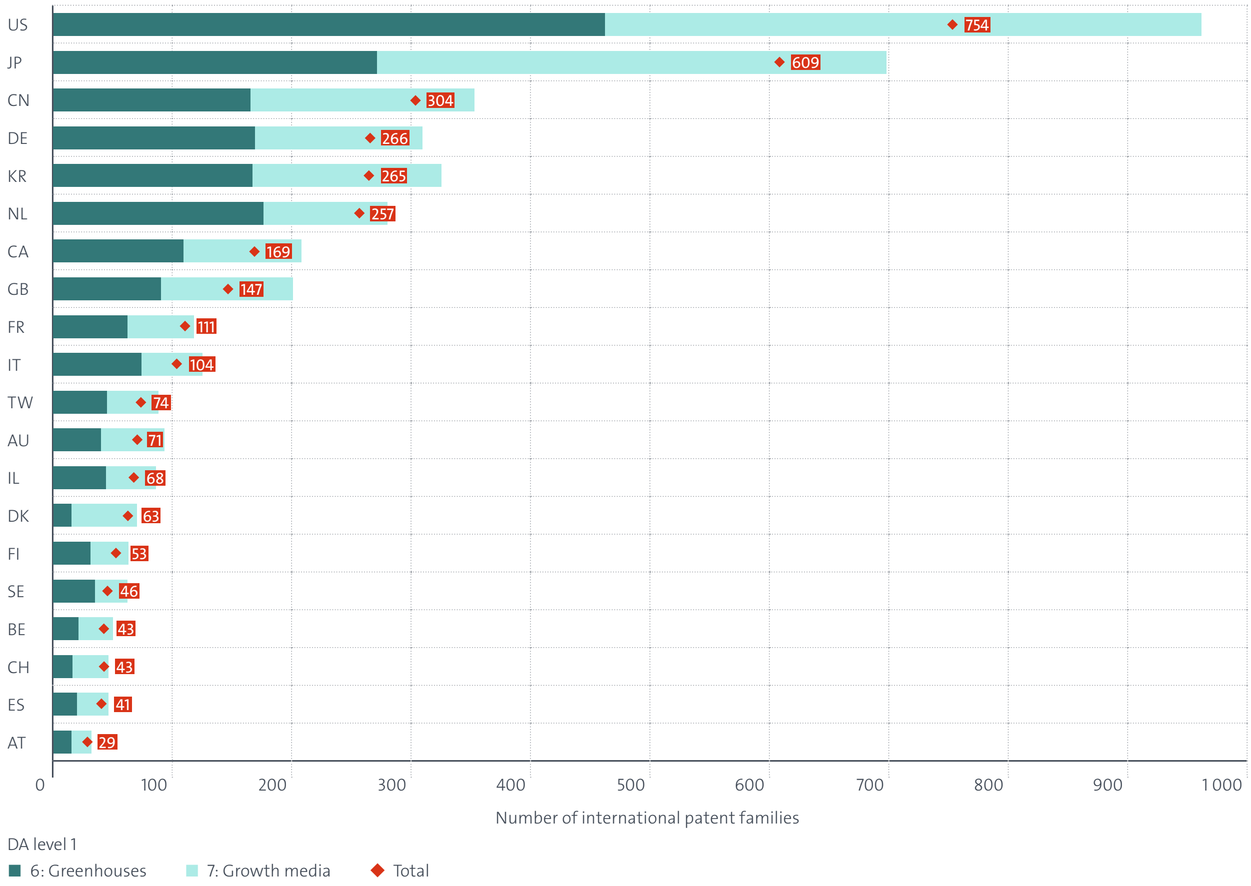
Trend in artificial growth conditions



The main applicant countries are the United States, Japan, China, Germany, Republic of Korea and the Netherlands.

Figure 29

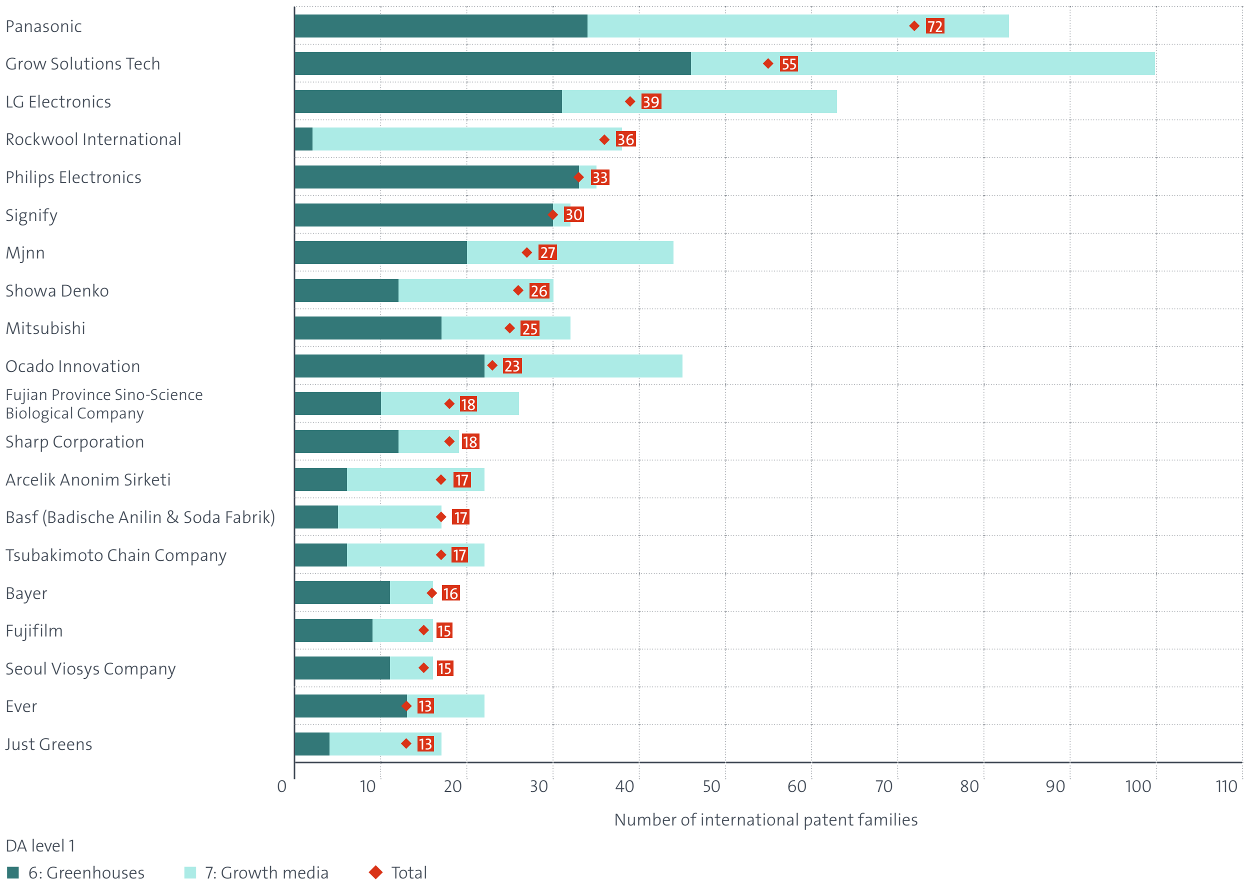
Top applicants in artificial growth conditions (2000–2022)



While the patents of many of the main actors relate to both greenhouses and artificial growth media, those of Philips and Signify specialise more in greenhouses.

Figure 30

Top applicants in artificial growth media (2000–2022)



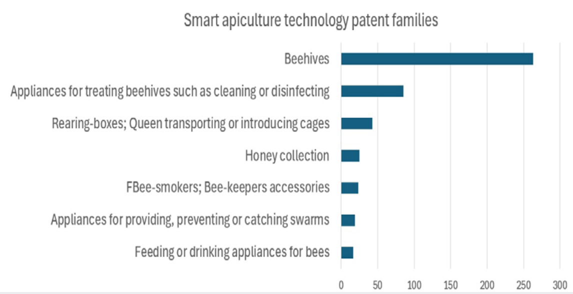
LIVESTOCK MANAGEMENT

6.8. Animal husbandry

Animal husbandry in agriculture refers to the practice of breeding and raising livestock for various purposes, including e.g. for meat, milk, wool and/or labour. It encompasses a wide range of activities aimed at managing and caring for animals to ensure their health, productivity and welfare. This includes selecting and breeding animals with desirable traits, providing appropriate nutrition, housing and healthcare and implementing management practices that optimise growth and reproduction. Animal husbandry is a critical component of agricultural systems, contributing significantly to food production and rural economies. Modern animal husbandry practices focus on enhancing efficiency and productivity whilst minimising environmental impact and ensuring ethical treatment of animals. By integrating traditional knowledge with modern techniques, animal husbandry aims to meet the growing demand for animal products whilst addressing challenges such as climate change, resource scarcity and animal health issues. This encompasses not only technical aspects such as sensing, detection, identification and monitoring activity, the status, position or health of animals and robotic technologies for animal husbandry, but also artificial beehives and honeycombs.

BEES AND WASPS ARE INDISPENSABLE FOR POLLINATION AND PEST CONTROL – ASSISTED AND PROTECTED BY AI

About 75 percent of the world's crops that produce fruits and seeds for human consumption depend, at least in part, on pollinators for sustained production, yield and quality. More than a third of the world's food crops rely on pollinators to reproduce, with honeybees alone pollinating about 75% of the fruits, vegetables and nuts. Wasps, particularly parasitic wasps, are being cultivated and used for pest control. They play a major role in protecting yields from harmful pests by praying on caterpillars, flies, aphids and other insects, helping to keep pest populations at bay.



