Technological Adoption Framework for Mitigating Food Insecurity in Caribbean Small Island Developing States: A Bibliometric Approach

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Small Island Developing States (SIDS) depend heavily on imported food. The COVID-19 pandemic disrupted food supply chains and further plunged SIDS into food and nutritional insecurity. To ensure sustainable development and food security, the dependence on external markets for food must be significantly reduced. It has been recognised that integrating appropriate technology into regional farming systems can bolster production. To this end, 3260 articles (published between 2010 and 2020) relating to technology and its adoption in agriculture, obtained from the Web of Science database, were systematically reviewed using a meta-analysis approach. Bibliometric analysis identified three data clusters (soil and agronomic research, remote sensing and imagery, and technology in agriculture) and a trend of moving toward the latter clusters in developed countries. Whereas content analysis highlighted developing country preferences for climate-smart and conservation agriculture technologies and practices, training, government subvention, change agents, and access to capital and credit as important determinants to technology adoption. These findings and specific conditions in SIDS were synthesised into a framework for the adoption of technology in Caribbean agricultural systems. The framework recognises the size and economic disparities in SIDS and suggests the adoption of high and medium-cost ubiquitous technologies in the Caribbean continental and larger island states. Conservation, climate-smart, and indigenous agricultural practices and technologies can be broadly integrated into regional agriculture production systems for increased food security, climate resilience, and sustainability.

Keywords: Food security, technology adoption, framework, Small Island Developing States, bibliometric analysis, content analysis

Introduction

Food supply chain disruptions have potentially compromised food and nutritional security in many developing states, due to rising external supply shocks and increasing volatility of global food supplies (Lal et al. 2020). Disruptions to the global food supply chain can cause sudden and dramatic increases in food prices. COVID-19 was declared a pandemic in March 2020, consequently, the global prices of wheat and rice increased by 8% and 25% respectively, as compared to the same period in 2019 (Torero 2020). The Food and Agriculture Organization (FAO)

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food price index indicated that food prices were 40% higher in August 2021 than in August 2020.

Small Island Developing States (SIDS) are particularly vulnerable to external economic shocks, exacerbated by their small size, remoteness, narrow resources, limited export base, and high dependence on imported foods. Caribbean SIDS have recognised the need to reduce their reliance on external markets by increasing intra-regional trade, developing regional food and nutritional policies, providing social protection through food assistance, and increasing domestic food production through agriculture subsidies (Figure 1). However, the diversity of culture, geography, climate, and economies, has made the development of an actionable plan challenging.

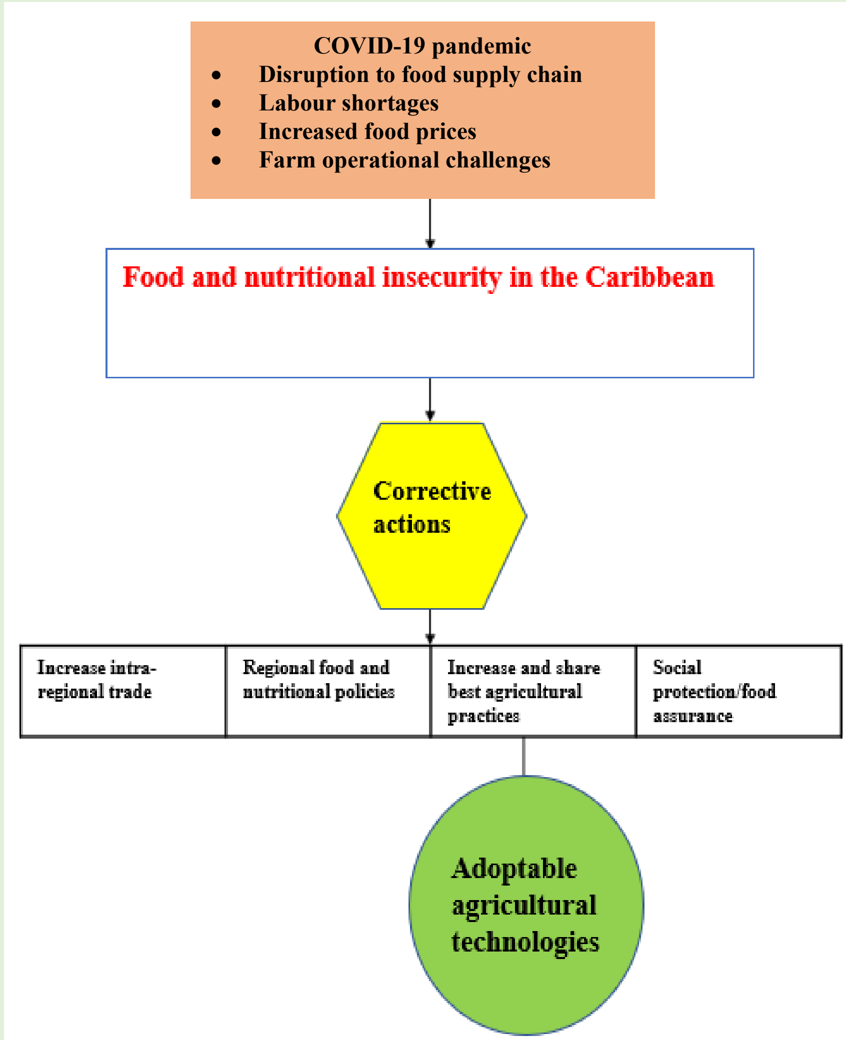

Figure 1: Conceptualising a framework for mitigating the increase in food insecurity in SIDS due to the COVID-19 pandemic through technological adoption

Most Caribbean countries are either SIDS members or associate members. This diverse region includes islands in the Caribbean Sea and the North Atlantic Ocean, as well as countries in South and Central America (Figure 2). They can be divided into three groups, smaller islands, larger islands, and continental states. The most obvious difference between these groups is physical size. Although continental states are substantially larger than other categories of Caribbean SIDS, limited land resources are dedicated to agriculture in some instances. For example, in 2013, arable land was as low as 0.4% in Suriname and as high as 25.6% in Barbados. However, there was a slight 0.2% increase in land under cultivation in Suriname between 1961 and 2013, as opposed to an alarming 11.6% decrease during the same period in Barbados. Overall, 25% of land in the Caribbean is used for agriculture. Low agricultural land inventories, high food import bills, and the small contribution of agriculture to GDP (Appendix 1) indicate that the current level of agricultural production is unable to sustain the region's 45.2 million population.

Figure 2: Map of the Caribbean highlighting the SIDS member states

Historically, the production and export of plantation crops such as sugar, coffee, cocoa, bananas, and rice, played a central role in the economies of many Caribbean countries. In more recent times the removal of preferences with importing countries for some of these crops forced Caribbean governments to diversify (Barker 2012). This divestment coupled with a decline in the once-profitable plantation crop systems fostered the downturn of regional agriculture and led to an increasing reliance on food imports. Since 1990 the proportion of imported food in the region has increased from around 40% to over 60% (Hickey and Unwin 2020).

Contemporary subsistence and commercial agricultural systems are overwhelmed by many of the factors that decimated traditional plantation farming such as high production costs, acute labour shortages, and low farm productivity. In addition, limited land capacity and small scales of production affect commercial agriculture in the region. These deterrents have forced many farmers to abandon agriculture or sell to niche markets. Climate change has intensified these pressures, as the frequency and severity of natural hazards have negatively affected domestic food production in SIDS member nations (Connell et al. 2020). Thus, there is need to integrate technology into agricultural systems to increase the resilience and stability of food systems in SIDS and ensure long-term farming sustainability.

The observation, quantification, and management of inter and intra-field agronomic variability that affects crop productivity can be achieved using agricultural technologies (Zhang et al. 2002). While spatio-temporal variability of agronomic parameters has been appreciated for centuries and small farm sizes allowed farmers to vary treatments manually, the industrialisation of agricultural farms led to the blanketed application of inputs. Consequently, technologies that measure, analyse, and manage the inherent variability of agronomic parameters, as well as increase the resilience to natural hazards in commercial farms, were developed. Although these technologies have become more affordable, agriculture in the Caribbean is dominated by undercapitalised, technologically conservative smallholder farmers, and therefore technology is underutilised in Caribbean farming systems. Exploiting technology and sustainable practices to manage high-value niche products, traditional commodity crops, and vulnerability to natural hazards can be achieved through the following:

- The adoption of technology to reduce production uncertainty within the highly heterogeneous landscape of SIDS.
- The use of climate-smart technology to reduce the impact of climate change.
- The use of spatial information technology to mitigate the vulnerability to climate hazards.
- The use of technology to compensate for declining production and increasing labour costs.

