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How Digital is Agriculture in South America? Adoption and Limitations

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Abstract.

A rapidly growing population in a context of land and water scarcity, and climate change has driven an increase in healthy, nutritious, and affordable food demand while maintaining the current cropping area. Digital agriculture (DA) can contribute solutions to meet the demands in an efficient and sustainable way. South America (SA) is one of the main grain and protein producers in the world but the status of DA in the region is unknown. Systematic review of official reports and surveys, literature, and case studies from Brazil, Argentina, Uruguay, and Chile was conducted to address the following objectives: i) quantify adoption of existing DA technologies, ii) identify limitations for DA adoption, iii) summarize existing metrics to benchmark DA benefits. The Region of study showed to follow the same trend than the world on DA adoption. The level of adoption was led by Brazil and Argentina followed by Uruguay and Chile. The GPS guidance systems, mapping tools, mobile apps and remote sensing were the most adopted DA technologies in SA. While, technology cost, lack of training, limited number of companies providing services and unclear benefits from DA were the most reported limitations for adoption. Clear economic, social, and environmental metrics that track the benefits of DA could promote adoption as well as help benchmarking future research and extension projects.

Keywords.
Digital agriculture, Adoption, Precision Agriculture, Sustainability, IoT

Introduction

A significant increase in demand for healthy, nutritious, and affordable food and feed is the consequence of a growing population in a context of land and water scarcity, and climate change (Fischer and Connor 2018; Tilman et al. 2002). South America (SA) is one of the main grain and protein producers in the world accounting for 10% of the world's agriculture product export (FAO 2021). Agriculture transformation in SA is continuously evolving due to joint efforts from research entities, who have developed new technologies, improved agronomic practices, entrepreneurial investment, and government support (A Odusola 2021). An evaluation of the level of adoption and limitations of recent innovations in agriculture technologies in Brazil, Argentina, Chile, and Uruguay (from here on "the Region"), is vital to guide future research, extension, and investment to satisfy future food demand.

The United Nations defined Digital Agriculture (DA)as "the use of new and advanced technologies, integrated into one system, to enable growers and other stakeholders within the agriculture value chain to improve food production" (United Nations 2017). DA is considered part of fourth revolution in agriculture addressing four essential challenges: increasing productivity, allocating resources reasonably, adapting to climate change, and avoiding food waste (Klerkx et al. 2019; Trendov et al. 2019). One of the most developed branches of DA is precision agriculture (PA) but also includes IoT, blockchain, big data, machine learning, and artificial intelligence, robotics, and automation (Robertson et al. 2019).

Digital Agriculture was proposed as an effective way to optimize agriculture production systems by improving yields, profitability, and reducing environmental impacts from agricultural practices (Balafoutis et al. 2017; Klerkx et al. 2019). Despite concerns related with the adoption of these technologies across countries, food production sectors, and size of stakeholders, there is evidence of benefits driven by rapid access to connectivity and mobile phone apps (GSMA 2020). Worldwide mobile phone adoption has dramatically increased both in developed and developing countries (Taylor and Silver 2019). In contrast, growers lack of knowledge about DA benefits can pose limitations for adoption (Bolfe et al. 2020; DeLay et al. 2021; R. J. M. Melchiori et al. 2018; Thompson et al. 2019). Most of the literature reported benefits from DA using economic metrics related with PA technology (Bongiovanni and Lowenberg-Deboer 2000; Borghi et al. 2016; Timmermann et al. 2003). References on other benefits of DA such as time-saving (Casaburi et al. 2019), increase input use efficiency (Balboa 2014; Kayad et al. 2021) are limited.

In this review we aimed to characterize the status of DA in a subset of countries of SA: Argentina, Brazil, Uruguay, and Chile (hereon the Region). We conducted a systematic review (i.e., official reports, surveys, and peer reviewed publications) to i) quantify adoption of existing DA technologies, ii) identify limitations for DA adoption, and iii) summarize existing metrics to benchmark DA benefits on food production systems.