With so many threats, farmers and beekeepers are looking not only into smart technical solutions to support pollination that is less dependent on insects, but also into technology to support and protect these useful insects so they can continue doing what they have been doing for centuries.

Apiculture (beekeeping) patents are represented in the patent data under a number of different classification codes covering technologies such as beehives, rearing boxes and feeding appliances for bees.

The fact that bees, wasps and bumblebees are suffering and have been dying in droves is a matter of concern for all of us. Colony collapse disorder, harmful viruses, the Varroa mite and bees' sensitivity to environmental conditions and pesticides are all well-documented problems, as is the spread of the Asian hornet (Vespa velutina), which is a significant threat to honeybee colonies in Europe because it preys on bees and can wipe out complete hives in very little time.

Although the number of "smart" patents is still rather limited, below is a list of interesting technologies that might mitigate the problems mentioned above, be it by protecting these useful insects or even replacing them. A number of AI solutions make use of detection systems to automate pest identification.

Cameras and sensors are often used to monitor and collect data such as heat, movement, location and sound. Machine-learning algorithms analyse these data points against massive datasets, enabling AI to not only identify pests and recommend treatment plans, but also optimise pollination processes.

Patent	Title and short description	Applicant	Pub. year
EP4417045	APPARATUS FOR IDENTIFYING POLLEN THROUGH LEARNING: accurately identifies the presence and quantity of pollen on bees by utilising a deep learning model trained on the characteristics of the morphology and colour of bees and pollen.	Farmconnect (KR)	2024
EP2793565	IMPROVEMENTS TO APICULTURE: beehives connected centrally with a control circuit that allows honey to be automatically extracted and volumes being monitored via honey sensors. Video cameras are also fitted in the hives to generate a data stream with images of the comb surface and bee activity in real time.	Flowbee Australia (AU)	2013
WO2021202065	SYSTEM FOR BEEHIVE HEALTH AND ACTIVITY MONITORING: monitoring the health of beehives using a sensor bar and base unit to provide machine-learning models, also using the interior and exterior sensor data and soundtracks combined into a cloud-based monitoring, tracking and diagnostics system on the health of the colony.	X Dev Llc (US)	2021
WO2022120496	SYSTEM AND METHOD FOR MONITORING, IDENTIFYING AND RECORDING BEEHIVE STATUS: monitor beehive phenomenon by fusing sensor data from inside a beehive and human collected data from the same beehive using machine-learning algorithms. Resulting sensor and labelled datasets are then used to train machine-learning algorithms to classify beehive health states using sensor data alone, allowing remote monitoring of hives using in-hive sensors.	Tech Nectar Inc (CA)	2022
EP4276700	TRACKING AND MONITORING BEE POLLINATION EFFICIENCY: computing device for managing honeybee colonies for pollination of crop(s), comprising internal and external sensors to monitor the state of a honeybee colony, indicating pollination effectiveness of the honeybee colony.	Beehero (IL)	2023

Patent	Title and short description	Applicant	Pub. year
EP4403028	APPARATUS FOR TRACKING AND ANALYSING THE TRAJECTORY OF BEES THROUGH LEARNING: tracking and analysing the trajectories of bees, utilising learning data obtained by training a deep-learning model in the morphological structure, colour, and other characteristics of bees so as to track and analyse the trajectories of bees.	Farmconnect (KR)	2024
KR101963648	GREENHOUSE BUMBLE BEE MANAGEMENT SYSTEM AND METHOD BUMBLE BEE BOX: managing greenhouse pollinating bees using an automatic access door with entrance sensor unit which counts pollinating bees during the flowering time.	Korea Inst Sci & Tech(KR)	2019
EP2834047 	SYSTEMS AND METHODS FOR PROVIDING FLEXIBLE ROBOTIC ACTUATORS: essential patent for the production of RoboBees and other insect-inspired robots for potential uses in crop pollination. Although most pollution still takes place via insects, researchers are looking into possible mechanical replacements. The RoboBee, a technological demonstration of technology, does not have a single specific patent in the traditional sense, but rather is a valid illustration on how mimicking nature can solve technical problems.	Harvard College (US)	2015
WO2020074686 	DEVICE FOR REGULATING TEMPERATURE WITHIN A BEEHIVE: system with photovoltaic panel on the roof and shutter/fan to regulate the temperature in a beehive. It may also be used to temporarily heat the beehive to >40°C to eliminate the dreaded Varroa parasite without having to use pesticides.	Beelife Sas (FR)	2020
CN114794021	PARASITIC WASP GROWTH AND BREEDING OPTIMISATION DEVICE BASED ON MAGNETIC BIOLOGICAL EFFECT: comprises an artificial magnetic field processing system, an environmental factor monitoring system, with an automatic feeder steered by machine-learning video and behaviour recognition software collecting data via fisheye cameras	Univ Nanjing Agricultural (CN)	2022
WO2022102911	BEE-BOX-MOUNTABLE HORNET REPELLING DEVICE: detecting a hornet approaching the entrance of a bee box and raising the temperature above a temperature tolerable by the hornet, while closing the entrance of the bee box at the same time. The system is steered by wasp detection modules being cameras and location units that acquire images by monitoring around the hives.	Shin Hyun Ju (KR)	2022
EP3554944	INSECT ELIMINATION SYSTEM AND USE THEREOF: unmanned aerial vehicle (uav) with integrated video, image and locations systems to detect harmful insects and calculate the best elimination start position under the insect to hit the insect with the propellers.	Mu-G Knowledge Management B.v.	2018
EP2745682	HIVE-MOUNTED DISSEMINATOR DEVICE: dissemination of biological control agents through the use of bees.	Biobest Belgium (BE)	2012

6.9. Milking

Milking is a specialised aspect of animal husbandry that involves the extraction of milk from dairy animals – primarily cows, goats and sheep – and which requires specific skills and equipment to ensure efficiency, hygiene and animal welfare. The introduction of robotics in milking has revolutionised this aspect of animal husbandry by enhancing efficiency and precision. Robotic milking systems, also known as automatic milking systems (AMS), enable automated milking of dairy animals without the need for constant human intervention. These systems use advanced sensors and software to identify individual animals, attach milking cups and monitor milk yield and quality in real time. Sensors connected to the milking process detect e.g. animal data and diseases (e.g. mastitis) on site, and deliver information for herd management. Robotics in milking not only reduce labour costs and increase productivity, but also improve animal welfare by allowing cows to be milked at their own comfort and frequency.

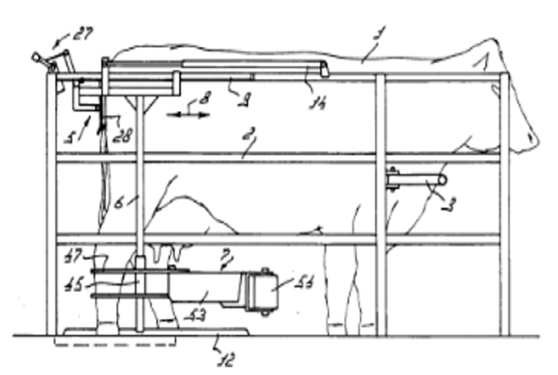
CASE STUDY: LELY MILKING ROBOT "ASTRONAUT"

Lely is a European company that has a history of innovation in agriculture that dates back to the first half of the 20th century. This case study focuses on one of their more recent innovative solutions for automated dairy farming.

An automated system designed by Alexander van der Lely and Karel van den Berg allows cows to choose when it is time to be milked. The invention brings benefits for both the cows and farmers. It reduces stress for the cows, enhances milk production and provides farmers with the information they need to manage the milking process and the herd.

The system that Lely developed and patented, the Lely Astronaut, allows the individual cows to enter the milking machine untethered. Once inside the milking machine, the cow can be identified using a collar sensor, and a robotic arm places the milking cups automatically. A further sensor tracks the cow's position as it moves around within the milking machine, enabling the robotic arm to reposition accordingly. The process management system furthermore monitors each individual cow's milk production data and feeding through the integrated feeding device. This data not only provides key monitoring information for the farmer, but also feedback into the process control system.

The Astronaut allows milking to become a natural part of the cows' day. The benefit to the farmer is that milk production is increased, as the system enables more cows to be milked. It is estimated that a farm with 120 cows could yield one extra litre per cow per day in production capacity when milking is done twice a day using the Astronaut versus conventional methods.



The first two patent applications were filed by LELY NV in 1986, and the invention was brought to market in 1994. Today, around 30 000 Astronauts are used on farms around the world.

Statistics on digital technologies in livestock management

Figure 31 shows the filing trends in 8) Animal husbandry and 9) Milking.