The meta-analysis approach used in this study combines bibliometric and content analyses. The results are integrated into a technological adoption framework specific to Caribbean SIDS. The objectives of this study were to:

- Employ bibliometric and content analysis to identify key themes, trends, and structural associations within the literature on technology and its adoption in agricultural systems.
- Identify factors that distinguish agricultural production in SIDS.
- Identify agricultural challenges in SIDS and how agricultural technology can address these challenges.
- Integrate findings into a scientifically informed framework for the successful implementation of agricultural technologies in Caribbean SIDS.

Materials and methods

Existing literature on technology in agriculture and its adoption over the period 2010 to 2020 was reviewed and summarised using bibliometric and/or content analyses. Bibliometric analysis uses statistical methods to analyse published materials (Maditati et al. 2018), while content analysis is used to identify themes in qualitative data.

Web of Science (WoS) bibliometric data retrieval

The reputable academic research database Web of Science (WoS) (Vanga et al. 2015; Maditati et al. 2018), was used to collect bibliometric data relating to agricultural technology. Keywords were input into the WoS topic field which searches titles, abstracts, and keywords of literature in the database to identify relevant documents. On 2 September 2020 two WoS searches were used to retrieve documents published between 2010 and 2020. The first sorted agricultural technology publications, while the other focused on the adoption of agriculture technology.

Precision agriculture (PA) management systems have pioneered the use of technology in farming systems, therefore, common terms related to PA were used as search inputs in this study. Thus, for general literature on common technologies utilised in agriculture, the keywords used were “precision agriculture”, “site-specific farming", "precision forestry", "precision aquaculture", "precision viticulture", "precision farming", "satellite agriculture" and "site-specific crop management". Quotation marks ensured that only records containing the exact terms were retrieved. Subsequently, documents published by developed countries and developing countries were retrieved by refining the search using the Countries/Regions field in WoS.

To retrieve information focused on the adoption of agriculture technology, the keywords “precision agriculture” and "adoption or integration" were input in WoS. Although the results were sorted by relevance, the abstracts of the studies were examined, and discretion was used to identify 38 of the most relevant papers to review utilising a content analysis approach.

Bibliometric mapping and clustering

VOS viewer version 1.6.15 was used in this study to analyse and map bibliometric data. Aleixandre-Tudó et al. (2018) provides an in-depth overview of the software and along with Costa et al. (2017) and Pallottino et al. (2018) used the software to review PA literature. In this study, VOS viewer was used to analyse terms and create bibliometric maps.

Full counting measures the total occurrence of a term and the results obtained were used to create a thesaurus file. Binary counting measures the absence or presence of a term in the documents and results in fewer terms than full counting. For this reason, binary counting was used to create terms maps for data volumes over 1,000 whereas full counting was used for mapping data volumes less than 1,000. Only words and phrases that occurred 20 times or more were taken into consideration for files with more than 1,000 records, whereas 10 was used for files with less than 1,000 records.

Quality control and quality assurance (QC/QA)

QC/QA was performed by extracting and scrutinising data obtained from the full count terms analysis for all the retrieved documents and using it to create a thesaurus file. The thesaurus standardised variants of terms, for example, "variable rate technology" was changed to "VRT", and spelling differences such as "leafe" were changed to "leaf" and "colour" to "color". Additionally, terms that were considered irrelevant were omitted within VOS viewer before the final analysis mapping. Impact factors cited in this paper were obtained from the Academic Accelerator database.

Content analysis

Content analysis was performed on the 38 most relevant papers on the adoption of technology in agriculture. NVivo, as described by Leech and Onwuegbuzie (2011), was used. This analysis identified and recorded underlying themes and nuances to the adoption of technology in agriculture. After the identification of themes and subthemes, the data were binary coded into a spreadsheet. This was done as both a QA/QC measure and for future binary regression analysis. The analysis was facilitated using a concept matrix (Pathak et al. 2019), consisting of the article title, in-text citation, research question(s), methodology, data type, countries covered, technologies used, and key findings of selected publications.

Review of relevant information not contained in the WoS database

One of the most limiting aspects of this approach is that the keywords used in the WoS search may have excluded relevant studies. Relevant information on this topic is often in reports, newspapers, and other sources, that are not captured in the WoS database. To overcome this limitation, targeted insight into the potential for technology in SIDS was considered by reviewing data not covered in the WoS database. The principal agriculture products produced by Caribbean SIDS were identified and used to provide specific targets against which relevant information was retrieved and assessed.

Results

Bibliometric review of technology in agriculture

Of the 3,260 documents obtained from WoS for the period 2010 - 2020, 91.9% were categorised as articles, 6.7% were review papers, the remainder (1.4%) were categorised as other. Aleixandre-Tudó et al. (2018)

searched the WoS database using the keywords terms 'precision agriculture' or 'precision farming' for the period 1994 to 2014 and obtained 2,027 documents. Although different keywords were used, this suggests an exponential increase in the subject area since 2014; this inference is supported by Figure 3. Data for 2020 was collected in September of that year and therefore the record is incomplete. For comparative measures, Aleixandre-Tudó et al. (2018) reported similar numbers (± 5) in overlapping years (2010 – 2014). The number of published papers was fairly constant for the first half of the decade with increasing numbers in the second half.

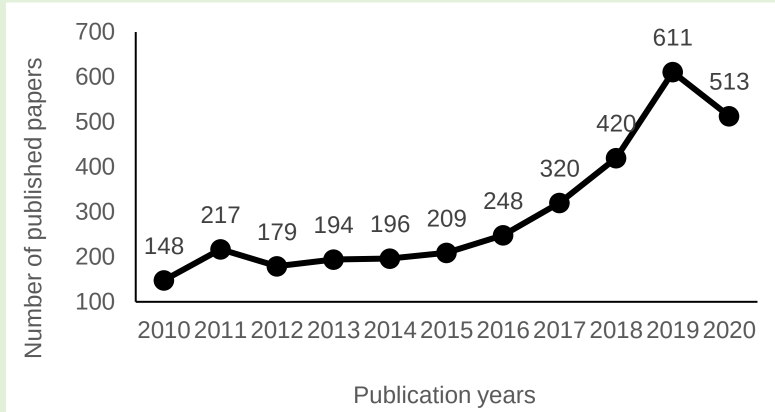

Figure 3: Number of agricultural technology published papers (2010-2020)

Of the retrieved documents, 95.1% were published in English while Portuguese and Chinese accounted for 2.6% and 1.2% respectively, the remaining 1.1% of documents retrieved were categorised as miscellaneous. Table 1 shows the 14 journals which were the most frequent publishers of the retrieved documents; only one journal in the list of publishers, Engenharia Agricola, publishes in a language other than English i.e. Portuguese.

Table 1: Sources of agricultural technology literature identified in the period 2010-2020

Source	Initials	Count	Citations	Citations/ paper	Impact factor	WoS primary category
Computers and Electronics in Agriculture	CEA	293	5171	17.6	4.02	Agriculture
Precision Agriculture	PA	224	3797	17.0	3.84	Agriculture
Remote Sensing	RS	189	3915	20.7	4.59	Remote sensing
Sensors	S	161	1991	12.4	3.51	Chemistry analytical
Agronomy-Basel	AB1	53	157	3.0	N/A	Agronomy
Transactions of the ASABE	ASABE	52	368	7.1	1.34	Agricultural engineering
Engenharia Agricola	EA	50	174	3.5	0.71	Agricultural engineering
Biosystems Engineering	BE	44	1179	26.8	3.59	Agricultural engineering
Applied Engineering in Agriculture	AEA	43	192	4.5	0.91	Agricultural engineering
Geoderma	G	43	672	15.6	4.52	Soil science
Spectroscopy and Spectral Analysis	SSA	39	95	2.4	0.59	Spectroscopy
IEEE Access	IEEE	38	227	6.0	4.64	Computer science information systems
Agriculture-Basel	AB2	32	137	4.3	2.07	Agronomy
International Journal of Agricultural and Biological Engineering	ABE	32	206	6.4	1.62	Agricultural engineering

