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Digitalization in Uruguayan agriculture: Digital technologies in livestock, dairy, and crop production

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Abstract

The increasing use of digital technologies worldwide has enabled more efficient agriculture through data usage and information analysis, impacting production models. This digital transformation poses a challenge in agricultural activities and rural areas, being a disruptive process that affects sectors, actors, and territories in different ways. At the national level, disparities in enabling factors such as infrastructure, connectivity, financing, skill development, and regulatory frameworks create differences in the adoption and use of technological tools across productive sectors. This article aims to identify and classify technological tools in livestock, agriculture, and dairy farming in Uruguay. The survey identifies 80 digital tools and technologies (41 in livestock, 25 in agriculture, and 14 in dairy farming). The classification proposal reveals a predominance of technologies aimed at quantifying, controlling, and managing processes and resources, highlighting the importance of data generation and information management for decision-making. These tools are primarily geared towards improving economic and productive efficiency, aiming at process control or traceability. It is noteworthy that these tools originate from various sources, including public entities, public-private organizations, and predominantly private companies. This reflects the country's strategic orientation towards adopting responsible and sustainable practices driven by a demanding global market.

Keywords: digital transformation, digital agriculture, classification of digital tools

Digitalización en el agro uruguayo: Tecnologías digitales en ganadería, lechería y agricultura

Resumen

El uso creciente de tecnologías digitales a nivel global ha permitido generar una agricultura más eficiente a partir del uso de datos y análisis de información, que impacta en los modelos de producción. Esta transformación digital ha implicado un desafío en las actividades agrícolas y en las áreas rurales, dado que es un proceso disruptivo que afecta de forma diferenciada a sectores, actores y territorios. A nivel nacional, la situación diferenciada de elementos habilitadores, como infraestructura, conectividad, financiamiento, desarrollo de habilidades, marcos regulatorios, etcétera, marca diferencias en la incorporación y la utilización de herramientas tecnológicas entre los sectores productivos. El artículo pretende identificar y clasificar herramientas tecnológicas presentes en ganadería, agricultura y lechería de Uruguay. Del relevamiento surgen 80 herramientas y tecnologías digitales (41 en ganadería, 25 en agricultura y 14 en lechería). A partir de la propuesta de clasificación, se observa una predominancia de tecnologías que procuran cuantificar, controlar y gestionar los procesos y recursos, poniendo en evidencia la relevancia de generar datos y gestionar información para la toma de decisiones. De este modo, las herramientas identificadas están mayormente orientadas hacia la mejora de la eficiencia económico-productiva, teniendo también como objetivo el control o la trazabilidad de los procesos. Es importante destacar que el origen de estas puede variar significativamente, abarcando entidades públicas, organismos público-privados y, principalmente, empresas privadas. Ello marca la orientación estratégica del país hacia la adopción de prácticas responsables y sostenibles, impulsadas por un mercado global exigente.

Palabras clave: transformación digital, agricultura digital, clasificación de herramientas digitales

Digitalização na agricultura uruguaia: Tecnologias digitais na pecuária de corte e leite, e na agricultura

Resumo

O crescente uso de tecnologias digitais em todo o mundo tem permitido gerar uma agricultura mais eficiente, baseada no uso de análises de dados e informações, que impactam os modelos de produção. Esta transformação digital tem implicado um desafio nas atividades agrícolas e nas zonas rurais, dado que é um processo disruptivo que afeta de forma diferenciada setores, atores e territórios. No nível nacional, a situação diferenciada de elementos facilitadores como infra-estruturas, conectividade, financiamento, desenvolvimento de competências, quadros regulamentares, etc., marca diferenças na incorporação e utilização de ferramentas tecnológicas entre sectores produtivos. O artigo tem como objetivo identificar e classificar as ferramentas tecnológicas presentes na pecuária de corte, agricultura e pecuária leiteira no Uruguai. Da pesquisa surgiram 80 ferramentas e tecnologias digitais (41 na pecuária de corte, 25 na agricultura e 14 na pecuária leiteira). Com base na proposta de classificação, observa-se um predomínio de tecnologias que buscam quantificar, controlar e gerenciar processos e recursos, destacando a relevância da geração de dados e do gerenciamento de informações para a tomada de decisões. Desta forma, as ferramentas identificadas estão majoritariamente orientadas para a melhoria da eficiência económico-produtiva, tendo também como objetivo o controlo e rastreabilidade dos processos. É importante destacar que a origem destes pode variar significativamente, abrangendo entidades públicas, organizações público-privadas e, principalmente, empresas privadas. Isto marca a orientação estratégica do país para a adoção de práticas responsáveis e sustentáveis, impulsionadas por um mercado global exigente.