Figure 31

Trend in livestock management

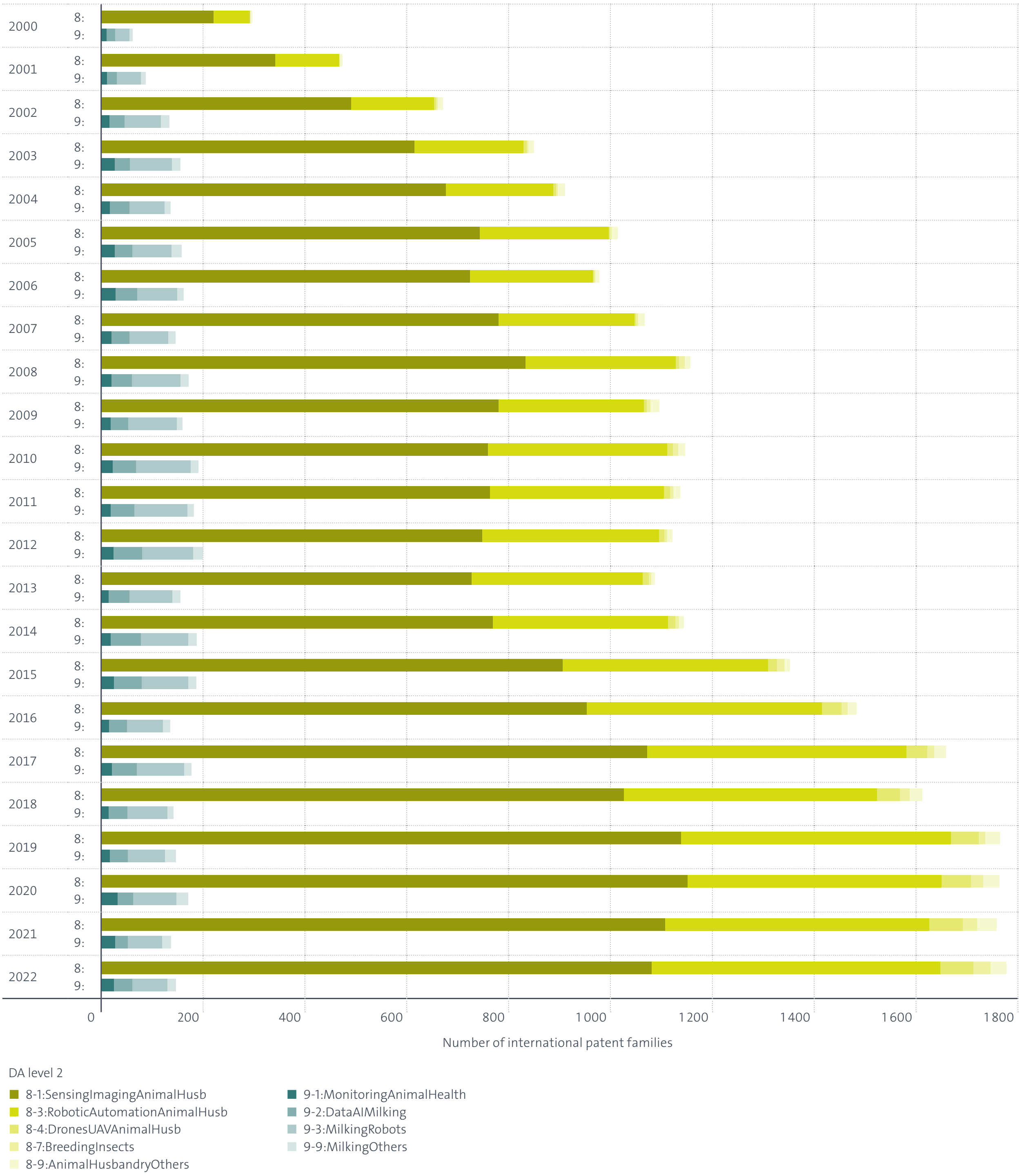


Figure 32

Top applicant countries in livestock management (2000–2022)

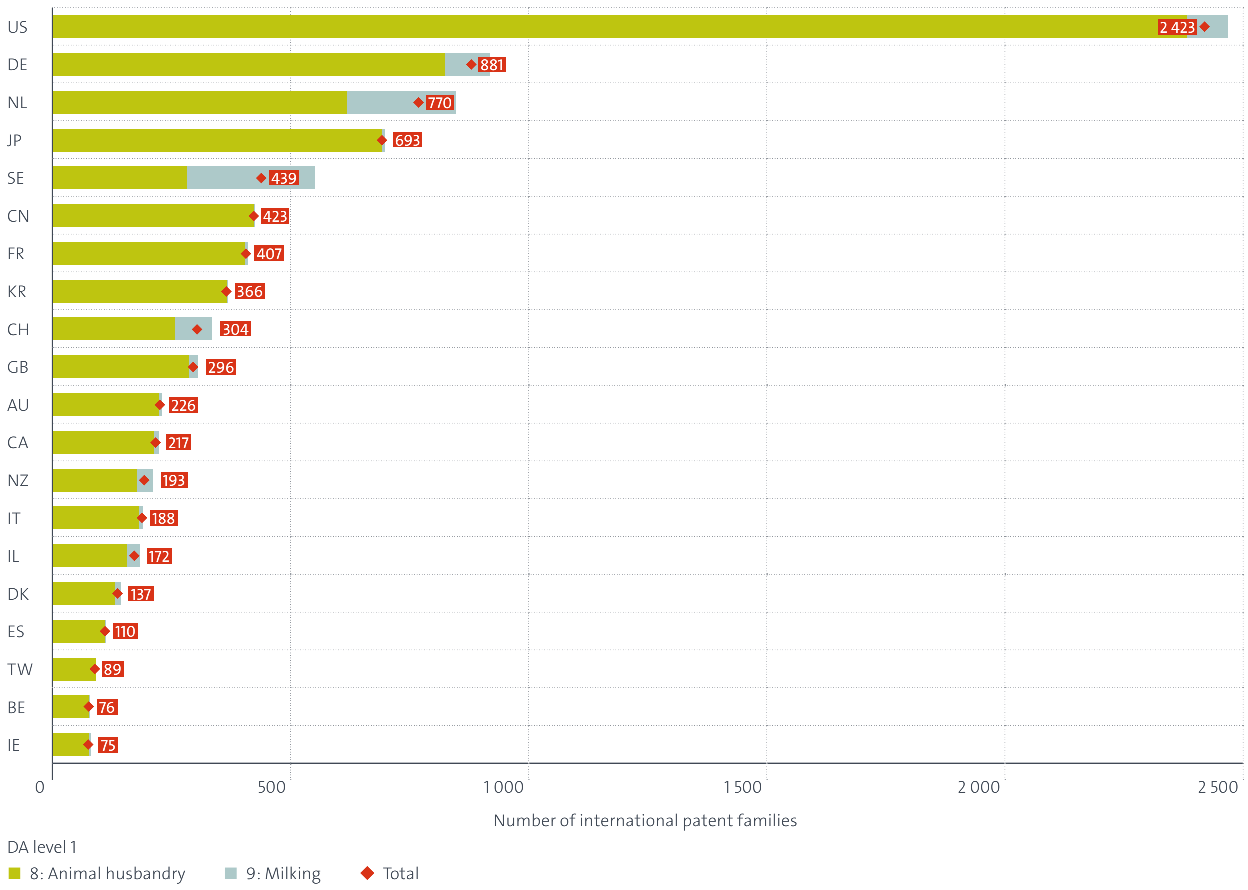
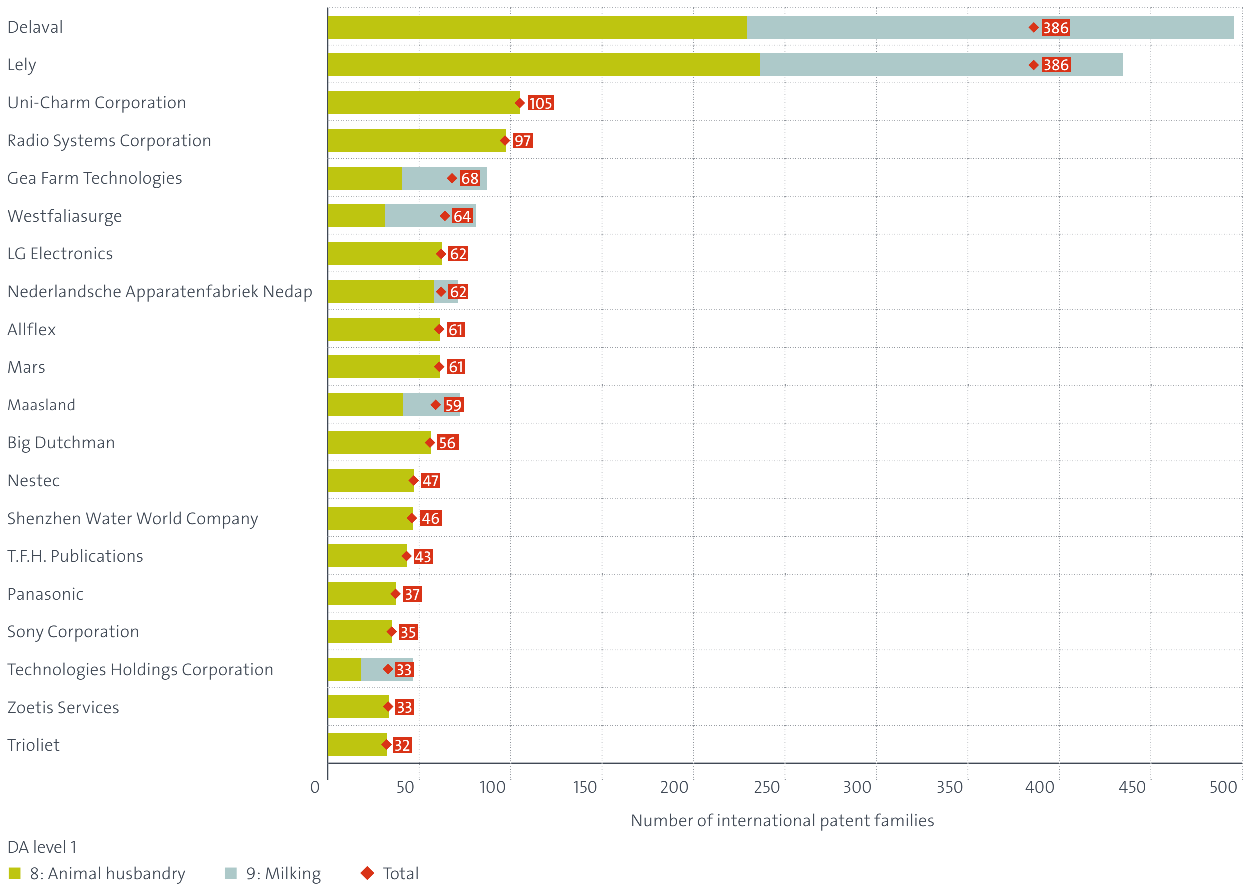


Figure 33

Top applicants in livestock management (2000-2022)



SUPPORTING TECHNOLOGIES

6.10. Watering

Smart watering in agriculture refers to the use of advanced technologies and data-driven approaches to optimise irrigation practices, ensuring efficient water use and enhancing crop growth. This involves the integration of sensors, weather forecasts and automated irrigation systems to monitor soil moisture levels, weather conditions and plant water needs in real time as well as the provision of precision watering devices such as GPS-based systems or watering robots. By delivering precise amounts of water only when and where it is needed, smart watering reduces water waste, lowers costs and supports sustainable farming practices, whilst also improving crop yields and resilience to climate variability. Thanks to precision irrigation, water savings of up to 44% have been reported (Papadopoulos et al, 2024).

