REPORT ON LOW-RISK TECHNOLOGICAL SOLUTIONS IN **THE AGRICULTURAL SECTOR**

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The TechReports are an initiative of the Emerging Technologies Laboratory of the IDB's IT department, known as TechLab, which is in charge of exploring, experimenting, and disseminating information about new technologies to learn about their impact on the IDB Group and the LAC region.

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EXECUTIVE SUMMARY

This report explores the application of emerging technologies in the agricultural sector of Latin America and the Caribbean (LAC), with a specific focus on low-risk solutions tailored to Mexico's agricultural context.

It provides a comprehensive overview of how these innovations are being employed to enhance efficiency and sustainability in agricultural practices, covering topics such as regenerative agriculture, precision agriculture, and agricultural technologies (AgTech). The report concludes with an analysis of the challenges and opportunities faced by farmers during the process of technology adoption.

The document is structured around the different stages of the agricultural cycle: soil preparation, sowing operations, crop protection and management, smart harvesting, and digital harvest management. For each stage, relevant technological solutions are described, such as soil and climate sensors, planting robots, pest management and irrigation systems, as well as digital management platforms. The analysis follows a deductive approach, tailored to the Mexican context, while considering local crop types and farming formats. The most recent available data have been considered, and where Mexico-specific information was unavailable, regional information or insights from similar crops in comparable areas have been included. The report also highlights technologies excluded due to high risks or implementation costs, offering detailed justifications for these exclusions.

DEFINITIONS

Intergovernmental organizations like the United Nations' Food and Agriculture Organization (FAO) advocate for ecological renewal to address climate change and population growth. These entities promote the adoption of precision, digital, and smart farming tools to improve productivity and efficiency in agriculture. However, the deployment of these technologies often occurs without sufficient analysis of the tools, a comprehensive understanding of the local context, or environmental assessments. As a result, the evaluation of potential negative impacts is frequently postponed.

A responsible and integrated approach to these technologies has the potential to transform agricultural management. By offering more accurate crop data, strengthening supply chains, and enhancing product traceability, such integration not only optimizes farming practices but also increases consumer confidence through sustainable and transparent production processes.

REGENERATIVE AGRICULTURE

Regenerative agriculture encompasses a set of agricultural and livestock practices strategically crafted to address soil health, biodiversity, and food security. Its main focus is on restoring the health of degraded soils and promoting biodiversity, thereby enhancing carbon sequestration and optimizing water cycles. Distinguished by its ability to enrich rather than deplete the land, regenerative agriculture provides benefits such as healthier soils and the production of high-quality food. It also contributes to the strengthening of

1. Digital Regenerative Agriculture
2. Digital Regenerative Agriculture
3. What is Regenerative Agriculture? - Regeneration International
4. Francis, C. A., Harwood, R. R., & Parr, J. F. (1986). The potential for regenerative agriculture in the developing world. American Journal of Alternative Agriculture, 1(2), 65–74. https://doi.org/10.1017/S0889189300000904

local communities and regional economies. Currently, an increasing number of farmers are integrating digital technology to streamline these sustainable practices while simultaneously boosting crop profitability.

AGRICULTURAL TECHNOLOGY (AGTECH)

AgTech—short for *"agricultural technology"*—refers to the application of science and knowledge to develop innovations that enhance the sustainability of agri-food systems.

This fast-growing sector focuses on agricultural technologies that improve productivity but also reduce the environmental and social impact of current farming practices.

This sector encompasses a wide range of technologies, including autonomous vehicles, robotics, satellites, drones, mobile devices, and software. In addition, the integration of big data and artificial intelligence solutions has become a critical component of technological advancements in agriculture.[8]

The advantages of employing AgTech are:

- **Cost Reduction.**
  Through efficient resource utilization.
- **Increased Crop Yield.**
  Thanks to improved raw material traceability and quality controls.
- **Enhanced Communication.**
  Enables remote coordination of agricultural activities.
- **Greater Inclusion.**
  Lower barriers to access agricultural insurance, financial services, and technological and market data that favor inclusion.

Due to the pressing need to produce more food to meet future demands , coupled with the environmental challenges our planet faces, innovations in agricultural technology have become imperative.

Latin America and the Caribbean are expected to consolidate their role as global suppliers of agricultural products, with an increase in their net exports between 2020

5. European Academies Science Advisory Council (Ed.). (2022). Regenerative agriculture in Europe: A critical analysis of contributions to European Union farm to fork and biodiversity strategies. EASAC Secretariat, Deutsche Akademie der Naturforscher Leopoldina - German National Academy of Sciences.
6. Science, Technology and Innovation | Food and Agriculture Organization of the UN
7. (Dutia, 2014)
8. Agricultural Technology For New & Advanced Farming Solutions
9. (Shukla et al., 2019)

and 2030. This trend highlights the economic, social, and environmental implications of adopting advanced technologies, reshaping the dynamics of global agricultural trade.

ESTIMATING ROI IN AGTECH

determining its feasibility.[11] However, estimating ROI in agriculture presents unique challenges due to the complexity of crop management, which makes it difficult to condense outcomes into a single metric. This complexity can hinder farmers' ability to make informed investment decisions, particularly when considering new or innovative solutions.[12]

Key challenges in ROI estimation:[13]

Low Traceability.
The complex and uncertain nature of agricultural systems makes it challenging to attribute specific results to each particular investment, complicating impact assessment.

Extended Validation Cycles.
The results of new technologies often depend on full agricultural cycles, which delays the understanding of their effectiveness until after harvest.

Lack of knowledge.
Potential users and beneficiaries of agricultural technology solutions are often unaware of them.

Resource Constraints.
Farmers, frequently operating with limited resources, tend to favor safe, traditional strategies over the perceived risks of adopting new technologies, which can slow innovation.

PRECISION AGRICULTURE (PA)

Precision agriculture is a management strategy that employs advanced technologies and specific principles to address spatial and temporal variability in all aspects of production. Its primary goal is to enhance both crop performance and environmental quality. The

10. OECD-FAO Agricultural Outlook 2021-2030
11. What Is ROI? How to Calculate Return on Investment | Definition from TechTarget
12. Aprendizajes para calcular el retorno de inversiones (ROI) en los campos de cultivos
13. El Dilema del ROI en la Agricultura (Parte I) | SpaceAG Blog

effectiveness of this strategy lies in the ability to assess and manage variability with high accuracy, integrating technologies such as automation to optimize diagnostics, decision-making, and execution.

While precision agriculture offers potential economic, environmental, and social benefits, its viability varies based on the adaptability of technologies to the specific conditions of each farming operation.

14. (Pierce & Nowak, 1999)

A REGIONAL OVERVIEW

Agriculture in Latin America and the Caribbean is highly diverse, ranging from large-scale commercial farms focused on exports to nearly 15 million small family units that contribute significantly to the region's food production. In particular, the Southern Cone is characterized by export-oriented agriculture with highly mechanized operations and significant capital investment, whereas Central America and the Andean countries rely on small-scale farmers for production.[16]

Approximately 17% of the Latin American population is engaged in agriculture, a sector that contributes 14% of the global net value of agricultural and fishery production, and accounts for over 17% of the region's total exports. According to the Organization for Economic Co-operation and Development (OECD) and FAO projections, agricultural production in LAC is expected to grow by 12% by 2032. This growth will depend heavily on the adoption of innovative technologies and efficient practices to boost crop yields and optimize fertilizer use.[19]

Despite being the world's largest net exporter of agricultural products, the region faces challenges related to food security and input efficiency. While commercial agriculture thrives, many small-scale farmers continue to struggle with low-productivity systems and persistent rural poverty. Paradoxically, despite food surpluses, millions across the region suffer from hunger, malnutrition, and related illnesses.[21]

LAC also generates 20% of global food waste, primarily due to untimely harvests, adverse

15. OCDE-FAO Perspectivas Agrícolas 2023-2032 | OECD
16. Panorama del ecosistema agrotecnológico para los pequeños agricultores de América Latina y el Caribe
17. Anuario Estadístico de América Latina y el Caribe 2023
18. OCDE-FAO Perspectivas Agrícolas 2023-2032 | OECD
19. OCDE-FAO Perspectivas Agrícolas 2023-2032 | OECD
20. OCDE-FAO Perspectivas Agrícolas 2023-2032 | OECD
21. Future Foodscapes : Re-imagining Agriculture in Latin America and the Caribbean (Spanish)

weather conditions, poor harvesting practices, and commercialization challenges. This waste has profound environmental consequences, contributing to 16% of the global carbon footprint, 9% of the land footprint, and 5% of the water footprint.[22, 23]

The region's agricultural success has come at a cost to the environment and public health. Despite LAC's rich agrobiodiversity, the expansion of monocultures threatens this ecological wealth. Agriculture consumes 70% of the available freshwater, contributes to deforestation, and generates high greenhouse gas emissions.[26]

Faced with these challenges, there is growing concern about how to meet projected food demand in the coming decades.[27] The population of Latin America and the Caribbean is expected to reach approximately 800 million by 2050, a 20% increase from current figures.[29]

Meeting future food production projections while minimizing environmental impact will require a transformation of the agricultural sector. This transformation must focus on sustainable practices that maximize crop potential without depleting natural resources. Technology will be a key ally in this transition, by enabling greater inclusion, efficiency, and digitization within agricultural processes.

