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Abstract. The world's rapidly growing population and increasing concern everywhere about food security and environmental sustainability requires - really demands - that agriculture accelerates its digital transformation and develops its smart digital ecosystem (SDE). Those systems are spreading fast in other sectors, whereas agriculture lags greatly behind. The professional introduction of a smart digital ecosystem offers large improvement opportunities in agricultural production, food security, and environmental sustainability. At the same time, fast developing technical solutions and the disruptive nature of technology innovation offer unique entrepreneurial opportunities.

This study first defines SDEs and then demonstrates their rapid but uneven spread in the global economy. The author offers a framework for classifying where a particular industry, branch or producing unit may be located in the evolving activity-sector matrix used for describing SDEs. Applying that matrix, he finds that the diffusion of technology innovation in agriculture is slower than expected. Much of the rest of the article demonstrates the large potential gains that the agricultural sector could enjoy by moving faster and better in the SDE area, offering case studies on the methods and experiences of some of the large and small pioneers.

Keywords: agriculture, Big Data, information technology, innovation, smart systems, sustainability

1. Digital transformation: leaders and laggards

“Software is eating the world” – Marc Andreessen, co-founder of Netscape and the venture capital firm Andreessen Horowitz, used this metaphor in the title of his article published by *The*

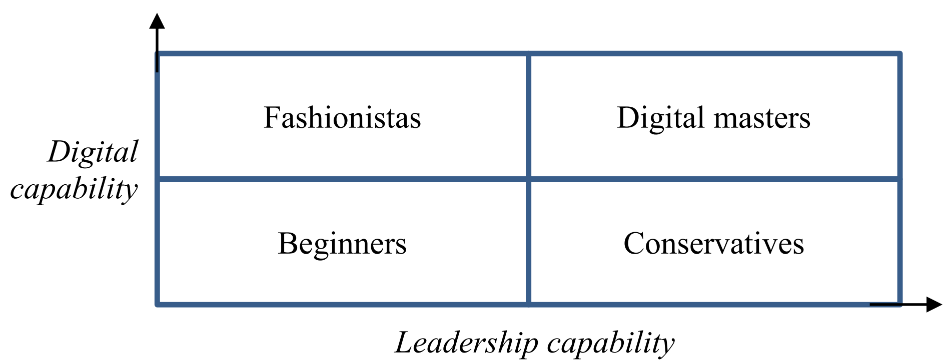
Wall Street Journal a few years ago *(Andreessen 2011).* He explained that the present popularity of technology companies is not the symptom of a new tech bubble. He believes that many of the leading internet companies, incumbents and new ventures alike, are building innovative and strategically defensible businesses with high margins and unique growth potential. Digitization is an unstoppable trend, more and more industries and companies run on software, and what is more, are to be disrupted by software. All the technologies (the Internet, cloud computing, mobile devices, data mining tools, real-time sensor systems, just to mention a few) required for digital transformation are available and work properly, knowledge and experience is accumulating, prices are decreasing, so change is knocking on many doors.

Digital transformation is not easy, it moves ahead at different speed in the economy, leaders and laggards alike can be found and observed.

In their book "Leading Digital", authors George Westerman, Didier Bonnet and Andrew McAfee describe how digital technologies change the business landscape, and how companies and entire industries try to adapt to the new opportunities and market conditions *(Westerman, Bonnet, McAfee 2014).* Their findings and recommendations are based on a rigorous and extensive research study of 400 companies in 30 countries.

Two dimensions and four levels are used to describe this transformation *(Exhibit 1).* The first dimension is for *digital capabilities*: what kind of digital infrastructure is available at the companies, the quality of hardware and software they use, and the knowledge and skills of their people. The second dimension represents *leadership capabilities* required to develop a vision and execute on it, to initiate and launch critical projects, to manage change, build momentum and ensure that all employees follow through.

Exhibit 1. Four levels of digital mastery



Source: prepared by *Westerman, Bonnet, McAfee 2014,* figure 1.1 in Chapter 1

The firms that excel at both dimensions are called *digital masters*: they have cutting-edge technology, relevant and unique knowledge, and are able to harness what they have for improving their productivity and competitiveness. Digital mastery, as described by the authors, can be achieved in various forms of technology-driven business reinvention. For example, masters may reengineer their processes, launch better products or services, develop their quality, reduce cycle time, may create new digital businesses and distribution channels, improve customer relationships, rethink their value proposition, and compete by a radically new business model.

Research findings presented in the book highlight that digital masters do exist, but they are rare. Many companies are in the other corners of the matrix defined by the two dimensions. *Fashionistas* are technology fans with impressive digital capabilities; they are ready to buy the most innovative (and expensive) technologies, but their leadership capabilities necessary for a real digital transition are weak, their business models are not changed in harmony with new technical tools, processes are not streamlined, and because of this, members of this group waste of much they spend, remain the same behind the curtain. *Conservatives* follow technical development slowly, they are unconcerned about new technical gadgets, build only limited digital capabilities. Firms in this third group are good in execution, but may fall in the governance trap paying too much attention to controls and rules. They move ahead slowly, are not ready to make radical steps, prefer to keep the status quo.

The fourth group called *beginners* are at the start of digital transformation. Companies in this group have only basic digital capabilities, many of them work by a “wait-and-see” infocommunications strategy or don’t have a digital strategy at all. When asked about it, they look for excuses for inaction, find negative cases quickly, keep on repeating the risks and digital pioneers’ mistakes.

Regarding the benefits of digital mastery, the three authors draw a simple data-based conclusion: profitability of digital masters is significantly higher than that of the other three groups. The worst case is that of the beginners, with many firms in the red. The position of fashionistas and conservatives is better but they also drop well behind the masters.

The researchers also analyzed digital mastery by industry and found significant differences. Just to mention a few examples, many high tech companies are digital masters (it can’t be a surprise), together with financial institutions and retail firms; the telecom industry is a fashionista, utilities are conservative, while many manufacturing and pharmaceutical companies are beginners.

2. Agriculture meets IT: the unfinished revolution

Despite its obvious importance, agriculture as an industry is not on this two dimensional map. We know that the economic significance of agriculture within the economy (measured as a ratio in GDP) has been in almost continuous decline over the last 50 years, but this lack of interest can't be explained only with this unquestionable fact. When digital capabilities are discussed, agriculture is frequently regarded as a field where one might least expect a technology revolution. Regarding digital mastery, the industry is described as a beginner at best by many observers, lagging well behind others.