6.11. Influencing weather conditions

Intentional manipulation of weather conditions in agriculture, often referred to as weather modification, involves techniques aimed at altering atmospheric conditions to benefit agricultural activities. The impact of these practices is significant, as they can help mitigate the adverse effects of climate variability and extreme weather events. The use of AI algorithms to optimise environmental parameters and drones for artificial rainmaking and cloud seeding has greatly increased technical innovation in this area of agriculture.

6.12. Pest control

Pest control in agriculture refers to reducing crop losses due to pests and diseases, increasing food production, minimising chemical usage, ensuring safer food and preserving ecosystems. Effective pest control strategies include the use of chemical pesticides, biological control agents like beneficial insects, cultural practices such as crop rotation, and integrated pest management (IPM) approaches that combine multiple methods for sustainable results. Digital advances in pest control cover GPS-guided sprayers that minimise pesticide use while maximising its effectiveness, autonomous drones and land robots for targeted pesticide application as well as image recognition algorithms to detect and classify pests using drone- or sensor-captured data. It has been estimated that, compared with conventional application, variable-rate application can achieve average pesticide (cost) reductions of anywhere from 60 to 67% (Idier, 2024).

Statistics on digital technologies in supporting technologies
Figure 34 shows the trend in 10 Watering, 11 Influencing of weather and 12 Pest control.

Figure 34

Trend in supporting technologies

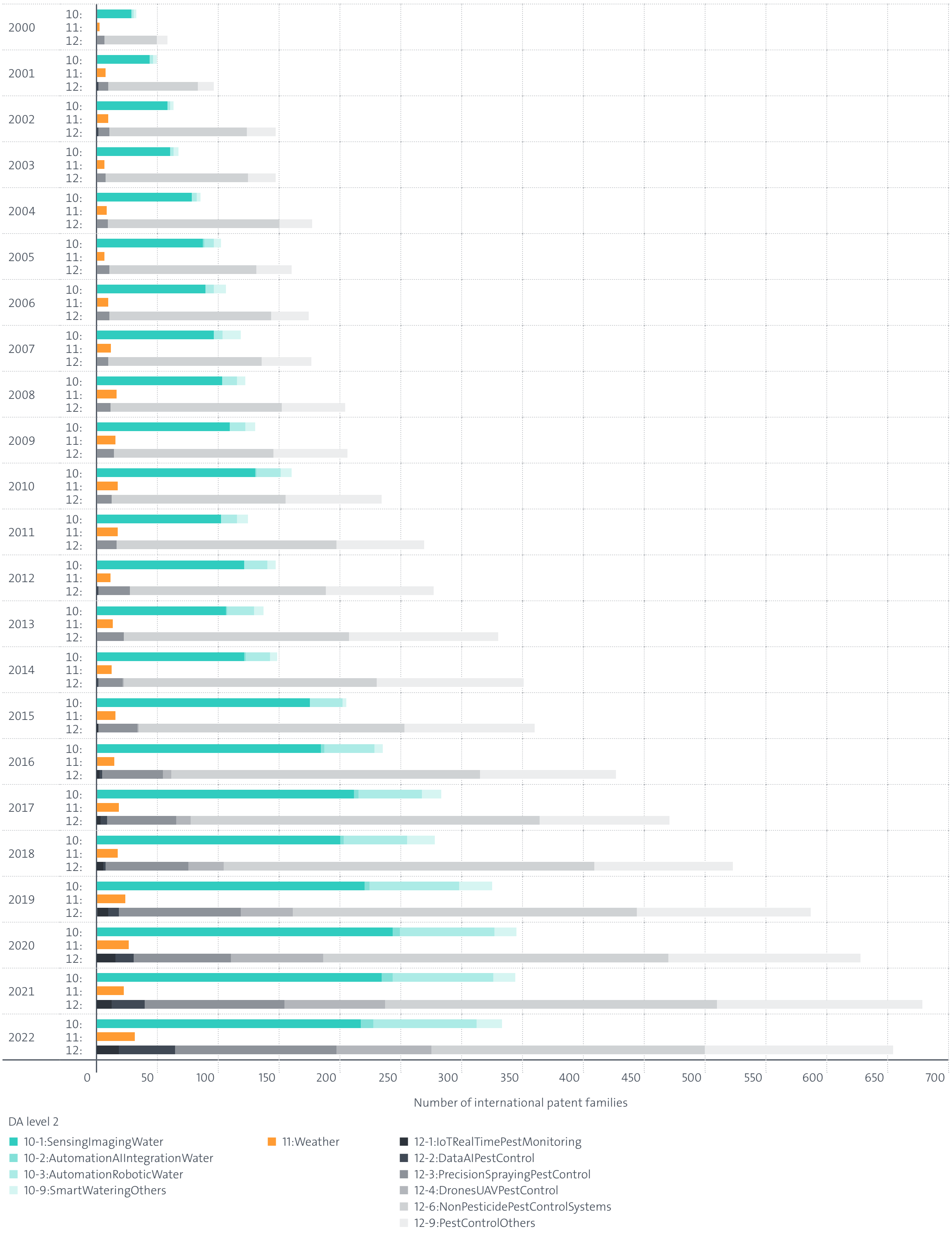


Figure 35

Top applicant countries supporting technologies (2000–2022)

