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INFORMATION AND COMMUNICATION TECHNOLOGIES FOR AGRICULTURE (ICT4Ag) IN SUB-SAHARAN AFRICA: A BIBLIOMETRICS PERSPECTIVE BASED ON WEB OF SCIENCE DATA, 1991–2018

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ABSTRACT

The purpose of this study was to assess research articles published on ICT4Ag in sub-Saharan Africa, with a view to determining the application of information and communication technologies (ICTs) in the agricultural sector in the region. The agricultural sector in sub-Saharan Africa is one of the most important sectors that have greatly benefited from the application of ICTs. Research on the application of ICTs is rapidly expanding and therefore requires synthesis to gauge the extent of publication, the subject focus of the research on ICTs for agriculture (hereafter simply referred to as ICT4Ag), and the trend of publication and countries contributing to research on ICT4Ag in sub-Saharan African countries. Relevant data were obtained from the Web of Science (WoS) citation databases using a search query, which combined a variety of agricultural terms and several key, words that constitute ICTs. It was found that ICTs are largely applied for communication and dissemination of agricultural information to and among stakeholders, including farmers and extension workers. Areas of application involve land use, crops [production], animal husbandry, conservation, [soil and crop] management, and climate change. In terms of the broad disciplinary context, the application of ICTs in agriculture in sub-Saharan Africa occurs mostly in agronomy, environmental sciences, and dairy and animal science. Although only a few specific names of ICTs were found in the literature on agriculture, ICT-led activities and applications such as remote sensing, GIS, computer programs, software, Landsat, and information systems, among others, provided insight into not only the areas but also the nature of ICT application in agriculture in the region. The internet, radio, computers and mobile phones were among the few types of ICTs that featured in the ICT4Ag literature and are, therefore, deemed to be the commonly used in agriculture in sub-Saharan Africa. Concerning the foreign countries that have collaborated with sub-Saharan Africa in ICT4Ag research, the USA, France and England featured the most, thereby signalling the continuation of colonial legacies in the region. Furthermore, the pattern of collaboration may signal the nature of knowledge and innovation diffusion for ICT4Ag in sub-Saharan Africa. Finally, results reveal a diversity of areas of ICT application in agriculture in the region. The study makes recommendations for further research in other geographical regions for comparison purposes; a study to explore other bibliographic databases such as Scopus; and a study to assess the impact of the ICTs on agricultural performance of the affected countries.

Key words: Sub-Saharan Africa, Information technologies, Innovations, ICTs, ICT4Ag, Agriculture, Farming, Bibliometrics

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INTRODUCTION

Information and communication technologies (ICTs) have emerged as indispensable tools and drivers of change in the 21st century and beyond. However, despite their relatively long history, ICTs do not have a universally agreed definition, nor are the technologies that comprise the ICTs clearly demarcated. The multifaceted nature of the application of ICTs seems to be the defining characteristic that has resulted in different views and definitions of ICTs, which largely depend on contexts of application. For example, it has been observed that:

> *Referring to ICTs within the context of education encompasses not only a reference to equipment (that is, devices) but also to a group of skills or competencies that teachers and students must possess in order to be considered having achieved a certain level of competencies as it relates to ICTs [1].*

The same author contrasts this observation with the understanding of the concept within the business/information technology context:

> *The definitions and application of ICTs within a business/IT context rely upon an established economic sector in addition to a well-fortified regional, national and international ICT infrastructure. Divergently, the term ICTs refers to devices and networks/systems related to the support those devices, which have become tools of inter/intra organizational communication to facilitate conducting business in a globalized economy [1].*

Despite the diversity of views about the concept, the concept of ICTs has been labelled as being a "generic term" used to express the convergence of technologies and information services in telecommunications, information management, and broadcasting; and the use of such technologies in the delivery of social and economic products and services at all levels of society [2, 3]. In the information services sector ICTs are broadly viewed as the integration of telecommunications, computers and necessary enterprise software, middleware, storage, and audio-visual systems, which enable information users to access, organise, store, transmit, and manipulate information [4]. The information and communication technologies include hardware, software, media for collection, storage, processing, transmission and presentation of information in any format (that is, voice, data, text and images), and include computers, Internet, CD-ROMs, e-mail, telephone, radio, television, video, digital cameras, tablets, and so forth [3].

In terms of their applications, ICTs have been associated with or applied in all spheres of human life, including health [5], education [6, 7], business, commerce and trade [8], among others. The ICTs have also been applied in the agricultural field or sector in Africa [9].

APPLICATION OF ICTS IN AGRICULTURE: A BRIEF LITERATURE REVIEW

It has been noted that the information age has essentially created an environment whereby information is exchanged to access agricultural expert knowledge and collaborate or enhance learning among farming communities [10], whilst enabling farmers to respond to opportunities to improve their agricultural productivity [11].

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Essentially, ICTs have revolutionised the agricultural sector in that farmers apply ICTs to improve the quality of their decision-making processes [12, 13]. Farmers' accessibility of agricultural information has led to improved agricultural production in various countries where ICTs have been adopted for agriculture [12]. Different types of ICTs have also been linked to knowledge management in agriculture [14].

In sub-Saharan Africa, several countries have embraced the inclusion of ICTs in their agricultural systems [2]. Previously, the predominant information disseminators in sub-Saharan Africa consisted of community radio stations, television and newspapers. The emergence of new ICTs such as digital information repository channels, Internet-based and mobile-based technologies, has expanded the channels and avenues through which agricultural information is created, shared and used. The deployment of ICTs has facilitated the provision of market access and information [15]. Some of the ICTs that have been identified as crucial to the success of agricultural practices in sub-Saharan Africa include the following.

- ***Mobile phones:*** Mobile phones have quickly become one of the most popular forms of ICTs in sub-Saharan African countries. They facilitate information access and exchange and thereby aid in decision-making [11, 13]. Farmers use mobile phones mainly for communication purposes and for executing financial services [12]. Mobile phones have a potential to connect farmers to markets, close the information gap and enable informed decisions [16]. They help farmers to gain access to markets for agricultural produce, make appropriate decisions regarding where to sell their produce and eliminate costs associated with the middlemen [4, 11].
- ***Computers:*** Computers (especially handheld devices) help to transmit information directly to a decision support system where diagnosis is done, and the farmers receive solutions promptly before the problem(s) escalate(s). In Tanzania, for example, the Family Alliance and Development Cooperation (FADECO) is using a range of ICTs including Personal Digital Assistants (PDAs) to access agricultural information [11].
- ***Radio and TV:*** Agricultural researchers and extension workers use radio and television to disseminate agricultural information to the farming community [17]. The interaction involves a call-in component where farmers are given the opportunity to pose agriculture-related questions to a panel of experts either via phone or SMS and seek the necessary guidance and assistance in real time.
- ***Remote sensors:*** The role of remote sensing in agriculture cannot be over-emphasized [18]. The Food and Agriculture Organization of the United States (FAO) states that, in developed countries, the "Internet of Things, cloud computing and Big Data are revolutionizing agriculture whereby, for example remote sensors collect data on soil moisture, temperature, crop growth and livestock feed levels, enabling farmers to achieve better yields by optimizing crop management and reducing the use of fertilizers, pesticides and water" [18].
- ***GIS (Geographic information systems):*** Geographical information systems have emerged as key tools in support of agriculture [19, 20].

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Despite the numerous benefits of using ICTs in the agricultural sector in sub-Saharan Africa, there are still challenges, including the following: poor ICT infrastructure [21]; inadequate technological skills [3]; lack of comprehensive institutional ICT policy [17]; lack of monitoring and evaluation system [17]; and inadequate provision of ICT tools and services [3]. Other obstacles are poor ICT maintenance as these projects do not convert into programmes [17]; over-reliance on donor-funded projects leading to low levels of sustainability [17]; high prices and tariffs in the telecommunication services and Internet access [21]; and capital cost of technologies, and high cost of on-going access and support [3]. While the studies have identified various types of ICTs and associated systems that are used in agriculture, linking specific aspects of agriculture or agricultural practices to specific ICTs will enhance the understanding of the applicability of ICTs in agriculture in sub-Saharan Africa.