Fortunately agribusiness is also changing, its digital transformation is in progress, the industry shows signs of technology innovation, exciting cases illustrate how digital technologies may improve the performance of plant cultivation and livestock breeding. In 2015, the American PrecisionAg magazine asked its readers what they considered to be the most important technology advancements in precision agriculture *(Schrimpf 2015)*. The following list generated by the survey, although it doesn't cover everything, confirms Marc Andreessen's statement cited above: key digital technologies, together with some others, are ready and wait for adoption.

1) Global Positioning Systems (GPS)
2) Yield monitoring
3) Information technology
4) Cell phones
5) Lightbar guidance
6) Variable rate fertilizers
7) Automatic steering
8) Automatic swath/planter control
9) Active sensors
10) Programmable controllers
11) Soil electrical conductivity measurement[1]
12) Roundup ready crops
13) Tablet computers
14) DTN weather terminals
15) Drain tile plow technology
16) Geographic Information Systems (GIS) software (color-coded maps)

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[1] Electrical conductivity reveals soil texture variability

17) Irrigation control

The sectors digital transformation started in the 1980s. One of the first steps was the introduction of a yield meter by an American company called Massey Ferguson at the beginning of that decade. Yields could be continuously recorded for the first time. Global Positioning System (GPS) became available on tractors in the early 1990s[2] but its accuracy was not good enough for precise mapping. The main goal of recording yield and using GPS mapping was to identify spatial variations and to gain insight into the factors affecting yield such as landscape, moisture, soil content and structure, etc.[3]

The term *precision agriculture*, together with GPS-guided tractors, also appeared in the early 1990s. Its fundamental principles were well known by farmers since the early days of agriculture *(Brase 2005; Srinivasan 2006; Tamás 2001).* Plant producers divided their land into smaller parts and tried to grow crops where the specific conditions were the most suitable. They did it because they were forced to do it, if they wanted to produce enough food for their families.

Although this traditional practice was based on accumulated personal experience, was rather rough, low resolution, and lacking scientific evidence, it highlighted the importance of understanding field and microclimate variations. It suggested that decision-making must be based on three main components: obtaining relevant data, acquiring insight through analysis, generate and execute efficient management response. Its central notion is the empirical fact that both soil and microclimate vary spatially and temporally. The logic of precision agriculture dictates that production inputs like fertilizers, pesticides, and water should be applied only where and when they are needed[4].

Precision agriculture is frequently interpreted as a production and farm management philosophy aimed at increasing efficiency, productivity and profitability while minimizing unintended negative environmental impacts. It is the modern form of site-specific crop management

[2] The U.S. government opened its Global Positioning System (GPS), a satellite-based navigation program for civilian use in 1983.
[3] In Hungary e.g. AgroForce International Ltd. and IKR Agrár Ltd. provide GPS-bases preceision soil sampling services for farmers.
[4] The core issue of precision agriculture is the identification of management zones defined as subfield regions with homogenous soil, landscape, etc. condition. *Chang et al. (2014)* describe how management zones were delineated using a special sensor technology on a tobacco field.

whereby decisions on resources and agronomic practices are fine-tuned to better match soil and crop variability[5].

In the 1980s and 1990s, with the advent of personal computers and computer networks, it became obvious that fast developing information technology can raise precision agriculture to a higher level, but it may take a few years to fulfill that promise.

Precision agriculture developed at varying pace geographically *(Zhang, Wang, Wang 2002*). The U.S., Canada and Australia are the traditional pioneers, the United Kingdom and France were the door openers in Europe, just like Argentina and Brazil in South America. Australia is, without doubt, at the forefront of the development of PA solutions and their practical application, not the least because of the unique production conditions in the country.

Despite early efforts, the sector's digital progress was slow. It takes time to asses and evaluate the short and long term effects of this kind of innovation, but we can assume that it will follow the same trajectory as that of other industries, but apparently slower.

The technical revolution of precision agriculture appears to be unfinished. Although the U.S. is a leader in precision agriculture, the country's Department of Agriculture reported that the technology is applied on less than 20% of corn fields *(Lowenberg-DeBoer 2015).* On the basis of personal interviews at agricultural exhibitions, German researchers concluded that 7-11% of their country's farmers used precision agriculture's toolkit in the late 2000s *(Reichardt et al. 2009, p. 525).* Penetration of 11% was reported in Hungary recently, and that figure may be overestimated because of sampling reasons *(Lencsés, Takács, Takács-György 2014)*. Precision agriculture technology is mostly used in developed counties today. Just to take one example, although over 70% of the population of Nigeria, the most populous country of Africa, depends on agricultural occupation directly, the scope of the technology's implementation is very limited *(Adekunle 2013).* The picture appears to be brighter only in a few countries, e.g. in Argentina where some policy measures and difficult economic conditions forced the sector to adapt creative solutions[6].

The truth is that a large number of farmers do not even now what precision agriculture means.

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[5] Vine-growing is a prominent and traditional example for the concept of variability. The world „terroir", frequently used by specialists, means the set of environmental factors affecting crop quality when that is grown in a specific habitat *(Báló et al. 2014).*

[6] The average age of the farmers may be also a factor influencing penetration: that is below 50 in Argentina while farmers in the U.S and Western Europe are much older.

Technology observers frequently express the concern that adoption of agricultural software solutions is slow, penetration is much lower than predicted, digital systems' capabilities are underutilized, many producers use them only to prepare simple tables, to-do-lists, and working schedules.

Slowness and low penetration rates are explained principally by factors like the complexity of the technology, the time needed for learning, hardware, software and consulting costs, missing or cursory training programs, weaknesses of knowledge sharing and advisory services, and the traditional conservativeness of the sector. Diffusion is also balked by sector-specific measurement problems. The exact profitability of the new technical solutions is a controversial point, it is very difficult to organize scientific experiments and comparative studies because of the large number and ambiguity of factors influencing production in general and crop yields in particular (see e.g. *Kilian et al. 2000*).

At the same time, the need for modern efficient, productive and sustainable agriculture can't be overemphasized. Here are a few ideas and data to explain this point. Let's discuss the demand side first.

3. The challenge of feeding more than 9 billion people

The world's population more than tripled during the 20th century from about 1.65 billion in 1900 to 5.97 billion in 1999. Growth did not stop: the United Nations projected a world population of 9.15 billion in 2050[7]. Population growth is especially high in some poor Third World countries, while some developed ones face the problem of demographic stagnation and aging population[8].