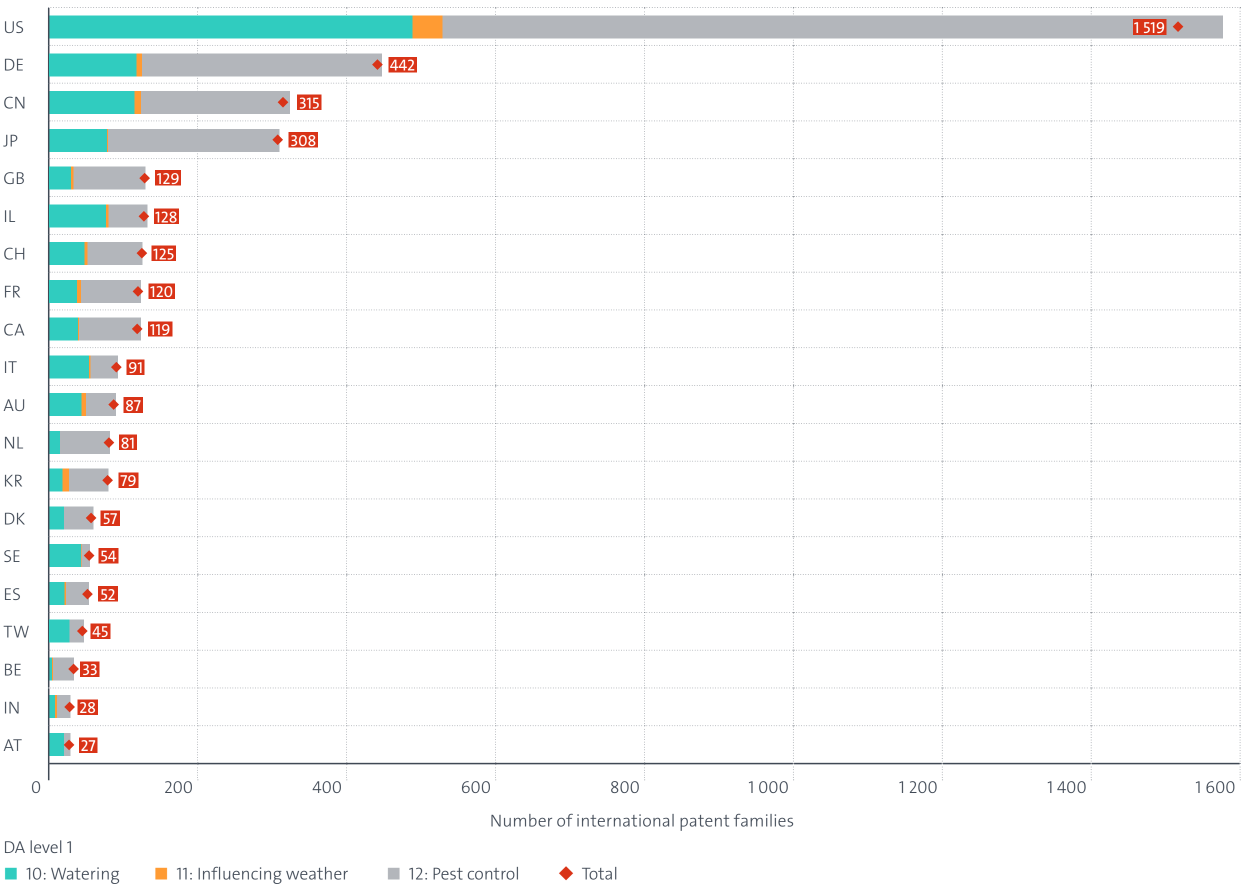
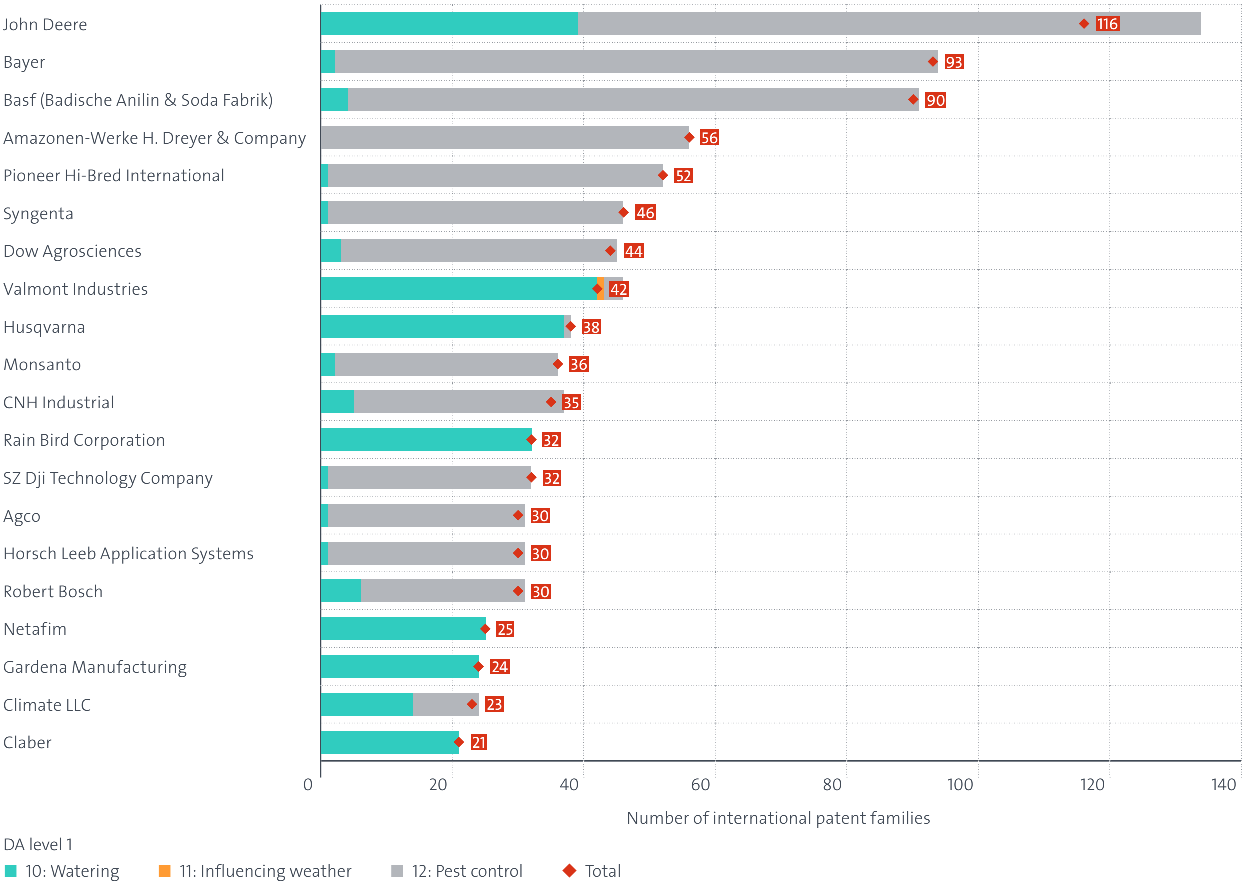


Figure 36

Top applicants in supporting technologies (2000–2022)



Here we see a more mixed picture of top applicants, reflecting the inhomogeneity of this area cluster. It is a mix of classical agri-tech giants such as John Deere and Amazonen-Werke with large established pest control companies, as well as companies specialising in watering.

7. Conclusions and outlook

This report reveals a transformative trajectory for digital agriculture that is crucial for meeting the global challenges of food security, sustainability and climate resilience. Since 2012, digital agriculture has experienced a remarkable acceleration in innovation, with a compound annual growth rate (CAGR) of 9.4%, outpacing the average growth of other technical fields by a factor of three. This surge reflects intensified investment in research and development efforts which has been mainly driven by a shift from individual inventors to large-scale corporate innovation. Corporate entities' overall share of relevant patent applications rose from to 88% in 2022.

In terms of patterns of innovation across the globe, whilst EPO member states have been the main originators of international patent families in digital agriculture, other regions are emerging rapidly. Asia and Latin America have exhibited CAGRs of 13.1 and 10.8% respectively, with Asia having overtaken North America in absolute numbers in 2020. This diffusion of innovation origins highlights the need for agricultural solutions fit to meet diverse regional needs.

Amongst the range of digital agriculture clusters, (open-field) plant agriculture has seen the largest share of more recent innovation, with a seven-fold increase in patent families since 2000 and a 13% CAGR from 2012 to 2022. This area cluster's growth has driven much of the overall expansion in digital agriculture, supported by foundational technologies such as imaging and sensing. These technologies deliver the precise data essential for control of automation in spraying, harvesting and other critical processes. The rise of artificial intelligence (AI) and drone technologies since the late 2010s is a further growth factor which has brought enhanced data analytics and operational efficiency.

Leading agricultural machinery manufacturers such as John Deere, CNH International, Kubota and Claas are at the forefront of innovation, followed by companies specialising in animal husbandry and smart greenhouse technologies. This corporate concentration highlights the integration of digital tools across diverse agricultural domains, from crop production to livestock management and controlled-environment agriculture.

The imperative for digital agriculture is directly linked to the pressing need to ensure food security for a projected global population exceeding ten billion by 2050. It is estimated that achieving this goal will require roughly doubling agricultural output from today's levels. This will most likely be achieved through intensification and technological improvements rather than by expanding the amount of land used for agriculture. Digital agriculture facilitates this goal whilst reducing environmental impacts such as soil erosion, biodiversity loss and pollution.

Moreover, the sector's technological transformation away from intensive manual labour through mechanisation to AI-driven connected robotics reflects a continuous evolution toward smarter, data-driven decision-making. This transformation is vital for meeting environmental challenges and addressing socio-economic pressures to ensure the required agricultural productivity whilst promoting sustainability and animal welfare.

ANNEX

8. Methodology

8.1. Using patent information

In essence, patents are legal rights that give patent holders the right to exclude others from commercially exploiting the patented invention. They can be valid in the country or region for which they are granted. Patents can help attract investment, secure licensing agreements and provide market exclusivity.

Accordingly, patent systems promote innovation, technology diffusion and economic growth by allowing patent holders to secure investment in research and development, education and infrastructure, whilst requiring them to make their inventions available to the public. The publication of patent applications is a key feature of the patent system, and creates a rich repository of technical and other content known as patent information. Patent information enables other inventors, researchers, engineers, managers, investors and policymakers to build on existing inventions, to access knowledge often unavailable elsewhere and to analyse trends in innovation and market developments. As a result, patent information is at the heart of any patent system.

Patent information enables inventors to build on the published inventions of others and thus avoid the mistake of investing in the development of a solution to a problem that has already been solved and potentially protected by others. Patent information contains a wealth of technical and other information, much of which cannot be found in any other source. As the leading provider of high-quality patent information worldwide, the EPO has collected, standardised and harmonised information on more than 150 million patent documents from over 100 countries in its databases, containing more than one billion records. These databases are growing by tens of millions of records every year.

Patent information from these databases is available through numerous free and commercial patent information services provided by patent offices and service providers around the world. The information can be used for a variety of analytical purposes, such as exploring technical trends and the filing strategies of applicants, or calculating indicators of innovation activity, commercialisation and knowledge transfer.

8.2. Methodology of this EPO technology insight report

This EPO technology insight report aims to provide useful insights into specific technologies related to digital agriculture.

The report is based on publicly available patent information and provides an overview of the relevant technologies.

The methodology of this report is based on a three-step process:

Step 1: Create and tune a basic dataset
A basic dataset is created, usually by using various custom search concepts such as building on keywords and on patent classification symbols for specific technologies.
It is usually necessary to remove unrelated patent documents, either automatically or manually, in order to improve the quality of the basic dataset.
One important aspect to improving the quality of the final graphs is a thorough applicant name harmonisation process. Patent data coming from over 100 different patent offices result in many different spelling variations, not only because of spelling errors and different character codes, but also because of slight variations in the legal entity that filed patents in a specific country. As an example: CNH Industrial (NYSE: CNH --> merger of Case and New Holland) has filed patents under the names: CNH INDUSTRIAL AMERICA, CNH (CASE NEW HOLLAND) BELGIUM, 凯斯纽荷兰(中国)管理有限公司, CNH INDUSTRIAL (HARBIN) CO., LTD., CASE NEW HOLLAND (CHINA) MANAGEMENT COMPANY, and other variations. To allow comparison of large companies, we have grouped all these entities under "CNH" to ease visualisation. Whilst such name harmonisation and grouping is done in various cycles using different methods and data sources, it starts with the PATSTAT standardised name. A final grouping on a set of 135 000 patent applicants was done using various cluster functions and manual tweaking in OpenRefine.
We did not explicitly take mergers and acquisitions into account.

The creation of a meaningful and clean basic dataset is critical to providing a reliable basis for sound patent analysis in step 2.