MEXICO

Mexico, with its rich diversity of soils, climates, and ecosystems, stands out as a major global agricultural producer. This geographical variety allows for a wide range of crops, making agriculture a vital sector for national food security, job creation, and rural income, with the United States as its primary market. Agriculture employs approximately 13% of Mexico's workforce —over 7.7 million people— 85% of whom are small- and medium-scale producers.[34]

Despite its importance, Mexico's agricultural sector remains under-industrialized, with most crops cultivated by small and medium-sized farmers. Limited economies of scale have resulted in low levels of technology adoption and relatively low land productivity.[35]

Major crops include grains such as white corn, yellow corn, and beans, as well as sugarcane, citrus fruits, and agave.[36, 37] The Central-West region, encompassing states like Jalisco, Veracruz, and Oaxaca, is a significant hub for grain and vegetable cultivation. Despite its biological and cultural wealth, Mexico has lost nearly 50% of its natural ecosystems due to deforestation and soil degradation. Climate change has further

23. América Latina representa el 20% del desperdicio de comida en el mundo.
24. Los sistemas agropecuarios y alimentarios de América Latina y el Caribe están listos para una profunda transformación
25. (NU. CEPAL, 2021)
26. (Springmann et al., 2018)
27. The future of food and agriculture – Drivers and triggers for transformation
28. The future of food and agriculture – Alternative pathways to 2050
29. Anuario Estadístico de América Latina y el Caribe 2023
30. Nuestro México| Secretaría de Agricultura y Desarrollo Rural | Gobierno | gob.mx
31. México — Ministério da Agricultura e Pecuária
32. México en una mirada | FAO en México | Organización de las Naciones Unidas para la Alimentación y la Agricultura
33. Comunicado de Prensa. Indicadores de Ocupación y Empleo
34. México en una mirada | FAO en México | Organización de las Naciones Unidas para la Alimentación y la Agricultura
35. Gobernanza Regulatoria en el Sector de Plaguicidas de México
37. Producción de los principales cultivos Censo 2022

strained the sector, exacerbating water resource pressures through atypical droughts and increasing vulnerability to cyclones and natural disasters. These adverse conditions have caused significant economic losses for agricultural operations due to deteriorating crops and livestock.[40]

In this context, Mexican farmers face additional hurdles in adapting to global market demands, meeting strict sanitary and phytosanitary standards to scaling operations to remain competitive internationally. Compounding these challenges is an aging agricultural workforce: only 27% of farmers are aged 18 to 30, while nearly half are older adults. This aging trend is driven by a lack of incentives for younger generations, preference for employment in other sectors, and migration.[43]

Looking ahead, the most pressing challenge will be transforming the agri-food system to become more productive, equitable, healthy, inclusive, and sustainable. Achieving this will require a renewed focus on more efficient and sustainable agricultural practices, facilitated by the incorporation of advanced technologies.[44]

CHALLENGES TO AGTECH DEVELOPMENT IN LATIN AMERICA AND THE CARIBBEAN

In recent years, the Latin American and Caribbean region has shown a remarkable growth in technological innovation within the agriculture and food sectors. Brazil and Argentina stand out due to their dynamic entrepreneurial ecosystems, which have driven the growth of AgTech startups in the region.[45]

Despite gradual progress in adopting digital solutions and the rise of local innovations, investment opportunities in the sector remain limited. The central role of agriculture in the region's economy and the pressing need to meet the global food demands are not matched by corresponding levels of investment, which ranks lowest in the world in this regard.[48]

38. Jalisco, Veracruz y Oaxaca: mayor producción agroalimentaria de México | Secretaría de Agricultura y Desarrollo Rural | Gobierno | gob.mx
39. Jalisco, Veracruz y Oaxaca: mayor producción agroalimentaria de México | Secretaría de Agricultura y Desarrollo Rural | Gobierno | gob.mx
40. México en una mirada | FAO en México | Organización de las Naciones Unidas para la Alimentación y la Agricultura
41. El sector agrícola mexicano en cifras: avances, retos y oportunidades del T-MEC | Secretaría de Agricultura y Desarrollo Rural | Gobierno | gob.mx
42. https://www.inegi.org.mx/contenidos/programas/ca/2022/doc/ca2022_rdnal.pdf
43. Los agricultores mexicanos envejecen
44. Sistema agroalimentario de México, un desafío de bienestar | Secretaría de Agricultura y Desarrollo Rural | Gobierno | gob.mx
45. Mapa de la innovación AgTech en América Latina y el Caribe
46. Mapa de la innovación AgTech en América Latina y el Caribe
47. AgroTech en América Latina: ¿Cómo es la disrupción tecnólogica del campo?
48. https://capria.vc/wp-content/uploads/2023/09/LABS-collection-9.pdf

The challenges faced in technology adoption in agriculture include:

Limited Financial Resources. Many entrepreneurs identify restricted access to capital as the primary issue hindering the emergence or growth of new AgTech ventures. In addition, the difficulty of accessing specific financing sources for digital businesses is a major obstacle to the expansion of agricultural technology in the region.[50]

Public-Private Collaboration Gap. The lack of collaboration between government institutions, the private sector, and digital agricultural research and development (R&D) companies is a major challenge in the region. According to a report, only 30% of countries are actively pursuing actions aimed at the digital transformation of the agricultural sector.[51]

Limited Academic-Business Collaboration. The low level of interaction between the scientific and business communities, combined with bureaucratic obstacles that impede and slow down the process of setting up a company, acts as a barrier to the growth of AgTech ventures in the region.[53]

Poor Regional Connectivity. The limited connectivity in the region poses a fundamental challenge to the adoption of AgTech technologies. While solutions that work without internet connectivity exist, the complete digitization of agricultural processes depends largely on the efficiency of connectivity in the region.[53]

Diversity of Agricultural Processes. The variety of agricultural and food systems within the region — even within individual countries — makes it difficult to widely adopt technologies and implement policies that reach all farmers, underlining the need for context-specific approaches.[54]

49. (Navarro et al., 2022, p. 38)
50. (Vargas et al., 2023)
51. (Echenique et al., 2021)
52. (Navarro et al., 2022, p. 33)
53. (Navarro et al., 2022, p. 33)
54. Future Foodscapes : Re-imagining Agriculture in Latin America and the Caribbean (Spanish)

AGRICULTURAL CYCLE AND **ASSOCIATED TECHNOLOGIES**

PREPARATION OF THE SOIL

Sensors

A sensor is a device that detects and responds to specific inputs from the physical environment, such as light, heat, motion, pressure, or other environmental phenomena. Soil and climate sensors help optimize agricultural production by providing accurate data on essential nutrient levels such as moisture, pH, CO_2, and NPK (nitrogen, phosphorus, and potassium), as well as on environmental conditions such as temperature, rainfall, and light intensity. Integrated with real-time monitoring systems, these devices enable early detection of issues requiring attention, helping prevent crop losses and maximizing yields.

Context

In 2023, berries became Mexico's top export product, with a market value approaching USD 4 billion—an increase of 4% compared to the previous year. This growth allowed berries to surpass traditional products such as beer, tequila, and avocado.[58]

55. What is a sensor?
56. Soil Sensors and Plant Wearables for Smart and Precision Agriculture
57. México se posiciona como país altamente productor y exportador de berries.
58. Estructura de información (SIE, Banco de México)

Proper soil preparation and climate control are critical for the healthy development of crops, particularly for berries, which have shallow roots and are highly sensitive to excess moisture and weeds. Implementing sensors to monitor soil conditions and water requirements can enhance soil preparation and irrigation practices, improving growth and boosting production for these crops.

Potential risks

The risks associated with sensor use in agriculture are similar to those of widespread use:[60]

Reliability Issues Sensors may become unreliable due to incorrect settings, dirt, defects, or damage, potentially impacting crop health.

System Security Malware and cyberattacks can become potentially dangerous in the absence of global enforcement policies and recovery strategies for compromised data.

Connectivity The quality of the Internet for gathering on-site information highlights the problem of the poor connectivity in the regions. At the same time, there is a risk of loss of internet connection, which may interrupt data transmission.

Examples

- **Invermex and 30MHz.** (Netherlands and Mexico). Offers solutions enabling farmers to create wireless sensor networks for detailed crop information, facilitating monitoring and control from any mobile device.[61]
- **NXTAGRO and BlueDrop Berries.** (Mexico). A solution developed to maximize berry production in Guadalajara, Michoacán, and Culiacán. The sensors, placed within plants, collect data on humidity, electrical conductivity, and pH levels.[62]
- **ICT International and Definium Technologies.** (Australia) Uses LoRa (Long Range) devices to optimize avocado production, particularly susceptible to stress during critical development stages. The sensors monitor humidity levels, allowing farmers to take immediate action in stressful situations, ultimately enhancing productivity.[63]

59. ¿Cuáles son las complicaciones durante la producción de Berries a los que se enfrenta el productor de clase mundial? - NXTAgro
60. (ACIL Allen Consulting, 2019, p. 64)
61. Invermex y 30MHz se unen para digitalizar la horticultura en México – AgTech América
62. NXTAGRO: la startup mexicana aumenta la producción de berries en un 20% • ENTER.CO
63. Semtech's LoRa Boosts Yield on Avocado Farms

Satellite Remote Sensing

Remote sensing refers to the technique of acquiring data from the Earth's surface using satellites, which are then processed to obtain interpretable information. These techniques provide relevant information related to crop development, gaining increasing acceptance in the agricultural sector due to its ability to provide accurate and up-to-date data supporting efficient resource management.[65]

Remote sensing helps to identify plots and monitor crop development, using indices such as the Normalized Difference Vegetation Index (NDVI), Normalized Difference Moisture Index (NDMI), Leaf Area Index (LAI), among others. This tool is especially useful in large plantations such as palm, corn, and sugar cane.[66]

Context

Mexico is one of the leading global producers of maize, with an estimated output of 23 million tons for 2023/24 and a trade value close to USD 6 billion. Despite widespread cultivation, maize yields are heavily influenced by soil and climate conditions. Prolonged droughts predicted for 2024 could significantly reduce production, increasing reliance on imports to meet domestic demand.[71]

In this context, satellite imagery could become an invaluable tool, offering historical climate data and identifying underutilized agricultural areas with high potential such as chinampas—ancient floating farming systems built on wetlands. This system offers naturally wet and fertile land that could be reused to offset maize production losses caused by droughts.

Spanning over 2,000 hectares across Tláhuac, Xochimilco, and Milpa Alta municipalities, these fertile lands are currently underutilized, with only 19% in use. By leveraging satellite technologies, these untapped areas could play a pivotal role in mitigating the effects of climate change on Mexican maize production.

