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Abstract. Cloud computing and big data applications are likely to have far-reaching and profound impacts on developing world-based smallholder farmers. Especially, the use of mobile devices to access cloud-based applications is a promising approach to deliver value to smallholder farmers in developing countries since according to the International Telecommunication Union, mobile-cellular penetration in developing countries is expected to reach 90% by the end of 2014. This article examines the contexts, mechanisms, processes and consequences associated with cloud computing and big data deployments in farming activities that could affect the lives of developing world-based smallholder farmers. We analyze the roles of big data and cloud-based applications in facilitating input availability, providing access to resources, enhancing farming processes and productivity and improving market access, marketability of products and bargaining power for smallholders. In the developing world's context, an even bigger question than that of whether agricultural productivity can be improved by using cloud computing and big data is who is likely to benefit from the growth in productivity. The paper analyzes the conditions under which at agricultural productivity associated with the utilization cloud computing and big data applications in developing countries may benefit smallholder farmers. Also investigated in the paper are important privacy and ethical issues involved around cloud computing and big data. While some analysts view that people in developing countries do not need privacy, the paper challenged this view and points out that data privacy and security issues are even more important to smallholder farmers in developing countries.

Keywords: cloud computing, big data, smallholder farmers

1 Introduction

Cloud computing (hereinafter: cloud) and big data (hereinafter: BD) are likely to be of tremendous benefit to developing countries. The cloud is likened and equated to the "Industrial Revolution" in terms of technological innovations, structural change and the sources of economic growth. Likewise, some argue that BD is the source of next revolution in farming [3]. It is anticipated that geo-locating a rural African farmer working in his farm with the help of an app installed in his cellphone, identifying the soil type and needs of the field and offering advice regarding appropriate seeds, where they can be purchased, and how they can be planted and harvested is not far in the future [23].

Our goal in this paper is modest and is simply aimed at deepening our understanding of facilitators and inhibitors of diffusion and effective utilization of the cloud and BD in farming and agricultural activities in developing countries. A related goal of this paper is to examine this issue in relation to the rapid diffusion of mobile phones in these countries.

The paper is structured as follows. We proceed by first examining the opportunities of using the cloud and BD in agriculture and farming activities. Next, we analyze the use of mobile devices to access BD- and cloud-based applications. Then, we investigate critical challenges and issues associated with using BD and cloud in agriculture and farming activities. The final section provides concluding comments.

2 Opportunities of Using the Cloud and BD in Agriculture and Farming Activities

An overview of the deployment of the cloud and BD in industrialized countries would be helpful for how the condition can be improved in developing countries. On this front, precision agriculture or precision farming has been a key trend in industrialized countries. Data collected on soil conditions, seeding rates, crop yields and other variables from farmers' tractors, combines and drones is combined with detailed records on historic weather patterns, topography and crop performance collected by the providers of prescriptive-planting technology *[7]*. Human experts may need to perform tasks involving decision problems and processes for which no algorithm exists or the algorithm has not yet been developed. In some cases, due to unknowns no algorithm can solve all instances of the problem. In agriculture, some examples of situations include tasks involving unknown soil types and extreme weather conditions, which often need to be performed by humans rather than algorithms. The data is thus crunched by algorithms and human experts and turned into customized useful advice and is sent directly to farmers and their machines instructing the optimum amount of pesticides, herbicides, fertilizer and other applications.

Many tractors and combines are guided by global positioning system satellites. An article published in usatoday.com explained that a corn and soybean farmer in Iowa used a $30,000 drone to study how yield in his 900 acre farm are affected by changes in topography and other factors *[6]*. This example is illustrative of a widespread adoption and diffusion of the cloud and BD in the agriculture sector in industrialized countries. Many farmers who have implement data-driven prescriptive planting based on the analysis of nutrients in soil and other factors have reported a significant increase in productivity *[3]*. The point is that even small alterations in planting depth or the distance between rows of crops can lead to a significant increase in agricultural productivity.