PURPOSE OF THE STUDY

Using bibliometrics techniques, this study sought to assess research articles published on ICTs as they relate to agriculture in sub-Saharan Africa, using the Web of Science (WoS) data, from 1991 to 2018, with a view to determining the application of ICTs in the agricultural sector in the region.

The specific objectives of the study were to:

a) Determine the volume and trend of research on ICT4Ag in sub-Saharan Africa from 1991 to 2018;
b) Examine the countries behind the research on ICT4Ag in sub-Saharan African countries;
c) Examine the subject areas in which ICTs are largely applied in agriculture in sub-Saharan African countries; and
d) Map and link various ICTs and their applications to specific agricultural practices or activities with which the ICTs are associated.

RESEARCH METHODOLOGY

The study adopted bibliometrics to explore research on ICTs as covered in the literature on agriculture. Bibliometrics is defined as the "application of mathematical and statistical methods to books and other media of communication" [22]. Bibliometrics is applied to study all forms of written communication, as it is patterned in its bibliographies [23]. Bibliometrics can be used to study words in a text, journals, author productivity, publications and citations to publications. A quantitative content analysis, which has increasingly become common in bibliometrics studies, was applied to analyse the data obtained from the Web of Science databases. Content analysis is used to provide a "detailed and systematic examination of the content of a particular body of material (for example, television shows, magazine advertisements, Internet websites, works of art) for the purpose of identifying patterns, themes, or biases within that material" [24]. Content analysis was used in the current study to explore the bibliographic data (that is, the content) associated with the papers on ICT4Ag in sub-Saharan Africa's countries as indexed in the Clarivate Analytics Web of Science's (WoS) citation indexes, namely:

Science Citation Index, Social Sciences Citation Index, Arts and Humanities Citation Index, and the Conference Proceedings Citation Index (Social Science & Humanities. Although the database has been criticised for its bias in the coverage of publications originating in developing countries, the WoS remains a reliable source of bibliographic information for bibliometrics studies. In recent times, the WoS has expanded its coverage to include journals published in many developing countries as indexed in different citation indexes, for example the Chinese Citation Index and the Indian Citation Index as well as the Scientific Electronic Library One (SciELO). In addition, the WoS was most suited as its citation indexes cover more science-based publications than other bibliographic databases. The search was limited to documents published in all languages between 1991 and 2018. The start date was settled on because preliminary searches indicated that there were only two ICT-related documents published prior to 1990; that is one article each in 1986 and another in 1988. The end date of 2018 was arrived at because the study was conducted in 2019.

First, a search for literature on ICTs in the databases was conducted using the following ICT-related terms: software*, sms*, e-mail*, email*, www, "world wide web", "information system*", ipod*, ipad*, "information and communication technolog*", phone*, "electronic device*", digital*, "social media", camera*, television*, intranet*, Internet, mobile phone*, radio*, computer*, ICT*, "communication technolog*", and "information technolog*". The terms were determined using various online thesauri such as the EBSCOHost databases' thesauri, the literature review, and the authors' own knowledge. The search was conducted within the title, abstract, and keywords fields, using the field tag *TS* (*Topic*) (for example, *TS=digital**).

Second, a search was conducted to obtain documents that were published in the subject domain of agriculture, using several terms that mainly included synonyms of the term "agriculture" as well as the term "agriculture", truncated as *agricultur**. The field tags *TS* and *SU* were used to conduct the search within the *topic* and *research areas,* respectively. Only one search was conducted within the *WoS research area* field, namely *agriculture.* The search that was conducted within the *Topic* field employed the terms agrar*, agricultur*, agronom*, agribusiness*, husbandr*, farm* and horticultur*. A search query to retrieve and obtain agricultural documents using the *research area* was formulated as *SU=Agric**.

The two search queries were combined to obtain documents that focused on ICTs and agriculture using the query *#1 AND #2*. Once the results were obtained, they were subjected to analysis using the WoS' built-in *Analyze Results* option. The analysis was conducted according to *Countries or Regions* of affiliation to isolate and extract the documents that were published in sub-Saharan African countries. A total of 1 043 documents were obtained and subjected to further analysis in order to obtain relevant results to meet the current study's objectives. Two approaches were adopted to analyse the documents on ICT4Ag in sub-Saharan Africa:

a) The WoS analysis option yielded the publications per year and the WoS subject categories. The two indicators proxied the trend of research and the disciplines or research focus areas in the topic of investigation, respectively.

b) The VOSviewer software was used to analyse the data so as to obtain the countries behind ICT4Ag research, most common keywords in the literature on ICTs in agriculture in sub-Saharan Africa as well as to map the various agricultural practices in which the ICTs are applied. This analysis produced the network maps in Figures 1 to 8.

RESULTS AND DISCUSSION

This section presents and, then, discusses the findings according to the four broad thematic areas of the study as reflected in the objectives of the study, namely:

- Volume and trends of research on ICT4Ag in sub-Saharan Africa;
- Countries behind the ICT4Ag research in sub-Saharan Africa;
- Subject areas of ICT4Ag research in sub-Saharan Africa; and
- Types of ICTs, ICT applications and systems for specific agricultural practices.

Volume and trend of research output on ICT4Ag in sub-Saharan Africa

Worldwide, 1,400,008 papers were published on ICTs and associated terms between 1991 and 2018. Of these, 29,370 were indexed in the research field of *agriculture*, posting a contribution of 2.10% of the world publication output on ICTs. Sub-Saharan African countries published a combined 16,333 papers on ICTs, thus accounting for a 1.17% of the world publication output on the subject. In terms of the world publications output in the field of agriculture, the databases yielded 913 823 papers, of which sub-Saharan African countries produced 37,381, thereby accounting for 4.10% of the world total number of papers on agriculture between 1991 and 2018. As mentioned in the methodology section, the series of searches that were conducted in the four citation databases yielded 1,043 documents that dealt with ICTs in agriculture (a phrase that is hereafter simply referred to as ICT4Ag) in sub-Saharan Africa. This number of papers accounted for 3.55% of the world total on ICT4Ag.

Table 1 shows that the frequency of occurrence of ICT terms in the agriculture literature has continued to increase, albeit with decreases in some time periods (as reflected in column 4 in Table 1). There were 36 articles on ICT4Ag in sub-Saharan Africa published between 1991-1995, thereby accounting for 3.45% of the 1043 documents published between 1991 and 2018. The 1996-2000 period yielded 58 (5.6%) documents while the subsequent years of publication posted the number of documents as follows: 2001-2005 (97; 9.3%), 2006-2010 (184; 17.6%), 2011-2015 (344; 33.0%) and 2016-2018 (324; 31.1%). The average number of papers per each in the five five-year periods was as follows: 1991-1995 (7.2), 1996-2000 (11.6), 2006-2010 (36.8), 2011-2015 (68.8) and 2016-2018 (108.0). In terms of the trend of research in ICT4Ag, it was observed that the number of publications rose from 4 in 1991 to 11 in 2000, thereby registering a 175% increase. By 2010, the number of publications had grown to stand at 50 while it reached 134 in 2018. There was a slow growth before 2009, after which a rapid increase in publications was witnessed.

Generally, the above results reveal that the volume of research on ICT4Ag in sub-Saharan Africa has continued to grow over time. In addition, the contribution of sub-

Saharan Africa to the world total number of publications in ICT4Ag is much higher when compared to the region's contribution in all fields of research. For example, it has been previously noted that Africa produced about 1.8% of the total number of publications between 2000 and 2004 worldwide [25, 26]. In a more recent study, it was observed that Africa's contribution to the world's knowledge base in terms of research publications is gaining momentum but is still below 2% of the world output [27]. The performance of agriculture which surpasses the average for all knowledge can be attributed to agriculture being the mainstay of most African economies and as such "agricultural sciences are considered an important research area for many of the African countries, particularly for the Sub-Sahara countries" [28], perhaps due to agriculture's major contribution to the countries' gross domestic product (GDP) as well [9]. The trend of research as shown in Table 1 reveals that ICTs became highly visible in agricultural research in the mid-2000s and specifically after 2003. It was around this time that social media technologies and/or platforms came into being or were used more frequently [29]. The emergence of social media and applications (commonly referred to as apps) in the mid-2000s may further explain the rapid growth of publications bearing the ICT terms in the literature on agriculture. This trend is likely to persist as the number of small businesses that are meant to support agricultural activities, using ICTs, on the continent keeps rising. The proliferation of software applications which are specifically developed for agricultural purposes is likely to result in further research which will in turn increase the number of publications on ICT4Ag. Specifically, the mobile phone capabilities will continue to transform the use of social media platforms and proliferate the use of the short message service (sms), and therefore become a common occurrence in agricultural practices in the future [13].