Potential Risks

While remote sensing provides valuable historical records and up-to-date crop information, its availability is contingent on weather conditions and does not accurately detect the presence of disease in crops. Known errors in the use of satellites with Landsat technology include:[76]

64. (Balbontín N. et al., 2016)
65. (Sishodia et al., 2020)
66. (Anaya Acevedo & Valencia Hernández, 2013)
67. Corn production by country 2023/24 | Statista
68. Crop Explorer - World Agricultural Production (WAP) Briefs - Mexico Central America and the Caribbean
69. Maíz: Intercambio comercial, compras y ventas internacionales, mercado y especialización | Data México.
70. Growing Sweet Corn
71. Cultivará México 9.2% menos maíz en 2024 e importará 45% del grano - TierraFértil®
72. México busca recuperar chinampas para la producción de alimentos
73. Chinampas: mexicanos preservan el maíz mediante milenario y eficaz sistema
74. Medalla de oro para el documental 'Chinampas de Xochimilco', una producción de la UOC y El Claustro de Sor Juana en la ciudad de México
75. Chinampas de la Ciudad de México producen más de 19 000 toneladas de alimentos | FAO en México

Data Loss Missing satellite data may be filled with random or null values, impacting analysis accuracy and decision-making.

Interference Environmental factors such as cloud cover and atmospheric conditions can interfere with the process, causing certain crop issues to go unnoticed, which affects the ability to intervene in a timely manner.

Processing Costs Processing satellite images for information can incur high costs. In addition, the acquisition of licenses for the use of images can be an economic barrier for small producers.

Examples

- **EOSDA and StarkSat.** (U.S. and Brazil). EOS Crop Monitoring is an online satellite monitoring tool. It includes features like crop rotation history, weather data, and notifications about field changes in a mobile app.[77]
- **Agriicola.** (Mexico) Offers a satellite-based management, learning, and monitoring system available through a low-cost annual subscription.[78]
- **Syngenta.** (Brazil) CLARIVA is a digital diagnosis and mapping solution for nematode pests through satellite images. Soybean farmers will use the tool to combat pests that cause up to 30% yield loss.[79]

Discarded Technology: 5G Connectivity

5G technology promises to revolutionize global connectivity with faster speeds, lower latency, and enhanced versatility. These advantages pave the way for advanced applications, such as large-scale integration of Internet of Things (IoT) devices, like sensors, in agriculture. However, 5G adoption in Latin America remains slow and costly, hampered by infrastructure and compatibility issues that limit its expansion.

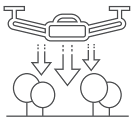
In Mexico, despite the deployment of 5G starting in February 2022[82], the digital divide between urban and rural areas persists. While 78% of the population has internet access, nearly half live in rural or remote areas, exacerbating inequalities in technology access.[83]

76. Landsat Known Issues | U.S. Geological Survey
77. EOS Data Analytics Se Asocia Con StarkSat
78. Agriicola
79. Syngenta lanza la primera herramienta digital comercial del mundo para detectar nematodos dañinos a través de imágenes de satélite - Technocio - Tech Trends
80. ¿Qué es 5G? - Cisco
81. (Tang et al., 2021)
82. México concentra 23.6% de accesos a 5G en América Latina al cierre de 2023 – El Financiero

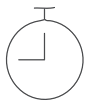
Across Latin America, less than half of the population has broadband, with significant disparities between urban and rural regions. Despite 5G's transformative potential, the region faces structural challenges that limit its impact on agricultural digitalization and other sectors.

To ensure that digital agricultural technology devices work properly, a fast and reliable Internet connection is generally required. However, existing networks face connectivity challenges in both rural and high-demand areas, resulting in insufficient network availability in many regions.[84]

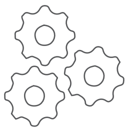
A more efficient and accessible 5G network could unlock numerous applications in agriculture:[85]



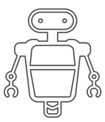
- **Unmanned Aerial Vehicles (UAVs).** Farmers could control drones over long distances, either manually or via programmed control points, potentially from anywhere in the world.



- **Real-Time Monitoring.** Using 5G, a single cell tower could connect a large number of sensors per square kilometer, allowing farmers to install more IoT devices for more efficient task management.



- **Predictive Maintenance.** Sensors in machinery could transmit real-time data, allowing for proactive monitoring of equipment and fuel levels to prevent breakdowns and ensure timely maintenance.



- **AI-Guided Robots.** The combination of Artificial Intelligence (AI) and low-latency communication could facilitate live monitoring, remote diagnostics, and precise control of drones and robots.

- **Data Analysis and Cloud Repository.** IoT sensors, drones, and robots could transmit data to the cloud for real-time analysis using 5G speeds and edge computing, optimizing automated agricultural processes.

PLANTING MANAGEMENT

Seed Sowing Robot

The use of robotics in planting offers farmers an opportunity to enhance efficiency, reliability, and productivity. These automated systems leverage technologies like GPS to ensure precise planting, optimizing crop spacing and depth. Large-scale farms use autonomous

83. El siguiente nivel de la red 5G en México
84. Estudio del IICA, BID y Microsoft concentró su trabajo en 24 países de América Latina y el Caribe. El promedio de conectividad en la ruralidad equivale a la mitad de la disponible en las áreas urbanas.
85. (Tang et al., 2021)

tractors, while smaller-scale farms benefit from robotic arms and mobile robots tailored to specific crop needs.[86]

Context

Seeders, including robotic ones, are critical tools for achieving successful harvests, by ensuring accurate distribution of seeds. Key considerations for optimal sowing include seed quality, the use of chemical fallow, equipment maintenance, planting depth control, and seed and fertilizer dispenser regulation. While planting equipment cannot influence seed genetics or quality, it plays a significant role in managing surrounding factors through effective practices. For example, in maize and soybean cultivation, soil density is a critical factor. Poor management of seeding unit pressure can lead to problems such as delayed emergence.[89]

Latin America's soybean industry is dominated by Brazil, Argentina, and Paraguay, global leaders in production. In particular, Brazil achieved a record soybean output in 2023, accounting for nearly half of total grain production, in part supported by government initiatives like the Safra Plan. In Paraguay, the soybean harvest is projected to reach 9.5 million tons for 2023/24, while Argentina has shown productive recovery in recent years.[94]

On the other hand, globally and regionally, the demand for agricultural robots is growing , driven by the need to address labor shortages in precision agriculture. Despite this, the adoption of robots in Mexican agriculture is at an incipient stage, with a lag of approximately five years in this technology. Experts anticipate a transformation in the coming years that will drive wider adoption in the second half of the decade.[98]

Risks

The use of autonomous technology in agriculture introduces risks to farms, farmers, and food security, including:[99]

Soil	Heavy robots could exacerbate soil compaction issues.[100]
Exclusion of Small Farmers	Small-scale farmers may be excluded from the benefits of robotics due to high entry barriers on investment costs. [101]
Cybersecurity	Automated agricultural systems could become targets for cyberattacks seeking economic or strategic gains. The short-term

86. Landsat Known Issues | U.S. Geological Survey
87. Soja: ¿qué le exige hoy a la sembradora? - Maquinac
88. Densidad de siembra en los cultivos
89.
90. Ranking Mundial – Capeco
91. Em agosto, IBGE prevê safra recorde de 313,3 milhões de toneladas para 2023 | Agência de Notícias
92. 2022/2023 — Ministério da Agricultura e Pecuária
93. Zafra 2023/2024 superaría 9 millones de toneladas de soja – Capeco
94. Balance regional de la soja 2023/24 | Bolsa de Comercio de Rosario
95. Farming Robots of 2023 and their Uses/Applications.
96. Latin America Agriculture Robots Market is expected to reach USD 1.49 billion by 2030
97. En cinco años, llegarán primeros 'agrobots' al campo mexicano: Bayer
98. En cinco años, llegarán primeros 'agrobots' al campo mexicano: Bayer
99. (Tzachor et al., 2022)
100. Robots in Agriculture: Prospects, impacts, ethics, and policy.
101. Meatpacker JBS says it paid equivalent of $11 mln in ransomware attack | Reuters

consequences of deliberate interruptions during the planting season could be significant and even disruptive in the medium term.[102]

Errores en la programación Errors in robot programming could lead to incorrect planting, resulting in poor seed distribution.

Daño a las semillas If seed sowing robots are not correctly adjusted or lack precise sensors, they could damage seeds during the process, reducing germination rates and affecting yield.[103]

Examples

- **YuMi.** (Peru). A robot that automates planting tasks. Experts in Sweden simulate, refine and implement the necessary programming for YuMi's tasks in the jungle. YuMi can plant around 540 seeds in a day, equivalent to two football fields, which is 9 times more than the work of an average person.[104]

- **RO G 500 from Horsch.** (Brazil). An autonomous and high-precision seeder capable of working without a driver, as planning is done through computers. Its engine has autonomy for up to 10 hours and is capable of sowing up to 20 hectares per hour.[105]

- **ExactShot by John Deere.** (U.S.) A planting sensor that records the moment each seed is introduced into the soil. When this happens, it sprays only the necessary amount of fertilizer on the seed, which helps resource efficiency.[106]

Seed Management

Seed management encompasses a series of techniques that impact the quality, availability, and diversity of seeds used by farmers.[107]

Traceability refers to the ability to track the journey of food, feed, animals, and substances from production to distribution. On the other hand, certified seed (i.e. quality assurance, genetic purity, germination, health, batch homogeneity and traceability) is closely linked to genetic and technological research to ensure its quality and traceability.

Common tools in seed management include sensors, smart tags, QR codes, and data management systems. Emerging technologies like blockchain are beginning to be tested, promising significant advancements in traceability and security throughout the process. These tools enable data collection at every stage of the supply chain, from source to distribution, providing accurate tracking and comprehensive analysis.

102. Robots in Agriculture: Prospects, impacts, ethics, and policy.
103. Siembra: claves para calibrar las máquinas y reducir las pérdidas | Argentina.gob.ar
104. Robot más remoto del mundo automatiza proyecto de reforestación del Amazonas | ABB
105. New developments in robotisation: HORSCH Gantry
106. John Deere Debuts New Planting Technology & Electric Excavator During CES 2023 Keynote
107. Understanding farmers' seed management practices
108. Food Traceability

Context

Seeds used in agriculture come from three main sources: farmers, the public sector, and the private sector. In 2022, the global seed market managed by private companies witnessed a growth of 7% in 2022, reaching almost USD 45 billion.[110]

By 2030, genetically modified (GM) seeds are expected to lead the market, driven by increasing adoption in Asian countries and the expansion of maize and soybean production in Brazil. This growth underscores the significant influence of the private sector on the production and distribution of specialized seeds.