Palavras-chave: transformação digital, agricultura digital, classificação de ferramentas digitais

1. Introduction

This study proposes an approach to the digitalization of the agricultural phase in different production chains in Uruguay. Its relevance lies in the sector's significant contribution to the national economy, the profound transformations that agriculture has recently undergone, and the expansion of information and communication technologies.

Uruguay is characterized by its insertion in the global market through agricultural and agro-industrial exports. While this has impacted the growth and development of the national economy, the fluctuations reflected in GDP *per capita* have not enabled closing the social welfare gap(1). This characteristic is fundamental to understanding the profound transformations occurring at the national level, driven by a strong flow of investments into the global commodity market. The transformations experienced by Uruguayan agriculture in the 21st century are such that Piñeiro and Moraes(2) compare them with those of the late 19th century, with the introduction of fencing and livestock crossbreeding. Among the changes, the increase and formalization of wage relations, indicated as a process of proletarianization(3), and the displacement of the local landowning bourgeoisie(2) stand out.

This scenario is part of the reconfiguration of a global agri-food regime, defined by profound transformations in trade and an intensification of the global division of agricultural labor, supported by two fundamental pillars: biotechnology and information technologies(4). This shift replaces the agro-industrial model with a new logic of accumulation known as agribusiness, characterized by cross-sectoral integration, the prioritization of the global consumer needs, the standardization of technologies, and land concentration(5). These dynamics manifest in diverse ways across territories; in Uruguay, technological change is central to understanding contemporary rurality and the possibilities for future transformation. The need for technological change has been highlighted as one of the main constraints for national development, particularly given the low rate of investment in science, technology, and innovation(6). In this context, digitalization is seen as fundamental for transformation, enhancing the efficiency, control, and management across production chains(7).

Based on this scenario, some questions that motivated the development of this study arise: What contributions does digitalization make to different productive sectors? What digital tools are available in the country? Who develops them, and who are their intended users? What role do they play within production systems?

Given the limited national research on digital technologies in the agricultural sector, this study aims to approach the presence of digital technologies in the agricultural phase by identifying tools available in agriculture, livestock, and dairy. Through a proposed classification, it analyzes and discusses the current state of affairs while raising questions for future inquiry from the perspective of agrarian social sciences.

1.1 Digitalization in Agricultural Production

Digital technologies are visualized by Patiño and Rovira(8) as essential tools to design, produce, and commercialize goods and services across sectors of the economy. Digital agriculture profoundly transforms agri-food systems. Also known as agriculture 4.0 or smart farming, it integrates advanced technologies such as robotics, artificial intelligence, big data, and automation to optimize resources, lower costs, and enhance sustainability. It relies on information and communication technologies (ICT) for the management of properties, improving both quantity and quality of products, while optimizing human work(9).

Digitalization applies ICTs across all stages of the food system, improving the flow of information, logistical efficiency, and food traceability(10)(11). These systems cover the entire food chain and are considered crucial for food security and economic development(12)(13). Digitalization also replaces human strength and cognition with sophisticated robots and algorithmic systems(14).

As for the concept of digitization, a distinction is made in English between *digitization* (converting analog information to digital) and *digitalization* (adoption and use of digital technologies), although in Spanish this difference is not always recognized. Some authors use them interchangeably, while others highlight the influence of digitalization on product platforms and organizational logics[(15)(16)]. In this article, the term *digitalization* will be used broadly, focusing on the availability of digital tools and technologies.