Step 2: Patent data analysis
In this second step, analyses are performed on the basic dataset by aggregating the data to patent families as a representative of inventions, generating descriptive statistics, testing hypotheses and identifying patterns in the data, etc.

Step 3: Further processing and visualisation
In this third step, the data are further analysed and processed and the results visualised and summarised.

Important observations to bear in mind when reading the charts.

If not otherwise specified, dates and years refer to earliest publication date (or year) of a given patent family. Double counting of patent families does occur in some cases. For example, Figure 5 shows both utility models (UM) and patents of inventions (PI). A patent family can include both forms of protection and will, as such, be part of both series in the graph. Patent families can cover multiple technological aspects. For example a drone (UAV) has a sensor, a camera and a liquid sprayer and will therefore belong to the respective relevant technology areas (see Figure 37). An application can have multiple applicants belonging to different sectors (see, for example, Figure 7). In the case of a university being co-applicant with a company and located in different countries, the family will be assigned to each respective applicant, sector and country.

Where relevant for the graphs, and to avoid companies appearing multiple times in rankings, different entities of a company located in different countries have been replenished and grouped to what the authors considered the main entity location. For example: CNH was assigned [NL] because that is where it has been incorporated, even though it has filed patents from over 20 CNH country locations (US, CA and BE being the largest ones). For John Deere [US], the indicated country is where it is headquartered (also largest filer), but the company also files patents via [FI] and [DE] entities[6].

8.3. Patent retrieval

For this report, EPO experts developed specific search strategies to identify patent documents related to specific technologies in digital agriculture. The search strategies combine relevant keywords and patent classification symbols (see Box 4: Technologies for digital agriculture and patent classification schemes). The search strategies were optimised for the EPO's in-house search tools (see Section 1.4, Annex). The patent classification symbols and keywords used for this report efficiently capture documents with a focus on digital agriculture.

The volume of search results obtained using the search methodology will increase over time due to the dynamic nature of the technical field and the patent databases, as patent documents related to digital agriculture are continuously added to these databases. Accordingly, we intend to update this report in the future, which would also give us an opportunity to review the latest patent trends related to digital agriculture.

Patent offices assign patent classification symbols to categorise the technical subject-matter of a patent or utility model. Patent classification symbols are defined as part of what are known as patent classification systems. There are various patent classification systems used today by national, regional and international patent offices.

Two patent classification systems are of particular importance.

The **International Patent Classification (IPC)** system is a hierarchical patent classification system used by the EPO and more than 100 patent offices on every continent. It breaks technologies down into eight sections with several hierarchical sub-levels. The IPC system has approximately 75 000 symbols, and is updated on an annual basis. Further information about the IPC system is available on a dedicated website.

The **Cooperative Patent Classification (CPC)** system builds on the IPC system and provides a more granular and detailed classification structure. The CPC system has more than 250 000 symbols and is updated four times a year. It is used by more than 30 patent offices worldwide, including the EPO. Further information about the CPC system is available on the CPC website.

IPC and CPC classification symbols can be used to quickly retrieve patent documents that have been assigned to a specific technology. Classification symbols are frequently

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[6] Link in Espacenet illustrating this for John Deere in Finland (FI) and Germany (DE).

used in search interfaces such as the EPO's free search interface Espacenet, available on the EPO website.

For the purposes of this study, sub-divisions in the IPC and the CPC systems were used and combined with other search terms to restrict the resulting dataset to patent documents closely related to digital agriculture. The following table shows a selection of the IPC and CPC symbols used:

Symbol	**Description**
A01	Agriculture; forestry; animal husbandry; hunting; trapping; fishing
A01B	Soil working in agriculture or forestry; parts, details, or accessories of agricultural machines or implements, in general
A01B63/1115	Lifting or adjusting devices or arrangements for agricultural machines or implements | For implements mounted on tractors | Operated by hydraulic or pneumatic means | Regulating working depth of implements | Using a mechanical ground contact sensor
A01B63/1117	Lifting or adjusting devices or arrangements for agricultural machines or implements | For implements mounted on tractors | Operated by hydraulic or pneumatic means | Regulating working depth of implements | Using a hitch position sensor
A01B76/00	Parts, details or accessories of agricultural machines or implements, not provided for in groups A01B51/00 - A01B75/00
A01B79/00	Methods for working soil
A01B79/005	Methods for working soil | Precision agriculture
A01C	Planting; sowing; fertilising
A01C11/00	Transplanting machines
A01C13/00	Machines or apparatus for consolidating soil around plants
A01C14/00	Methods or apparatus for planting not provided for in other groups of this subclass
A01C21/002	Methods of fertilising , sowing or planting | apparatus for sowing fertiliser; fertiliser drill
A01C3/023	Treating manure; manuring | Storage places for manure, e.g. cisterns for liquid manure; installations for fermenting manure | Digesters
A01C3/028	Treating manure; manuring | Storage places for manure, e.g. cisterns for liquid manure; installations for fermenting manure | Covers, roofs or other structures for covering manure storage places
A01C7/00	Sowing
A01C7/006	Sowing | Minimum till seeding
A01C7/105	Sowing | Broadcast seeders; seeders depositing seeds in rows | Devices for adjusting the seed-box ; regulation of machines for depositing quantities at intervals | Regulating or controlling the seed rate | Seed sensors
A01C9/00	Potato planters
A01D	Harvesting; mowing
A01D41/00	Combines, i.e. harvesters or mowers combined with threshing devices
A01D41/127	Combines, i.e. harvesters or mowers combined with threshing devices | Details of combines | Control or measuring arrangements specially adapted for combines
A01D41/1278	Combines, i.e. harvesters or mowers combined with threshing devices | Details of combines | Control or measuring arrangements specially adapted for combines | For automatic steering
A01D45/00	Harvesting of standing crops
A01D46/00	Picking of fruits, vegetables, hops, or the like; devices for shaking trees or shrubs
A01D51/00	Apparatus for gathering together crops spread on the soil, e.g. apples, beets, nuts, potatoes , cotton, cane sugar
A01F	Processing of harvested produce; hay or straw presses; devices for storing agricultural or horticultural produce
A01F2015/076	Baling presses for straw, hay or the like | Rotobalers, i.e. machines for forming cylindrical bales by winding and pressing | Wrapping devices | Wrapping device incorporating sensors
A01F25/00	Storing agricultural or horticultural produce; hanging-up harvested fruit
A01G15/00	Devices or methods for influencing weather conditions
A01G23/00	Forestry
A01G23/10	Forestry | Tapping of tree-juices, e.g. caoutchouc, gum

Symbol	Description
A01G24/00	Growth substrates; culture media; apparatus or methods therefor
A01G25/00	Watering gardens, fields, sports grounds or the like
A01G25/16	Watering gardens, fields, sports grounds or the like | Control of watering
A01G25/167	Watering gardens, fields, sports grounds or the like | Control of watering | Control by humidity of the soil itself or of devices simulating soil or of the atmosphere; soil humidity sensors
A01G31/00	Soilless cultivation, e.g. hydroponics
A01G31/02	Soilless cultivation, e.g. hydroponics | Special apparatus therefor
A01G7/04	Botany in general | Electric or magnetic or acoustic treatment of plants for promoting growth
A01G7/045	Botany in general | Electric or magnetic or acoustic treatment of plants for promoting growth | With electric lighting
A01G9/029	Cultivation in receptacles, forcing-frames or greenhouses ; edging for beds, lawn or the like | Receptacles, e.g. flower-pots or boxes ; glasses for cultivating flowers | Receptacles for seedlings
A01G9/0291	Cultivation in receptacles, forcing-frames or greenhouses ; edging for beds, lawn or the like | Receptacles, e.g. flower-pots or boxes ; glasses for cultivating flowers | Receptacles for seedlings | Planting receptacles specially adapted for remaining in the soil after planting
A01G9/14	Cultivation in receptacles, forcing-frames or greenhouses ; edging for beds, lawn or the like | Greenhouses
A01G9/24	Cultivation in receptacles, forcing-frames or greenhouses ; edging for beds, lawn or the like | Devices or systems for heating, ventilating, regulating temperature, illuminating, or watering, in greenhouses, forcing-frames, or the like
A01G9/243	Cultivation in receptacles, forcing-frames or greenhouses ; edging for beds, lawn or the like | Devices or systems for heating, ventilating, regulating temperature , illuminating, or watering, in greenhouses, forcing-frames, or the like | Collecting solar energy
A01G9/249	Cultivation in receptacles, forcing-frames or greenhouses ; edging for beds, lawn or the like | Devices or systems for heating, ventilating, regulating temperature , illuminating, or watering, in greenhouses, forcing-frames, or the like | Lighting means
A01J	Manufacture of dairy products
A01J1/00	Devices or accessories for milking by hand
A01J3/00	Milking with catheters
A01J5/01	Milking machines or devices | Monitoring milking processes; control or regulation of milking machines | Milkmeters; milk flow sensing devices
A01J5/013	Milking machines or devices | On-site detection of mastitis in milk
A01J5/017	Milking machines or devices | Automatic attaching or detaching of clusters
A01J7/00	Accessories for milking machines or devices
A01K	Animal husbandry; aviculture; apiculture; pisciculture; fishing; rearing or breeding animals, not otherwise provided for; new breeds of animals
A01K1/00	Housing animals; equipment therefor
A01K1/01	Housing animals; equipment therefor | Removal of dung or urine, e.g. from stables
A01K1/015	Housing animals; equipment therefor | Floor coverings, e.g. bedding-down sheets ; stable floors
A01K1/0209	Housing animals; equipment therefor | Pigsties; dog-kennels; rabbit-hutches or the like | Feeding pens for pigs or cattle
A01K1/10	Housing animals; equipment therefor | Feed racks
A01K13/00	Devices for grooming or caring of animals, e.g. curry-combs; fetlock rings; tail-holders ; devices for preventing crib-biting; washing devices; protection against weather conditions or insects
A01K15/00	Devices for taming animals, e.g. nose-rings or hobbles; devices for overturning animals in general; training or exercising equipment; covering boxes
A01K29/005	Other apparatus for animal husbandry | Monitoring or measuring activity, e.g. detecting heat or mating
A01K31/00	Housing birds
A01K31/02	Housing birds | Door appliances; automatic door-openers
A01K35/00	Marking poultry or other birds
A01K41/00	Incubators for poultry
A01K43/00	Testing, sorting or cleaning eggs ; conveying devices ; pick-up devices
A01K47/02	Beehives | Construction or arrangement of frames for honeycombs
A01K47/04	Beehives | Artificial honeycombs
A01K5/00	Feeding devices for stock or game ; feeding wagons; feeding stacks