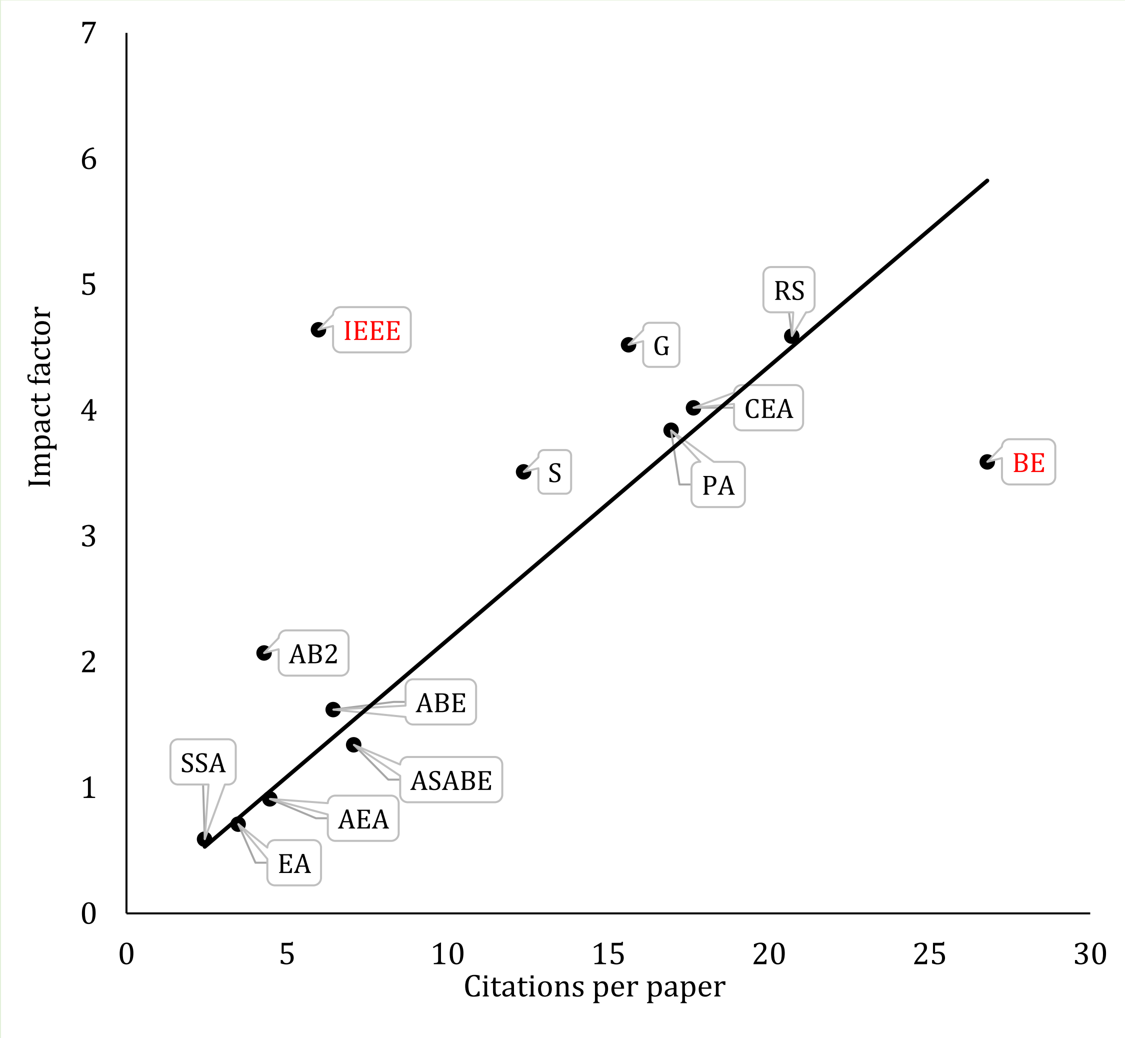

Figure 4: Relationship between impact factor and citation in agricultural technology journals.
Outliers highlighted in red. Refer to Table 1 to identify initials of journals

Impact factor (IF) and citation/papers are closely related (r^2 = 0.91, Figure 4). The exceptions are IEEE Access, which has the highest IF but one of the lowest citation/paper ratios, and Biosystems Engineering, which is cited approximately twice as often as journals with similar IFs. Agricultural engineering was the most featured WoS category in the list of top journals.

Global trends in agricultural technology research

Terms mapping and analysis were critical in identifying data clusters and trends within global agricultural technology literature over the study period. In VOS viewer, the default binary counting option, which measures the presence or absence of a term in the bibliometric data and terms appearing over 20 times, was considered for the creation of terms maps; 460 terms met the criteria. Unsurprisingly, agriculture was the focal point of the retrieved research in the last decade.

Related terms were clustered into three groups using general themes i.e., remote sensing and imagery, soil and agronomic research, and technology in agriculture (Figure 5). Pallottino et al. (2018) also observed three clusters in the terms mapped between 2010 and 2016 using the Scopus database and VOS viewer.

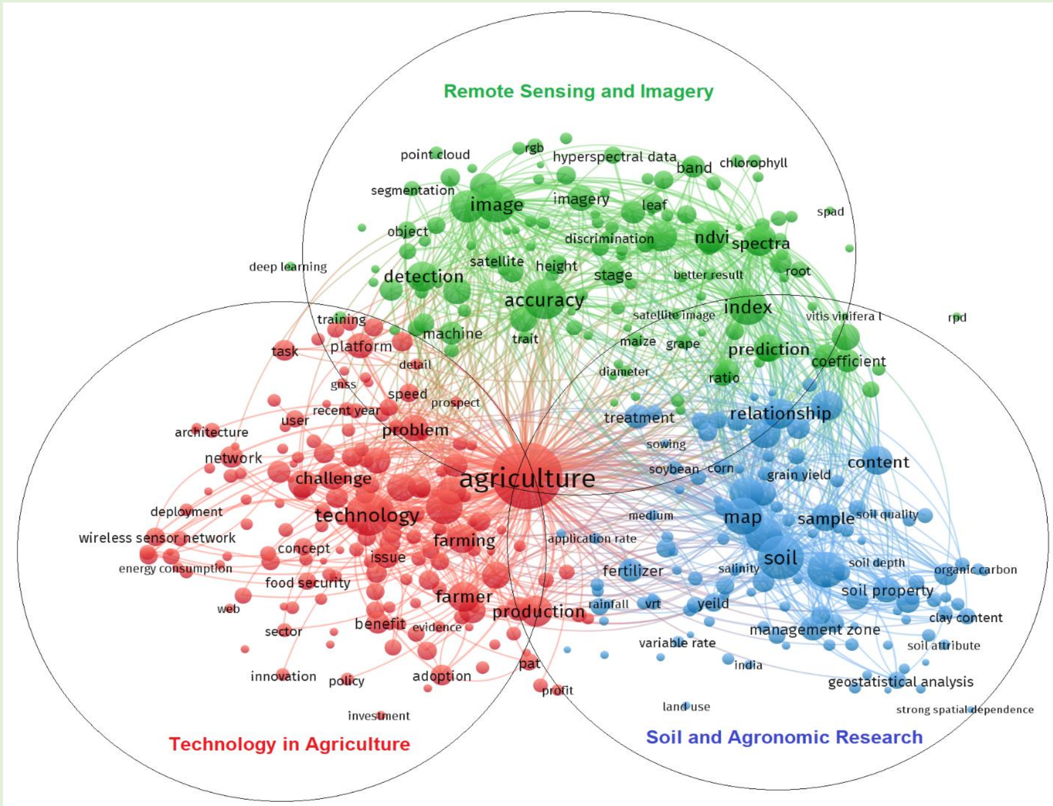

Figure 5: Terms map showing three distinct clusters each relating to a broad theme

Table 2: Top 20 terms for each cluster theme between 2010 and 2020

Cluster theme					
Soil and agronomic research		Remote sensing and imagery		Technology in agriculture	
Term	Count	Term	Count	Term	Count
Soil	1402	Image	1340	Agriculture	2398
Variability	1197	UAV	1323	Farmer	1415
Spatial Analysis	928	Index	1188	Technology	1136
Nitrogen	689	NDVI	933	Network	690
Content	607	Spectra	596	Challenge	578
Variable	599	Detection	571	Environment	558
ECa	581	Estimation	567	Practice	540
Management zone	566	Prediction	493	Control	437
Relationship	495	Imagery	480	Feature	436
Sample	462	Regression	445	Solution	363
Treatment	454	RMSE	429	Platform	351
Soil property	453	Camera	398	Operation	348
Wheat crop	378	Canopy	345	Adoption	337
Concentration	319	Leaf area index	338	Decision	280
Soil moisture content	293	Band	326	Device	258
Property	287	Biomass	305	Framework	255
Fertiliser	280	Disease	300	GPS	221
Correlation analysis	263	Temperature	277	Implementation	213
Coefficient	246	Reflectance	267	Benefit	211
Soil Sample	243	Leaf	245	PAT	183