In Latin America, the adoption of technologies such as GPS systems, mapping tools, mobile apps and remote sensing is expanding, with Brazil and Argentina leading the way, followed by Uruguay and Chile[(17)]. This process requires responsibility and reflection on the inclusive and exclusive effects of digital technologies and their role in shaping transitions to future agriculture and food systems[(11)]. In addition, strategic management using digital technologies can contribute to sustainable development in rural areas, increasing productivity and technological efficiency[(18)].

The emergence of digital technologies in agriculture, as well as their aforementioned promotional arguments, is part of agricultural innovations. This concept is applicable in various areas, including the agricultural sector, where it unfolds in a complex and relational way[(19)(20)]. According to Johnson and Lundvall[(21)], social innovation focuses on satisfying unmet human needs, conceived as a cumulative, interactive, and institutionalized process that takes place in specific learning environments. This approach highlights the importance of learning processes within innovation systems. Arocena and Sutz[(22)] agree that innovation systems improve with greater connectivity and cooperation between actors, facilitating learning spaces that guide innovation towards the resolution of substantive social problems.

For some authors, big data technologies have the potential to significantly alter the relationships between actors in the agri-food system, facilitating greater efficiency and precision in agricultural practices[(23)]. Also, this type of tool can modify the power dynamics among the “players” of the food system and raise concerns over the privacy of the data collected[(23)]. Another aspect identified as relevant in the literature is the interoperability of technological systems, considered essential to maximize the effectiveness of these technologies, but which in turn increases vulnerability to cyber attacks[(24)].

Digitalization in agri-food systems is a disruptive process that, while promising benefits, can also intensify inequalities and foster exclusion and conflict. Alcántara and others[(25)] highlight that differential access to these technologies can widen existing gaps, resulting in unequal adoption and conflicts among different actors in the agri-food sector. In this regard, Carolan[(11)] introduces the concept of “cruel optimism” to describe situations where technologies, perceived as solutions, end up exacerbating pre-existing problems, creating unforeseen dependencies, and reinforcing existing inequalities.

This article is structured in five sections. The first introduces the research problem and explains its conceptual framework. The second one describes the methodology used in the study. In the third section, the results and their analysis are presented, followed by a discussion in the fourth section, and ending with some conclusions.

2. Materials and Methods

This study is part of an exploratory study[I], based on the proposal of grounded theory to construct conceptualizations and categories emerging from the data[(26)].

[I] The exploratory nature lies in the fact that it studies a phenomenon that has been little addressed, although it generates interest due to its problematic aspects, approaching and seeking to understand the problem without providing conclusive answers about the object of analysis[(30)].

To identify available technologies in Uruguay's agricultural, livestock, and dairy sectors, information was compiled from secondary sources, including public reports (from public, public-private and private institutions and organizations), academic articles (national and linked to the subject), business data (extracted mainly from websites or social networks), journalistic articles (related to the subject and somewhat recent), among others. Most of the information came from business data and public reports, collected primarily from websites[II] between February and March 2024. Keywords such as digital tool, digital technology, agricultural software, and digitalization were used individually and in association with each of the productive sectors surveyed. The selection of the items was based on their economic contribution to the national GDP, land use, and the number of producers involved[III].

Based on the conceptual framework adopted for the research, digital tools or technologies were considered in this study as computational instruments (platforms, programs, applications, devices) that support production system design and management, productivity growth, process optimization, and value addition.

2.1 General Characteristics of the Productive Sectors Studied

Uruguayan livestock farming covers approximately 12.8 million hectares[(27)], with its main forage resource being the natural grasslands. It is concentrated in the north, northeast, and center of the country, highlighting its heterogeneity in scale, specialization, applied technologies, and integration with other activities[(28)]. According to the latest agricultural census, there are 25,523 livestock farms, mainly oriented to breeding[(29)], with predominance of mixed systems (sheep and cattle graze together). Currently, the stock is 11.6 million cattle and 6.2 million sheep[(27)]. Livestock contributes around 5% of GDP, representing 24% of national exports (4.6% of the world beef market). These exports correspond to 94% of industrially processed products, and the rest correspond to live cattle sales[(27)(31)].