Meanwhile, new regulations in major trade destinations are accelerating the adoption of digital solutions in agriculture. In June 2023, the European Parliament approved the EU Deforestation Free Regulation (EUDR), which requires all agricultural products exported to the European Union to demonstrate that they do not come from deforested land. Agribusinesses and farmers in coffee, cocoa, palm oil, livestock, and soybean supply chains will be most affected. Similar legislation is under consideration in the United States, forcing Latin American exporters to digitize their processes to comply with quality standards. Consequently, these regulations are expected to drive the adoption of technologies like QR codes, RFID tags, and satellite monitoring to meet market requirements.[112]

In Mexico, the seed market, valued at USD 1 billion annually, comprises social and commercial enterprises that produce certified seeds to supply the country's agricultural land.[113] Approximately 600,000 tons of certified seeds per year are required to meet agricultural demand. About one-quarter of this market involves vegetable seeds with the highest use of certified seeds seen in crops like wheat, maize, oats, potatoes, soybeans, barley, and rice.[115]

In the past year, vegetable seed sales showed slight growth, but still faced a trade deficit exceeding USD 466 million. Despite the potential benefits of improved seeds in optimizing crop yields, Mexico's production has not reached its full potential. This shortfall is partly due to the persistent practice in several regions of using grains from the previous harvest instead of improved varieties. Currently, only 5% of all seeds used are certified.[117]

Risks

Being able to guarantee the quality, safety, and authenticity of the seeds is a differential aspect, although it can also face certain risks:

Fraud and Counterfeiting A vulnerable system is susceptible to the falsification of information in order to sell lower-quality products or seed of different varieties as high quality.

Technology Dependence Digital traceability relies on consistent and functional technological systems. Failures or technical issues in these systems can disrupt the process, hindering end-to-end quality assurance.

109. India turns to blockchain for seed distribution as adoption soars
110. Perspectiva sobre los mercados de protección de cultivos y semillas
111. Perspectiva sobre los mercados de protección de cultivos y semillas
112. Agritech LATAM
113. Programa Nacional de Semillas 2020-2024.
114. Semillas certificadas para agricultores mexicanos
115. Certificación de las semillas Mexico
116. (Luna-Mena et al., 2016)
117. Semillas certificadas para agricultores mexicanos

Interoperability Incompatibility between different digital traceability systems in the supply chain can limit its effectiveness, by preventing chain participants from sharing and accessing data.

Examples

- **BASF.** (Argentina). Integrated proposal to assist producers from seeding to harvest, offering traceability for each bag, quality controls, and technical recommendations for germination power analysis.[118]
- **Tracestory.** (Argentina). Startup providing collaborative traceability software, aiming to achieve real-time end-to-end integration of information regardless of the chain or the customer's location worldwide.[119]
- **TrackitAgro.** (Chile). Integrated platform with traceability modules for harvest, post-harvest, phytosanitary, seeds, and pallets within storage environments, allowing tracking every moment of the process, measuring production, and real-time risks.[120]

Discarded Technology: Biotechnology and Genetic Editing

Agricultural biotechnology involves modifying the genetics of organisms in agricultural production[121] through scientific developments like CRISPR-Cas9. While this alternative has the potential to enhance crop yields and productivity,[122] its small-scale adoption presents several challenges:

Costs. The development and implementation of biotechnological technologies, such as genetic editing and the creation of genetically modified organisms (GMOs), require considerable investments in R&D, as well as the expenses and time involved in obtaining government approval for each transgenic product.

Regulation and Legal Requirements. Agricultural biotechnology is subject to strict regulations in many countries to ensure food and environmental security. This adds complexity and additional costs to the adoption process, and in some cases, its commercialization and use are outright prohibited.

118. BASF
119. Trazabilidad Colaborativa en la Industria Frutihortícola
120. TrackitAgro
121. 2. ¿Qué es la biotecnología agrícola?
122. (ACIL Allen Consulting, 2019)

Production Scale. Many biotechnologies are designed for large farms, posing challenges for cost-effective application on small plots.

Corporate Dependence. The adoption of biotechnologies may increase farmers' dependence on corporations, potentially concentrating power within the agricultural industry and reducing local control over seeds and crops.

Despite these challenges, countries like Brazil have seen notable growth in adopting biotechnological crops, especially in soybean, maize, and cotton production. These developments highlight the importance to responsibly address the financial, regulatory and social aspects of agricultural biotechnology in different agricultural contexts.

CROP PROTECTION

Pest Monitoring

The FAO estimates that pests account for 20–40% of annual crop yield losses, emphasizing the importance of early detection. Climate change is likely to exacerbate pest damage, increasing their intensity, range, and spread. Integrated Pest Management (IPM) is a strategic approach that combines various techniques to effectively control pests while minimizing their impact. This method emerged in response to excessive pesticide use, which led to issues such as pest resistance, secondary outbreaks, and health and environmental concerns.[126]

Precision agriculture enhances IPM through technologies like sensors and electronic traps, enabling more accurate and timely monitoring. These tools improve the efficiency of pesticide application, reducing both costs and environmental risks. Commonly used technologies include low-power image sensors, acoustic sensors, thermal imaging for disease detection, hyperspectral spectroscopy, and gas chromatography. These tools not only advance agricultural sustainability but also provide viable alternatives to traditional agrochemical dependence.

Context

While pesticides are essential for protecting crops, their intensive use raises significant concerns about health and environmental impacts, including pollution and biodiversity

123. (ISAAA, 2019)
124. Pest and Pesticide Management
125. Es sumamente difícil dar una definición unificada de MIP. A los fines del presente informe la ofrecida alcanza (Deguine et al., 2021).
126. Manejo integrado de plagas y plaguicidas | Organización de las Naciones Unidas para la Alimentación y la Agricultura | IPM and Pesticide Risk Reduction

loss. In 2022, 3.7 million tons of pesticides were used globally, with Brazil leading consumption, followed by the United States, Indonesia, and Argentina. In Latin America, countries like Colombia show high pesticide use per hectare, reflecting a heavy reliance on these products in regional agriculture.[128]

This intensive use has sparked growing concerns. Transgenic plants engineered to resist herbicides have increased the application of chemical mixtures, whose full impact remains poorly understood. Key regional crops like rice, maize, and soybeans, critical to local diets, rely heavily on potentially hazardous pesticides, further exacerbating environmental challenges. Additionally, climate change is driving pest proliferation, such as caterpillars targeting soybeans, compounding agricultural production issues.[130]

In the 2023/24 season, Brazil projects a harvest exceeding 300 million tons of grains, with rice, maize, and soybeans accounting for 92% of production and 87% of harvested areas. However, this growth comes with risks, including pest outbreaks and intensive agrochemical use, reaching over one million tons annually, 90% of which are classified as hazardous. In Argentina, similar concerns exist, with exceptional pest outbreaks reducing soy and maize yield estimates by 20%, underscoring the urgent need for more sustainable alternatives in both countries.[134]

Mexico faces parallel challenges, relying heavily on agrochemicals —many of which are banned elsewhere— to improve efficiency and reduce costs. Excessive use has triggered concerns about soil, water, plant, and animal contamination. This has negatively impacted human health, especially among children, and led to ecosystem degradation, including bioaccumulation in aquatic species. To combat pest outbreaks, Mexican authorities have implemented early detection measures like sensors in palm trees and suction traps in citrus-growing regions.[139]

Risks

Complexity in the Analysis Optical sensors face challenges due to the quantity and complexity of collected data. Effective use requires advanced data analysis and statistical approaches addressing various issues related to pests. This includes early detection, distinguishing between pest species, identifying damage and accurately measuring disease severity.

Various Incidents Involuntary physical modification of a perception device, deviating it from its usual operation. Devices are usually installed outdoors and lack tamper-proof cases to avoid increased costs, exposing them to interactions with external agents such as people, animals, or agricultural equipment.

127. Farm Revolution – Sensors for Crop Pest Detection
128. Pesticides use and trade 1990–2022
129. Bosques más vulnerables a plagas: un efecto del cambio climático que ya se observa en México
130. Clima faz pressão de lagartas explodir na safra brasileira de soja 2023/2024
131. Conab - Nova estimativa para a produção de grãos na safra 2023/2024 está em 297,54 milhões de toneladas
132. Em agosto, IBGE prevê safra recorde de 313,3 milhões de toneladas para 2023 | Agência de Notícias
133. Alerta sobre el impacto de los agrotóxicos en América Latina y el Caribe
134. Las principales plagas que representaron un dolor de cabeza en la campaña 2023/2024 • Agroverdad - Noticias e Información del Agro
135. Glifosato en México: ¿por qué el gobierno pospuso su prohibición?
136. Los Plaguicidas Altamente Peligrosos en México
137. Gobernanza Regulatoria en el Sector de Plaguicidas de México
138. Instalan sensores en palmeras para prevenir presencia de plagas
139. Trampas de succión para el monitoreo de plagas de alta movilidad

Research Issues

Research on IPM is often fragmented, focusing on isolated aspects such as biological knowledge and control techniques without a holistic perspective. There is a lack of comprehensive and interdisciplinary studies addressing biodiversity, agroecosystem interactions, and landscape ecology. Additionally, socio-economic research on markets, practical applications, and social ecology in relation to IPM is insufficient.

Ecological Considerations

The ecological dynamics within agroecosystems and their ability to resist pest pressures are often overlooked. In addition, there is a noticeable lack of emphasis on agronomic factors and non-chemical preventive measures in IPM research.