ECa: apparent soil electrical conductivity; UAV: unmanned aerial vehicle; NDVI: normalised difference

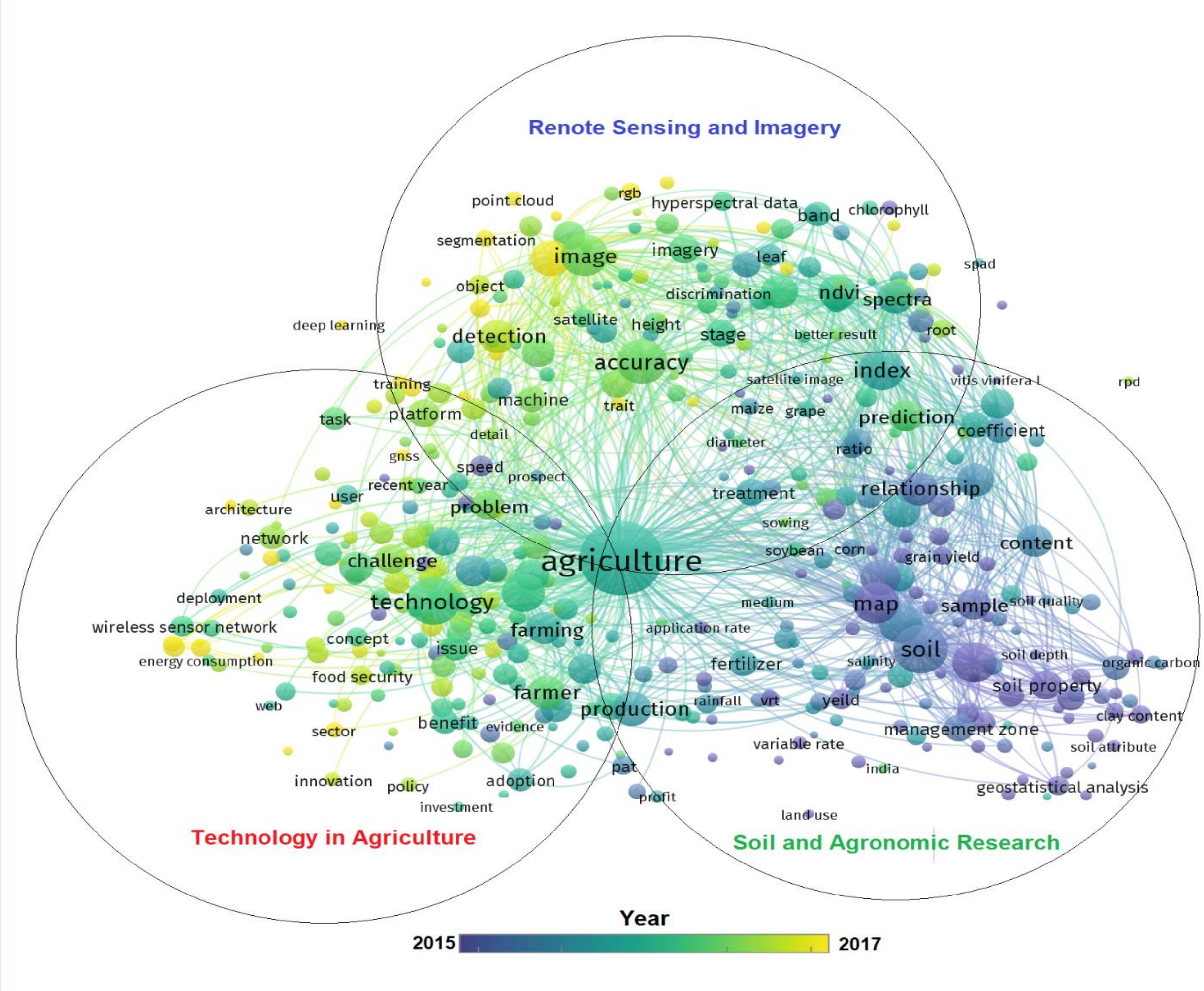

Figure 6: Terms year map based on global precision agriculture publications over the period 2010- 2020. The colour of a term indicates the average publication year of all precision agriculture publications in which the term occurs (in the title and abstract)

Agriculture (n = 2,398), soil (n = 1,402) and image (n = 1,340) were the top 3 terms used in the cluster themes (Table 2). Soil and agronomy research trended toward spatial variability of soil and agronomic properties, determination of soil and plant nitrogen content, and the use of apparent soil electrical conductivity (ECa) for the delineation of management zones. Remote sensing and imagery focused on imaging, the use of unmanned aerial vehicles, indices such as the normalised difference vegetative index (NDVI), leaf area index (LAI), and spectral data such as reflectance for the detection, estimation, and prediction of biomass and disease. In the technology in agriculture category, the emphasis was placed on the adoption of frameworks, practices, devices, and platforms into farm and environmental systems. Technology such as wireless networks, PA technology, GPS, variable rate technology, and the internet was explored to solve problems.

Additional trends were observed from term year mapping and term citation mapping. The term year map (Figure 6) suggests that research is moving away from soil and agronomic studies and

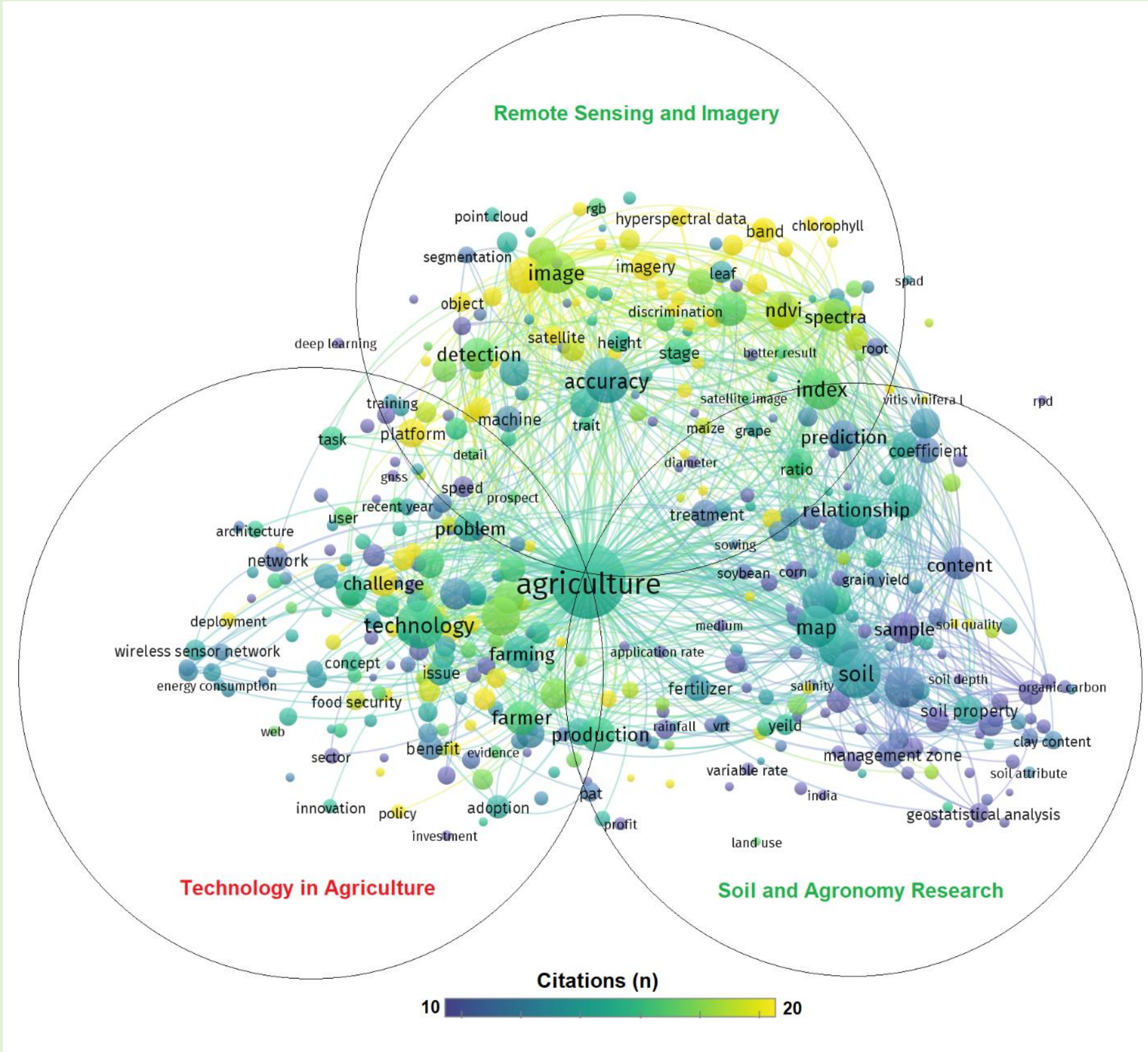

Figure 7: Terms citation map based on global precision agriculture publications (n = 3256) over the period 2010- 2020. The colour of a term indicates the average citation impact of the publications in which the term occurs