The dairy sector comprises 2963 producers[IV], including dairy farms and artisanal cheese makers[(32)]. Of this total, 72% supply milk to plants, with Conaprole processing about 70% of that volume[(33)]. The area covers approximately 649,000 hectares, with almost half of the dairy farms being between 50 and 199 ha. The productive nucleus is located to the southwest and along the coast of the Uruguay River[(27)]. This sector ranks ninth as the world's exporter of dairy products, commercializing 70% of national production to over 60 markets[(27)], being one of the sectors that generates the highest added value.

On the other hand, agriculture[V] is mainly located on the southern and northern coastlines, and central and southern regions of the country, covering an area of approximately 1.3 million hectares (harvest 22/23)[(27)]. Historically, the area was dominated by winter crops over summer crops, but since 2010, this relationship has been reversed[(34)], mainly due to the "soybean boom" that began in 2003, driven by the increase in its international price[(35)]. This scenario brought new farmers who intensified and diversified production[(36)]. Agriculture represents 46.1% of the total valued agricultural production[(27)], with the main summer crops being soybeans, corn, and sorghum, and winter crops including wheat, barley, and rapeseed. Its commercialization is export-oriented, representing 26.5% of agricultural exports[(27)].

In recent years, all three sectors have shown strong productivity growth, largely due to intensification processes driven by technological adoption and diverse technical advances[(31)].

[II] Additional information is available to readers upon request by contacting the authors.
[III] Although afforestation meets the first two differentiating characteristics, production is carried out by transnational companies whose logics differ from those of agricultural producers.
[IV] Taking into account that a producer can own more than one DICOSE, so this figure does not accurately represent different farms.
[V] It does not include rice cultivation.

3. Results

3.1 Proposed Classification of the Digital Technologies Surveyed

The survey identified 80 digital tools and technologies (DT) used by these sectors: 41 main DTs were surveyed for livestock, 25 for agriculture, and 14 for dairy.

For their classification, the study by Lachman and López[(37)] was taken as a relevant reference, which categorizes *agtech* services by their main uses. Based on this, the present study expands the categories according to the objectives these technologies address:

1. PROCESS CONTROL EFFICIENCY (40 DT) (**Table 1**): It brings together those technological tools that improve processes and productive outcomes, while also aiming at cost minimization and more effective cost control. It includes three dimensions:

- Process control and automation (21 DT): Related to the monitoring and follow-up of processes, they perform tasks in an automated way, report on status through records and data, among others, with varying degrees of human interaction.

- Production simulation (4 DT): They improve production processes through data and information processing, generating outputs from specific inputs, which, through simulation models, provide results for decision-making.

- Activity and resource management (15 DT): Enable management, administration, or planning of systems, involving a global scale.

2. CONNECTIONS AND EXCHANGES (27 DT) (**Table 2**): Technological tools that allow for communication, articulation, transactions, and networking between the different actors in agri-food systems.

- Commercialization (3 DT): Designed to optimize and diversify the methods of buying and selling products and services, facilitating the direct connection between producers, distributors and consumers.

- Dissemination of information (5 DT): Aimed at expanding and diversifying the approach of information between the different actors.

- Information or alert systems (19 DT): Provide rapid and useful data and information at scales larger than individual production systems, and contribute to decision-making.

3. REGULATIONS AND CERTIFICATIONS (13 DT) (**Table 3**): Encompasses those necessary –whether mandatory or not– for carrying out processes in the different sectors, enabling compliance with relevant accreditations and requirements.

Table 1. Technological tools found in the Production Efficiency category

PRODUCTION EFFICIENCY		
Process Control and Automation	**Production Simulation**	**Activity and Resource Management**
Soil Moisture Sensor	INIA-Grass	Farm Management Software
Pivot Irrigation	MEGanE	Water Level Sensor Reservoirs
Automated Ground Leveling Tools	UPIC PRO	Load Calculator
Variable seeding density	EfiCarne	Property Indicators Calculator in Grazing
Variable Rate Fertilization		Pasture growth visualizer
Selective application of herbicides		Comprehensive Property Management
Control Sections Application		Uruguay Family Farming Improvement Project (UFFIP)
Harvest and Productivity Mapping Monitor		OvinApp
Technology Application Teejet Spray Select		Livestock Management System (SGG)
CuthillHydroReader and DropLeaf		Grazing net
Drone		Mu App
Conditioning and harvesting of wool		Competitive Production Project
CLU-sheep count		GRASS-FED Certification Program
Electronic Scales		Lecheck
Caravan reader		
Livestock Environmental Assessment		
SRGen Program		
SULAR Program		
Diagnosis of ovarian activity and pregnancy		
G. PGanad		
Voluntary milking system		