Countries behind the ICT4Ag research in sub-Saharan Africa

An examination of the countries contributing to research on ICT4Ag was conducted to identify the countries shaping research in the subject domain as well as the countries that are involved in knowledge exchange and diffusion as far as ICT4Ag in sub-Saharan Africa is concerned. The mapping of the data produced a network map of the collaborating countries with four main clusters coalescing around four pairs of sub-Saharan African countries namely: South Africa and Nigeria, Ethiopia and Kenya, Tanzania and Uganda, and Senegal and Madagascar. In terms of the number of publications on ICT4Ag, Table 2, which provides the top 50 countries that conducted ICT4Ag research in the region, shows that South Africa yielded the most (that is, 362; 34.7%) followed by Kenya (141; 13.5%), Nigeria (135; 12.9%), Ethiopia (103; 9.9%), and Tanzania (91; 8.7%). International collaboration involving sub-Saharan Africa and countries from outside Africa was visible, with the USA producing the highest number of publications (that is, 154; 14.8%) and France and England following with 91(8.7%) and 77 (7.4%) papers, respectively. Other foreign countries that engaged in ICT4Ag research in collaboration with the countries in the region include Netherlands (65; 6.2%), Germany (57; 5.5%), Belgium (48; 4.6%), and Australia (40; 3.8%), just to name the countries that yielded 40 and more documents.

It is evident that the top-ranked countries in Africa in terms of research output [28] performed equally well in terms of ICT4Ag. Although South Africa was ranked top, agricultural sciences is not the most important research area in the country [28]. Foreign

countries' participation in research emanating from sub-Saharan African countries is not new; the patterns and nature of the collaborations have been identified in various studies [27]. Researchers based in the United States of America (USA), the United Kingdom (UK), and France have long participated in research, together with their counterparts in sub-Saharan African countries. Colonial legacies have been cited as a factor that largely influences the collaborative patterns between researchers in Africa and their peers in foreign countries [28, 30]. Research funding, originating from outside Africa, and African students studying in foreign countries especially at post-graduate level, could be other factors that might be influencing collaboration between African and foreign countries. In addition, the visibility of foreign countries in ICT4Ag in sub-Saharan Africa might also imply knowledge diffusion in ST&I (science, technology and innovation) for agriculture in the region in line with the widely held belief that collaboration breeds knowledge exchange and diffusion which in turn leads to increased innovativeness [31, 32]. Therefore, the countries that are mostly engaged in ICT4Ag research and, by extension ST&I knowledge diffusion in sub-Saharan Africa, are the USA, France, England, Netherlands, Germany and Belgium.

Subject areas of ICT4Ag research in sub-Saharan Africa

This section provides the findings based on the analysis of the 1,043 publications according to (a) the broad WoS subject categories and (b) author-supplied keywords. The co-occurrence of ICTs and agricultural topics or subjects (using author-supplied keywords and broad subject categories) was analysed to identify the disciplines or subject domains that have greatly contributed to ICT4Ag research in sub-Saharan Africa as well as the domains or areas in which ICTs are largely applied within the context of agriculture.

Table 3 reveals the top 50 WoS subject categories where ICT terms appeared in the literature. *Agronomy* leads the pack with 128(12.3%) documents, followed closely by e*nvironmental sciences*, which yielded 117(11.2%) documents. Other agriculture-related disciplines or subject categories that ranked high in Table 3 include *multidisciplinary agriculture* (106; 10.2%), and *dairy* [and] *animal science* (100; 9.6%). *Water resources*, *soil science and ecology*, v*eterinary sciences* and p*lant sciences* constituted the categories that were in the second tier of disciplines. The least ICT4Ag publications were recorded in such subject categories as *women's studies*, *urology and nephrology*, *surgery*, *spectroscopy*, *biomedical social sciences*, *physiology*, *peripheral vascular disease*, *palaeontology and optics*, among others, which yielded only one (1) document each on ICT4Ag. The high position that *environmental sciences* holds in the Table is illustrative of its influence on agricultural activities. One of the major key words that commonly appeared in ICT4Ag literature is *climate change*, which is within the scope of *environmental sciences*. Other disciplines that may be classified as influencers of agriculture in the region and in which ICTs have been applied, as shown in Table 3, include *geosciences*, *information science and library science, genetics and heredity, meteorology and atmospheric sciences* and *forestry*.

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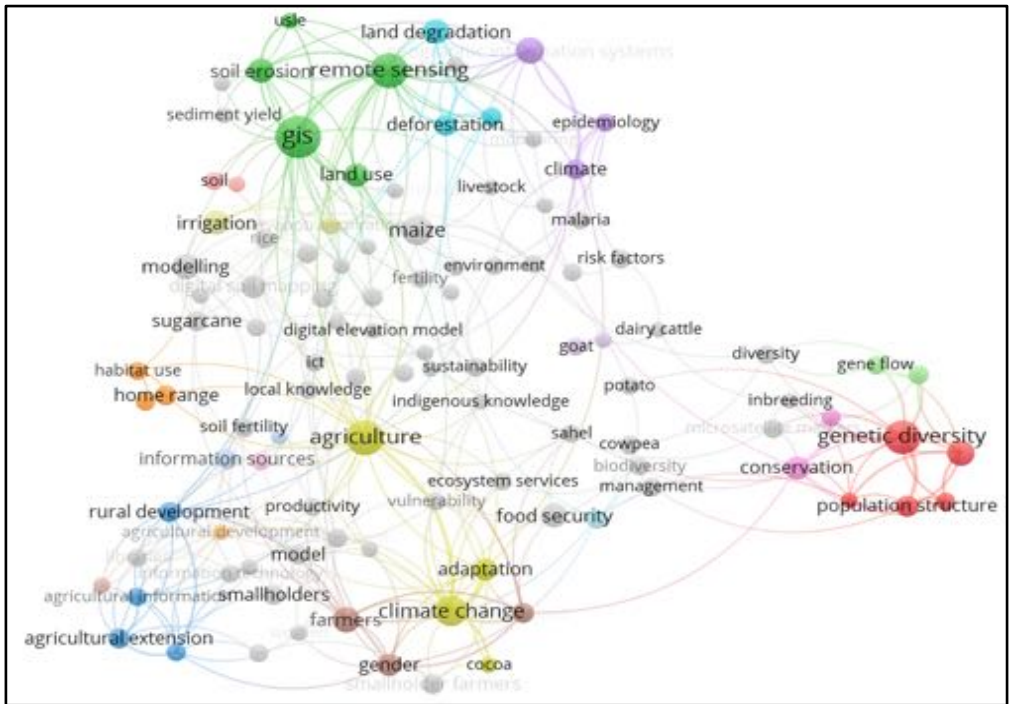

Figure 1: Network map of the most common author-supplied keywords (threshold ≥ 4), 1991–2018

Another way of identifying the subject content of the literature in a specific domain is the analysis of key words. Figure 1 is a visual map that was generated with the VosViewer software using author-supplied key words that appeared in four (4) or more documents. There was a total of 81 key words that met the threshold of appearance in 4 or more documents. The keywords that appeared in more than 1.5% of the documents were *GIS*, which appeared in 41 (3.9%) documents, followed by *agriculture* (27; 2.6%), *remote sensing* (27; 2.6%), *genetic diversity* (24; 2.3%), *climate change* (19; 1.8%) and *maize* (18; 1.7%).