Varied Effectiveness

In certain cases, IPM may not be as effective as traditional pest control methods, especially when dealing with resistant pests or advanced infestations. In such circumstances, more intensive control measures, such as the use of chemical pesticides, may be required.[140]

Examples

- **SIMA AgTech.** (Argentina). Geo-referenced monitoring platform that analyzes information and generates insights to aid decision-making. Together with Bayer, they work on controlling corn leafhoppers (cigarrinha do milho) in Brazil, exclusive to this crop, causing stunting and potential losses of up to 90% if not treated promptly.[141]

- **Trapview.** (Slovenia). Allows remote control of insects caught in pheromone traps. Real-time alerts are sent when fumigation is needed, based on the high number of insects detected. In addition, images are uploaded to the cloud at least once a day, processed, and analyzed using machine learning to identify each photographed insect.[142]

- **Field Manager by Xarvio.** (Germany). Platform that detects over 120 types of weeds and 200 diseases in more than 40 crops. Enables 24/7 monitoring of plots through high-quality satellite images and specific maps.[143]

- **iSCOUT by Metos.** (Austria). Lightweight device with integrated electronics and sticky pad. Self-sufficient, as it is powered by a solar panel and a battery. Multiple cameras take high resolution images of the sticky pad, which are sent via GPRS to the platform, where they are analyzed with automatic pest detection.[144]

140. (Deguine et al., 2021)
141. SIMA
142. Trapview

IA and Machine Learning

Artificial Intelligence can be defined as a field of study that combines computer science with robust data sets to solve complex problems. Machine Learning (ML), a subset of AI, focuses on leveraging data and algorithms to mimic human learning processes, aiming to improve accuracy over time.[146]

By understanding training models, ML can be used to make predictions based on input data in areas such as water level control, disease detection through image analysis of fruits and leaves, and estimating crop yields in various regions. This close connection between these technologies and the agricultural sector highlights their critical importance.[147]

Context

The application of AI in agriculture is not new—automated driving systems for crops like maize have been in use for over two decades. However, its adoption has accelerated significantly in recent years. ML has emerged as a valuable tool in modern agriculture, particularly in managing crops, irrigation, soil, and livestock. This technology is used to predict crop yields, detect diseases, identify weeds, classify crop types, and evaluate product quality. The data comes from sensors that enhance understanding of changing conditions in crops, soil, climate, and agricultural machinery. This enables faster, more accurate decision-making through intensive data processing combined with big data and high-performance computing.[150]

AI is a versatile tool adaptable to various crops, regions, and stages of the agricultural process. It facilitates pest and weed control, soil quality monitoring, and the automated management of irrigation and fertilizers. By 2030, AI is expected to contribute up to USD 15.7 trillion to the global economy, with approximately USD 6.6 trillion tied to increased agricultural productivity.[151]

In Latin America and the Caribbean, 55% of tech startups focus on AI-based agricultural and food solutions. Brazil leads with 51%, followed by Argentina with 23%, the Andean region with 18%, and Uruguay and Paraguay collectively at 5%. Central America and the Caribbean have a minimal share.[152]

Mexico, on the other hand, stands out in AI adoption, being the first country in the region and one of the top ten in the world to launch a National AI Strategy. With a focus on digitalization, the country has established internet access as a human right and fostered a multisectoral ecosystem to facilitate AI adoption.[154]

Key initiatives focus on using satellite imagery and algorithms to identify and analyze agricultural crops. These tools aim to address labor shortages, high production costs, and sector waste. Additionally, technologies like UAVs and ML are helping estimate nitrogen levels in plants. Predictive models created from this data optimize production, improve resource efficiency, and minimize environmental impact, fostering sustainability in a.[156]

143. FIELD MANAGER
144. Vigilancia de insectos - METOS® by Pessl Instruments
145. BID Tech Report AI
146. What is Machine Learning? | IBM
147. (Casadiego, 2020)
148. Las granjas estadounidenses están dando un paso urgente hacia la inteligencia artificial, que podría ayudar a alimentar al mundo
149. (Benos et al., 2021)
150. (Liakos et al., 2018)
151. (PwC, 2017)

Riesgos potenciales

There are risks related to the reliability and relevance of agricultural data, unintended socio-ecological consequences of ML models, and security concerns tied to the large-scale implementation of these platforms:[157]

Negative Environmental Impact

If errors occur—whether accidental or deliberate—AI systems may be programmed to ensure only short-term crop yield, ignoring their environmental consequences. This could lead to the overuse of fertilizers and pesticides, resulting in soil and water pollution and long-term erosion, harming environmental sustainability.[158]

Inequality in Agriculture

While AI offers benefits in agricultural decision-making, its adoption can lead to inequalities, especially for smallholder farmers. Lack of access to advanced technologies, such as drones and sensors, due to marginalization and the digital divide could leave them excluded, negatively affecting sector equity.[159]

Bias

ML models are trained on initial data that must be representative of possible scenarios. If the training data is biased, the model may produce inaccurate, unstable, or incomplete results. In addition, the intentional or unintentional exclusion of certain groups raises ethical concerns by skewing the algorithm's results.

Dynamic Calibration

ML is a dynamic field that is constantly evolving. Models adjust their parameters to adapt to new data patterns. This requires a dynamic risk management approach tailored to the agricultural context, as traditional periodic monitoring is not sufficient.[160]

Examples

- **Neltume Agro.** (Chile). This service monitors weather, population, and phenology using AI, sensors, and cameras. It enables remote pest monitoring via trap photographs, while sensors measure temperature and humidity. Based on this data, pesticide use is recommended, synchronized with pest life cycles.[161]
- **Instacrops Crop Advisor.** (Chile). This system collects minute-by-minute data to gather relevant information for decision-making. Using AI, ML, and computer vision techniques, it generates periodic reports with highly focused management recommendations and forecasts.[162]
- **Xarvio SCOUTING from BASF.** (Germany). A digital solution equipped with image recognition and machine learning algorithms to monitor fields for stressors such as weeds and disease.[163]

152. (Mont et al., 2020)
153. Estrategia de Inteligencia Artificial MX 2018
154. Mexico: the story and lessons behind Latin America's first AI strategy Policy Brief #15
155. Registran cultivos agrícolas con algoritmos de deep learning
156. El auge de la agricultura inteligente: explorando las aplicaciones de drones
157. Los riesgos que representa para la seguridad alimentaria el uso de Inteligencia Artificial
158. (Tzachor et al., 2022)
159. Ver también los riesgos de "Robots para cosecha", más arriba.
160. Por qué a veces la Inteligencia Artificial no termina de despegar

Drones

The term "drone" refers to unmanned aircraft, also known as UAVs. These UAVs vary in size from aircraft to hand-sized units.[164]

Drones have the ability to use specific agricultural technologies, such as multispectral cameras that capture images in multiple wavelengths to detect changes in crop health through infrared variations. Their specialized software provides mapping, photogrammetry and topography solutions, making them ideal tools for agricultural monitoring and tracking. These multispectral imaging enables early detection of crop stress and generates Normalized Difference Vegetation Index (NDVI) maps. This data is used to optimize the application of fertilizers, pesticides, and herbicides.[165]

Thanks to technological advancements and decreasing costs, the agricultural sector has been able to fully leverage drone technology. According to the FAO, drones offer notable advantages in agriculture, such as versatility, lower costs compared to traditional aircraft such as planes and helicopters, the ability to access remote areas and efficiently monitor large areas of land, and the ability to collect data about specific crop areas.[166]

Context

In 2016, the global drone market was already worth over USD 127 billion, with the agricultural sector accounting for 25% of the total (equivalent to USD 32 billion) In Latin America; Brazil, Mexico, and Argentina lead drone sales.[168]

Despite these positive developments, drone regulations across the region remain highly inconsistent. Approaches range from outright bans to complete lack of restrictions, highlighting a fragmented and uneven regulatory landscape:

- **Argentina, Brazil, Ecuador, Mexico, Costa Rica and Puerto Rico.** Regulate the use of drones under the "line of sight" principle, i.e., operators must maintain visual contact with drones and generally obtain licenses or permits.
- **Chile, Peru, and Colombia.** Have regulations that require drone registration and, in some cases, additional permits.
- **Uruguay, Paraguay, and Bolivia.** No specific legislation regarding drones.
- **Cuba and Nicaragua.** Prohibit the use of drones altogether.

These regulatory differences underscore the challenges of widespread drone adoption in agriculture and the need to address safety and privacy concerns while promoting their use across various sectors.

161. Neltume Agro
162. CROP ADVISOR | Instacrops
163. BASF lanza xarvio® SCOUTING en México para ayudar a los productores en la toma de las mejores decisiones agrícolas
164. What Is a Drone? Uses of Drones and Definition. | Built In
165. https://agrifutures.com.au/wp-content/uploads/2019/01/18-047.pdf
166. E-Agriculture in action: drones for agriculture | FAO
167. Global market for commercial applications of drone technology valued at over $127bn - Press room

In Mexico, agricultural drone adoption is growing, with around 1,500 drones in operation, including usage by large companies that have integrated drones into their farming processes.[169] These devices enhance productivity and efficiency, proving to be a cost-effective investment despite the initial expense. Long-term benefits, such as reduced labor costs and higher yields, ensure significant returns on investment.[170]

Risks

Flight Duration and Range Agricultural drones, which carry relatively heavy loads, typically have short flight durations ranging from 20 to 60 minutes, resulting in limited land coverage per load. The cost of drones increases with longer flight durations.[171]

Initial Cost While affordable drones exist, adding imaging sensors, software, hardware, and specific tools significantly raises their price.

Connectivity Internet coverage is often unavailable in remote agricultural areas. In such circumstances, any farmer wishing to use drones must invest in connectivity or purchase a drone with local data storage capacity in a format that can be transferred and subsequently processed.[172]

Weather Dependency Flying drones in windy or rainy conditions is challenging, unlike traditional aircraft.

Misuse There is a risk of improper use, including violations of privacy, unauthorized surveillance, and illegal data transfers.

Examples

- **SpaceAG Air.** (Peru). Provides crop monitoring and variables such as irrigation issues, plant vigor, targeted field inspections and harvest projections. The information provided allows for additional profits of over 10% per hectare.[173]
- **Arpac.** (Brazil). Offers self-build professional drones for chemical and biological application and mapping. They also include maintenance and direct contact to create new specific solutions for farmers.[174]
- **DJI AGRAS T40 de Akron.** (China). All-electric “Megadrone” with a 40-liter tank and 50 kg payload capacity for fertilizers. It is suitable for spraying, fertilizing, cover cropping and soil surveying. It also has a collision avoidance system for safety.[175]
- **HD540Pro de Huida Technology.** (Mexico). A drone has been deployed in Ensenada de Mexicali to spray nutrients and pesticides in local orchards, improving planting efficiency by 60%.[176]

168. La industria de los drones en Argentina
169. Corteva registro en México para la aplicación con drones de uno de sus productos.
170. Aplicaciones de drones en la agricultura: monitoreo de cultivos
171. (Pathak et al., 2020)
172. Ver el apartado sobre conectividad 5G.