Urbanization of the world is a massive migration trend, the majority of the world's population lives in towns now, huge megacities are emerging generating burning problems for food supply

[7] The United Nations revised its demographic projections in July 2015. By the new report, „the world population is projected to increase by more than one billion people within the next 15 years, reaching 8.5 billion in 2030, and to increase further to 9.7 billion in 2050 and 11.2 billion by 2100*" (United Nations 2015, p. 2).*

[8] The fertility rate across the richest OECD members dropped from 2.98 children per woman int he early 1960s to 1.66 today (Kenny 2015, p. 10).

chains. Adding all these trends together, it is highly probable that we will need to grow 50-100% more food[9] within a few decades to meet the needs of the growing population.

While demand is growing, land size available for agricultural purposes is decreasing because of a few reasons like urbanization, highway building, climate change, scarcity of clean water, erosion, and environmental pollution. In many parts of highly populated Asia almost all cultivated land is already in use, and the position of the Middle East and North Africa is even worse. More land is available in South America, but e.g. in Brazil, where it is possible to extend the size of cultivable land, this can be done at the expense of native forests, a key component of the world's biological ecosystem.

One should not forget that by FAO's estimation more than 75% of the Earth's land is unsuitable for rain-fed agricultural production. Decisions to produce biofuels on agricultural land also increased the pressure.

When demand is growing and sources are limited, productivity becomes the decisive factor of long term development.

The analysis of agricultural labor productivity is a difficult task. The key indicator is the ratio of gross value added in agriculture per annual work units. To calculate the denominator, namely the labor input, part-time and seasonal work must be taken into account, both of which are widespread in agriculture. There are high geographic differences in production structure what may influence the comparability of productivity figures, e.g. production of fruits and vegetables is more labor-intensive than that of arable crops. Agricultural labor productivity can be influenced by quite a few factors such as average farm sizes (e.g. farms in Eastern and Southern Europe are generally much smaller than in northern Germany where average farm size is the highest in the EU), the level of mechanization, and the share of production for on-farm consumption.

Reliable and comparable productivity figures are rare but it is obvious that there is a huge gap between developed nations and Third World countries. European statistics also show a stark divide in relation to agricultural productivity: highest productivity is recorded in The Netherlands and some regions of France and the United Kingdom where gross value added per annual work unit reached EUR 45 000 in 2011, while it was at or below EUR 5 000 in some regions of Romania, Slovakia, Portugal, and Latvia *(Eurostat 2014).*

[9] Variability of predictions is high, but typical figures are within the range of 50-100%.

Besides productivity, waste and pollution are also hot issues of agriculture. The sector is now a major force behind many environmental hazards. Agriculture occupies about 40% of Earth's terrestrial surface, rain-fed agriculture is the world's largest user of water. Food production has important negative externalities such as release of greenhouse gases, chemical pollution, soil degradation, loss of biodiversity, and ecosystem disruption.

Nitrogen consumption is a good example. Nitrogen is used by many farmers to influence plant growth and improve crop yields, but the use of a nitrogen fertilizer also has environmental impact. The cost of nitrogen fertilizers increased fast in the recent past, having a negative effect on plant producers' bottom line. In the United States, agriculture is the largest source of nitrogen compounds entering the environment. Nitrogen fertilizer consumption is the highest in China, a country with dreadful pollution problems.

Fertilizers are usually applied uniformly, consequently some parts of the field are likely to be more depleted in nutrients than required. There are regions where less than 50% of the fertilizers used on the fields actually goes to the plants, much of the rest leaks into the environment. Pesticides are generally sprayed evenly on large pieces of land without any differentiation and optimization, what is expensive and environmentally hazardous. The same can be said about water consumption for irrigation. A major challenge is to identify the fields which need more or less of the chemicals or irrigation water.

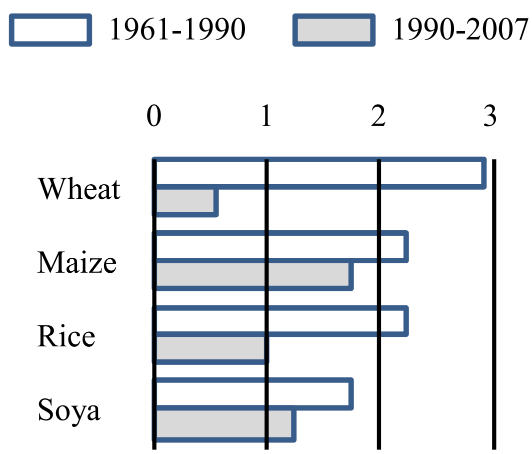
Growing demand, limited resources, huge productivity gap, need for sustainability – agriculture faces all these problems. Farmers and firms have to produce more from less land, protect the environment, ensure food security[10], and answer legal quality and safety requirements at the same time. Agriculture must be intensified to raise production, but growth is constrained by the finite resources of the Earth. The ultimate goal is not maximum productivity, but the joint optimization of production, environment protection and social justice.

This need is not new and producers have done a lot to improve their output. Crop yields increased significantly in the second half of the 20th century, e.g. global production of major cereals doubled. This growth came mainly from developed countries and without adding more land. It was the result of multiple factors like more irrigation, better machinery, greater use of herbicides, pesticides, and fertilizers, improved crop varieties, more efficient process management and monitoring.

[10] By Maplecroft, a leading British risk management agency, the top 5 counties with the highest food security risk were Yemen, Somalia, Afghanistan, Pakistan, and Iraq (report on 2013, published in 2012).

Efforts have their limits, face the law of diminishing returns, increase input costs and may pollute the environment. Advances based on traditional solutions are slowing. Average global crop yields increased by 56% between 1965 and 1985, and only by 20% from 1985 to 2005, and this growth was driven mainly by increased inputs of non-renewable resources *(Foley 2011).* Yields have plateaued or declined in some important food-producing regions *(Grassini-Eskride-Cassman 2013)*[11]. *Exhibit 2* shows how global yield growth changed in case of the four most important agricultural products: wheat, maize, rice, and soya.

Exhibit 2. Global yield growth, annual average %



Source: *The Economist 2011*, p. 8

It is important to note that a series of R&D efforts and knowledge transfer initiatives tried to increase agricultural production worldwide, especially in developing countries, during the sector's *Green Revolution* occurring between the 1940s and 1960s *(Hesser 2006).* Investments in hybridized seeds, modern equipment and management systems, irrigation infrastructure, synthetic fertilizers, new pesticides etc. raised agriculture's growth potential significantly, so the first period on *Exhibit 2* can be interpreted as the "harvest season" of the Green Revolution. By the numbers, this revolution passed its saturation point and some negative consequences, e.g. environmental damage became obvious. At the beginning of the 2000s growth of crop yields was slower than that of population, or to be more precise: population growth also slowed down, but crop yields slowed more.