Materials and methods

A literature review was conducted to characterize the Region in terms of DA, summarize different surveys about adoption and limitation of DA and retrieve a list of metrics to benchmark DA benefits. Papers were retrieved from Web of Science Core Collection, Scopus, Springer, Agricola, and Google Scholar using the following keywords, individually and in combination: Digital Agriculture, Argentina, Brazil, Chile, Uruguay, South America, IoT, Precision Agriculture, Big Data, digital platforms, DA survey, DA adoption, and DA benefits. SGray literature, defined as the one produced in print and electronic format, by any levels of government, academics, business and industry, but not controlled by a commercial publisher (Saleh et al. 2014). This review includes surveys with different data collection methods. This limits quantitative comparison between countries of the Region. However, the methodology is an impressionistic comparison providing an overall picture of the state of DA in the Region (Lowenberg-DeBoer and Erickson

2019).

Surveys conducted by public research institutions from Brazil (Brazilian Agricultural Research Corporation, EMBRAPA; Borghi *et al.* 2016; Bolfe *et al.* 2020), Uruguay (Berger et al. 2019), and Argentina (R. Melchiori et al. 2013; R. J. M. Melchiori et al. 2018) were compiled to characterize the adoption of DA technologies. Our review indicated that here is no official survey records in Chile and we reported findings from a survey conducted by the Agronomical Engineer Association in Chile (Palacios Duran et al. 2021). No new surveys were conducted in this study. A list of sustainability indicators was compiled to benchmark DA benefits (**Table 2**).

Results and discussions

Adoption and DA technology in the Region

Technology adoption is a path to increase farm productivity and improve food security. The process of technology adoption is heterogeneous across farms and across the Region (Chavas and Nauges 2020). The literature review allowed to compile a list of surveys, reports, and manuscripts to describe the level of adoption of DA and their limitations. Adoption percentages (expressed as % of the responses to each survey) by technology by country in the Region is presented in **Fig. 1**.

Table 1. List of papers and reports that met the search criteria for the review on adoption of Digital Agriculture in South America.