Discarded Technology: Nanotechnology

Nanotechnology involves the manipulation of matter on an extremely small scale and presents interesting opportunities for agriculture through applications such as nanofertilizers, nanopesticides, and nanoherbicides, that can sustainably boost food production and reduce environmental impact.[178]

Nanomaterials (NMs) stand out as a promising alternative to conventional materials due to their enhanced properties. Pesticides and fertilizers engineered at the nanoscale have proven highly efficient in delivering agrochemicals in a targeted and controlled manner. This increases their biological efficacy, leading to improved crop yields and productivity.[179]

However, nanotechnology raises concerns about potential health and environmental risks, particularly due to the accumulation of nanomaterials and their possible introduction into the food chain.[180] For example, soybeans exposed to NMs may accumulate metals in their leaves and grains,[181] negatively impacting soil fertility and raising questions about soil and water quality.[182]

While global investment in nanotechnology research and development has grown in recent years,[183] developing countries face significant barriers to adopt this technology as they include financial constraints, insufficient infrastructure, and limited human resources. It is therefore crucial for these nations to focus on specific areas of nanotechnology where they can achieve competitive advantages, as competing with leading producers remains a considerable challenge.[184]

CROP MANAGEMENT

Automated Irrigation Systems

In agriculture, an efficient irrigation system is as important as the quality of the seeds that are planted. Proper irrigation ensures crop success and helps achieve the expected yield. Meanwhile, water scarcity — a global issue particularly affecting remote and arid farming areas — has driven the adoption of automated irrigation systems as a solution to optimize water use, monitor agricultural operations, and reduce costs.

These smart systems integrate advanced technologies, sensors, and algorithms to manage irrigation with precision and automation. They monitor parameters such as temperature, air and soil humidity, and autonomously adjust the timing and volume of water application. Many systems also incorporate fertigation, enabling simultaneous application of water and fertilizers through the same system.

173. SpaceAG Air: Drones en la agricultura
174. Arpac Drones
175. Dji - Akron
176. Agricultores mexicanos utilizan el dron HD540Pro para mejorar su eficiencia en huertos
177. (FOLADORI et al., 2008)
178. La nanotecnología en la agricultura y rehabilitación de suelos contaminados
179. Uso de nanomateriales en la agricultura y sus implicaciones ecológicas y ambientales
180. (Gruère et al., 2011)
181. (Chen et al., 2003)
182. (Priester et al., 2012)
183. Nanotechnology Update: Corporations Up Their Spending as Revenues for Nano-enabled Products Increase
184. (Foladori & Invernizzi, 2005)

Recent innovations in this field leverage AI and ML, allowing these systems to adapt to changing conditions and further optimize water usage. These advancements represent a crucial opportunity to address the challenges of water availability and enhance agricultural efficiency while reducing environmental impact.

Context

Agriculture accounts for approximately 70% of global freshwater withdrawals, representing a significant share of this vital resource's usage. While only 20% of global cultivated land is equipped with irrigation systems, this area contributes 40% of the world's food production, underscoring irrigation's crucial role in global food security. Efficient management of irrigation systems is becoming increasingly urgent in the face of growing water scarcity driven by climate change, rising temperatures, and human activities that negatively impact the environment.

In Latin America, drought is an increasingly frequent issue. Over the past two decades, the region has experienced 74 droughts, causing damages estimated at over USD 13 billion. These events have severely affected agricultural production and the livelihoods of farmers, especially those in vulnerable situations. A clear example is the Dry Corridor along Central America's Pacific coast, more than 50% of smallholder farmers face drought and food insecurity, exacerbating precarious conditions.[190]

Prolonged drought in Mexico is creating a severe crisis in the agricultural sector, where 82% of farms rely on rainfall for crop and livestock production. States like Chihuahua, Sinaloa, and Tamaulipas have experienced a reduction in cultivated areas and a decrease production of key crops such as maize, beans, and chilies, driving up food prices and impacting both growers and consumers. While short-term measures, such as financial aid for farmers, promotion of more efficient irrigation techniques, and development of drought-resistant crop varieties, are being implemented, long-term solutions are necessary. These must address climate change and improve water management to mitigate the effects of the crisis and ensure the sustainability of Mexico's agricultural sector.[193]

In this context, adopting automated, and drip irrigation systems emerges as a solution to optimize water use, ensure consistent crop hydration, and mitigate the effects of drought. These systems not only enhance irrigation efficiency but also contribute to food security and agricultural sustainability in Mexico, helping to combat the adverse impacts of climate change on crop production.

Risks

In large-scale crops, irrigation systems often face challenges in terms of efficiency. [194]

Environmental Impact

Improperly managed automated irrigation systems can contribute to the depletion of local water resources and water wastage if not properly programmed and controlled.

185. Sistema de riego por goteo automatizado

187. ¿Que es la Fertirrigación? - Marco A. Oltra
188. El agua en la agricultura
189. Cada gota cuenta: es tiempo de actuar en América Latina y el Caribe
190. Cada gota cuenta: es tiempo de actuar en América Latina y el Caribe
191. Consecuencias de la sequía en México
192. Crisis en el campo: sequía prolongada afecta severamente la agricultura en México

Reliability System standardization and parameter calibration often require on-site adjustments, which are prone to human error. This can lead to irrigation failures, jeopardizing crop efficiency.

Connectivity Machine-to-machine (M2M) connectivity has been a problem in rural areas, which has hindered the implementation of technological solutions.

Environmental Conditions Elements like mud, calcium salts, sand, and other solids can clog devices, disrupting irrigation processes.

Examples

- **BrioAgro.** (Spain). An intelligent system that works as a robotic irrigator, which adapts to soil and crop types, achieving savings in water, electricity, and fertilizers. The system autonomously provides crop input when needed, with water savings ranging from 20% to 50%, along with labor savings associated with irrigation and fertilization.[195]
- **Knitink Technologies.** (Spain). An irrigation and fertigation control system tailored to crop needs. It establishes a wireless network managing from pumping and filtering, to fertigation, field valves and sensors, enabling real-time monitoring and information management.[196]
- **Netafim.** (Mexico). Combines automatic irrigation with fertilizer application. Precision fertigation is the optimal tool for root zone management as it provides the right combination of water and nutrients directly to each plant's root, according to each crop cycle.[197]
- **Kilimo.** (Argentina). Integrates satellite imagery and meteorological data using AI and big data to advise farmers on how much water to apply to their crops. Customers receive a message indicating exactly how many millimeters of water they need to irrigate.[198]

Smart greenhouses

Environmental Agriculture, including Smart Greenhouses, exemplifies the application of IoT in agriculture. These greenhouses create an autonomous microclimate for plant growth by incorporating sensors and monitoring systems. They can be used in various types of greenhouses, including hydroponics, aeroponics, and vertical farming.

Hydroponics immerses plant roots in water, while aeroponics keeps roots in the air and sprays them with a nutrient solution. Vertical farming organizes crops in stacked layers. These techniques have gained significance due to the unequal distribution of farmland

193. Crisis en el campo: sequía prolongada afecta severamente la agricultura en México
194. Agrotech: Soluciones IoT para un uso inteligente de los recursos hídricos – Monolitic
195. Riego automático Aqua - Brioagro
196. KNITINK

between large-scale operations and small-scale producers. A study highlights that vertical wheat farming on a single hectare could yield up to 600 times more than traditional methods.[201]

Context

Small-scale farmers, who operate on less than two hectares of land, produce about one-third of the world's food supply. However, they face significant challenges integrating into supply chains. Although 90% of agricultural operations are family-run, the largest 1% of farms control 70% of arable land, primarily supplying corporate food systems.[203]

Greenhouses have emerged as a solution for agriculture in limited or urban spaces, enabling year-round production. Ideal for crops like vegetables, tomatoes, and berries, greenhouses offer a controlled environment for consistent yields. Vertical farming, which focuses on leafy greens and herbs, provides an intensive alternative by optimizing water use, reducing production-to-market distances, and fostering food autonomy through precise control over essential growth conditions.[205]

In Mexico, protected agriculture has proven technically, agronomically, and economically viable in regions like northern Tamaulipas. This approach diversifies production schemes and ensures a continuous supply of vegetables such as tomatoes, cucumbers, and chilies to local, national, and international markets — even during adverse climatic months. Greenhouse systems have enabled up to 30% water savings compared to open-field irrigation methods.[206]

This model has significant potential for boosting the production of tomatoes and cucumbers in the country. Currently, Mexico exports approximately 1.7 million tons of tomatoes per year. The 2024 agricultural cycle in the coastal area of Baja California shows a 51% of the cultivated area planted, led by tomatoes, followed by chilies, onions, and cucumbers. The primary technology used in this region is Protected Agriculture, which includes greenhouses and shade nets to control environmental conditions.[208]

Mexico has surpassed one million tons of cucumbers in 2023, consolidating its position as the world's fifth-largest producer and third-largest exporter of this vegetable. The widespread implementation of protected and vertical farming techniques could further improve these yields, offering an opportunity to maximize efficiency in vegetable production, even in extreme conditions such as drought.

Risks

Risks associated with the implementation of these solutions include:[211]

Initial Cost Installation and operation can be expensive (LED lighting, automated irrigation systems, sensors, etc.). These initial costs can be prohibitive for farmers with limited resources.

197. Fertirrigación de precisión
198. Kilimo
199. Smart greenhouse - Designing Buildings
200. El (impactante) estado de la desigualdad de la tierra en el mundo
201. Wheat yield potential in controlled-environment vertical farms | PNAS
202. Los pequeños agricultores familiares producen alrededor de un tercio de los alimentos del mundo
203. El (impactante) estado de la desigualdad de la tierra en el mundo
204. ¿Qué cultivar en un invernadero? | Agropinos
205. Proyecto Agricultura Vertical: Innovación para la horticultura en América Latina y el Caribe (ALC)

Scalability The number of crops and production volume is not as large as traditional agriculture, and scaling up can add costs and complexity. It also does not support the cultivation of extensive products like maize and wheat.

Energy Use and Sustainability There is a high energy cost associated with the amount of light needed for different types of plants. Depending on the crop type, there is also a need for heating, ventilation, and cooling, which contributes to the carbon footprint.