The VosViewer software also permits analyses of other versions of key words namely: all key words, and key words plus, in addition to author-supplied key words. The "key words plus" option draws key words from the titles and abstracts of documents under investigation. "All key words" is a combination of author- supplied key words and key words plus. The results based on *key words plus* analysis are provided in Table 4 which depicts the top 50 key words that were obtained from the 1043 documents analysed in the current study. As the number of frequencies in Table 4 indicates, the most prominent key words were *management* – with 115 links (L), 234 total link strength (TLS) and 71 occurrences (Freq.). Other key words that appeared the most in the ICT4Ag literature are: *software* (L=66, TLS=210, Freq.=63), *GIS* (L=66, TLS=105, Freq.=51), *agriculture* (L=90, TLS=146, Freq.=45), *diversity* (L=57, TLS=156, Freq.=41), *conservation* (L=70, TLS=141, Freq.=40), *model* (L=72, TLS=99, Freq.=40), *systems* (L=74, TLS=112, Freq.=37), *farmers* (L=49, TLS=75, Freq.=28) and *genetic diversity* (L=41, TLS=124, Freq.=28). The links represent the number of key words with which a specific key word co-occurred in a document, while the total link strength represents the total number of

ties a key word had with other keywords. It follows, therefore, that *management, software, diversity, agriculture, conservation, genetic diversity, systems, population-structure,* and *GIS* exhibited strong relationships among themselves and with other key words. These key words may be taken to be the core areas in which ICTs are commonly applied.

As reflected in Table 3, *Agronomy* e*nvironmental sciences*, *multidisciplinary agriculture, dairy* [and] *animal science, water resources*, *soil science and ecology*, v*eterinary sciences* and p*lant sciences* were the areas that yielded the most number of papers while the following broad subjects yielded the least number of ICT4Ag publications: *women's studies*, *urology and nephrology*, *surgery*, *spectroscopy*, *biomedical social sciences*, and *physiology*. A deeper analysis of the dominance of agronomy portrays specific areas of agriculture in which ICTs are mostly applied. For instance, the prominence of agronomy among the broad subject categories implies that ICTs are largely applied in or associated with soil management and/or crop production. This pattern is reinforced in the next section on the analysis of the keywords as presented in Figure 1. The most common author-supplied key words in the literature as reflected in Figure 1 include: *remote sensing*, *crops, genetic diversity*, *climate change*, *maize, management, conservation* and *population-structure*. The top ranked subject categories and the most common key words in the literature are evident of and reflect the main agricultural activities in sub-Saharan Africa. For example, the dairy or livestock farming, and crop production are the mainstay of the livelihoods of many poor families in the developing countries, including sub-Saharan Africa [33] and therefore, it is not surprising for agronomy to top the list of subject areas applying ICTs. It can also be argued that not only do the top subjects and key words mirror the important areas in which ICTs are applied in agriculture in sub-Saharan Africa but, they also mirror the areas that are reliable receptors of the application of ICTs. It has been observed that the adoption of and use of ICTs is partly dependent on ease of use and perceived usefulness of the ICTs in any given context [34]. It has also been noted that farmers adopt and use ICTs based on such factors as farm size, and the type of agricultural activity [35]. The subject categories and key words with the least number of ICT4Ag papers were either not closely associated with agriculture or were peripheral and not core areas of the published literature on agriculture. Their appearance among the subject areas within which ICT4Ag research is conducted can be attributed to increased attention to interdisciplinary and/or multidisciplinary scientific investigations in the 21st century. It is also widely acknowledged that research on the application of ICTs is multidisciplinary and, as a result, studies on ICT4Ag are not solely conducted by researchers in one field (that is, agriculture) but they cut across and bring together scholars from many disciplines and fields of study, hence the presence of such fields as *library and information science*, *women's studies*, *urology and nephrology*, *surgery*, *spectroscopy*, *biomedical social sciences*, *physiology*, *peripheral vascular disease*, and *palaeontology and optics*, which also featured among the broad subjects in Table 4 identified from a key words-plus analysis.

Types of ICTs, ICT applications and systems for specific agricultural practices

Table 5 offers a list of labels that were extracted from the ICT4Ag literature in an attempt to identify the types of ICTs and their associated applications in agriculture in sub-

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Saharan Africa. In a network visualization, items (for example, countries, keywords, journals, authors, and organizations) are represented by their labels and circles (that is, nodes). Table 4, therefore, provides the labels (that is, names of ICTs and their applications, as author-supplied key words) and their frequencies of occurrence in ICT4Ag literature. The analysis produced 18 clusters with some clusters consisting of only one label. At the top of Table 5 is the label *software*, which appeared in 63 documents as a keyword, followed by *GIS* (51), *systems* (37), *remote sensing* (27), and *computer-program* (17). These terms mirror the ICT applications while the actual ICTs included m*obile phones*, which occurred in 10 documents, followed by the *Internet* (6), and *radio* (5). This section discusses the findings on the emerging and most prominent ICTs or ICT-based applications and their associated agricultural practices.

Geographic information systems

The literature on ICT4Ag yielded several variations of the term *Geographic Information Systems*. The variations of the concept and their frequencies of occurrence in ICT4Ag literature were as follows: g*eographical information system* (4), g*eographical information-system* (2), *geographical information systems* (9), *geographical information-systems* (2), g*eographic information system* (8), g*eographic information-system* (2), g*eographic information systems* (13), and g*eographic information-systems* (2) while *GIS* appeared in 51 documents. For purposes of mapping the key words with which the variations of the concept were linked, this section maps the most common term (that is, *GIS*). Figure 2 links *GIS* to the following agricultural subjects: *irrigation, maize, livestock, soil, soil erosion, sugarcane, millet, landscape, agriculture, soil organic carbon, land use, land coverage change, sediment yield, market access,* and *erosion*, among others. Some ICT-associated terms, to which the concept is linked, are *remote sensing, image analysis,* and *landsat*. The linkage of *GIS* to agriculture was limited to Ethiopia, Ghana, Kenya, Nigeria, and Zimbabwe.

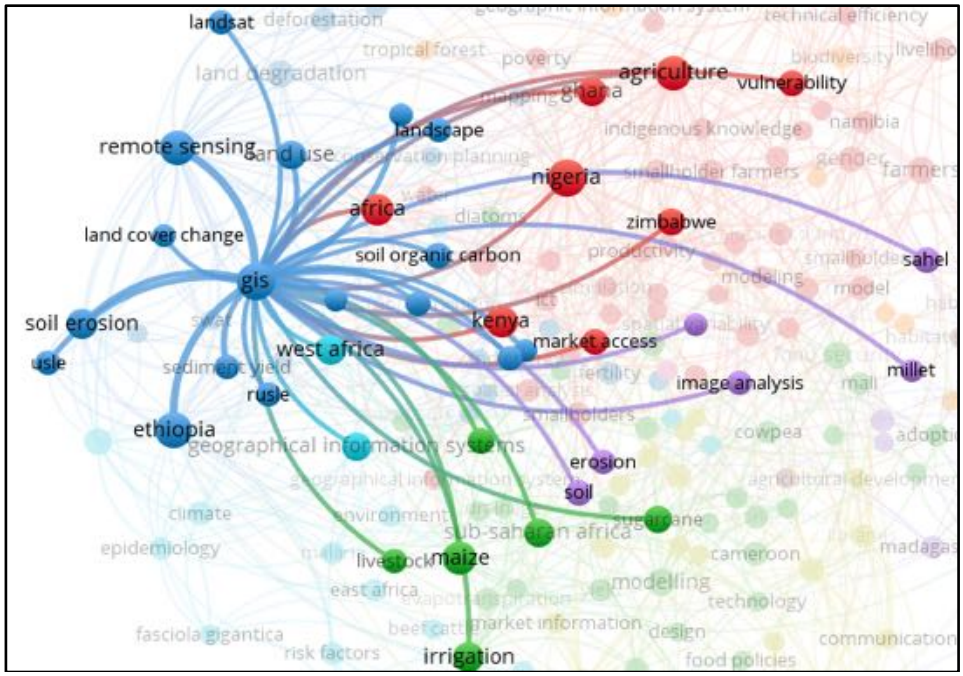

Figure 2: Network map of *GIS* as reflected in the ICT4Ag literature, 1991–2018

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Computers

Research that links computers, and more particularly computer programming or programs, to agricultural practices has focused largely on the following areas as shown in Figure 3: *management, climate, dynamics, ecology, population, conservation, differentiation, diversity, genetic diversity, resistance* and *gene flow*. The countries that are mentioned in relation to computer programs are *Ethiopia, Niger,* and *South Africa*. It is only *Ethiopia* that appeared among the terms associated with *GIS*.