[11] Research findings of Grassini, Eskride, and Cassman *(2013)* indicate that as yields move up towards the potential threshold during the adoption phase of new farm management practices, it becomes more difficult and expensive to push de gain ahead, and the associated marginal costs may outweight the benefits.

Organic farming may solve some problems but it also has some drawbacks and can't promise to feed the growing population.

There is wide geographic variation in agricultural productivity even across regions having similar climate conditions. Yield gaps, defined as a difference between realized productivity and the best that could be achieved using up-to-date materials and technologies, are experienced in many parts of the world. The advent of precision agriculture technology opened the yield gap; this gap is still open in many places, whilst productivity frontiers are pushed ahead again by forces of innovation.

Because of the constraints and concerns described in this chapter, big gains in food production can't be expected from taking in uncultivated land, using more water for irrigation or putting more chemicals on fields. Reducing food waste[12] also has its limits. The main gains must come from efficiency and productivity. There are different ways to do it. Closing the present yield gap is a low hanging fruit: laggards can learn a lot from leaders, usage of hybrid seeds can be promoted, animal husbandry can be more rigorously standardized and controlled, etc. The question raised in the present study is how technology innovation and digital transformation, as described by the aforementioned book of Westerman, Didier, and McAfee, can change agriculture's present and future productivity trajectory. We have already described in a nutshell how precision agriculture developed and unfolded in the last two decades of the 20th century, and indicated that although this transformation is still unfinished[13], recent technology innovations a new opportunity space *(Exhibit 3).*

Before focusing on agriculture again, let's discuss the main technology development trends affecting many industries, especially the proliferation of data-based smart systems, the general structure of the new entrepreneurial space, and how companies compete for profitable positions in it.

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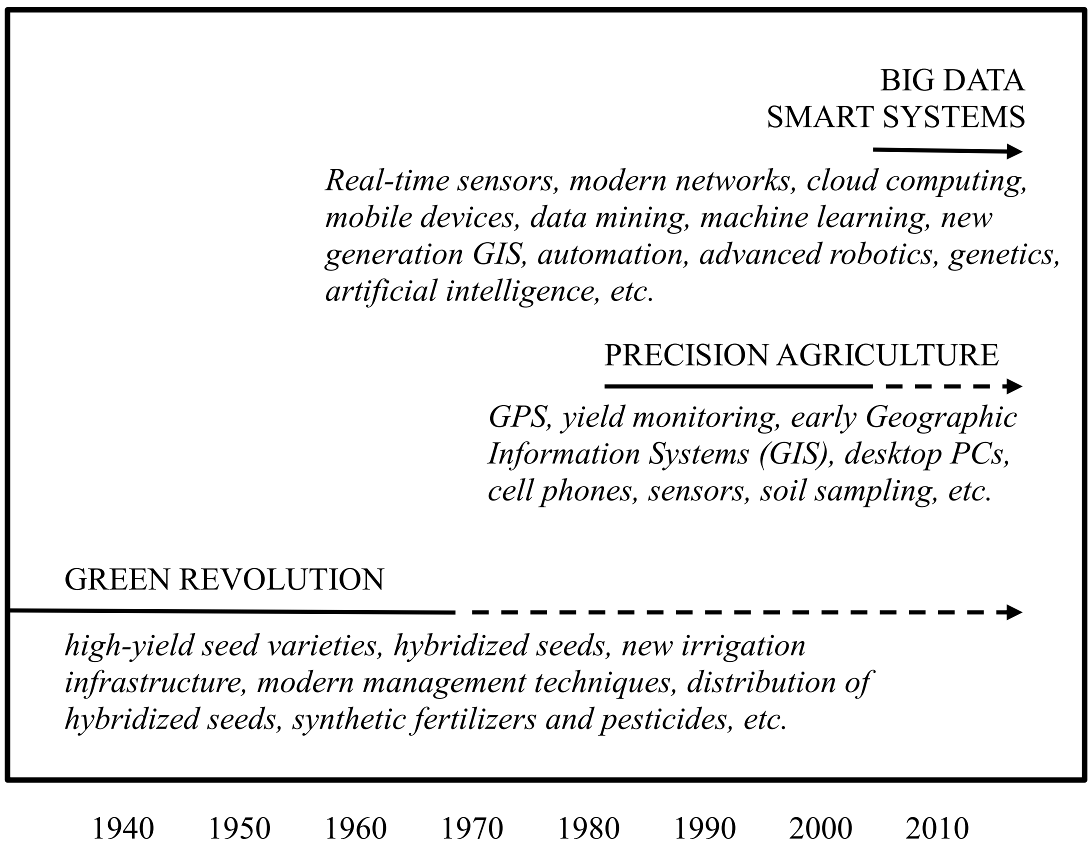
[12] Roughly 30-40% of food in both the developed and developing worlds is lost to waste *(Godfray et al. 2010, p. 816)*, consequently waste reduction measures are of high importance.

[13] The very basics are missing in some parts of the world, e.g. according to a World Bank report released in 2013, more than 90% of Africa's rural land is undocumented *(Byamugisha 2013).*

Exhibit 3. Phases in the development of agriculture with some prominent technologies



4. Big Data, smart systems and the new entrepreneurial space

Mu Sigma Inc. is one of the fastest growing companies of the world now. It was founded by the former consultant Dhiraj C. Rajara in 2004. The company’s name is derived from the statistical symbols „Mu” (mean) and „Sigma” (standard deviation).

The name is a message for the market: the company is a master of data-driven analytics and related decision support systems. Mu Sigma, headquartered in Chicago and operating its main delivery center in Bangalore (India), works for many Fortune 500 companies nowadays. By the help of its analytical services, customers can make better predictions about future demand for their products, can increase the efficiency of their processes, the insight generated by data-based models help them to identify and manage risks, to implement growth strategies and to reduce costs. Mu Sigma is active in many industries including airline, entertainment, healthcare, retail, technology, telecom, etc. It managed to attract the interest of investors, raised its first institutional investment round of $30 million from FTVentures and the second one of $25 million from Sequoia Capital, the flagship venture fund of Silicon Valley.

Mu Sigma represents a new breed of knowledge-based private ventures of the fast developing *Big Data* world. 2004, the year when it was founded, closed the "nuclear winter" of the IT industry, a period after the dotcom crisis when many internet companies went bankrupt and technology investment hit the bottom. Fortunately technological progress did not stop in this period, technology entrepreneurs and investors learned a lot from the crisis and company failures *(Bőgel 2015, chapter 6)*. The widespread enthusiasm of the late nineties did not return, business thinking became more realistic and cautious, but pessimism gave way to optimism, and the vital role modern information technology and innovation may play in business strategy became really apparent for many decision makers.