The diffusion of the cloud and BD is associated with and facilitated by measures taken by the providers of prescriptive-planting technology to strengthen their resources and capabilities. In 2013, Monsanto acquired the weather data mining firm, Climate Corp. Likewise, the agricultural cooperative Land O'Lakes bought satellite-imaging specialist, Geosys. In the same vein, in order to provide real-time climate and market information to its data services users, DuPont announced collaboration with the weather and market analysis firm, DTN/The Progressive Farmer. In 2013, Deere agreed to send data from its tractors, combines and other machinery to the computer servers of DuPont and Dow *[3]*.

Nutrient management is one area where the cloud and BD may be relevant. In Africa, for instance, outdated knowledge is pervasive and ubiquitous in recommendations for nutrient management. This often leads to too much fertilizer in relation to potential crop demand and on a uniform basis irrespective of the type of land. A model-based and data-driven approach is thus likely to reduce the costs of fertilizer and increase productivity.

Another area in which the cloud and BD might have potential to facilitate agricultural and farming activities in developing countries relates to the availability of near-real time data and information regarding farmers' needs and capabilities, which can be used by value chain partners to effectively serve the farmers.

One example is the cloud-based platform, AgriLife, which is accessible via mobile phone. It is used for collecting data and analyzing farmers' production capability and history. In order to ensure fast, easy and efficient availability of resources and services to distant, rural farmers, the platform also acts as an integration point for financial institutions, mobile network operators, produce buyers, and their agents *[30]*. The data analysis provides a better understanding of small farmers' needs and production capability. Service providers can tailor their offerings such as crop insurance, input payments, and savings accounts based on the data*[30]* . Uganda's Farmers Centre (FACE) was an early adopter of AgriLife. FACE started uploading information on its 10,000 farmer clients, who travel long distances to purchase inputs and aggregate their produce at FACE warehouses for processing/sale. Before using AgriLife, FACE collected information by paper-based questionnaires. The data was stored on a computer, which had crashed. Small farmers' transaction data would help them build a credit history, which is used by value-chain actors to provide credit and other resources such as seeds, fertilizers, and pest-control chemicals agents *[30]*.

As of September 2013, Agrilife facilitated over US$ 2 million in revolving credit lines to about 120,000 small farmers in Kenya and UgandaAgriLife was developed by Kenya's MobiPay. Mercy Corps supported the expansion to Uganda and helped build relationships with service providers and integrate into the platform in order to reach rural clients more effectively. . The AgriLife platform is also being used in Zimbabwe, Zambia and Senegal *[8]*.

Prior researchers have recognized that developing world-based farmers face difficulties in meeting the quality and safety standards set by the developed world *[21]*. In this regard, the availability of easily accessible data that include digital records of farming activities such as the amounts of seeds and pesticides will obviously play a major role in documenting quality standards of agricultural products. It would be interesting to assess the above examples related to the use of data in farming activities in developing countries in terms of BD dimensions. Obviously higher volume of data on farming activities is available than in the past. For instance, data such as farmers' credit history and the amounts of seeds and pesticides used were not available in the pre BD-environment. As to the data speed, near-real time data and information on farmers' needs and capabilities are available. This means that financial institutions, produce buyers, and other relevant actors can fulfill farmers' needs more quickly than in the past. Regarding the variety, most data currently used in farming-related activities is structured data. Such data can be combined with unstructured data. For instance, farmers can upload pictures and videos related to a problem they are facing, which can be analyzed by experts to offer customized advice.

In one way, transnational corporations (TNCs) are likely to be a driving force behind the diffusion of the cloud and BD in the agricultural sector of developing countries. TNCs, which are often producers, processors, or traders of agricultural products or sellers of inputs or machinery, engage in a contracting system in which they assume a variety of responsibilities including providing technical assistance and marketing to developing world-based small farmers *[9. 10]*. TNCs such as Monsanto and Syngenta, which have become a driving force behind the utilization of the cloud and BD in the industrialized world, are thus likely to act as a key channel in the international technology transfer of the cloud and BD.

Other potential mechanisms and determinants of the cloud and BD diffusion among farmers also exist. For instance, Oluoch-Kosura *[21]* reported that NGOs, farmers' organizations and the private sector in Africa are playing important roles in facilitating farmers' education, access to agricultural information, and training. International supply chain structures often tend to exclude smallholder farmers. In Mozambique farmers, who are engaged in contract farming, pool resources to get technical advice and other services. More than 400,000 smallholders with less than one hectare of land each are reported to benefit from such arrangements *[14]*.