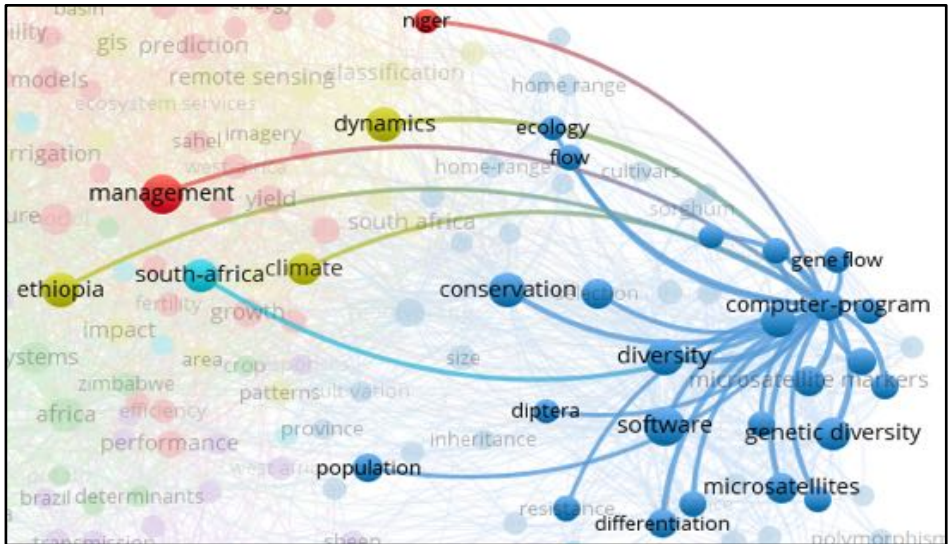

Figure 3: Network map of *computer program(s)* as reflected in the ICT4Ag literature, 1991–2018

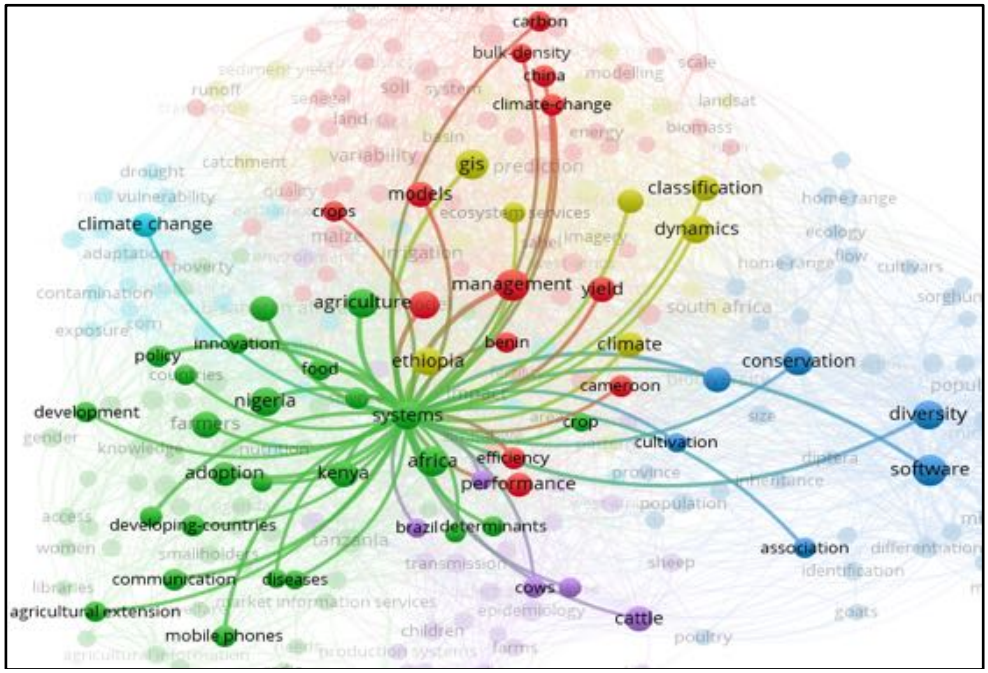

Figure 4: Network map of *systems* as reflected in the ICT4Ag literature, 1991–2018

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Systems

Although the key word "*systems*" does not necessarily relate to ICTs only, as Figure 4 shows, its linkage to *software* and *mobile phones* influenced the decision to map it so as to identify the main keywords with which it is linked. The concept had one of the largest networks of terms and showed strong links with *management, yield, diversity, climate change, climate, models, agriculture, dynamics, food, policy, farmers, agricultural extension,* and c*lassification*. The African countries that were most linked with the key word *systems* are: *Cameroon, Ethiopia, Kenya,* and *Nigeria* and the ICT-associated applications and devices that were mentioned together with *systems* in the literature are *mobile phones*, *GIS*, and s*oftware*. The application of *systems* seems to surpass its relationship with ICTs only to extend to such areas as *communication, management, classification, conservation, cultivation* and *modelling*.

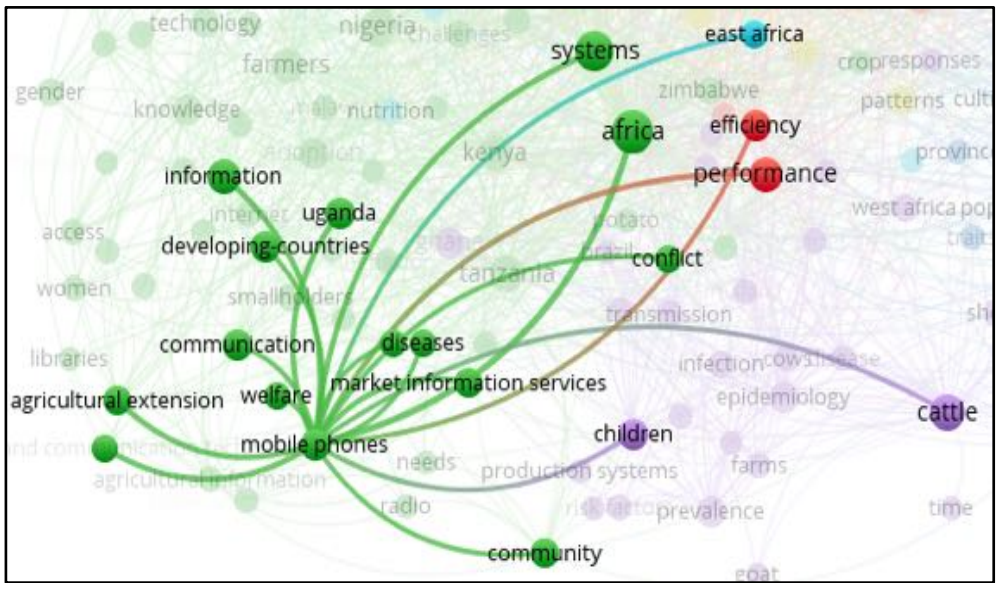

Figure 5: Network map of *mobile phones* as reflected in the ICT4Ag literature, 1991–2018

Mobile phones

The term *mobile phones* was associated with sixteen (16) key words, including geographical regions or territories. The concept was majorly linked with *agricultural extension*, *communication*, *information*, *market information services*, *community*, and *performance* and *efficiency* (see Figure 5). The use of mobile phones for communication and information sharing is clearly demonstrated in the network map, and in line with several authors who have associated mobile phones with communication (see [12, 17]). The type of information that is communicated or shared includes *market information* and information on *diseases*. The visibility of *agricultural extension* is illustrative of the type of workers and/or work that utilises the mobile phones. Three geographic territories were linked to *mobile phones* – that is, *Africa, East Africa* and *Uganda*.