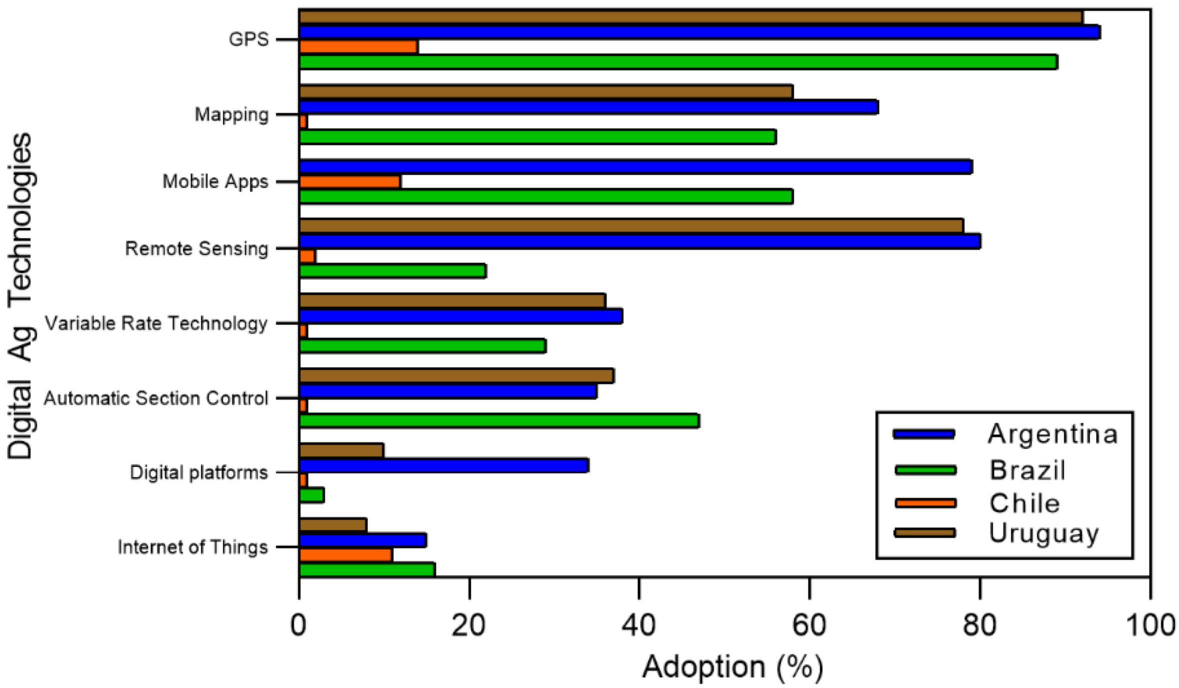
Author	Publication year	Country/Region
Melchiori *et al.*	2018	Argentina
Melchiori *et al.*	2013	Argentina
Kemerer *et al.*	2020	Argentina
Bolfe *et al.*	2020	Brazil
Berger, A *et al.*	2019	Uruguay
Duran *et al.*	2021	Chile
Borghi *et al.*	2016	Brazil
Bragachini *et al.*	2004	Argentina
Villalobos Mateluna *et al.*	2009	Chile
Villarroel *et al.*	2020	Argentina
Best and Vargas Quiñones	2020	Chile
Sotomayor *et al.*	2021	Latin America
Nagel J.	2012	Latin America
Fonseca Silveira Massruhá *et al.*	2020	Brazil
Pivoto *et al.*	2019	Brazil
Lachman and López	2019	Argentina
International Development Bank	2019	Latin America and Ca
Figueiredo *et al.*	2021	Brazil
Steinfeld *et al.*	2021	Uruguay
Bongiovanni *et al.*	2006	Latin America
Castaño J.	2006	Uruguay
Roel A.	2005	Uruguay

Across the Region, GPS, mapping tools, mobile apps and remote sensing were the most used DA technologies, except for Chile, whit relative low adoption of all the mentioned above (**Fig. 1**). Similar adoption percentage for GPS was reported in United States (60%) (Erickson et al. 2017) and in Australia with 77% (Llewellyn and Ouzman 2014). Global Navigation Satellite Systems (GNSS) guidance and associated technologies have been adopted as fast as other major agricultural technologies throughout history. On the other hand, variable rate technology (VRT) does not exceed 20% of adoption at world level (Lowenberg-DeBoer and Erickson 2019).

The 2018 INTAs' survey in Argentina (n=306), reported 86% of the responses from Pampas Region that concentrate most of the row cropping area. The DA technologies that reported the highest level of adoption were GPS (94%), remote sensing (80%), mobile apps (79%) and mapping (68%) (**Fig. 1**) while IoT devices adoption was below 20% in agreement with all countries in the Region Adoption of PA technologies increased from 2013 to 2018 for automatic pilot (40 to 61%), ASC in Planters (7 to 21%), VRT seeding (27 to 35%) and VRT fertilizer (29 to 41%).

Among users, 85% reported to import and visualize data and 80% performed field management zones (MZ). Only 56% of this pool of participants used MZ to direct soil sampling. It was reported that 45% and 50% of growers that performed MZ were used for variable rate seeding and fertilizer prescriptions, respectively. Those percentages remained approximately stable from 2013 to 2018 (Kemerer et al. 2020).

Fig 1. Adoption (%) of digital agriculture technology (DA) for Argentina, Brazil, Chile, and Uruguay. Data sources: Argentina (Melchiori et al. 2013, 2018; Kemerer et al. 2020; Villarroel et al. 2020), Chile (Villalobos Mateluna et al. 2009; Duran et al. 2021; Ortega pers comm 2021), Uruguay (Berger et al. 2019), Brazil (Borghi et al. 2016; Bolfe et al. 2020). The % of adoption is indicated in relation to responses to each survey.