is trending toward remote sensing and imagery and technology in agriculture. This is attributable to the fact that soil and agronomy research was the least cited, whereas the highest cited theme was remote sensing and imagery (Figure 7).

Content analysis of key literature

Numerous studies focusing on the barriers and/or determinants to the adoption of technology in agriculture have been published. Although the literature is relatively broad, no study presenting a theoretical framework aimed at integrating technology in agricultural systems in SIDS was retrieved from the WoS search. Reviewing the literature to understand underlying factors that influence the adoption of technology in agriculture is vital. An in-depth analysis of the most relevant literature, relating to the adoption of technology in agriculture, was used to identify pertinent information that should be considered when developing a framework that applies to SIDS (Appendix 2).

Many authors employed one or more theories or models to explain end-user technology acceptance behaviours. The Diffusion of Innovation (DOI) (Aubert et al. 2012; Shahbaz et al. 2012; Lubell and McRoberts 2018), Technology Acceptance Model (TAM) (Rezaei-Moghaddam and Salehi 2010; Aubert et al.

Table 3: Themes within the adoption of precision agriculture literature

Themes	Variables	Total	%
Farmer attributes (n = 35; 92.1 %)	Education and skill	30	78.9
	Age	29	74.4
	Attitude or perception	17	44.7
	Experience	15	39.5
	Social networks	12	31.6
	Gender	10	26.3
Institutional services (n = 33; 84.6 %)	Extension services	16	42.1
	Private company services	14	36.8
	Government subvention Programmes	12	31.6
	and training	11	28.9
	Demonstration or observability	8	21.1
Agroecological (n = 31; 81.5 %)	Farm size	27	71.1
	Agronomic	15	39.5
	Farm type and structure	14	36.8
	Labour	11	28.9
	Distance from market	8	21.1
	Land tenure	7	18.4
Economic (n = 21; 55.3 %)	Income	14	36.8
	Access to credit	7	18.4
	Return on investment	4	10.5
	Access to capital	2	5.2
	Financing	1	2.6
Technological attributes (n = 21; 55.3 %)	Advantage	15	39.5
	Cost	10	26.3
	Ease of use or familiarity	7	18.4
	Availability or triability	7	18.4
	Compatibility or adaptability	4	10.5
Information and marketing (n = 18; 44.4 %)	Information source and availability	16	42.1
	Marketing and communication	11	28.9

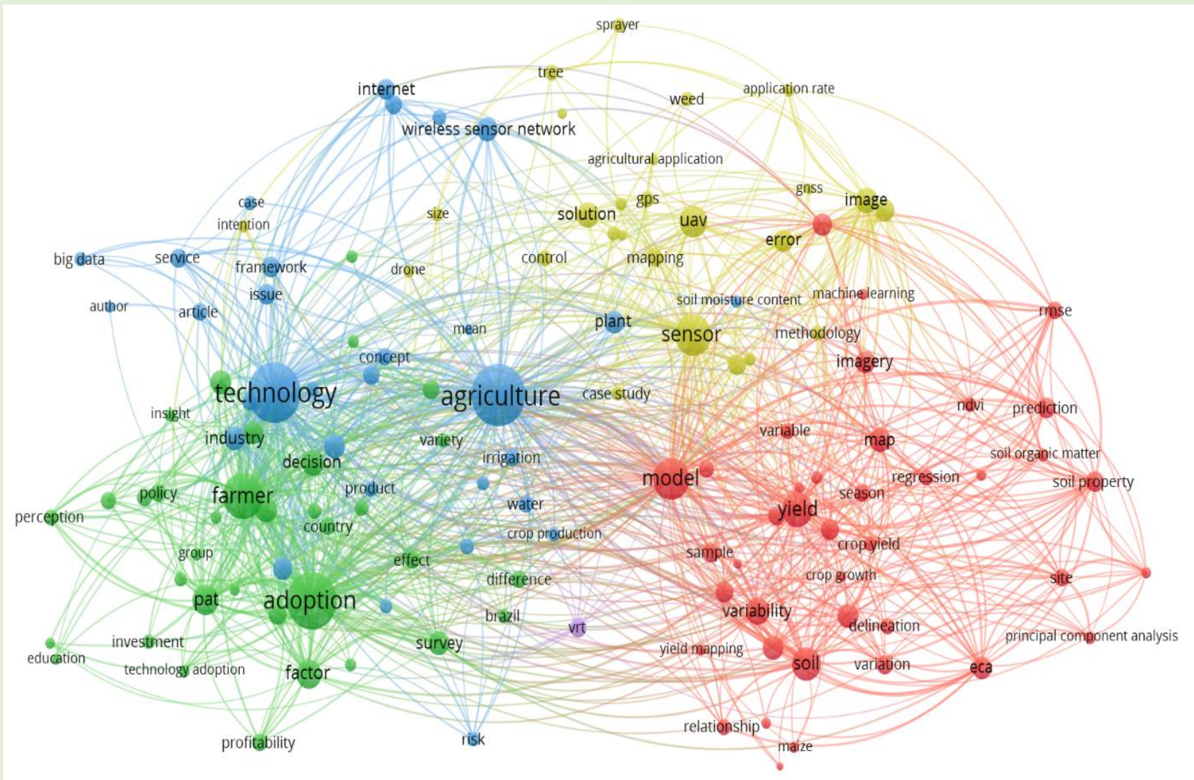

Figure 8: Terms map for the adoption of technology in agriculture

2012; Landmann et al. 2020), Theory of Planned Behavior (TPB) (Faisal et al. 2020; Landmann et al. 2020), and the Model of Determinants of Diffusion, Dissemination, and Implementation of Innovations (MDDDII) (Pathak et al. 2019) have all been employed by researchers in the last decade to explain the adoption of technology in agriculture. Articles were thoroughly coded and analysed for themes, which resulted in the following: farmer attributes (92.1%), institutional services (84.6%), agroecological factors (81.5%), economic factors (55.3%), technological factors (55.3%), and information and marketing (44.4%) (Table 3). Notably, some aspects of the abovementioned themes closely relate to technology adoption models categories such as, perceived usefulness which was coded as 'advantage' (39.5%), ease of use (18.4%) and attitude (44.7%), and DOI, for example, subjective norm or social influence, coded as 'social network' (31.6%), and accessibility coded as availability or triability (18.0%). Many of the terms identified during bibliometric analysis of literature on the adoption of technology in agriculture (Figure 8) were coded in the themes developed through content analysis.

Farmer attributes, institutional services, and agroecological factors were, by and large, the most impactful themes. Subthemes such as the education and skill level of the adopter (78.9%), age (74.0%), and farm size (71.1%) were identified as the most important determinants to the adoption of technology in agricultural systems. Large farms run by younger, educated operators with economic means are most likely to adopt new and or improved technologies. Change agents such as extension officers and private company agents can influence the adoption of technology by advertising its benefits to farmers through demonstrations, workshops, and training programmes. Government subventions are especially important in developing countries as most studies (75.0%) found subsidies, policies and grants significant for the adoption of technology in agriculture were conducted in developing countries

(Adenle et al. 2019; Li et al. 2017; Ouédraogo et al. 2019; Pathak et al. 2019; Senyolo et al. 2018; Wu and Ma 2020). Whereas, the majority of authors who did not find subventions impactful were based in developed countries (Aubert et al. 2012; Asare and Segarra 2018; Lubell and McRoberts 2018).