Examples

- **Verde Compacto.** (Mexico). A smart container farming system that enables year-round vegetable production. The system uses vertical hydroponics and can produce up to 200 times more vegetables per square meter than traditional methods. It also saves up to 90% of water and is fully automated.[212]
- **Karma Verde Fresh.** (Mexico). Grow racks and LED lights use 90% less water and 95% less space than traditional farming. They are characterized by being completely herbicide- and pesticide-free, with annual harvests taking no more than 25 to 40 days.[213]
- **Ays Proje.** (Turkey) Double-ventilated greenhouse for berry production. Its infrastructure systems are designed to adapt to tomato plants, including climate control, special shading screens, CO2 injections and forced ventilation.[214]

Discarded Technology: Augmented and Virtual Reality

Virtual Reality (VR) creates immersive 3D environments that allow users to simulate real-world scenarios, while Augmented Reality (AR) overlays digital elements onto the real world, enhancing real-time interaction.[215]

In recent years, these technologies have garnered attention, particularly in manufacturing, where they are used in applications like assembly lines. They have also been explored for enhancing consumer experiences and education.[217]

In precision agriculture, these technologies could potentially optimize crop management through digital field tours, crop surveys, agricultural machinery training, and repair support.[218]

However, the use of AR and VR in agriculture remains experimental. Their effectiveness is limited by technological immaturity and reliance on complementary tools such as sensors, networks, machine learning, and connectivity. A lack of research and publications on AR

206. Mayor rendimiento en cultivo de hortalizas en invernadero
207. De Nuestra cosecha...
208. Lidera el cultivo del tomate, las siembras del PV 2024 en la zona costa de BC
209. Reporte Anual PEPINOS
210. El pepino y su vocación exportadora.
211. These are the 7 biggest DISADVANTAGES of vertical farming — Home
212. Verde Compacto

in agriculture—evidenced by the low number of studies between 2016 and 2021—indicates that these technologies are still in an early development stage and have not yet reached practical maturity.[219]

SMART HARVESTING

Harvesting Robots

Agrobots range from automated harvesters to autonomous devices that use computer vision and GPS to navigate fields safely.[220] Specially designed to fill labor shortages, increase speed and improve the efficiency of agricultural operations.[221]

Autonomous tractors are unmanned ground vehicles driven by an intelligent system of sensors that collect information for analysis. They are often used in large areas on farms, among other reasons, to minimize the risk of collision.[222]

In some cases, these harvesting robots have mechanical arms that handle fruit with care and precision, harvesting and transporting only ripe food thanks to an automatic detection system.[223]

Context

The harvest is a crucial time in agricultural production, as its timing directly influences the quality, quantity, and availability of food and raw materials, with a substantial impact on the agricultural economy. Automatic harvesters are used across a variety of crops, where the investment in technology is justified by efficiency gains. These machines are commonly used in extensive crops such as grains, cereals, tubers, and legumes, as well as in high-precision crops like fruits, vegetables, and coffee.[224]

Coffee, the second most traded commodity in the world, is exclusively cultivated in tropical regions. Latin America plays a major role in global coffee cultivation and trade.[225] For 2024, Brazil anticipates a 7% increase in its coffee harvest compared to the previous year,[226] while Honduras, a Central American leader, expects an 8% growth for the 2024/25 season.[227] These figures underscore the continued growth of coffee production and exports across the Central American region.[228]

In this context, automatic harvesters are proving indispensable in coffee production, where the quality of the final product depends on precise berry collection. These machines not only enhance harvesting efficiency but also gather valuable data on plant health, including

213. Karma Verde Fresh
214. Pagina Principal - Sistemas de invernaderos modernos llave en mano
215. BID Tech Report Metaverse
216. (Bottani & Vignali, 2019)
217. Discover the practical applications of AR and VR in various sectors
218. Augmented Reality Revolutionizing Agriculture Industry
219. (Hurst et al., 2021)
220. Agricultura automatizada y robótica agrícola - Ventajas y Desventajas
221. Agricultural Harvesting Robot Concept Design and System Components: A Review

the condition of branches and leaves, while enabling early detection of pests and diseases.[229]

Modern harvesters can collect coffee beans in seconds, a task that traditionally requires hours of manual labor. Equipped with advanced technologies such as intelligent image processing, these machines can analyze fruit quality and automatically sort berries by color.[230]

Automation is also transforming fruit picking. In Chile, AI-powered robots selectively pick apples, minimizing fruit damage.[231] Although Chile is the leading apple producer in Latin America, Argentina's apple harvest was expected to increase by 24%, while Brazil's was projected to grow by 12% in 2023.[232]

Risks

Many risks are not unique to robots and are also associated with industrial techniques in agriculture in general. These include:[233]

Political Impact Automation could concentrate economic power among capital holders, leading to job losses, labor tensions, and shifts in rural-urban relationships.

Social Impact Reduced employment opportunities in rural communities may exacerbate economic inequality.

Security Highly automated operations are vulnerable to hacking and sabotage. This could affect food production at critical moments and pose a risk in times of conflict or even for economic gain.

Examples

- **Four Growers.** ((U.S.) An autonomous tomato harvesting robot using a calibrated robotic arm with four cameras that can detect and harvest with high precision.[234]
- **XAG.** (China). Offers autonomous robots whose battery can store 4 hours of charge in just 15 minutes. They are suitable for working in crops such as legumes, grapes, mangoes, cocoa, and coffee.[235]
- **Agrobot.** (Spain). The first company in the world to market a strawberry harvester equipped with up to 24 independent robotic arms working in a coordinated manner. It adapts to any agricultural environment.[236]

222. Autonomous Tractor - an overview | ScienceDirect Topics
223. Agricultura automatizada y robótica agrícola - Ventajas y Desventajas
224. Maquinaria Agrícola: Tipos Y Efecto En La Agricultura
225. Los 10 principales países productores de café del 2024
226. Cosecha de campaña de café 2024/25 en Brasil avanza al 81%
227. Pronóstico café Honduras.
228. Instituto Hondureño del Café - Informe Estadístico 2020-2021
229. Hand-Picked vs Mechanized Coffee Harvesting - Perfect Daily Grind

231. História do café no Brasil: conheça tudo por trás dessa produção!
232. Chile: cosechan manzanas con robots voladores en Linares | Chilealimentos
233. Chile: cosechan manzanas con robots voladores en Linares | Chilealimentos

235. Últimos datos de la próxima temporada del hemisferio sur de la Asociación Mundial de la Manzana y la Pera - PortalFruticola.com
236. (Sparrow & Howard, 2021)

Discarded Technology: 3D Printing

3D printing, also known as additive manufacturing, creates three-dimensional objects by layering material. This technology has aided manufacturing by streamlining prototyping and production processes, offering significant improvements in the creation of physical products.[238]

In some countries, especially those with lower incomes or high restrictions, farmers struggle due to limited access to mechanized equipment. 3D printing could present a valuable solution by enabling them to produce their own tools and spare parts for agricultural machinery, potentially boosting productivity.[239]

However, several factors must be considered. The initial cost of acquiring a 3D printer can be high, making it less accessible for small-scale farmers. Additionally, printed objects often require post-processing, which adds extra costs and extends production times.[240]

In agriculture, where environments and needs are constantly evolving, the production speed of 3D printers may not be adequate. Moreover, utilizing these printers requires technical skills in 3D modeling, posing an additional learning curve for users.[241]

3D printing may not be a suitable investment for all farmers. In particular if they lack specific needs that justify the costs, or if their operations would not benefit significantly from the limited flexibility and scalability of this technology, compared to larger-scale methods. Therefore, a thorough analysis of needs and resources should be conducted before considering the adoption of 3D printing in the agricultural sector.

DIGITAL HARVEST MANAGEMENT

Agricultural Management Platforms

Agricultural management platforms provide integrated solutions for the agricultural sector, streamlining processes from crop planning and monitoring to supply chain management. These platforms centralize operations in a single system. Its primary goal is to facilitate data-driven decisions, resulting in significant improvements in efficiency, productivity, cost, and risk reduction in agricultural production. Increasingly, farmers are turning to cloud-based solutions for their advantages in data storage, speed, and processing capabilities.[245]

Agricultural e-commerce refers to digital platforms that facilitate online transactions of agricultural inputs and products. Although most platforms primarily target urban consumers in domestic markets, they also offer small-scale producers opportunities to reach international buyers.[246]

237. Four Growers
238. XAG - Unmanned Ground Vehicles
239. Robotic Harvesters | Agrobot
240. Impresión 3D, ¿qué es y cómo funciona? | Dassault Systèmes®
241. Las ventajas de la impresión 3D para la producción en masa
242. 3D printing for agriculture: Top 7 of the best projects | Sculpteo Blog
243. Advantages of 3D printing (and disadvantages) Complete guide
244. Advantages of 3D printing (and disadvantages) Complete guide
245. Software de gestión agrícola: ejemplos, aspectos claves y requisitos
246. Agritech LATAM

Context

The global health crisis accelerated the digitization across all sectors, including agriculture, achieving in months what was previously expected to take years. The increased use of smartphones, social media, and communication platforms has facilitated this transition, enabling rural areas to access new technologies.