Relatively new DA tools such as digital platforms, connectivity, data interoperability and new hardware (electric motors to action mechanisms) might positively impact input VRT adoption. Solving issues related to data management and processing, to process from field data layers (yield, soil, and EC maps) to input prescriptions.

The main factors limiting the adoption of DA technologies in Argentina were technology cost (50%), lack of specialized labor (38%), limited training opportunities for agronomist and machine operators (27%), reduced number of services providers (33%), and the lack of clear agronomic and economic benefits (18%) (Bragachini et al. 2004; Kemerer et al. 2020; R. J. M. Melchiori et al. 2018). The main limitation reported by users, once technology was adopted, were the need for greater specialization for data processing (62%), compatibility issues between software and/or hardware (46%), lack of post-sale service from companies (39%), and agronomic background for input variable rate decisions (36%). In summary Argentina DA technologies users demands more training (83%), availability of agronomic data to support decisions (96%) and discussion and interchange sessions among PA tools users (70%) to increase adoption of DA (Kemerer et al. 2020).

The reviewed survey from Uruguay (n=124) covers 300,000 ha (25% of the cropping area). Technologies that reported more than 50% of adoption were GPS, satellite imagery, light bar, georeferenced soil sampling, automatic pilot, and yield maps (Berger et al. 2019). More than 50% of participants attended workshops and ~40% took training courses. Among responses in Uruguay, 20% used weed sensors or sensors for variable rate N application. Variable seeding rate was implemented by 24% of participants. In Uruguay, the main driver for adoption was associated with economic aspects such as increases in profits (68%), crop yields (63%), production quality (43%), and decreases in input use (56%), environmental impact (48%), and labor hours (32%). The main limiting reasons reported in Uruguay that limits adoption were the lack of labor specialized (50%), lack of training courses (43%), and machinery operators (42%), number of companies providing DA services (39%) and high technology cost (36%)(Berger et al. 2019). The INIA Uruguay is investing efforts developing IoT sensors networks to promote their adoption in intensive systems (Silveira et al. 2021).

In Brazil (n=502) survey responses indicated that 84% of growers used at least one DA tool (Bolfe et al. 2020). Most of the growers (70.4%) reported to have connectivity on their property and 58% use mobile apps, digital platforms, or software to gather general information. In Brazil, 95% of growers use smartphones (Michels et al. 2019) and 71% use mobile apps to assess specific management practice or pest and diseases detection and prediction. The technology with highest adoption was GPS (89%), followed by mobile apps (58%), mapping (56%) and automatic section control (47%). The main drivers of DA adoption identified were increased productivity, better process quality, reduced cost, and greater knowledge of the farming area (Pivoto et al. 2019). Technology implementation cost (68%), lack of internet connection (45%), cost of service providers (45%) and lack of knowledge about technology (42%) were the main factor identified by growers that limited adoption of DA (Bolfe et al. 2020). Brazilian farmers (57%) consider internet connection in the total perimeter of the farm as regular and 25% consider it poor connection.

In Chile, only one survey was conducted by the Agronomical Engineer Association. No other official survey about the percentage of adoption of DA or PA technologies is available. In 1997, research studies demonstrated high variability in soils properties and crop yields in Chile, which justified the use of variable spatio-temporal management (R. A. Ortega and Santibáñez 2007; R. Ortega and Esser 2003). The use of PA technologies in Chile agriculture started in 2000. The main technologies incorporated were GPS and remote sensing tools. Publications shows that a major obstacle is the limited number of companies providing DA-related services and adequate training programs. Research efforts are focused on identifying technologies to measure and diagnose spatial variability rather than improving data interpretation and developing prescription frameworks. Two main drivers for DA adoption in Chile are cost reduction and increase in production quality. While the lack of knowledge about DA technology from farm and company managers is one of the main limitations for adoption (Villalobos Mateluna *et al.* 2009; Best *et al.* 2014). The reviewed survey from the Agronomical Engineer Association in Chile was conducted in 2021 and showed that 95% use at least one DA mobile app in their daily activities. This survey identified connectivity, training, and generational issues as main limitations for DA adoption. As a result, a special commission for Innovation and digital transformation was created in the Association. Only 5% of the area in Chile is managed using PA technologies, vineyards and fruit crops represented most of the area (Palacios Duran et al. 2021). A small and fragmented DA industry and the lack of research and development difficult the promotion of DA benefits across Chilean agriculture producers (Best and Vargas Quiñones 2020). Adoption of DA techniques is driven by the larger export sector with a 60% adoption in vineyards and 30% in horticulture while the level of adoption for extensive crops is close to 15% (Stanley Best 2021).