Symbol	Description
A01K67/36	Rearing or breeding animals, not otherwise provided for; new or modified breeds of animals | Rearing or breeding invertebrates | Insects | Industrial rearing of insects, e.g. insect farms
A01M	Catching, trapping or scaring of animals ; apparatus for the destruction of noxious animals or noxious plants
A01M1/02	Stationary means for catching or killing insects | With devices or substances, e.g. food, pheronones attracting the insects
A01M1/023	Stationary means for catching or killing insects | With devices or substances, e.g. food, pheronones attracting the insects | Attracting insects by the simulation of a living being, i.e. emission of carbon dioxide, heat, sound waves or vibrations
A01M1/026	Stationary means for catching or killing insects | With devices or substances, e.g. food, pheronones attracting the insects | Combined with devices for monitoring insect presence, e.g. termites
A01M1/145	Stationary means for catching or killing insects | Catching by adhesive surfaces | Attracting and catching insects using combined illumination or colours and adhesive surfaces
A01M7/00	Special adaptations or arrangements of liquid-spraying apparatus for purposes covered by this subclass
A01M7/0089	Special adaptations or arrangements of liquid-spraying apparatus for purposes covered by this subclass | Regulating or controlling systems
B60W2420/403	Indexing codes relating to the type of sensors based on the principle of their operation | Photo, light or radio wave sensitive means, e.g. infrared sensors | Image sensing, e.g. optical camera
B64U	Unmanned aerial vehicles [UAV]; equipment therefor
C02F2101/00	Nature of the contaminant
C05F17/80	Preparation of fertilisers characterised by biological or biochemical treatment steps, e.g. Composting or fermentation | Separation, elimination or disposal of harmful substances during the treatment
G01C21/26	Navigation; navigational instruments not provided for in groups G01C1/00 - G01C19/00 | Specially adapted for navigation in a road network
G05B	Control or regulating systems in general; functional elements of such systems; monitoring or testing arrangements for such systems or elements
G05D	Systems for controlling or regulating non-electric variables
G05D23/00	Control of temperature
G05D7/0617	Control of flow | Characterised by the use of electric means | Specially adapted for fluid materials
G06	Computing; calculating or counting
G06N20	Machine learning
G06N5/02	Computing arrangements using knowledge-based models | Knowledge representation; symbolic representation
G06Q	Information and communication technology [ICT] specially adapted for administrative, commercial, financial, managerial or supervisory purposes; systems or methods specially adapted for administrative, commercial, financial, managerial or supervisory purposes, not otherwise provided for
G06Q50/02	Information and communication technology [ICT] specially adapted for implementation of business processes of specific business sectors, e.g. utilities or tourism | Agriculture; fishing; forestry; mining
G06T2207/10032	Indexing scheme for image analysis or image enhancement | Image acquisition modality | Satellite or aerial image; remote sensing
G06T2207/30188	Indexing scheme for image analysis or image enhancement | Subject of image; context of image processing | Earth observation | Vegetation; agriculture
G06V10/70	Arrangements for image or video recognition or understanding | Using pattern recognition or machine learning
G06V20/188	Scenes; scene-specific elements | Terrestrial scenes | Vegetation
G16Y10/05	Economic sectors | Agriculture
H04L	Transmission of digital information, e.g. telegraphic communication
Y02A40/20	Adaptation technologies in agriculture, forestry, livestock or agroalimentary production | In agriculture | Fertilizers of biological origin, e.g. guano or fertilizers made from animal corpses
Y02P60/12	Technologies relating to agriculture, livestock or agroalimentary industries | Using renewable energies, e.g. solar water pumping
Y02P60/14	Technologies relating to agriculture, livestock or agroalimentary industries | Measures for saving energy, e.g. in green houses
Y02P60/20	Technologies relating to agriculture, livestock or agroalimentary industries | Reduction of greenhouse gas [GHG] emissions in agriculture, e.g. CO2
Y02P60/52	Technologies relating to agriculture, livestock or agroalimentary industries | Livestock or poultry management | Use of renewable energies

8.4. Data sources and tools used

The quality of patent data analysis largely depends on the completeness, correctness and timely availability of relevant patent information in the patent databases from which the basic dataset for the subsequent analysis is extracted.

It is not possible to guarantee the absolute completeness of the relevant patent information since not all data are available from all patent offices. However, there are several patent databases with very good or excellent coverage of patent information from the main patent offices. These patent databases are mostly based on EPO worldwide patent data as a central source of prior art patent information.

EPO worldwide patent data contain bibliographic and other information on more than 150 million patent documents from more than 100 patent authorities on every continent. These data are available via the EPO's patent information products and services, and other major free and commercial patent search interfaces.

Patent searches were carried out for this EPO technology insight report using EPO worldwide patent data from the EPO's internal data platforms and search interfaces such as ANSERA[7] in order to create the basic dataset for subsequent patent analyses.

The resulting basic dataset was combined with value-added data contained from the EPO's PATSTAT product line,[8] which provided the enriched basis for the patent data analysis step and was used for further processing and visualisation of the data.

8.5. Notes on the limits of the study

This report provides a snapshot of specific technologies in the field of digital agriculture taken in the light of patent data.[9] The methodology on which this report is based can be used freely, which means that everyone can adapt the chosen search and analysis approach to their needs, for example to follow trends and developments in other established or emerging technical fields.

This report makes use of publicly available EPO worldwide patent data as well as EPO in-house and publicly available search and analysis tools.

As is the case for many patent analyses, this report is based on specific search strategies combining keywords and patent classification symbols.

For most patent analyses, it is impossible to simultaneously achieve 100% recall, i.e. to retrieve as many relevant documents as possible and 100% precision, which is to exclude as many non-relevant documents as possible. This study is no exception. The search queries chosen to create the basic dataset for the field of digital agriculture were designed to strike a balance between recall and precision in order to provide a meaningful overview of the field.

8.6. Information on non-international patent families

This report centres on published international patent families (IPF) as a metric to assess innovation activity in specific technologies in the field of digital agriculture.

Putting IPFs into context can also be helpful to get a clearer view of local conditions, such as regulatory and legal constraints.

9. Cartography for digital agriculture

The following table presents the first three levels of the digital agriculture hierarchy of the search concepts, indicating the number of IPFs and non-IPFs from digital agriculture.

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[7] See Demey and Golzio (2020) and Scheu et al. (2006)

[8] The Autumn 2024 edition of the PATSTAT product line was used for this report.

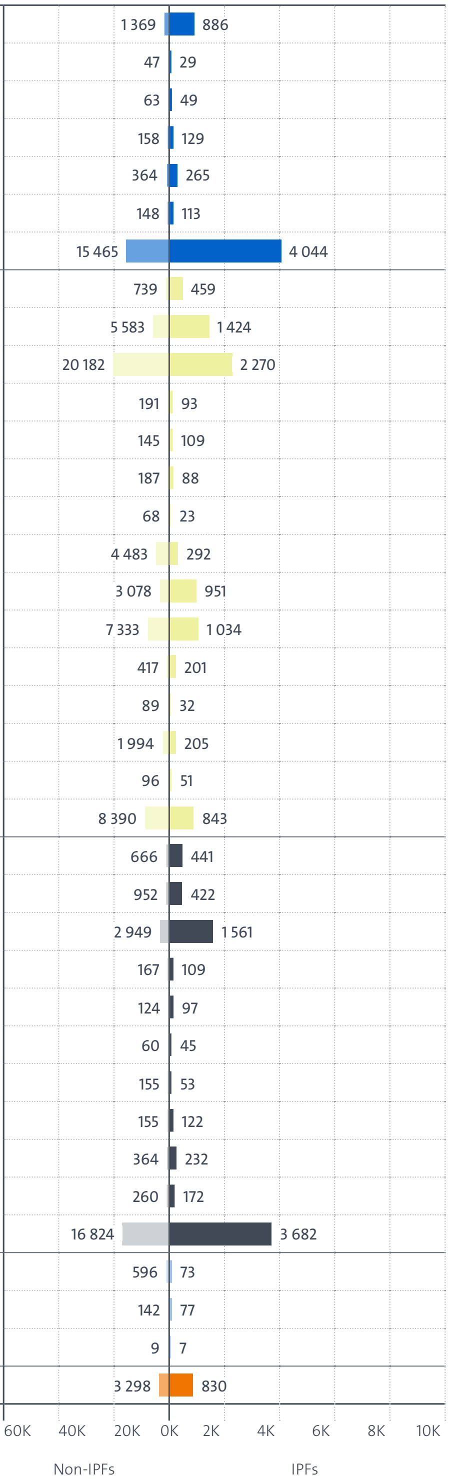
[9] Date of extraction of the basic dataset from the EPO's internal data platform 25.04.2025:. The basic dataset was combined with data from the EPO's PATSTAT product line (Autumn 2024 edition), which used backfile data extracted from the EPO's master documentation database (DOCDB) in Week 31, 2024.