Discussion

Challenges faced by SIDS and agricultural technology adoption

Understanding the underlying factors that prevent the adoption of agricultural technology in developing countries is vital for the development of a technological adoption framework for increasing food production. A review of the relevant literature not captured in the WoS database was used to identify challenges faced by SIDS. The most impactful themes were climate change, market specialisation, labour, small size, and government subventions.

Climate change

Natural disasters are one of the major crises that affect food supply chains at the production level (Reddy et al. 2016). SIDS are most vulnerable to natural disasters as a result of climate change due to their geographic location and small size. Storms, hurricanes, cyclones, and earthquakes have caused great economic damage for SIDS. Global warming driven by extreme temperatures has resulted in severe droughts, reduced rainwater, saltwater intrusion, and shifting agricultural seasons with impacts on food production, natural resources, and transportation (Ghadge et al. 2019). Rapid urbanisation also makes SIDS increasingly vulnerable to natural disasters, this occurs due to a lack of adequate infrastructure planning and land management. The implementation of climate-smart agricultural technology can help reduce greenhouse gas emissions, water pollution, and soil degradation. Reduced greenhouse gas emissions are vital in slowing the global warming processes. Climate-smart applications play an essential role in ensuring food security through the development of resilient production systems. Technology can also be used to mitigate the vulnerability of SIDS agricultural systems to natural hazards by utilising spatial information to increase resilience.

Market specialisation

Market specialisation and the dependence on a few export commodities and markets have compromised the food supply chain of SIDS. Exports from traditional cash crops have decreased with increased competition. Preferential market access conditions have gradually been eroded, limiting foreign exchange for these countries. As result, many SIDS have turned to private finance and capital markets as a source of agricultural development assistance to reduce market volatility and reversals of financial flows. Crop diversification and intensification are needed to combat threats to agricultural production. Agricultural technology compliments crop diversification and intensification by securing a stable agricultural system. The use of agricultural technology matches agricultural inputs and practices based on the exact needs of crops grown in specific ecosystems. It avoids overuse or underuse of inputs, minimises waste, protects soil health and the environment.

Labour

Limited education and skilled agricultural labour are major threats facing agricultural production in SIDS. Many farmers prefer traditional practices passed down rather than embracing best practices to increase production yields. Labour-driven disruptions can result in disruptions to downstream value-added processes. Employment and wage dynamics, especially in the face of COVID-19, have resulted in an adjustment to wages and significant delays. Agricultural technology can reduce labour use, eliminate risk, improve accuracy, and reduce the cost associated with hiring labour.

Small size

The scarce land area associated with SIDS suggests fewer land resources for manufacturing and agricultural production. As a result, SIDS often experience high production costs with low output volumes as a result of low quality, unavailable or expensive inputs. Small market sizes often do not allow SIDS to benefit from economies of scale, this constraints productive and export capacities (UNCTAD 2019). Precision agriculture promotes the efficient use of limited resources. Site-specific application of inputs, crop diversification, and intensification can all increase yields on limited land space.

Government subventions

Government subventions are especially important in SIDS. Policies and grants are significant for agricultural inputs, loss of crops due to natural disasters, and for the purchase of equipment (Adenle et al. 2019; Li et al. 2017; Ouédraogo et al. 2019; Pathak et al. 2019; Senyolo et al. 2018; Wu and Ma 2020). Without subventions, the agricultural sector becomes less resilient and the economy more volatile. Additionally, subventions allow for the adoption of new and improved technology, improved crop varieties, and quality of breeding stock. Change agents such as government extension officers and private company agents can influence the adoption of technology by conducting demonstrations, workshops, and training programmes for farmers. Over time, this reduces the need for subventions as individual farms become more sustainable.

Integrative technology adoption framework for SIDS: A case study of the Caribbean region

The methodology employed provided valuable insights into agricultural technology trends, determinants of adoption of technology in agriculture as well as the challenges faced by SIDS. As in landlocked developed and developing countries, integrating technology in SIDS is important to increasing food security and meeting specific UN developmental goals. The removal of barriers such as inadequate access to improved crop varieties, improved technologies, lack of credit facilities, high labour costs, limited agronomic mapping and monitoring, lack of skilled educated farmers, unavailable or expensive feed, praedial larceny, and low-quality breeding stock, can significantly increase the region's agricultural productivity (FAO, CDB 2019).

Despite these hurdles, the agricultural sector is an important contributor to the GDP of many Caribbean SIDS (Appendix 1). The agricultural sectors in the continental states and in Haiti continue to grow, however, this is usually accompanied by harmful, unsustainable practices with a low increase in productivity. Although Caribbean SIDS operate small-scale farms that are limited by a lack of financial resources, access to credit, technologies, and extension services, a well-developed technology adoption framework can be beneficial to both small-scale and commercial regional farmers. An environmentally sustainable increase in productivity and competitiveness in the arable and livestock farming sectors can be achieved through a comprehensive integrative technology adoption framework that includes adoptable agriculture technologies and climate-smart/conservation agriculture technologies and practices. A framework for the Caribbean is presented (Figure 9). The proposed framework takes a mixed approach (top-down and grassroots) with major foci on technology in SIDS agricultural systems, change drivers, and performance measures.

Adoptable technology covers ubiquitous low-cost

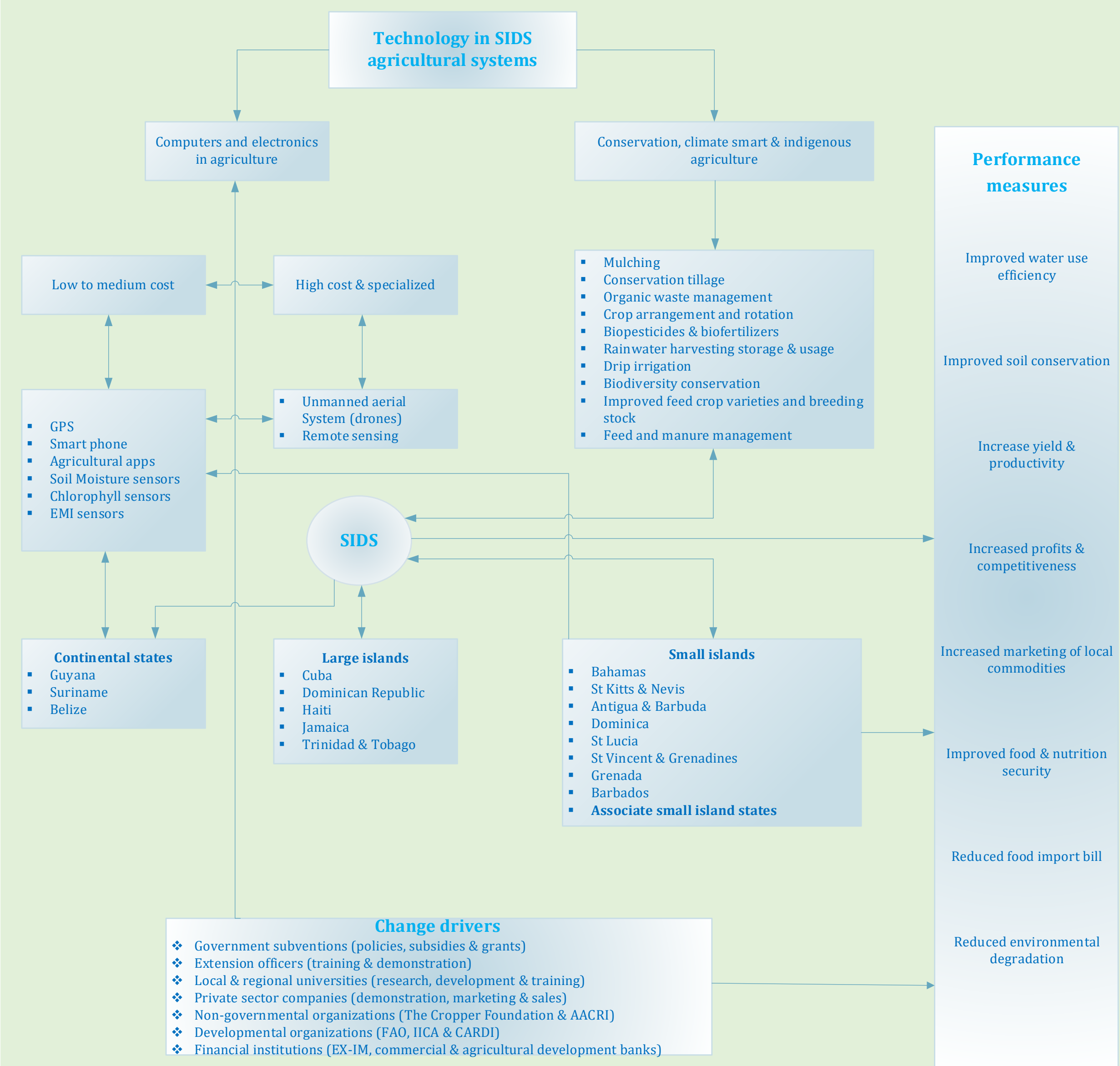

Figure 9: Integrative technology adoption framework for Caribbean SIDS

technologies such as GPS, which can be used to o btain georeferenced agronomic data. GPS is a principal technology since it can be integrated with remote and proximal sensing technologies, as well as agricultural machinery. In a 5.81 ha cocoa field in Trinidad and Tobago, De Caires et al. (2014) and De Caires et al. (2015) utilised data collected using GPS attached to an electromagnetic induction device, and a multivariate geostatistical approach to analyse spatiotemporal stability and delineate management zones in the field.