Benchmarking metrics for DA benefits

Articles reviewed mentioned the need for current, future research and extension programs to report metrics to benchmark benefits from DA. We compiled from the literature a set of indicators that can be grouped into economic, social, and environmental (**Table 2).** The economic related metric is the most reported in the literature. Despite local, regional, or worldwide research and extension efforts, there is a perception from growers and stakeholders of lack of local knowledge and experimentation to demonstrate the benefits of DA. There is a need for more socioeconomical studies to demonstrate benefits on DA (Klerkx et al., 2019).

Table 2. Literature review of sustainable indicators to benchmark digital agriculture benefits and examples of them.

Classification	Indicator	Unit	Reference
Economic	Output	$, quantity	(Chopin et al. 2021; FAO 2017; Lebacq et al. 2013)
	Inputs	$, quantity	
	Net Profit	$	
	Output quality	*	
	Total factor productivity	Outputs inputs^{-1}	
	Partial factor productivity	Output input^{-1}	
Social	Advisory contact per year	n yr^{-1}	(Chopin et al. 2021; Lebacq et al. 2013)
	Quality of life	Not reported	
	Education	Not reported	
	Total labor	Person d ha^{-1}	
	Time-saving for a labor	h labor^{-1}	
Environmental	Input efficiency	product input^{-1}	(Chopin et al. 2021; Lebacq et al. 2013)
	Pesticides Usage	kg ha^{-1}	
	Agro-diversity	(n) crops per farm	
	Greenhouse gas emission	Mg CO_2 eq ha^{-1}	
	Farm gate N balance	kg ha^{-1}	
	Water use efficiency	l kg^{-1}	
	Soil loss	Tn ha^{-1}	
	Crop rotation		
	Crop diversification	N crops year^{-1}	

A large proportion of reported indicators are related to application of PA tools and techniques. Benefits are the result of an increment in production, with the same or with less quantity of inputs (thus improving input productivity) (**Table 2**). From the environmental point of view, increasing concerns from society about the impact of production practices are pushing to incorporate research objectives to evaluate environmental indicators. such as carbon (Accorsi et al. 2016; Bondeau et al. 2007) and N balance (Tenorio et al. 2020). These metrics could provide a benefit to farmers considering that there are markets offering an increase in price for a product if the seller can provide traceability of the product and demonstrate that it was produced sustainably (Rejeb et al. 2020).

Conclusions

Brazil and Argentina led DA tools adoption, followed by Uruguay and Chile. The GPS guidance systems, mapping tools, mobile apps and remote sensing were the most adopted DA technologies in SA. The adoption of agriculture apps was promoted by access to mobile phones by growers and the support of private sector and public institutions.

The most reported limitations for adoption were technology cost, lack of training, a limited number of companies providing services, and the unclear communication of benefits from DA. To address these limitations there is a need of new educational curriculum to fulfilling in demand job skills such as data processing, analysis, and interpretation. In addition, we compiled a set of economic, social, and environmental metrics that can be implemented in future research and extension efforts to better communicate the benefits from DA.

The future adoption of DA is expected to keep evolving and the institutional support will be fundamental over the long-term. A standardized survey in the Region is needed to cover other countries and topics like social implications of DA adoption. These efforts will allow stakeholders to design better initiatives to promote DA towards increasing sustainability of food production in the Region.

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