The content of business strategies has also changed: as the economy has been moving out of the financial crisis by the end of the new century's first decade, the focus is no longer on cost savings and economic efficiencies but rather on growth and technology's potential for business transformation *(Davenport 2014).* Technology innovation, lessons learned during the crisis, and new growth opportunities - all these factors mixed together generate a fertile environment for ambitious companies like Mu Sigma.

Some technologies have matured enough to enable traditional and new businesses in many areas. Let's see just a few examples. Computers are more powerful now, networking is global and ubiquitous. Companies, especially new ones don't have to build and maintain their own ICT infrastructure because cloud computing became an accepted platform. Instead of buying expensive server farms companies can simply rent computing and storing capacities from huge data centers and pay by usage. Capacity and service prices are decreasing continuously thanks to competitive forces. Service models combined with mobile tools increase business flexibility and adaptability. Digitization is a massive trend everywhere, more and more physical objects, tools, machines and other devices are equipped with electronics, computing and communication capabilities *(Gleick 2011)*. The "internet of things" is growing faster than the "internet of people", billions of cars, production tools, household devices, sensors, etc. will be connected to the network in the near future, connectivity and data will get cheap and globally accessible. Sensor and identification technology has developed a lot.

Many organizations have already built their “digital nervous system”, installed ERP, CRM, SCM and other company applications, streamlined their processes by digitalizing transactions. Datafication of the world is in progress, and this process appears to be unstoppable *(Andreessen 2011; Baker 2008)*. Progress in infrastructure and software improved the ability to collect data throughout the enterprise and complex international supply chains. Virtually every part of modern organizations and their environment is open now to data collection. This almost unlimited availability of data has led to the so called *Big Data* phenomenon and raised the interest in methods for extracting useful information and knowledge from huge and permanently growing datasets of enormous volumes and high variety *(Barabási 2010).*

Data became a key business asset, data management and analysis are business capabilities of high importance. Companies and other organizations try to exploit data for competitive advantage, better customer understanding, designing and launching new products and services. The data-centered convergence of important digital technologies has given rise to modern data science and powerful data-mining techniques *(Fajszi, Cser, Fehér 2013).*

The main promise of the Big Data phenomenon is the ability to build *smart systems* everywhere *(Mayer-Schönberg, Cukier 2013; The Economist 2010; Bőgel 2015).* Smartness stems from a combination of comprehensive, relevant and real-time data, sophisticated analytical algorithms, efficient decision support, fast and effective execution. Cutting-edge smart systems are not only smart but capable for learning and self development. Smart systems pop up everywhere, more and more things get a “smart” prefix before their name: smart commerce, smart manufacturing, smart agriculture, smart town, smart commerce, etc.

The potential for designing and building smart systems opens a new entrepreneurial space. Many of these opportunities will be spotted and utilized by new ventures which will start to compete with industry incumbents. Smartness, namely the ability to collect and digest Big Data for insight, prediction, innovation and improvement may have a transformative impact on many sectors, may change the nature of competition and even disrupt some industries. Large visionary companies have ample resources to design and manage this transformation successfully, but technology innovation always opens the door for disruptive and agile new ventures experimenting with the new tools and solutions, using modern technology as a weapon in competition.

The aforementioned company Mu Sigma, a representative player of the new technology world, is focusing on statistical analysis and modelling, as key components of this new entrepreneurial space. Its fast growth properly illustrates the market’s potential. This opening and growing space can be described as a, expandable two dimensional matrix of activities and sectors *(Exhibit 4).*

Exhibit 4. The entrepreneurial space of big Data and smart systems

Sector

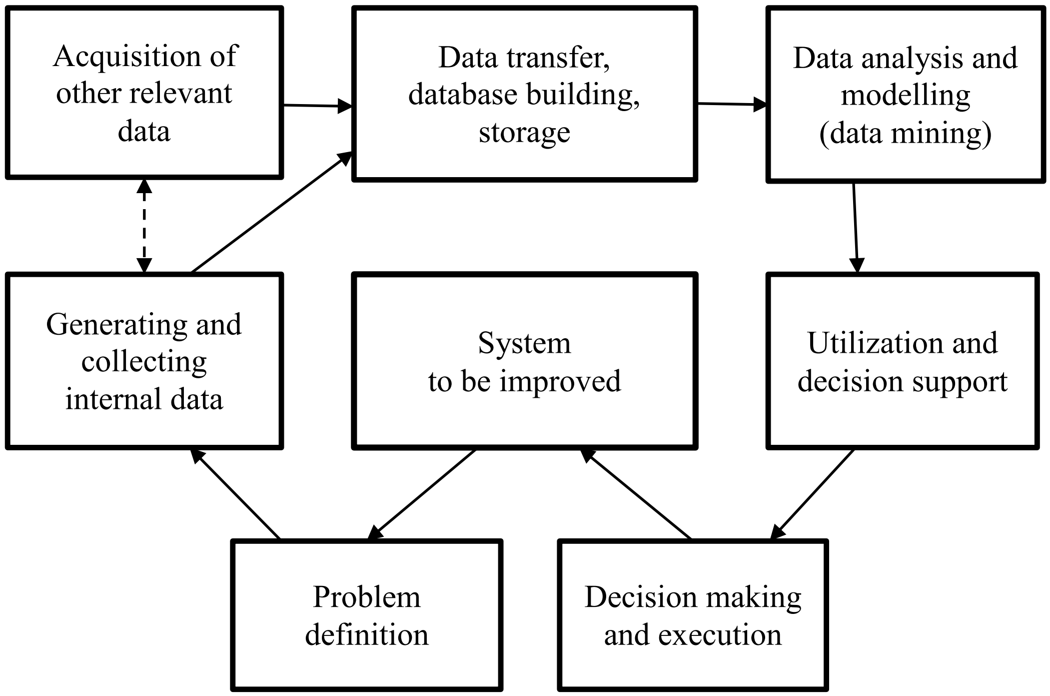
activity	Energy	Healthcare	Agriculture	
Problem selection				
Problem translation				
Data collection				
Data acquisition				
Data transfer				
Data analysis				

The first dimension represents the following logically ordered imbedded activities of functioning smart systems:

- Selecting a subject and identifying its problems or needs for improvement
- Translating the problems to the language of data science
- Collecting relevant data on the system and its environment
- Mixing the collected data with other accessible relevant and valuable data
- Transferring the data to a place where the necessary computing power, storage capacity and data management knowledge is available
- Analyzing (mining) the data, acquiring insight, building decision-support models
- Using the models for decision support, presenting findings and recommendations to decision makers.
- Implementing the decisions, changing and developing the selected system, measuring and evaluating the results.
- Closing the loop by using the acquired experience for learning, improving the activities listed above.