Landmann et al. (2020) and Dhehibi et al. (2020) suggested that ICT, smartphones, can provide an effective platform for the development of small rural farmers as they provide fast access to continually updated, reliable information and reduce the need for face-to-face interactions with change agents. Reliable information is especially important for the adoption of technology in developing countries where information on these technologies is usually unreliable (Lowenberg-Deboer and Erickson 2019). AgriMaps is an ICT application that is used in Caribbean SIDS, particularly Trinidad and Tobago for farm management and agricultural planning through the provision of land information and crop recommendations (Jordan et al. 2016). The application provides an e-extension officer, which is an improvement of the e-extension web-based tools currently available in the Caribbean such as JAMIS and NAMIS that supply pricing details for local produce in Jamaica and Trinidad, respectively. Despite these contributions to ICT platforms in SIDS, many old farmers do not have access to a smartphone or computer. To bridge the digital divide, the adoption of ICT technologies for improved agricultural production requires interventions such as duty-free electronic devices, stable internet access, adequate bandwidth, increased training, troubleshooting, maintenance, and upgrades (Renwick 2012). These technologies will engage young people in agriculture who will help modify future work ethics and culture surrounding the fast-decision-making process of ICTs.

The use of high-cost remote sensing technologies in regional agriculture has been woefully underexplored. Soesilo and Rambaldi (2018) surveyed African, Pacific, and Caribbean countries on the perception and application of drones in agriculture. Among the surveyed, there was support for the development and use of drones in agriculture. However, apprehensions over a lack of awareness, cost, and appropriateness for small farmers were expressed. Despite these concerns, drone operators proved vital in assessing the damage caused by Hurricane Maria to Puerto Rican farms in 2017 (Agremo 2020). In 2016, Jamaica welcomed its first drone company, Agrocaelum, which provides a wide range of agricultural services (Skyers 2016). In the same year the Jamaican Ministry of Industry, Commerce, Agriculture, and Fisheries, initiated a collaboration with another local company, D & C Drones. The ministry demonstrated, to farmers, the instrument's efficacy for praedial larceny, assessing damage following natural disasters and increasing crop yields (Davis 2016).

Unlike drones, satellite imagery has yet to be applied to agriculture in the Caribbean. However, it has been used to map species (Wang et al. 2004), habitats (León-Pérez et al. 2019), land uses (Clark et al. 2012), assess trends, and predict cover management factors (Melville et al. 2020). Satellite imagery has been proven to improve agricultural meteorology (Sivakumar et al. 2003) and statistics (GSARS 2017), thereby improving food production systems. Regional universities and private companies have both the expertise and technology needed to calculate biomass, provide site-specific agrochemical spraying, assess fertility, water stress, and other agronomic parameters. Thus, it is suggested that remote sensing services be offered to large-scale commercial farmers through these regional bodies. Though variable rate technology and automation technologies were identified in the content analysis, these technologies are mainly employed by commercial mega-farms in developed countries and therefore would not be feasible in Caribbean SIDS.

While technology is ingrained in the agricultural systems employed in developed countries, most developing countries prefer climate-smart and conservation agriculture technologies and practices. Caribbean SIDS's inability to cope with adverse climate effects coupled with their developmental profiles has created a significant risk to food systems and security (Lincoln Lenderking et al. 2021). Climate-smart applications play an essential role in ensuring food security through the development of resilient production systems ranging from protected (greenhouse, container, and vertical) agriculture to hydroponic systems. Furthermore, practices such as agroforestry that help to diversify production outputs (lumber, fruits, and cash crops) whilst protecting soils against erosion and moisture loss present viable alternative options to traditional monocropping systems. Climate-resilient practices are reinforced with indigenous byproducts created from organic waste streams such as biopesticides, biofertilisers, and organic mulch. These organic byproducts, once tested, can aid in increasing biodiversity, reducing agricultural inputs, and conserving soil moisture.

Recently the Caribbean has been recognising the importance of creating technology. This increased regional awareness has led to the support and creation of St. Lucia's first indigenous biotech company, Algas Organics, which provides a total plant tonic sargassum seaweed-based fertiliser (Ewing-Chow 2019). Emerging regional agri-business options such as Algas Organics highlight the interdependency of change drivers, ecological systems, and technology in capturing indigenous approaches and turning them into profitable practices and byproducts that can drive food production. Additionally, the development of regional crops and animals that have greater tolerance to abiotic stresses is necessary. Overall, SIDS can gain significant benefits from these practices, which help farmers mitigate and adapt to climate change while ensuring food and nutrition security.

Government subvention coupled with change agents (extension offices and private company operatives) and effective dissemination approaches are imperative for successful technology transfer to end-users in the developing world (Damba et al. 2020). Dhehibi et al. (2020) recognised the need to educate farmers, adopt useful practices and technologies, and disseminate local agricultural research through an alliance between government and private company stakeholders. The reviewed studies emphasise that factors affecting the adoption of technology and management practices in developed and developing countries differ due to wealth and size disparities. Thus, access to capital (Mariyono 2019; Tey and Brinda 2012) and credit (Senyolo et al. 2018; Adenle et al. 2019; Makate et al. 2019; Mariyono 2019; Ouédraogo et al. 2019; Tran et al. 2020; Damba et al. 2020) is necessary to finance the adoption of modern agricultural technologies.

The framework recognises the size and economic disparities in the Caribbean and divides the regional SIDS into three groups. It is anticipated low to high-cost agriculture technologies will be viable in continental states as well as large islands, whereas small islands should focus on the use of low-cost to medium-cost technologies, conservation, and climate-smart and indigenous agriculture practices to increase sustainability and profitability. Drivers such as government subventions, extension officers, private companies, local and regional universities, key NGOs, developmental agencies, and financial institutions can undoubtedly play an immense role in propelling the adoption of new technologies and practices. These change drivers will be responsible for the diffusion of information, making the technologies, applications, and platforms available, applying external pressure through the enactment of new laws, providing support and incentives, and making credit accessible to farmers.

To overcome some of the limitations of this study, performance measures such as increases in crop productivity, food security, and the reduction in the food import bills should be used to ascertain the success of the conceptual framework.

Conclusion

Bibliometric and content analyses of the literature from the WoS database were conducted to identify key trends and themes in agricultural technologies within the 2010 to 2020 period. The reviewed articles emphasised the disparity in the use of technology in agriculture, as most developing countries prefer climate-smart and conservation agriculture technologies and practices. Government subvention, change agents, access to capital and credit, effective dissemination approaches such as the use of ICT, namely smartphones, for fast access to continually updated reliable information, are imperative for the successful transfer of technology to end-users in the developing world. Based on these critical observations, themes, trends, and future research directions from bibliometric and content analyses, as well as, the review of relevant publications not contained in the WoS database, a framework for the adoption of technologies in the agricultural sector in Caribbean SIDS was developed.

The conceptual framework recognises the size and economic disparities in the region. However, the adoption of appropriate technologies within the highly heterogeneous landscapes in the region can reduce uncertainty, increase profitability and yield in the agriculture sector in most countries. For example, smaller countries that are core producers of many high-value products can benefit from crop and animal breeding technology. Larger countries can apply technology to manage the spatial heterogeneity of large and medium-scale plantation cropping systems. Spatial information can be used throughout the region to increase resilience to natural hazards and could be an important contribution of technology in improving the resilience of regional agri-systems to the increasing occurrence of natural hazards due to climate change. This meta-analysis approach can be applied to other regions toward increasing food security through the development of an information-based technology adoption framework for increased resilience and sustainability while simultaneously minimising harmful environmental impacts in the agricultural sector.