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Information and communication technologies

The term ICT appeared in diverse forms, such as *ICT* (8), *information and communication technologies* (6), *ICT4Ag* (2), *ICT4D* (2), and *ICTs* (2). Figure 10 maps the keywords linked with the term that occurred most frequently in ICT4Ag literature – in other words, information and communication technologies (10). *Rural development*, *development*, *communication*, *agricultural extension*, and *agricultural information* were the main keywords that were linked to the keyword *information and communication technologies* as shown in Figure 6. It is illustrative that the concept (information and communication technologies – ICTs) share some terms with *mobile phones*, among them being *communication,* and *agricultural extension*. The relationship in terms of the keywords with which the two keywords are linked lies in the fact that mobile phones are a type of ICTs. The terms *development* and *rural development* suggest the focus of agricultural research and more particularly the area of ICT application in agriculture in sub-Saharan Africa. *Uses of information and communication technology (ICT) in agriculture and rural development in sub-Saharan Africa: experiences from South Africa and Kenya* is a typical example of studies that have focused on agriculture and rural development in sub-Saharan Africa [36]. The geographical territories that were associated with the *information and communication technologies* are *East Africa* and *Africa*, which explains the regions under investigation.

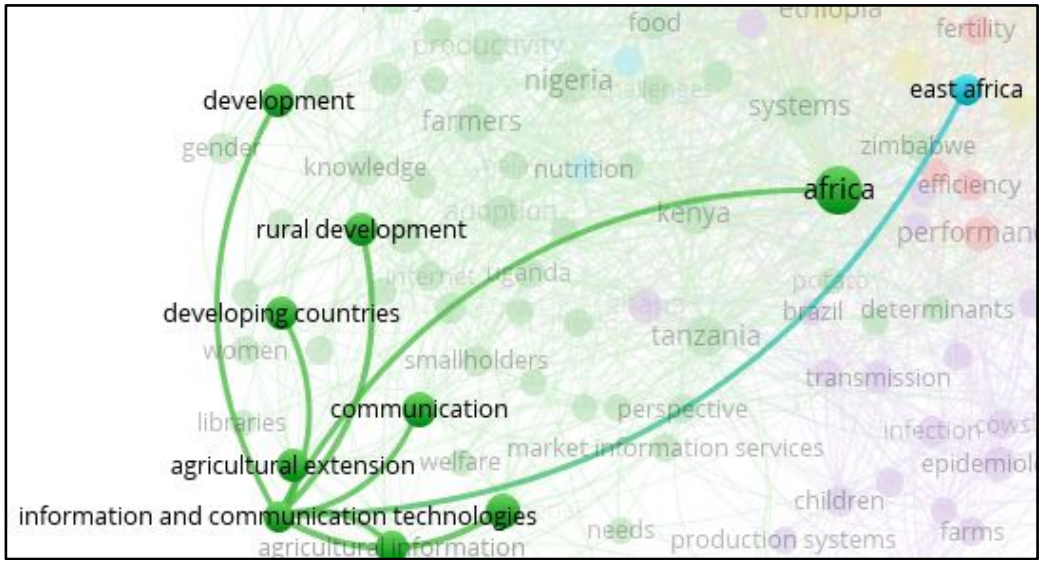

Figure 6: Network map of *information and communication technologies* as reflected in the ICT4Ag literature, 1991–2018

Software

Figure 7 depicts the visual map of 58 keywords associated with the term *software*. The outstanding links were between *software* and *management*, *climate change*, *agriculture*, *conservation*, *population*, *diversity, cattle, classification, dynamics, soil, irrigation, yield* and *genetic diversity.* The linkage of software to many key words, as shown in Figure 7, implies a wider application of this ICT-enabler in many aspects or areas of agricultural practice. It is acknowledged that most ICTs require some sort of *software* or application to execute functions. *East Africa, South Africa,* and *Africa* are the only geographic territories that were mentioned together with *software* in the documents on ICT4Ag.

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Remote sensing

Remote sensing was equally well linked with many key words. The scanning of the earth, a process that is simply known as *remote sensing*, is conducted to obtain information about it. The interest of the researchers on *remote sensing* seems to focus on *land use change*, *land degradation*, *water, drought, soil erosion, water basin, evaporation, desertification, agriculture, dynamics,* and *climate* (see Figure 8). Other areas of interest of the researchers with which *remote sensing* is associated are *conservation*, *impact, area*, *construction*, *communities*, and *epidemiology*. The geographical regions that are of great interest to researchers who are mostly interested in *remote sensing* are *Ethiopia* and *Nigeria*. It is interesting but not surprising to note that *remote sensing* is closely linked to *GIS* and *Landsat*, two of the ICT applications that were identified in the study. *GIS* and *Landsat* are also processes associated with scanning of the earth, just as it is the case with *remote sensing*.

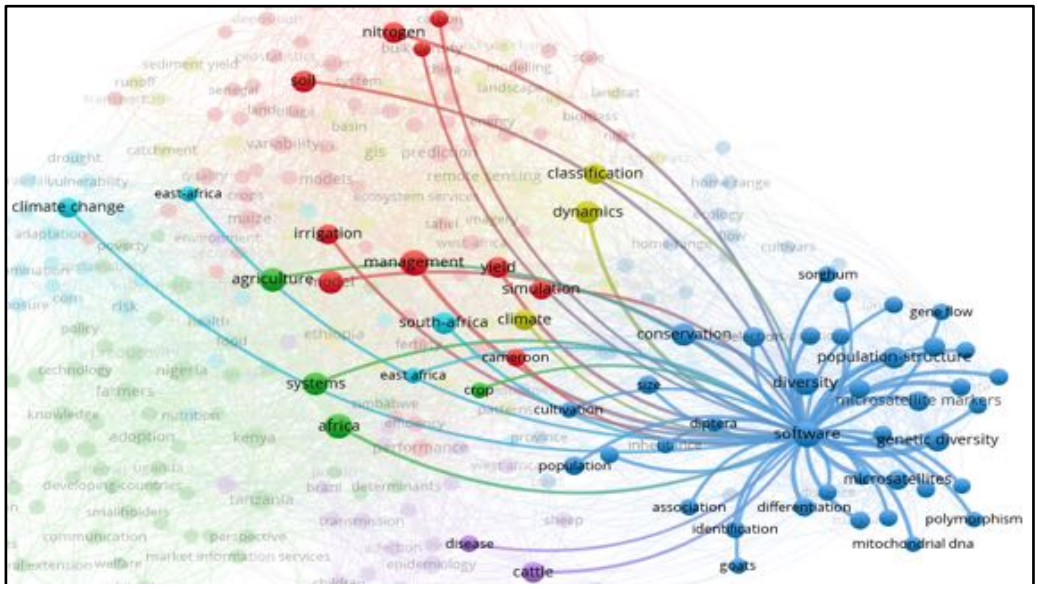

Figure 7: Network map of *software* as reflected in the ICT4Ag literature, 1991–2018

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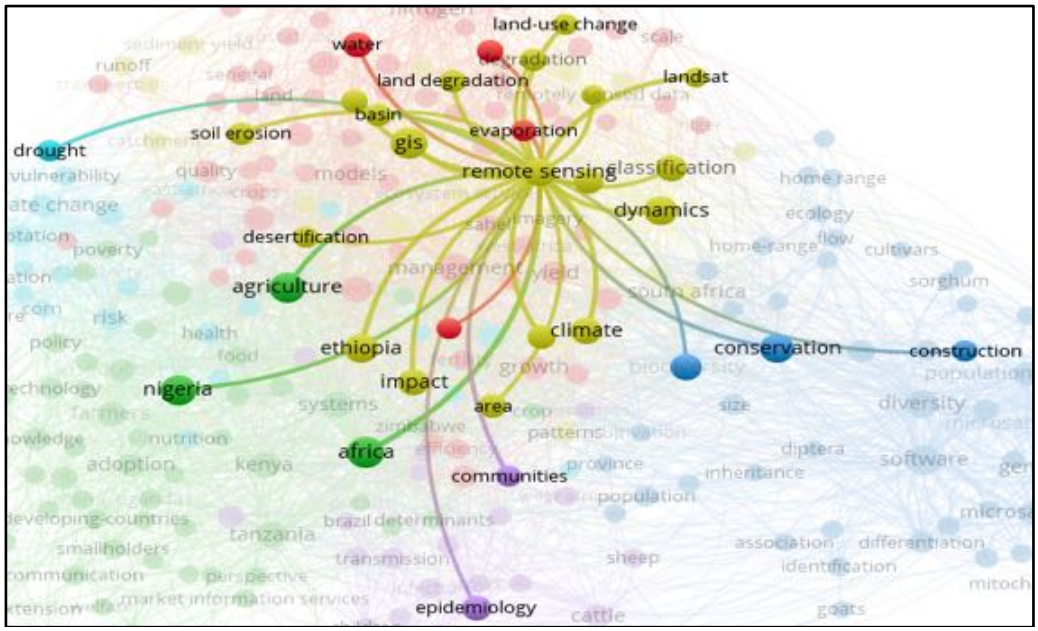