Exhibit 5 presents a simplified dynamic model of the activity loop above. The whole loop is liable to rapid innovation because of the fast development of its components.

Exhibit 5. Simplified model of building and operating smart systems



The second dimension is for the sectors which may benefit from the development and spreading of smart technologies: trade, manufacturing, finances, government, healthcare, agriculture, education, marketing, etc.

Many companies and other organizations (e.g. university departments, research labs, consultants) try to find a good position in the activity-sector matrix matching the new opportunities with their financial, technological and intellectual capabilities.

Big incumbents like IBM may occupy almost all the horizontal (activities) and vertical (sectors) portions of the entrepreneurial space. Some of them design and build complete smart towns with many modern data-based smart services like transport, healthcare, education, government services *(Townsend 2014).* One of the leading examples is Santander, a Spanish coastal town where thousands of installed sensors feed the smart algorithms providing support to the city's inhabitants. The systems' main designer and operator is Telefónica, a Spanish broadband and telecommunications provider with a global presence. Cisco's test field is the town of Songdo in South Korea, IBM is especially active in Portland, USA. In Hungary, the large ICT incumbent

Hungarian Telkom is building the infrastructure for smart town services in Szolnok and Nyíregyháza[14].

One of the most attractive sectors is energy where smart meters may generate a huge amount of data what can be used for reducing consumption, and managing the complexity of modern multi-source energy systems. Healthcare is also very promising; precision agriculture's healthcare tally is *individualized medicine* that is tailoring of medical treatment to the individual characteristics of each patient. By the help of cutting-edge digital diagnostics tools, high-capacity data centers, sophisticated machine learning systems, and artificial intelligence it is possible to obtain multiple layers of data for any individual, recognize patterns, making predictions and develop personalized treatment *(Topol 2014).* General Electric is using Big Data to produce smarter turbines: intelligent machines equipped with hundreds of sensors can communicate their operating data to help the machines, their operators and maintenance staff to work better. The company opened Predix, its cloud-based Big Data analytics platform for software developers in 2014, connecting people machines and data through the industrial internet

Small and medium-sized companies, and especially startups try to focus on specific activities or vertical subsectors. Mu Sigma, a venture mentioned at the beginning of this section, concentrates on data analytics and modelling in the activity loop, but otherwise it is sector-neutral that is it may serve anybody who has a problem which can be approached with data analytics tools (Provost, Fawcett 2013).

To find a meaningful and exploitable niche, new ventures and R&D groups may increase the granularity of the activity-sector matrix. Energy supply of special sensors may be a good example: it is technically impossible or very expensive to change the exhausted batteries in sensors used e.g. inside a living organism or spread over a large field, consequently special batteries must be developed which can draw energy from their environment[15].

5. Innovation for smart agriculture

Agriculture is a vertical sector of the entrepreneurial space outlined above. Its progress on the "smartness trajectory" looks to be relatively slow, but its development potential is high. By the help of modern technology, many decision factors can be translated to rich digital data sets what

[14] The Nyíregyháza smart town project was announced by the company in 2014.
[15] A leading researcher workin in this field is Prof. Zhong Lin Wang at the Georgia Institute of Technology. His „nanogenerators" may be used for powering nanoscale sensors.

can be fed into sophisticated algorithms providing insight and suggesting decisions. Innovation is essential for this kind of transformation and it is coming in many forms and from many sources.

Grand visions are evolving about modern digital agriculture where sensors and drones collect and transfer real time data on everything, cloud-based data centers digest Big Data and build sophisticated and self-learning decision-support models, recommendations are sent to farmers' mobile devices or directly to automated self-driving machines (robots) which take care of perfect execution. In the last section of this study, we will use a few examples to illustrate how agriculture may get closer to this vision and buy its ticket to the club of digital masters.

Just like in other industries, some big companies, large incumbents looking for new growth opportunities and climbing up the value chain may figure out technology's transformative potential quickly. They can leverage their large R&D budget, accumulated knowledge base, and extended partner network for building complex smart systems and to position themselves as system integrators and vertical providers of smart services.

Monsanto[16], a multinational agrochemical and agricultural biotechnology corporation headquartered in the US, launched the trial version of its prescriptive-planting system called FieldScripts in 2013, and it went on sale in some states in 2014 *(The Economist 2014).* The system is based on precision farming principles: using data-based decision-making support and modern equipment, farmers can plant the sections of their fields with different seed varieties at different spacings and depths. This practice is called variable rate planting, what means using different plant populations across an entire field. It may replace static rate planting, i.e. planting a uniform population everywhere. The ultimate goal is to take into consideration the complete yield environment that is all the interacting factors that may impact the yield from a field, e.g. weather conditions, soil type, disease history.

Monsanto's FieldScripts is an algorithm-based smart system using Big Data, telling farmers with high precision which seeds to plant and where, and how to cultivate them. Monsanto had to acquire and mix databases from different sources to feed its models. The company itself has a library of hundreds of thousands of seeds and their yields. To add an appropriate soil and weather database, it acquired Climate Corporation in 2013, a firm founded by to former Google employees in Silicon Valley in 2006. Climate Corporation uses remote sensing and sophisticated cartographic techniques for mapping millions of fields in America. Their database, originally

[16] Monsanto is a pioneer of genetically engineered seeds. The company's policies and practices are frequently criticized for several reasons.

planned to sell crop insurance, is growing very fast, by 2010 it contained 150 billion soil observations and 10 trillion weather-simulation points[17].

The third crucial component of the system came from Precision Planting, also acquired by Monsanto in 2012. This firm makes seed drills and other agricultural devices pulled by tractors. Modern planters use GPS and some of them can steer themselves. Loaded with data the machines can adapt to soil and weather microenvironments and can plant a field with different seed varieties.

This kind of data-based precision planting has become a competitive field by now. To manage complexity, alliances are built and acquisitions are initiated. Another global seed producer, Du Pont Pioneer fashioned an alliance with farm-machinery manufacturer John Deere[18] in the recent past. In 2013, Land O'Lakes, a leading agribusiness and food industry company, announced the acquisition of Geosys, a global technology company providing satellite imaging services to agribusiness. Machinery producer Case IH and high-tech equipment maker Ag Leader are also early adopters of precision agriculture technologies and predictive analytics solutions. Topcon, headquartered in Tokyo, developed a sensor-based system for monitoring plant conditions to enable farmers to apply fertilizers only as needed.