In particular, the COVID-19 pandemic not only accelerated the digital transformation of the global economy, but also reshaped the way farmers manage their operations, fostering greater reliance on digital tools to connect with markets and improve efficiency. This shift is revolutionizing production models, driven by trends in data collection, storage, management, transfer, and analysis of large volumes of data.[245] Today, the digitization of agriculture covers a wide spectrum, from solutions that use mobile devices and cloud platforms for decision-making services to high-tech digital farms with integrated IoT systems.[246]

In Latin America, agricultural e-commerce platforms provide comprehensive solutions that go beyond merely connecting buyers and sellers. They incorporate customer acquisition, training, financing, transportation, storage, and online payments. Some platforms even handle logistics, such as product collection and delivery, to boost productivity and efficiency for farmers.[247]

Despite notable advances in the digitization of agriculture throughout the region, challenges persist and comprehensive strategies to promote technological adoption in the sector are still lacking.[248] Many areas, especially in Central America and the Andes, still lack access to reliable mobile networks, affecting up to 9% of the population, despite the progress made since 2020. Additionally, high poverty rates in rural areas hinder access to smartphones and mobile data services, mainly impacting smallholder farmers.[249] A study revealed that inadequate coverage and affordability issues leave up to 80% of rural populations without connectivity.[250] To ensure a successful future in the implementation of technologies in agriculture, addressing these barriers will be critical.[251]

Risks

High Cost The end-to-end cloud solutions provided tend to be expensive, representing a financial hurdle for small farmers and cooperatives.[252]

Vendor Lock-in Vendor lock-in refers to the inability to replace a product and service provider without incurring significant costs. This creates barriers to market entry.[253]

Connectivity Limitations Many of these solutions are designed for large-scale farms with fast Internet access. However, many of the rural areas lack connectivity, which limits their adoption and requires asynchronous alternatives.[254]

Data Security Concerns Online solutions can be vulnerable to unauthorized access, exposing sensitive crop data.[255]

247. Agritech LATAM
248. Digitalización y cambio tecnológico en las mipymes agrícolas y agroindustriales en América Latina
249. Digital Opportunities for Better Agricultural Policies | OECD iLibrary
250. Agritech LATAM
251. (OECD, 2020)
252. Agritech LATAM
253. Conectividad rural en América Latina y el Caribe. Un puente al desarrollo sostenible en tiempos de pandemia
254. (OECD, 2019)
255. Software de gestión agrícola: ejemplos, aspectos claves y requisitos
256. Software de gestión agrícola: ejemplos, aspectos claves y requisitos
257. Software de gestión agrícola: ejemplos, aspectos claves y requisitos
258. Software de gestión agrícola: ejemplos, aspectos claves y requisitos

Examples

- **AgroWin.** (Colombia). Leading agricultural software in Latin America for accounting and administrative management, specializing in perennial and temporary crops. It offers modules for total and automated crop control and three plans according to the needs and type of client.[256]
- **AGRI.** (Chile). Specialized software in the agricultural sector for centralized field management from any device. It includes modules for harvest control, processing and irrigation, and offers three plans depending on the customer's needs.[257]
- **Hispatec México.** (Mexico). Comprehensive agricultural software, ERPagro controls all processes from seed to delivery to the final customer.[258]

Discarded Technology: Tokenization and Blockchain

Blockchain technology enables the creation of decentralized and immutable digital records, facilitating the secure exchange of physical and digital assets.[260]

In agriculture, blockchain has the potential to transform production traceability by creating publicly accessible, auditable records across the supply chain, including for end consumers.[261] Furthermore, crop tokenization could unlock opportunities in decentralized finance (DeFi), reducing the need for intermediaries, cutting costs and transaction times, and enabling investors to participate in smaller or more remote agricultural projects.[262]

In Latin America, blockchain adoption in the agricultural and food sectors was expected to steadily grow by 45% between 2020 and 2023. On a global scale, investments in blockchain are projected to reach USD 1.48 billion by 2026.[264]

Blockchain development has proven complex and costly, remaining in an early and largely unregulated stage. Despite investments, many proof-of-concept (PoC) projects have struggled to demonstrate clear technological or commercial benefits.[265] In addition, the need for collaboration and standardization among companies to implement blockchain has proven to be a challenge. Some institutions have recalibrated their strategies, focusing on more specific use cases and overseeing governance and compliance operations. Although the financial sector has led blockchain experimentation, doubts and perceptions of low performance are now spreading to other industries due to the gap between initial expectations and the reality of the technology.[266]

259. AgroWin
260. Agri - Argentina - Software de gestión agrícola
261. Hispatec México
262. BID Tech Report Blockchain
263. What is blockchain? | McKinsey
264. Casos de uso de blockchain en las cadenas de valor agropecuarias: América Latina y el Caribe
265. (Grasso et al., 2022)
266. La inversión en Blockchain en España llegará en 2020 a 103,5 M$ y alcanzará los 377,7 M$ en el año 2023, según el informe elaborado por AMETIC
267. Tecnología Blockchain para todas las industrias | Globant Reports
268. Blockchain development and the Occam problem | McKinsey
269. What is blockchain? | McKinsey

IDB INITIATIVES IN **AGRICULTURAL TECHNOLOGY**

- **Plataforma de resiliencia agroforestal (Regional):** PThis project aims to improve efficiency and competitiveness in the production of coffee, cocoa, and honey in Mexico, Guatemala, and Honduras through the digitalization of processes and the Sirio tool. The initiative focuses on mitigating and adapting to climate change.[268]

- **Disease Monitoring and Prediction (Paraguay):** The program employs early warning systems using imaging and predictive algorithms to detect and control diseases in large-scale crops, reducing losses and boosting productivity. The Smartsoil solution automates monitoring through photovoltaic sensors and a real-time alert app, optimizing fungicide use and benefiting the environment.[268]

- **Innovation in the Rice Value Chain (Panama):** A pilot program involving 100 rice producers applies precision farming technologies and official best practices. The initiative aims to increase profitability, reduce greenhouse gas emissions by 40%, and capture 13,200 tCO2 equivalent. These reductions could be converted into carbon credits, providing additional income for producers.[269]

- **AgTech for Smallholders (Regional):** This project seeks to catalyze AgTech solutions to improve productivity, financing access, market connectivity, and climate resilience for smallholder farmers. It will support producers in Peru, Bolivia, Paraguay, Colombia, Honduras, and El Salvador through funding, training, and technical assistance, implementing 15 to 20 tailored technological solutions.[270]

270. SIRIO: Plataforma para competitividad de negocio y resiliencia climática de productores de cultivos agroforestales
271. SMART SOIL - Monitoreo y predicción de enfermedades en cultivos
272. Blockchain y Precisión: Innovando junto a productores de cadena de arroz en Panamá
273. Innovación en tecnología agrícola y agricultura digital para pequeños productores

- **PA in Cooperativa Naranjito (Paraguay):** This initiative supports small- and medium-scale producers in Paraguay by providing access to and adoption of PA technologies. The program includes financing, technical assistance, and high-tech machinery to enhance yields, optimize inputs, and reduce production costs, thereby improving farmers' incomes and livelihoods.[271]
- **Greenhouses 2.0 (El Salvador):** A pilot project using precision agriculture and data management is being implemented with the "Canasta Campesina" cooperative to improve crop production, quality, and marketability. The initiative will start involving cooperative-associated farmers (75% women) and expand to six cooperatives nationwide. The model promotes technology adoption, climate resilience, and market connectivity, with a focus on sustainability and the empowerment of women in agriculture.[272]

274. Cooperativa Naranjito: Agricultura de Precisión para productores de pequeña y mediana escala en Paraguay
275. Invernaderos 2.0: Adopción de tecnología e innovación para pequeños productores agrícolas de El Salvador

OPPORTUNITIES, CHALLENGES, AND FINAL REMARKS

Latin America and the Caribbean is a region of remarkable agricultural diversity, encompassing large-scale, mechanized commercial farms in the Southern Cone and smallholder farmers in the Andean and Central American countries. This diversity reflects the region's varied production capacities and the differing needs of its agricultural systems. LAC plays a critical role in global food production, standing as the world's largest net food-exporting region. However, the sector faces pressing challenges related to sustainability, efficiency, and resilience in the face of environmental degradation and climate change.

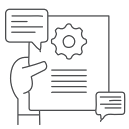
The region's agricultural success has come at a considerable environmental and social cost. Agriculture in LAC accounts for nearly three-quarters of freshwater use and almost half of the region's greenhouse gas emissions. Despite consistent food production surpluses, millions of people in the region suffer from hunger, malnutrition, and related health issues. Moreover, food waste and structural barriers prevent smallholders from accessing the resources needed to improve productivity. Limited connectivity, inadequate digitalization, and an aging farmer population further hinder the adoption of new technologies, threatening the long-term sustainability of the agricultural system.

Mexico is a major producer and exporter of products such as maize, avocados and tomatoes, with the agricultural sector playing a key role in its rural economy. However, the sector is highly fragmented, with many small-scale farmers struggling to access advanced technologies, financial resources, and international markets. While progress has been made in areas like protected agriculture and avocado cultivation, significant hurdles persist regarding productivity, access to credit, and infrastructure development to improve global competitiveness. Additionally, compliance with food safety, labeling, and sanitary and phytosanitary standards remains an obstacle for some Mexican producers.

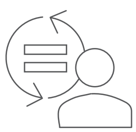
In this context, the adoption of technology presents an opportunity to overcome these obstacles by leveraging advancements from the Fourth Industrial Revolution. Innovations in AgTech, such as precision agriculture, AI for input optimization, and digital management platforms, can enhance crop efficiency, reduce costs, and minimize losses. Emerging technologies also enable greater traceability and transparency across value chains, helping producers comply with international regulations and access broader markets. Furthermore, these tools can support the incubation of new agricultural enterprises, making farming more appealing to younger generations and boosting employment among this demographic.

Despite recent increases in AgTech innovation, the region still faces a long road ahead to effectively reach smallholders and vulnerable populations.

Key challenges include:



Viable Solutions: Latin American investors must develop technologies tailored to a highly fragmented agricultural landscape dominated by small-scale farms with limited capacity, affordability, and implementation readiness. This fragmentation has skewed investment toward large-scale farmers, making it difficult for smallholders to adopt new technologies widely.



Equitable Access: Connectivity gaps, disparities in education, economic resources, age, and gender can hinder the adoption of new technologies. High upfront costs, insufficient infrastructure, and the concentration of power among technology providers, limit competition and slow innovation in the region.

Technological Scalability: For agricultural innovations to scale, adoption must extend across a wide range of actors with limited resources. IoT and application programming interfaces (APIs) are anticipated to be pivotal in driving the integration of sensors and satellite data, accelerating AgTech adoption in the years ahead.

Advancing connectivity and digitalization in rural areas will be essential to extending the benefits of these technologies to LAC producers. Investments in digital infrastructure and technical education can accelerate the adoption of AgTech solutions, improving resilience against external crises such as climate change and market volatility. Additionally, innovations in financing mechanisms, including fintech and credit access programs, could enable smallholders to invest in technologies that help them improve productivity and sustainability.

In this context, the Inter-American Development Bank (IDB) has a crucial part to play in facilitating the implementation of these technologies. By supporting the creation of public-private partnerships and promoting pilot projects, the IDB can demonstrate the tangible benefits of AgTech to smallholders in Latin America, fostering broader adoption and improving the region's agricultural efficiency and sustainability.

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