Figure 8: Network map of *remote sensing* as reflected in the ICT4Ag literature, 1991–2018

The mapping of ICTs and their associated applications in Figures 2 to 8 reveals that the ICTs are linked to several and diverse keywords, which reflect agricultural practices in the region. The main agricultural terms that co-occurred with ICTs in the ICT4Ag literature and which reflect the specific agricultural areas (or research areas) or practices that may be said to benefit the most from the application of ICTs relate to *land use, irrigation, deforestation, agricultural extension, food security, epidemiology, crop production, animal husbandry, conservation, soil and crop management,* and *climate change*, among others. The conspicuous use of some of these key words in the ICT4Ag literature fairly correlates with the pattern observed in the analysis of the broad subject terms. *Crop production, animal husbandry, food security, conservation* and *land use* are some of the main agricultural undertakings that are pertinent agricultural practices in the region. It was, furthermore, noted that some of the key words were closely linked to some ICTs than they were to others. For example, *remote sensing* (sensors) was heavily linked to land use and soil management (for example, soil erosion) while mobile phones were mostly linked to agricultural extension work, information communication, and market information services. In other words, whereas remote sensors are used to map land use in order to check soil erosion, among other agricultural practices, mobile phones are largely used to communicate information as well as marketing agricultural products. These patterns are supported by several scholarly works, for example, [11], [12], [16], and [18]. As expected, the term ICTs (and its variations) was linked to many key words that were also linked to several other ICTs despite many scholars focusing on specific ICTs in their studies. The computer, which became popular in agriculture in the early 1980s, is used to execute many tasks in agriculture such as financial accounting, communication, transactions processing and information retrieval [35], and many more. In fact, some of the ICTs that are applied in agriculture (for example, Internet) were initially exclusively used via computers, hence the linkage of computers to a variety of agricultural terms as well as other ICTs in the current study. On its part, GIS is one of

what some scholars have called 'precision technologies', which use "information from multiple sources to assist farmers in making crop production and management decisions based on the variability of production potential within fields" [37]. The importance of GIS in agriculture cannot be overemphasised as it allows the use of numerous technologies, processes, techniques and methods to capture and analyse spatial and geographic data to boost agricultural practices. Its application as illustrated in Figure 2 revolved around *irrigation, soil erosion, landscaping, land use, land coverage change,* and *market access*. Some of these key words were also linked to remote sensing. A quick scan of the published literature indicates that scholars often study GIS alongside remote sensing [38].

CONCLUSION

In conclusion, it is evident that the application of ICTs in sub-Saharan Africa has slowly pervaded the agricultural sector. There are several ICTs that are applied in agriculture in the region. They include mobile phones, computers, radio and the Internet as the main ICTs used in agricultural practices in sub-Saharan Africa. However, the ICT4Ag extend beyond specific devices as they were implied through the occurrence of such keywords as "remote sensing", "systems", and "geographic information systems" (and its variations). The dominance of keywords that reflect agricultural areas that are the mainstay of most livelihoods of many poor families in sub-Saharan Africa imply that there are deliberate attempts to use the ICTs in strategic areas for maximised agricultural production and development in the region. The current technological developments, which have witnessed the proliferation of farming innovations around the world and more particularly in sub-Saharan Africa are likely to result in increased use of ICTs in agriculture and in turn increase research in ICT4Ag. There are several initiatives in sub-Saharan Africa that are meant to increase the usage of ICTs in agriculture (see for example, [39]). The following innovations, among others, serve as examples of initiatives that are geared towards revolutionising farming in sub-Saharan Africa: dairy hubs, farm management software, drones and mobile apps. A scan of the Android App Store, furthermore, indicates that there are tens of apps that have been developed to support farming. However, the extent to which these apps have been adopted and used to improve agricultural practices in sub-Saharan Africa is an area that this study strongly recommends for further research. It will also be interesting to investigate the impact of ICTs on agricultural efficiency and food production in the region – as such a relationship could not be investigated in the current study due to lack of data. The study further recommends further research in other geographical regions for comparison purposes; a study to explore other bibliographic databases such as Scopus and Agricola, and a study to assess the impact of the ICTs on agricultural performance of the affected countries.

IMPLICATIONS OF THE STUDY

The study provides a practical example of how bibliometrics can be applied to investigate a phenomenon beyond the field of library and information science where bibliometrics is widely applied. Theoretically, the study contributes to the theoretical understanding of the application of bibliometrics in mapping and visualizing knowledge, right from its production to use and re-use. The visualisation of keywords, linking ICTs and specific

keywords that represent agricultural practices, presents an alternative technique and/or method to understand the application of ICTs in agriculture. In addition, the acquisition of knowledge about which ICTs are closely linked to which agricultural practice or specific task would increase efficiency in ICT application. Finally, this paper provides scholars with a basis for further discourse on the use of bibliometrics (and content analysis) to investigate the use of ICTs in agriculture, the collaboration linkages amongst and between sub-Saharan African countries and foreign countries, the linkages between specific ICTs to various agricultural terms, and the role of specific ICTs in agricultural practices, among others.

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Table 1: Publications output in ICT4Ag in sub-Saharan Africa, 1991–2018 (N = 1,043)

Publication year	Number of Documents	Percentage contribution	Change in Documents	Percentage change
1991	4	0.4		
1992	3	0.3	-1	-25.0
1993	12	1.2	9	300.0
1994	7	0.7	-5	-41.7
1995	10	1.0	3	42.9
1996	11	1.1	1	10.0
1997	15	1.4	4	36.4
1998	9	0.9	-6	-40.0
1999	12	1.2	3	33.3
2000	11	1.1	-1	-8.3
2001	13	1.2	2	18.2
2002	20	1.9	7	53.8
2003	20	1.9	0	0.0
2004	20	1.9	0	0.0
2005	24	2.3	4	20.0
2006	32	3.1	8	33.3
2007	28	2.7	-4	-12.5
2008	38	3.6	10	35.7
2009	36	3.5	-2	-5.3
2010	50	4.8	14	38.9
2011	62	5.9	12	24.0
2012	90	8.6	28	45.2
2013	69	6.6	-21	-23.3
2014	59	5.7	-10	-14.5
2015	64	6.1	5	8.5
2016	96	9.2	32	50.0
2017	94	9.0	-2	-2.1
2018	134	12.8	40	42.6

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Table 2: Top 50 countries behind ICT4Ag research in sub-Saharan Africa, 1991-2018 (N = 1,043)