Large-scale, complex and ambitious smart agriculture projects need partners who can provide the necessary domain knowledge and technology components. In Hungary, Széchenyi István University teamed up with the local unit of Hewlett-Packard, Hungarian Academy of Sciences' Institute for Computer Science and Control, and internet research venture eNET to launch the AgroDat.hu research project. The partners aim to create an agricultural information system and knowledge depository using big data technologies. By the project's blueprint, special low-energy agricultural sensors are grouped and installed above and under the surface at many field observation points. These sensors generate high volume data on many factors, e.g. humidity, water content, temperature, vapor pressure, radiation, leaf wetness, ice formation, carbon-dioxide concentration, electric conductivity[19], wind direction. Data is sent to central servers (supercomputers) via GSM network where, after mixed with other data, predictive and prescriptive models are built and constantly fine-tuned. Users can access this database and the

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[17] To make the picture complete, Climate Corporation bought the soil analysis business line of Solum, and agriculture technology venture in February 2014.

[18] A farm management and decision support software called APEX is an integral part of John Deere's product line. The company also developed a soil monitoring system that applies sensors to indicate water levels in the soil, in order to guide farmers if their crops need watering and how much.

[19] Electric conductivity, also mentioned in *footnote 1*, correlates with salt content, and salt influences plan growth.

related decision-support services through and interactive and personalized web portal *(Paller, Szármes, Élő 2014)*[20].

Large companies may assume very complicated and challenging tasks. Most of agriculture is directly driven by weather, consequently "holy grail" of smart or precision agriculture is accurate, automated, and continuous weather forecast. IBM's Deep Thunder system, based on high-performance computing, aims to improve short-term local, high resolution weather forecasting customized to weather-sensitive operations.

Yamaha is a leading supplier of agricultural drones. As Japan faces the problem of a rapidly aging population, these automated machines may help to ease the hard work of farmers. Yamaha's drone business is a small portion of the group's sales now, but high growth is predicted for connected and automated agricultural drones capable to collect field and crop data, and to execute activities like pesticide spraying.

The network of cooperating partners may be very colorful. Customers of Airinov, a French venture founded in 2010, a remote sensing pioneer, use a drone for collecting real-time high resolution data about their crops, while the results of the analysis is fed into the computer of their multipurpose John Deere tractors for direct execution.

Small and medium-sized companies, and especially startups try to focus on specific activities or vertical subsectors. Some of them develop really innovative and sometimes disruptive technologies. Blue River Technology, established by a group of university students, built an automated machine for lettuce thinning. The machine, moving rather fast over straight rows of small lettuce plants, collects data via digital photographs, then a smart algorithms decides what to keep and what to cut. Execution is also automated: unnecessary plant are killed with precisely aimed shots of fertilizers. Rowbots, an other a US-based startup, experiments with small, self driving, multi-use robots, which work in jointly controlled teams, can apply fertilizers in sync with corn needs, and continuously collect data for current and future work.

The Hungarian QuantisLabs' SmartVineyard system is predicting grape diseases with modern tools of data collection and data-based decision support. The system captures real-time microclimatic data with a set of sensors. The data is transferred to the cloud where smart,

[20] Collecting and processing relevant data and building a database large enough for statistical analysis is a real challenge. A significant barrier to the utilization of Big Data's full potential and to the adoption of smart technologies is the incompatibility of data formats through various platforms and farmers' understandable concerns about data ownership, security, and privacy. One of the initiatives aiming to find a solution is the Open Ag Data Alliance founded in early 2014. The long-term goal of this open standards group is to create a data a knowledge sharing backbone, a platform where farmers, engineers, scientists, and others can share their data, ideas, code, and technologies easily and safely. Some of the members: Purdue University, OnFarm, The Climate Corporation, Granular, Geosys, Monsanto, Ayrstone, AgReliant.

scientifically tested algorithms calculate the probability and the intensity of local grape diseases, then properly visualized real-time forecasts and alerts are presented to vine-growers, who can expect higher productivity and lower costs. Human decision-making and intervention (e.g. spraying chemicals) is an integral part of this system, but data collection, transfer and analytics is automated.

Dacom is a venture of about two dozen people in The Netherlands. Its customers are farmers who try to improve their business efficiency and to reduce risk. Dacom combines sensor technology, data analysis and internet connectivity to optimize agricultural production. It develops and sells hardware and software that measure weather conditions in farm field, which means rainfall, humidity and soil moisture content. Its sensors are very easy to install, farmers can do it without help, and they can also switch them on by their cellphones. All the data from the sensors are collected and consolidated in the cloud where Dacom processes and analyzes it, then sends the results to customers' smartphones. Farmers can use the raw data and the results of data analysis in their daily routines, plus share it with their partners as necessary for optimizing harvest and productivity. By the help of this smart systems, farmers can manage irrigation problems on a day-to-day basis, can see from their home offices if crops need water, receive alerts by the smartphone app when to go to the field and check it personally. Precious human time is saved this way, farmers have to go to the field only when it is necessary.

A Hungarian venture called Moow.farm develops a special device made of durable materials for measuring cattle's rumen acidity levels and temperature. Detected irregularities may indicate a disease or problems in foraging. The device is put in the rumen of the cattle and data is transmitted directly and automatically to a base station and then to the cloud where analysis is conducted and alerts are sent out to farmers and veterinarians. This case illustrates how smart system may appear and evolve in livestock breeding, and how "smart stalls" can be built[21]. The device was developed in cooperation with a design venture called Maform, automation expert Cubilog, and the University of Pécs.

An Israeli startup called Sol-Chip provides solar power for sensors planted in agricultural fields. The technology replaces traditional batteries that have to be replaced and disposed regularly. Instead of a separate power source, the venture's solution integrates energy supply into the manufacturing process, so that solar energy harvesting and conversion becomes an integral part of the sensors, and farmers don't need to worry about replacements. Shany Keysar, the

[21] Bewley, J. *(2012)* provides a long list of data which can be collected by modern technologies for the purpose of precision dairy farming (PDF): milk yield, milk conductivity, body weight, odor, glucose, acoustics, body temperature, animal positioning and activity, ruminal pH, feeding behavior, etc. The author defines PDF as „the use of technologies to measure physiological, behavioral, and production indicators on individual animals to improve management strategies and farm performance" (p. 65).

company's CEO thinks that the market for precision agriculture sensors will be over $800 million by 2017 *(Shamah 2013)*.