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Appendix 1:

The contribution of agriculture to the GDP of SIDS Caribbean member states.

	Country	Primary produce			Primary animal produce		Contribution to GDP	Total Population
		Vegetables	**Fruits**	**Crops**	**Meats**	**Products**		
Larger islands	Cuba	Tomato Pepper Legumes Lettuce Chard Carrot Beet Squash Okra	Banana Citrus Avocado Pineapple Papaya Coconut	Corn Sugar Tobacco Potato Soy Rice Plantain Cassava Coffee Cereal Sweet Potato	Beef Poultry	Honey Eggs	5%	11,266,000
	Dominican Republic	Tomato Sweet pepper Lettuce Onion Eggplant	Banana Mango Coconut Lemon Orange Pineapple Avocado Melon	Sugar Cocoa Coffee Tobacco Rice	Poultry Pig Buffalo	Eggs	11%	10,404,000
	Haiti	Spinach Watercress Beans Pigeon Peas	Mango Papaya Banana	Vetiver Cocoa Mahogany Nuts	Fish Lobster Shrimp		25%	10,317,000
	Jamaica	Pimento Tomato Beans	Banana Citrus	Sugar Coffee Cocoa Ground Provisions Ginger Tobacco Rice	Poultry Beef Goat	Dairy products	7%	2,784,000

	Country	Primary produce			Primary animal produce		Contribution to GDP	Total Population
		Vegetables	**Fruits**	**Crops**	**Meats**	**Products**		
	Trinidad and Tobago	Sweet pepper Pak choi Lettuce Melongene Black eye peas String beans Pigeon peas Bodi Seim	Citrus Coconut Sugar Banana Pineapple Mango Golden apple Papaya Avocado Watermelon Plantain	Sugar Cocoa Rice Coffee Dasheen Cassava Eddoes Sweet potato Breadfruit Sweet corn	Pork Fish Poultry	Eggs Milk	16.7%	1,341,000
	Antigua and Barbuda	Cucumber	Banana Coconut Mango	Sugar Cotton	Fish	Milk	<4%	90,000
Smaller islands	Bahamas	Onion Okra Tomato Cucumber	Banana Orange Grapefruit Lemons	Sweet potato Irish potato Pigeon peas Sugar	Poultry Beef	Milk	5%	377,000
	Barbados	Tomato Cucumber Cabbage Lettuce Carrot Okra Pepper Beans	Cherry	Cereal Sugar Beets Cotton	Fish Lamb	Dairy products Eggs Milk Honey	3.8%	285,000
	Dominica	Hot pepper Tomato Pumpkin Pak choi String beans Carrot Eggplant Pigeon peas Okra Cabbage Cucumber Breadfruit	Banana Citrus Coconut Mango Guava Papaya Avocado Watermelon Passion Fruit Pineapple	Coffee Cocoa Plantain Sweet potato Dasheen Yam Tannia Maize	Fish Prawns Poultry Beef Goat Sheep Pork	Eggs Milk Honey Beeswax Wool Silk	17%	72,000

	Country	Primary produce			Primary animal produce		Contribution to GDP	Total Population
		Vegetables	Fruits	Crops	Meats	Products		
	Grenada	Peas Beans	Mango Avocado Limes	Cereal Cocoa Nutmeg Mace Cinnamon Clove Coffee Yam Sweet potato Corn	Fish Chicken Beef Lamb Goat Chicken Turkey	Dairy products Honey Eggs	5.6%	106,000
	St Kitts and Nevis	Hot pepper Onion Tomato Cabbage Carrot	Coconut Banana	Irish potato Sweet potato Peanuts Cotton Rice Yam Breadfruit	Pork Poultry		2.5-5%	54,000
	St Lucia	Cabbage Lettuce Tomato Christophene	Coconut Banana Mango Avocado Citrus Soursop Pineapple Guava				3%	182,000
	St Vincent and the Grenadines	Tomato	Banana	Dasheen	Lamb	Honey	6.2%	109,000
Continental states	Belize	Beans	Citrus Banana Papaya Oranges Grapefruit	Sugar Rice Maize Plantain Cocoa	Fish Lobster Conch Shrimp		12%	332,000
	Guyana	Tomato Cucumber Eggplant Eschalot Bora	Coconut Pineapple Citrus Banana	Rice Sugar Ginger Ground provisions Coffee Cocoa Tobacco Copra	Shrimp Beef Pork Poultry Fish		21.8%	800,000

Country	Primary produce				Primary animal produce		Contribution to GDP	Total Population
	Vegetables	**Fruits**	**Crops**		**Meats**	**Products**		
Suriname	Tomato Cabbage Lettuce Carrot Cucumber Olive Lentil Beans Pigeon peas	Banana Coconut Citrus Palm Kernel	Rice Sugar Peanut Plantain Cassava Potato Beetroot Radish Turnip Sweet corn Mushroom		Fish shrimp Beef Poultry Pork		10%	539,000

Appendix 2:

Concept matrix used to systematically review key articles using content analysis

Author	Data type	Technology	Coverage
Pathak et al. (2019)	Qualitative	Precision Agriculture Technology (PAT)	US, Germany, Australia, Denmark, Turkey, Hungary, Nigeria, Canada, Brazil, and Iran
Michels et al. (2020)	Survey	Drones (UVA)	Germany
Kumar et al. (2020)	Survey	Improved Technologies	Nepal
Asare and Segarra (2018)	Survey	PAT	US
Silva et al. (2011)	Survey	PAT	Brazil
Paustian and Theuvsen (2017)	Qualitative	PAT	Germany
Mitchell et al. (2018)	Survey	PAT	Canada
Rezaei-Moghaddam and Salehi (2010)	Survey	PAT	Iran
Robertson et al. (2012)	Survey	PAT	Australia
Dhehibi et al. (2020)	Survey	Improved agricultural and livestock technologies	Tunisia
Lambert et al. (2015)	Survey	PAT	US
Lubell and McRoberts (2018)	Survey	Information and communications technology (ICT)	US
Tran et al. (2020)	Survey	Climate smart technology	Vietnam
Landmann et al. (2020)	Survey	ICT (smartphones)	India
Damba et al. (2020)	Survey	Dissemination approaches	Ghana
Shahbaz et al. (2012)	Survey	Feed technology	Pakistan
Wu and Ma (2020)	Theoretical model (evolutionary game model)	Internet of things (IoT)	China
Gardezi and Bronson (2020)	Survey and biophysical	PAT	US
Tey and Brindal (2012)	Qualitative	PAT	Australia and the US
Tamirat et al. (2018)	Survey	PAT	Denmark and Germany
Li et al. (2017)	Survey	Not available	China
Lencsés et al. (2014)	Interview	PAT	Hungary
D'Antoni et al. (2012)	Survey	PAT	US
Senyolo et al. (2018)	Interview	PAT and climate smart	South Africa

Author	Data type	Technology	Coverage
Maffioli et al. (2013)	Panel data	Improved practices and technologies	Uruguay
Barnes et al. (2019)	Survey	PAT	UK, Germany, the Netherlands, Belgium, and Greece
Khataza et al. (2018)	Survey	Conservation agriculture technology	Malawi
Aubert et al. (2012)	Qualitative	PAT	Canada
Khanal et al. (2019)	Survey	PAT	US
Faisal et al. (2020)	Survey	Climate smart technology and practices	Pakistan
Gallardo et al. (2019)	Survey	PAT	US
Lowenberg-DeBoer and Erickson (2019)	Survey	PAT	US, UK, Australia, Denmark, Argentina, Brazil, Canada, Turkey, Italy, Finland, Germany
Mariyono (2019)	Survey	Technology	Indonesia
Adenle et al. (2019)	Qualitative	Various low-cost technology and sustainable agriculture practices	Africa
Makate et al. (2019)	Survey	Climate smart agriculture technology	Africa
Freeman and Qin (2020)	Survey	Agricultural inputs	Africa
Watcharaanantapong et al. (2014)	Survey	PAT	US
Ouédraogo et al. (2019)	Interview and Survey	Climate smart agriculture technology and practices	Mali