3 The Use of Mobile Devices to Access BD- and Cloud-based Applications

The cloud, BD, and mobile device combination (CBDMC) stands out as a particularly appealing and promising choice for developing countries. Among the most compelling is that whereas only a little over a quarter of the population in developing countries owns a PC, close to 90% owned cellphones in 2013. While mobile phone (broadband plus non-broadband) subscription is 33% higher in developed countries compared to developing countries, mobile broadband, fixed broadband and fixed telephone subscriptions are 278%, 350% and 275% respectively as high. Likewise, the proportions by which developed countries' Internet and computer penetrations exceeded those of developing countries ranged from 149% to 177% .

3.1 Some examples of CBDMC tools useful for smallholder farmers

CBDMC tools differ widely in the roles individual smallholder farmers play in the production and consumption of data and information. In some tools, farmers play active roles in the production and consumption of information. As an example, Farmforce, a US$2 million cloud-based mobile platform developed by Syngenta Foundation and backed by the Swiss government operates on a subscription-based SaaS model, which tracks pesticide residues in produce. Smallholders in Kenya access it freely online via mobile phones to store and manage data on pesticide contents in crops *[24]*.

As another example, the Apps4Africa Award-winning mobile app, iCow developed by Kenya's Green Dreams helps small-scale dairy farmers track and manage cows' fertility cycles. The app informs farmers about important days of cow gestation period, collects and stores milk and breeding records, and sends best practices. It also helps find the nearest vets and other service providers. Green Dreams has formed a system involving Google Docs. If Green Dreams and a vet contacted by a farmer are unable to answer the farmer's question, it is uploaded on the system. The vets send messages among themselves and come up with the best answer, which is forward to the farmer. As of 2012, iCow was used by 42,000 farmers in 42 countries. iCow is expected to be accessed by 1.6 million Kenyan farmers soon.

In some CBDMC tools, most individual farmers have minor or no roles in the production and consumption of information. CBDMC tools are used to obtain information on farmers, their farms and practices as well as external conditions affecting farming productivity. For instance, Uganda's so called "community knowledge workers" (CKWs) use phones loaded with open-source data-collection applications. The concept was developed by the Grameen Foundation. It offers selected farmers, who act as CKWs, loans to buy Android phones. The phone is loaded with information about the time and methods of planting crops, caring for farm animals and finding markets for products. Data is automatically fed into Salesforce.com clouds. As of 2011, about 400 CKWs interacted with farmers and gathered information *[12]*. They use solar power, bicycles and other means to recharge phone batteries.

The project created a cloud-hosted database for Ugandan farmers. Farmers contribute questions and answers about agricultural practices for the database. It also contains answers to frequently asked questions, which can be accessed via a free SMS service. The project generated US$1 million when government agencies and commercial organizations paid for farming data. A brewery wanted information on barley crop supply chains *[17]*.

As a further example, the social enterprise Kilimo Salama ("safe agriculture" in Swahili) has developed a weather-based index insurance which uses weather stations across Kenya to serve small farmers. Kilimo Salama is a partnership between the Syngenta Foundation, UAP Insurance, and Safaricom. Farmers buy the insurance at the beginning of the season for 10-20% of the amount invested in seeds and inputs *[15]*. The insurance is completely automated and distributed through dealers who use an advanced phone application with camera to scan and capture policy information. The information is uploaded to Safaricom's mobile cloud-based server, which administers policies. Farmers receive information about policy and payouts via SMS *[25]*. Weather stations are equipped with wireless SIM-cards that transmit data every five minutes to clouds. At the season's end, the data is aggregated and coupled with satellite data, and is used to map out rain patterns. Kilimo Salama works with agronomists to calculate the index to identify locations with too much rain, too little rain, or rain at the wrong time. Farmer payouts are based on crops, location, and amount of seeds purchased *[15]*.

3.2 CBDMCs' impacts on smallholders' farming systems

CBDMCs' roles in facilitating input availability, providing access to resources (e.g., loans, seeds and insurance), enhancing farming processes and productivity and improving market access, marketability of products and bargaining power for smallholders are illustrated in Table 1.