Figure 37

Cartography for digital agriculture (2000–2022)

Technology overview

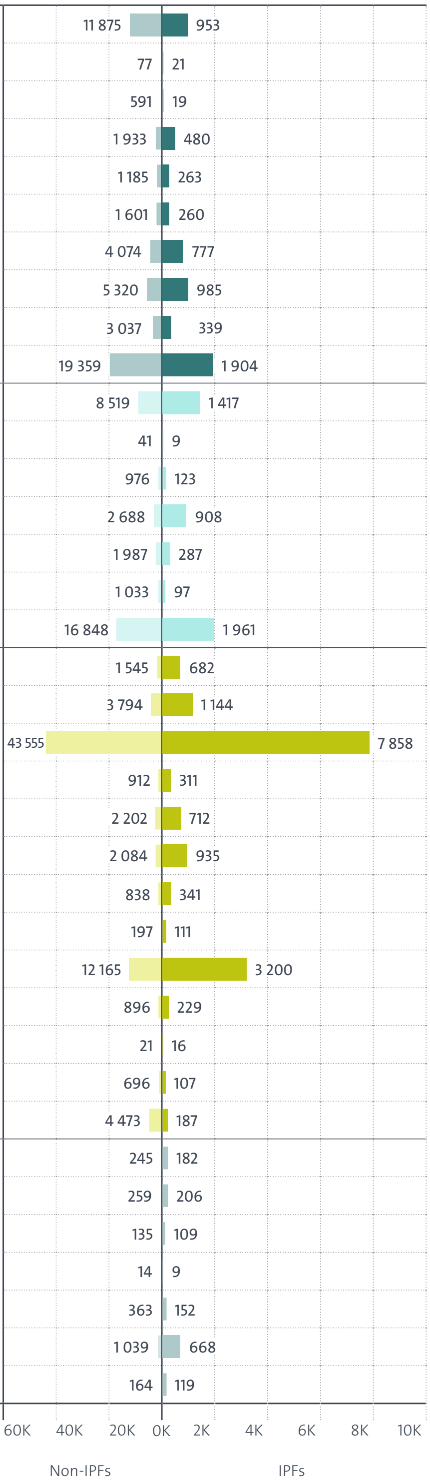
DA level 1	DA level 2	DA level 3	Non-IPFs	IPFs
1: Soil A01B	1-1:SoilConditionSensing		1 369	886
	1-2:DataAISoil	1-2-1:HealthPredictionSoil	47	29
		1-2-2:YieldImprovmtDataAnalyticsManagement	63	49
		1-2-9:DataAISoilOthers	158	129
	1-3:SmartTillageSystems		364	265
	1-4:DronesUAVsSoil		148	113
	1-9:SoilOthers		15 465	4 044
2: Seeding fertilising A01C	2-1:Sensors	2-1-1:SeedingSensorsInMachine	739	459
		2-1-2:FurrowSensors	5 583	1 424
		2-1-9:SensorsOthers	20 182	2 270
	2-2:DataAISeedFert	2-2-1:ImageRecognitionEstimatFertNeeds	191	93
		2-2-2:FertilizationRecommendations	145	109
		2-2-3:SeedingRecommendByYieldForecast	187	88
		2-2-9:DataAISeedFertOthers	68	23
	2-3:LandVehSeedFert	2-3-1:PrecisionSeedingFertilising	4 483	292
		2-3-2:RoboticAutonomSeedFert	3 078	951
		2-3-9:LandVehSeedFertOthers	7 333	1 034
	2-4:DronesUAVSeedFert		417	201
	2-6:EnvAspectsPlantingSeeding	2-6-1:MinimumTillSeeding	89	32
		2-6-2:TreatmentsCropResidues	1 994	205
		2-6-3:AvoidanceCollectionGasPollutants	96	51
	2-9:SeedingFerilizingOthers		8 390	843
3: Harvesting A01D	3-1:SensingImagingHarvest	3-1-1:SpatialYieldMapping	666	441
		3-1-2:MultispectralImagingSystems	952	422
		3-1-9:HarvestSensingOthers	2 949	1 561
	3-2:DataAIHarvest	3-2-1:YieldOptimizationModels	167	109
		3-2-2:PostHarvestQualityControl	124	97
		3-2-3:YieldDataManagementHarvest	60	45
		3-2-4:RemoteMonitoringHarvest	155	53
		3-2-5:LossAnalysisHarvest	155	122
	3-3:PrecisionHarvestingMachines	3-3-1:RoboticBasedHarvesters	364	232
	3-4:DronesUAVHarvest		260	172
	3-9:HarvestOthers		16 824	3 682
4: Spoil reduction A01F	4-1:SortingGrading		596	73
	4-2:DataAISpoilReduction		142	77
	4-6:EnergyEfficiency		9	7
5: Forestry A01G23	5:Forestry		3 298	830



🟦 1: Soil A01B 🟨 2: Seeding fertilising A01C ⬛ 3: Harvesting A01D 🟦 4: Spoil reduction A01F 🟧 5: Forestry A01G23

Technology overview

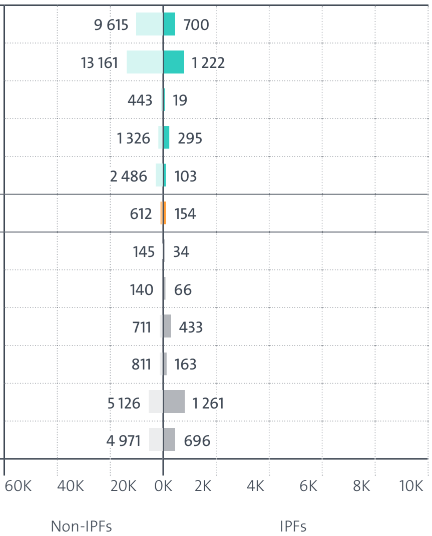
DA level 1	DA level 2	DA level 3	Non-IPFs	IPFs
6: Greenhouses	6-1:GreenhouseSensing		11 875	953
	6-2:DataAIGreenh	6-2-1:AIMachineLearningGreenh	77	21
		6-2-2:RemoteManagementGreenh	591	19
		6-2-3:IrradiationModellingGreenh	1 933	480
		6-2-9:DataAIGreenhOthers	1 185	263
	6-3:RoboticAutomationGreenh	6-3-1:HandlingPrecisitionGreenh	1 601	260
		6-3-9:RoboticGreenhOthers	4 074	777
	6-5:Verticalfarming		5 320	985
	6-6:SolarAndEnergyOptimizationGreenh		3 037	339
	6-9:SmartGreenhousesOthers		19 359	1 904
7: Growth media	7-1:SensingImagingGrMedia		8 519	1 417
	7-2:AutomationAIIntegrationGrMedia		41	9
	7-6:EnvAspectsGrMedia	7-6-1:SymbioticEnvironmentsSoilless	976	123
		7-6-2:HighDensitySoilless	2 688	908
		7-6-3:ReducedSoilSubstrate	1 987	287
		7-6-4:ReducedWaterSubstrate	1 033	97
	7-9:GrowthMediaOthers		16 848	1 961
8: Animal husbandry	8-1:SensingImagingAnimalHusb	8-1-1:AutomaticIdentificationDevices	1 545	682
		8-1-2:MonitoringMeasuringActivity	3 794	1 144
		8-1-9:AnimalSensingOthers	43 555	7 858
	8-3:RoboticAutomationAnimalHusb	8-3-1:RoboticStableMaintenance	912	311
		8-3-2:RoboticFeeding	2 202	712
		8-3-3:AutomatedAnimalCare	2 084	935
		8-3-4:AutomatedAnimalTrainingExercising	838	341
		8-3-5:AutomatedEggHandling	197	111
		8-3-9:RoboticAnimalHusbOthers	12 165	3 200
	8-4:DronesUAVAnimalHusb		896	229
	8-7:BreedingInsects	8-7-1:InsectsConsumption	21	16
		8-7-2:ArtificialHivesHoneycombs	696	107
	8-9:AnimalHusbandryOthers		4 473	187
9: Milking	9-1:MonitoringAnimalHealth		245	182
	9-2:DataAIMilking	9-2-1:AIMachineLearningMilking	259	206
		9-2-2:HerdManagementOrganisation	135	109
		9-2-9:DataAIMilkingOthers	14	9
	9-3:MilkingRobots	9-3-1:RemoteManagement	363	152
		9-3-9:MilkingRobotsOthers	1 039	668
	9-9:MilkingOthers		164	119



🟩 6: Greenhouses 🟦 7: Growth media 🟨 8: Animal husbandry ⬜ 9: Milking

Technology overview

DA level 1	DA level 2	DA level 3	Non-IPFs	IPFs
10: Watering	10-1:SensingImagingWater	10-1-1:SoilMonitoringWater	9 615	700
		10-1-9:SensingWaterOthers	13 161	1 222
	10-2:AutomationAIIntegrationWater		443	19
	10-3:AutomationRoboticWater		1 326	295
	10-9:SmartWateringOthers		2 486	103
11: Influencing weather	11:Weather		612	154
12: Pest control	12-1:IoTRealTimePestMonitoring		145	34
	12-2:DataAIPestControl		140	66
	12-3:PrecisionSprayingPestControl		711	433
	12-4:DronesUAVPestControl		811	163
	12-6:NonPesticidePestControlSystems		5 126	1 261
	12-9:PestControlOthers		4 971	696



🟩 10: Watering 🟧 11: Influencing weather ⬜ 12: Pest control

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