No.	Country/region	Documents	%		No.	Country/region	Documents	%
1	South Africa	362	34.7		26	Japan	20	1.9
2	USA	154	14.8		27	Malawi	20	1.9
3	Kenya	141	13.5		28	Spain	20	1.9
4	Nigeria	135	12.9		29	Botswana	17	1.6
5	Ethiopia	103	9.9		30	Scotland	17	1.6
6	France	91	8.7		31	Sudan	17	1.6
7	Tanzania	87	8.3		32	Mali	16	1.5
8	England	77	7.4		33	Madagascar	14	1.3
9	Netherlands	65	6.2		34	Niger	13	1.2
10	Germany	57	5.5		35	Austria	12	1.2
11	Belgium	48	4.6		36	Brazil	12	1.2
12	Ghana	43	4.1		37	Denmark	12	1.2
13	Australia	40	3.8		38	Malaysia	12	1.2
14	Uganda	39	3.7		39	Cote Ivoire	11	1.1
15	Zimbabwe	35	3.4		40	Colombia	10	1.0
16	Italy	29	2.8		41	Mozambique	10	1.0
17	Burkina Faso	26	2.5		42	Rwanda	10	1.0
18	Benin	25	2.4		43	Mauritius	9	0.9
19	Canada	24	2.3		44	Norway	9	0.9
20	Peoples R China	24	2.3		45	Togo	9	0.9
21	Senegal	24	2.3		46	Mexico	8	0.8
22	Sweden	23	2.2		47	Namibia	8	0.8
23	Switzerland	23	2.2		48	Zambia	8	0.8
24	Cameroon	21	2.0		49	Indonesia	7	0.7
25	India	20	1.9		50	Wales	7	0.7

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Table 3: Top 50 WoS subject categories in which ICTs appeared the most, 1991–2018 (N = 1,043)

No.	Web of Science Categories	Documents	Percentage
1	Agronomy	128	12.27
2	Environmental Sciences	117	11.22
3	Agriculture Multidisciplinary	106	10.16
4	Agriculture Dairy Animal Science	100	9.59
5	Water Resources	87	8.34
6	Soil Science	83	7.96
7	Ecology	77	7.38
8	Veterinary Sciences	59	5.66
9	Plant Sciences	51	4.89
10	Geosciences Multidisciplinary	49	4.70
11	Information Science Library Science	49	4.70
12	Biology	43	4.12
13	Horticulture	41	3.93
14	Food Science Technology	40	3.84
15	Environmental Studies	36	3.45
16	Genetics Heredity	35	3.36
17	Meteorology Atmospheric Sciences	35	3.36
18	Forestry	33	3.16
19	Biodiversity Conservation	32	3.07
20	Public Environmental Occupational Health	32	3.07
21	Agricultural Engineering	28	2.69
22	Multidisciplinary Sciences	25	2.40
23	Parasitology	23	2.21
24	Green Sustainable Science Technology	22	2.11
25	Zoology	22	2.11
26	Energy Fuels	20	1.92
27	Economics	19	1.82
28	Tropical Medicine	18	1.73
29	Biotechnology Applied Microbiology	17	1.63
30	Agricultural Economics Policy	16	1.53
31	Computer Science Interdisciplinary Applications	15	1.44
32	Remote Sensing	14	1.34
33	Computer Science Information Systems	13	1.25
34	Entomology	11	1.06
35	Nutrition Dietetics	11	1.06
36	Geography	9	0.86
37	Geography Physical	9	0.86
38	Imaging Science Photographic Technology	9	0.86
39	Instruments Instrumentation	9	0.86
40	Engineering Environmental	8	0.77
41	Health Care Sciences Services	8	0.77
42	Reproductive Biology	8	0.77
43	Education Educational Research	7	0.67
44	Engineering Civil	7	0.67
45	Engineering Electrical Electronic	7	0.67
46	Infectious Diseases	7	0.67
47	Chemistry Analytical	6	0.58
48	Management	6	0.58
49	Behavioral Sciences	5	0.48
50	Business	5	0.48

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Table 4: Top 50 keywords in ICT4Ag literature, 1991–2018

No	Label	Cluster	Links	Total link strength	Frequency
1	Management	5	115	234	71
2	Software	4	66	210	63
3	GIS	2	66	105	51
4	Agriculture	5	90	146	45
5	Diversity	4	57	156	41
6	Conservation	2	70	141	40
7	Model	1	72	99	40
8	Systems	3	74	112	37
9	Farmers	3	49	75	28
10	Genetic diversity	4	41	124	28
11	Remote sensing	2	43	72	27
12	Maize	1	35	53	26
13	Population-structure	4	39	111	26
14	Soil	1	51	74	26
15	Cattle	6	32	46	24
16	Growth	1	38	46	23
17	Biodiversity	2	44	75	22
18	Variability	5	59	76	22
19	Models	1	42	53	21
20	Nitrogen	1	49	82	21
21	Yield	1	50	70	21
22	Classification	2	48	69	20
23	Climate	2	49	68	20
24	Impact	2	52	67	20
25	Climate change	5	31	56	19
26	Irrigation	1	43	58	19
27	Adoption	3	33	50	18
28	Deforestation	2	45	66	18
29	Microsatellite markers	4	30	72	18
30	Prediction	1	35	42	18
31	Productivity	3	40	47	18
32	Computer-program	4	21	51	17
33	Land-use	2	44	55	17
34	Microsatellites	4	29	74	17
35	Simulation	5	39	50	16
36	Epidemiology	6	24	37	15
37	Information	3	30	40	15
38	Knowledge	3	36	44	15
39	Prevalence	6	21	34	15
40	Water	1	35	51	15
41	Adaptation	5	31	51	14
42	Food security	5	27	33	14
43	Geographic information systems	2	28	35	13
44	Landscape	2	30	35	13
45	Population	4	25	29	13
46	Transmission	6	24	33	13
47	Vegetation	2	31	36	13
48	Forest	2	41	54	12
49	Health	3	26	27	12
50	Modelling	1	26	32	12

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Table 5: ICT labels that occurred in sub-Saharan Africa's ICT4Ag literature, 1991-2018 (N = 1,043)

No.	ICT label	Cluster	No. of Links	No. of Total Link Strength	Frequency	% of 1043
1	Software	3	9	33	63	6.04
2	GIS	1	8	15	51	4.89
3	Systems	1	11	18	37	3.55
4	Remote Sensing	1	6	16	27	2.59
5	Computer-Program	3	3	9	17	1.63
6	Geographic Information Systems	1	1	3	13	1.25
7	Modelling	5	4	5	12	1.15
8	Digital Soil Mapping	5	2	2	10	0.96
9	Mobile Phones	4	7	9	10	0.96
10	Geographic Information System	1	2	2	8	0.77
11	ICT	2	8	9	8	0.77
12	Internet	2	6	6	6	0.58
13	Mobile Phone	2	4	4	6	0.58
14	Networks	2	4	4	6	0.58
15	Information and Communication Technologies	4	4	5	5	0.48
16	Information Technology	1	1	1	5	0.48
17	Information-Systems	4	1	1	5	0.48
18	Landsat	1	3	6	5	0.48
19	Radio	4	3	3	5	0.48
20	Radio-Tracking	15	0	0	5	0.48
21	Decision Support System	3	2	2	4	0.38
22	Digital Elevation Models	9	0	0	4	0.38
23	Database	3	3	4	3	0.29
24	Expert System	2	2	2	3	0.29
25	Information Communication Technologies	11	0	0	3	0.29
26	Information-Technology	2	3	3	3	0.29
27	Microsatellite	3	1	2	3	0.29
28	Sensors	3	2	2	3	0.29
29	Aerial Photography	1	1	1	2	0.19
30	Agricultural Information Systems	2	1	1	2	0.19
31	Artificial Neural Networks	5	2	2	2	0.19
32	Communication Technologies	7	0	0	2	0.19
33	Community Radio	4	3	3	2	0.19
34	Computer Model	8	0	0	2	0.19
35	Decision-Support-System	1	1	1	2	0.19
36	Digital Mapping	6	2	2	2	0.19
37	Digital Photogrammetry	10	0	0	2	0.19
38	Electromagnetic Induction	6	1	1	2	0.19
39	GIS-MCDA	1	2	2	2	0.19
40	ICT4Ag	1	2	3	2	0.19
41	ICT4D	1	4	5	2	0.19
42	ICTs	4	2	2	2	0.19
43	Information System	12	0	0	2	0.19
44	Machine Learning	13	0	0	2	0.19
45	Photomacrography	14	0	0	2	0.19
46	Satellite	16	0	0	2	0.19
47	Stella Software	17	0	0	2	0.19
48	Systems Simulation-Model	5	1	2	2	0.19
49	Wireless Sensor Networks	2	1	1	2	0.19
50	Zonation Software	18	0	0	2	0.19

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