First, CBDMC tools have enhanced farmers' access to inputs/resources. As noted earlier, the information created by Agrilife, which provides financial institutions and suppliers "near-real-time information" on farmers' ability to pay for services, facilitated over US$ 2 million in revolving credit lines to about 120,000 farmers in Kenya and Uganda *[8]*.

Likewise, thanks to Kilimo Salama's insurance scheme, banks and microfinance institutions are more comfortable in giving loans to farmers. As of 2013, Kilimo Salama insured over 100,000 farmers in Kenya and Rwanda *[15]*. As a further example, iCow helps farmers find nearest vets and other service providers.

Many examples can be cited of CBDMC's impacts on farming process and productivity. iCow has reportedly helped increase milk production by 2–3 liters/cow/day. Likewise, Farmforce eliminated the need to use manual record keeping of farm activities/operations. Similarly, FACE's use of AgriLife to collect information about farmer clients led to lower data collection costs compared to paper-based questionnaires.

Finally, CBDMC tools have increased small farmer's access to market, marketability of products and bargaining power. For instance, despite the rising demands in industrialized countries of fruit and

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vegetables, developing-world-based small-scale farmers face barriers related to quality standards and pesticide traceability *[5]*. The use of Farmforce would help small-scale farmers identify and document important requirements related to quality standards and pesticide traceability in order to improve marketability of their crops. Likewise, in Mauritius and Ghana, Esoko, a mobile-enabled cloud service collects and provides information to farmers on such topics as current market prices, bids/offers, weather, and tips. Advisories are sent by voice messages and live call centers of agricultural experts are available *[1]*. Similarly, AgriLife and CKWs help find markets for products.

4 Critical Challenges and Issues

Against the backdrop of rapid diffusion of cloud and BD among big farmers in industrialized countries, a comparison of their BD ecosystems with those of developing countries would be helpful to understand critical challenges and problems in the effective utilization of BD for developmental issues. First, and perhaps most important, agriculture firms in the industrialized world has a long history of data production and consumption. For instance, DuPont has been making use of farm-level data since the early 2000s [3]. Likewise, it is increasingly common for farmers to monitor progress of their agricultural activities on iPads and tablets. In industrialized countries, firms in diverse industries such as satellite-imaging, weather-data-mining, weather-and-market analysis have enabled a rich ecosystem of BD.

While large growers can afford specialized machineries, small farmers are not in a position to do so [9, 10]. The conditions that stimulated the growth of BD in the U.S. farming industry such as the widespread adoption of mechanized tractors, genetically modified seeds, computers and tablets for farming activities are less prevalent in developing countries. Most small-holders in developing countries are not in a position to do so. Smallholder farmers often have no means to access the data and cannot interpret it. A main concern is that BD collection efforts will only benefit big and well-educated farmers [22].

Accurate and actionable data requires considerable technical skills to handle data mining and analysis method and system. The lack of human resources and expertise represents another major barrier to the implementation of BD projects.

As an upshot of the above discussion, there is a lack of appropriate database systems for agribusiness development, agriculture management and produce distribution. A BD attempt is greatly hampered by the lack of reliable infrastructure to collect information. Consider, for instance, climate-related historical data. African countries have limited capacity to develop, generate, disseminate and effectively use climate data and information [4]. National institutions, leadership and the civil society are inherently weak and cannot determine the types of climate data and information needed for agriculture and other economic activities. Among the problems faced by policy makers and practitioners to work more effectively to respond to climate changes and other climate related effects concern extremely low number of meteorological stations for climate data collection, and the lack of digitization of the data.

As another example, the lack of information has been a main barrier to an effective implementation of healthcare systems. For instance, while there is a rising prevalence of diabetes in Indonesia, there is no data available to measure the effects beyond intermediate outcomes such as the number of people trained; percentage of health centers providing education; or development of training material and guidelines (e.g. training's impact on detection rate and outcomes and screening's impact on complications) [28].