Table 2. Technological tools found in the category Connections and Exchanges

CONNECTIONS AND EXCHANGES		
Commercialization	**Dissemination of Information**	**Information Systems or Alerts**
Grain Price Coverage	Meteorological Radars Network Extension	INIA-SARAS
Virtual Productive Animal Auctions	Water Information Viewer	INIA-DONCast
Muuu	Culti Data Viewer	Phytosanitary Application Management and Monitoring System
	Technology Guides	Comprehensive Monitor of Risks and Impacts (MIRA)
	TV and Radio Plan	Predator Bigging and Attack Information System (SIAAP)
		Web and App Geographic Information System (SIGRAS)
		-Chillindex
		-Prediction of conditions predisposing to heat stress (meat)
		-Agroclimatic data bank -Monitoring forage productivity of natural grasslands
		-Monitoring (APAR) vegetation growth indicator
		-Normalized vegetation index
		CultiDatos_uy
		National Livestock Information System for Producers (SNIG)
		Bovine genetic evaluations
		Sheep genetic evaluations
		Farmer's website (web)
		INAC info (App)

Table 3. Technological tools corresponding to the Regulations and Certifications category

REGULATIONS AND CERTIFICATIONS
Supply Registration and Management System
Agricultural Traceability
Land Use and Management Plan Registration
Property and transit guides
Environmental Sustainability Certifiers
Livestock traceability
Livestock traceability
Property and transit guides
Supply Registration and Management System (SRGA)
Digital transformation in Uruguay's artisanal cheese factory
Dairy Effluent Management System Certification
Export Digitalization
Sanitary certification for the export of milk and dairy products

4. Discussion

A prevalence of DT was observed across all three productive sectors, particularly in process control and automation, linked to process control efficiency. This suggests an orientation towards efficient and sustainable agricultural production systems, characterized by lower costs and reduced reliance on human labor, which involve the various sectors and agents that participate in the production chains. Collectively, these tools optimize production processes through the regulation of variables for an increase in efficiency and productivity. They operate through the implementation of monitoring systems and automatic sensors that can adjust conditions in real time based on specific data, optimizing the use of resources and improving yields. Examples include livestock programs to control wool conditioning and harvesting records (SIRO), platforms for bovine and sheep genetic improvement records (SRGen and SULAR); in precision agriculture, tools such as environmental management (variable seeding density and yield mapping with harvest monitors), and in dairy, robotic milking systems.

Technological tools also strengthen decision-making, since they enable the collection, analysis, and processing of large volumes of data in real time. The improvement of production simulation models allows predicting the impact of different management strategies on yields, supporting the selection of optimal options. An example of the three addressed areas is the availability of eco-physiological prediction models (INIA-Gras).

Automation and process control align with environmental sustainability by minimizing the impact of agricultural practices. Examples include the Livestock Environmental Assessment tool, technologies for precision in the application of agricultural inputs (selective application of herbicides and fertilization with variable doses), and the certification of the Dairy Effluent Management System. These tools not only lower production costs but also minimize input losses due to excess, contributing to more sustainable production.

Another aspect to point out is resilience to changes in the production environment. The ability to adapt quickly to changing conditions can be considered as another significant effect of automation and process control. In the face of climate variability, these technologies can mitigate risks by ensuring the continuity of production. Nationally, this is evident in the Pasture Growth Visualizer for beef and dairy systems, and in the Soil Moisture Sensors in irrigated agriculture.

The organization of work changes with the widespread adoption of DTs, moving from intensive and manual tasks, variable in their precision, to managing standardized agricultural systems. In the case of livestock, an example is the sheep counting; in dairy, the organization of herd management tasks (MuApp), and in agriculture, the implementation of the drone.