Farmers are concerned about the potential misuse of information at the firm level related to their farming activities and at the industry level. For instance, the trade group, American Farm Bureau Federation (AFBF) warned its members that seed companies' prescriptive planting programs have vested interests in higher crop yields associated with BD's use [3]. Big agricultural firms such as Monsanto might influence farmers to buy specific seeds, sprays and equipment and are likely to profit from the costs of their services and higher seed sales [26]. The gathering of data from sensors on tractors, combines and other farm equipment by large seed companies is receiving the same level of attention as immigration reform and water regulations [7]. Another key concern that farmers have expressed is that their data and information could be used by competitors. For example, other farmers' access to the crop-yield information may create

direct and unwanted competition to rent farmland, which may cause a new spike in land values and seed prices [3]. The issue regarding who owns farmers' crop data is also of equal concern [26].
Another fear is that Wall Street traders could use the data to make bets that could hurt the farmers. For instance, if conditions early in the growing season lead to lower futures contract prices, it may reduce the profits farmers could have made from crops by locking into sell the futures [3]. Likewise, farmers are concerned that hedge funds or big companies might use real-time data at harvest time from a large number of combines to speculate in commodities markets long before official crop-production estimates are available [7]. This fear has some foundation as the developments in BD technologies make it possible to do so. For instance, a group at the MIT Media Lab used location data from mobile phones to estimate the number of people in Macy's parking lots on Black Friday. The estimate made it possible to estimate the retailer's sales on that day even before Macy's had recorded those sales. Insights like this are expected to provide competitive advantage to Wall Street analysts and managers [18].
In the developing world's context, an even bigger question than that of whether agricultural productivity can be improved using BD is who is likely to benefit from the BD-led growth in productivity. One possibility is that agricultural productivity associated with BD utilization in developing countries may provide benefits primarily to foreign companies. This is because while a number of positive outcomes of agricultural TNCs' operation in developing countries have been recorded, there are also possible negative effects such as the potential abuse of their market power and dominant position. The increasing globalization of agriculture and the food chain means that industrialized world-based agricultural giants may expand such activities globally.
Security and privacy issues associated with BD have attained at least some degree of institutionalization in industrialized countries, which is a small comfort for the farmers. Most industrialized countries have more well-developed regulations related to data privacy and security. They also have industry standards, company-specific guidelines, and performance measures. For instance, U.S.-based food and agricultural companies such as Monsanto, DuPont and other corporations claim that they do not use data for purposes other than providing services requested by farmers, keep the data secure and do not sold [7]. Some companies get consent from customers before sharing their data. The AFBF has put together a "privacy expectation guide" to educate its members. In addition, it has drafted a policy which has emphasized that data should remain the farmer's property [7]. Some U.S. farmers are reportedly contemplating a new initiative to aggregate data on their own so that they can decide the type of information to sell and at an appropriate price. Other farmers are teaming up with smaller technology companies in order to challenge the domination of big agricultural giants in the prescriptive-planting business [3]. Many developing countries currently have no regulatory safeguard in place to protect farmers and citizens from possible data misuse. This means that BD-related issues are being considered in a setting of nascent institutionalization. Farmers in developing countries are even more prone to exploitation by big businesses.

Concluding comments

Cloud computing and BD applications have contributed to significant transformations in farming systems and practices of smallholder farmers in developing countries. In formulating policies and designing systems aimed at developing countries it is helpful to consider the end uses that are technologically unsavvy or less savvy. Due to ease of use, affordability and convenience, iCow has high retention and satisfaction rates. For instance, iCow's surveys indicated that 82% of farmers who started using the platform in June 2011 were still using until January 2012.
Among the most intriguing aspects of the data and information created by the cloud and BD applications is the functioning of markets by matching smallholders with providers of inputs and facilitating the exchange of information, goods, services and payments. This function has a critical role in the overall well-being of smallholders because developing economies are characterized by the lack, or poor performance, of credit rating agencies providing information about the creditworthiness of SMEs. Whereas national credit bureaus collect and distribute reliable credit information, increase transparency

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and minimize banks' lending risks in developed countries, most developing economies lack such agencies. This situation puts smallholders in a disadvantaged position in the credit market since they tend to be more informationally opaque than large corporations because of the lack of certified audited financial statements for banks to assess or monitor their financial conditions *[6]*. The AgriLife platform has created an information broker system, which has functioned as an efficient intermediary between the financial institutions and small farmers. The databases created as a result of the deployment of CBDMC are also contributing to the efficient functioning of the market by helping information exchange and allocate resources more efficiently.

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