As for the category of Connections and Exchanges, the survey for the three productive sectors reflects a differential distribution but is less heterogeneous than the category analyzed above. It is possible to account for the predominance of information systems or alerts indicating a trend towards the valorization of the collection, analysis, and efficient distribution of data for decision-making. The ability of these systems to provide real-time data and alerts on crop, climatic, or market conditions is key to the resilience and adaptability of production systems. An example of these three sectors is SIGRAS, which provides real-time national soil water balance data.

Likewise, dissemination of information also emerges as key to the transmission of knowledge on sustainable practices, new technologies, market trends, and development opportunities. The preference for these technologies evidences the value given to information. A shared example across the three analyzed sectors is the extension of the network of meteorological radars.

Regarding the commercialization dimension, the technologies surveyed suggest room for improvement in the platforms and tools that facilitate the commercialization of products. Efficient commercialization is essential for market access and profit maximization. Some examples include televised and online livestock auctions such as Pantalla Uruguay, Plaza Rural, Lote 21, and the Muuu application.

Finally, within the category related to regulations and certifications, Uruguay offers emblematic tools such as the national bovine traceability system (SNIG), which records all cattle (meat and milk), from birth to final destination. Agriculture also includes traceability schemes and sustainability certifications; an example of this is the Land Use and Management Plans.

The presence of the categories analyzed in the different sectors shows particular digitization strategies. This research suggests that the relationship between the agricultural and industrial phases shapes the way in which technologies are adopted. While the dairy sector reflects strong industry leadership, in livestock and agriculture, DT adoption remains fragmented and often uncoordinated among chain actors.

This raises the need to further explore different elements that underlie digital tools, such as the distribution of power both in the control of data and in the appropriation of the aforementioned tools. In this regard, Rotz and others[24] suggest that large corporations can centralize control over data, exacerbating inequalities among farmers, which can lead to the exclusion of smallholders. This phenomenon echoes other global processes such as supermarket consolidation, financialization and data hoarding, and land concentration[12][38].

5. Conclusions

The approach to the DTs available in Uruguayan agriculture has not yet been explored in the agrarian social sciences. This review of agriculture, dairy, and livestock in Uruguay has evidenced their availability in the three sectors, although their presence is uneven, and classified them into three categories according to the objective of each digital technology: efficiency of process control, connections and exchanges of the production chain, regulations, and process certifications.

The analysis of these DTs reflects a strategic orientation of Uruguay's agricultural sector towards the adoption of responsible and sustainable practices, driven by a demanding global market for safe, high-quality products with low environmental impact. Consumer preferences would explain the presence of digital technologies that ensure process transparency and traceability from production to final destination.

Likewise, the predominance of digital technologies that seek to quantify, control, and manage processes and resources highlights the relevance of data generation and information management to make informed decisions, leading to the efficient use of productive, monetary, natural, human, and financial resources, and more. This requires capacity-building and training for actors, as well as stronger integration across agri-food system stages. Nonetheless, the study has some limitations: i) restrictions on access to information, given that a large part of digital tools and technologies are for private use and belong to companies; ii) rapid evolution of technologies and availability of new ones, which could make the proposed typology obsolete; iii) complexity and diversity of productive sectors, which require selection criteria, and iv) the exploratory nature of the study, which did not allow for an in-depth study of the influence that digitalization has on the different types of producers and actors in agricultural production, among others. These limitations and the results obtained raise new questions for future research, such as: can all actors in the agricultural sector incorporate digital tools and technologies in the same way? What impact does digitalization have on agricultural work? How do digital technologies influence producer-extension interaction? What role do enabling infrastructure, digital literacy, information ownership, etc., play in the digitalization process?

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Transparency of Data

Available data: Most of the data supporting the results of this study were published in the article itself.

Author Contribution Statement

	PL	HP	IFR	MM	DP	MP	LS	VC
Conceptualization	■	■		■	■	■	■	■
Investigation	■	■		■	■	■	■	■
Supervision								■
Visualization	■	■		■	■		■	■
Writing – original draft	■	■		■	■		■	■
Writing – review and editing		■						

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