At the indoor vertical farms of Green Sense Farms, sensor systems control and optimize energy, water, and fertilizer consumption. Pesticides and herbicides are not used at all. AeroFarms is also building large high-tech indoor vertical farms with financial backing from Goldman Sachs and Prudential. The Japanese Mirai, founded in 2004 after an earthquake and a tsunami caused food shortages in the country, teamed up with General Electric to develop LEDs generating light in wavelengths adapted to plant growth in its half-automated vertical greenhouses. A startup called BioCarbon Engineering uses remote sensing, automated mapping, and high-velocity, air-fired planting systems for industrial scale reforestation.

Sensor technology, a key component of smart agricultural systems, develops very fast[22]. Farmers can measure a crop's nitrogen requirement with the British Yara company's tractor-mounted N-sensors as the tractor passes across their fields, and vary the fertilizer application rate accordingly. A team based at the University of California, Santa Barbara, develops an implantable microfluidic-electrochemical sensor capable of providing continuous, real-time tracking of drug levels in animals. An MIT group works on a nanotube which, when implanted below the surface of an animal's skin, can detect levels of nitrit oxide to monitor inflammation. Special biosensors developed at Georgia Institute of Technology are powered from the hydraulic force of the bloodstream.[23]

OnFarm, founded in California, is a firm providing an internet-of-things platform that integrates farm hardware technologies into a single user-friendly management and decision platform. Farmers get access to agronomic information from any device or location through customizable dashboards.

Understanding plant genetics approved a lot and one can observe a dramatic fall in the costs of generating and processing genetic data. Whereas a few years ago the cost of identifying a single plant's single gene was $2, it is only a few cents now. The cost of genetic identification and building genetic databases ceased to be a serious constraint. Plant genetics is a broader subject than the highly debated genetic modification, namely putting the gene of one plant species into another: genetic marking e.g. allows faster and more precise breeding. Having a vast genetic library is a serious advantage in research and agribusiness *(Grotewold, Chappell, Kellogg 2015)*. Institutions of genetics are setting ambitious goals. Britain's John Innes Centre receives funding

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[22] Liaghat and Balasundram *(2010)* analyze the agricultural utilization of remote sensing technologies including aerial, satellite, and spacecraft observation tools.

[23] *Sensors*, an open access, peer-reviewed journal, provides up-to-date information on sensor technology innovation, with sections dedicated to biosensors, chemical sensors, physical sensors, remote sensors, and sensor networks.

from the UK Biotechnology and Biological Sciences Research Council for four main strategic programs directly addressing problems like crop productivity and food security, e.g. they try to figure out how plants sense and “remember” seasonal changes. Knowledge acquired in this field may improve plant control, for example flowering may become more manageable[24].

We can expect that a growing number of old and new ventures, research spin-offs will realize the opportunity, consequently competition will get tougher, massive competitive advantages must be built and maintained for success. New ventures are hungry for capital, but unfortunately, as numbers on *Exhibit 6* indicate, agriculture, for obvious reasons, is not on the radar screen of typical venture funds. Venture investment in agricultural firms was zero in Hungary in 2013 and 2014, and European figures are also very low.

Exhibit 6. Venture capital investments in Europe by sector, 2012 (% of total VC investment)

Sector	**% of VC investment**
Life sciences	28.4
Computer and consumer electronics	19.0
Communications	18.2
Energy and Environment	11.0
Consumer goods and retail	5.7
Consumer services	4.8
Financial services	4.1
Business and industrial products	3.5
Business and industrial services	1.7
Chemicals and materials	1.5
Transportation	1.1
Construction	0.3
Agriculture	*0.3*
Real estate	0.2
Unclassified	0.1
Total	100 %

Source*: European Private Equity and Venture Capital Association, 2015*

[24] Professor Caroline Dean discusses this line of research on a YouTube video: *https://www.youtube.com/watch?v=-DqUkAFQbiY*

Interest may grow in the future, especially for high-tech ventures building smart agricultural systems or developing their critical components. The number of promising examples is growing. AgTech Innovation Fund, a venture capital fund investing in early-stage food- and agricultural-technology companies in North America, managed to raise $50 million in the recent past. By its mission statement, it supports ventures which are developing innovative solutions to improve productivity, increase sustainability, streamline supply chains, and create innovative products. Another fund, Cultivian Ventures focuses on the US Midwest, a region with the highest concentration of public and private R&D spending for agribusiness. One of the fund's portfolio companies, AquaSpy develops intelligent water monitoring systems, another one, Divergence, applies data-intensive genomics to identify compounds, proteins, and genes to control parasitic infections in plants and animals.

High-tech opinion leaders and celebrities may point the way forward. Google's Chairman Eric Schmidt' Innovation Endeavors VC fund invested in a Silicon Valley-based ag-tech company called CropX, a venture selling sensors and software designed to help farmers to decide how much water to use in different parts of their fields. The firm claims, famers can use up to 25% less water by the help of their solution. What makes this venture even more interesting is an unusual collaboration between genomics researchers from Israel and irrigation technologists from New Zealand. One of the founders is a medical doctor who launched life-science firms in Israel. He saw an opportunity in applying the same basic technologies his genomics company used to provide personalized medicine to generate location-specific irrigation recommendations to farmers.

As Big Data and analytics becomes the driver of agricultural growth, some data-driven companies try to facilitate the diffusion of innovative ideas and knowledge sharing. One of the investors behind the startup called Farmers Business Network is Google. This venture, launched in 2014, aims to help farmers to learn from each other had data on 7 million acres of farmland across 17 states in the U.S. in early 2015.

High-tech smart solutions can be combined with other agricultural innovations. One of China's fastest growing companies, Tony's Farm, focuses on the new urban elite of the country, producing and distributing organic vegetables. The company operates large computer-controlled greenhouses full of sensors, its fields are spanning thousands of acres across eight Chinese provinces. The country feels double pressure as its population raises to 1.47 billion projected for 2030, and this demographic trend coincides with soil degradation, climate change, water shortage, and extremely high pollution levels. Experiments demonstrate how smart farming techniques may improve yields while taking care of the environment.

Chinese experience may be especially instructive for the rest of the world *(Zhang, Chen, Vitousek 2013).* The country managed to increase its cereal production by approximately 32% in the period of 2003-2011, largely by improving the productivity of its farms. This improvement is impressive but far from being enough to meet the growing demand on the long run. Spare land is sparse, water shortages are normal, fertilizer usage has reached its limits, the country has more than 200 million very small farms, typical farm widths is only a few meters. Among other things, modern agronomics combined with information technology is needed to push yields closer to biological limits. Scientists are studying fields as ecosystems, they are tracking various inputs and outputs and develop algorithms to optimize production and achieve the greatest yields. This approach provides insight into the optimal times to add chemicals, planting dates and densities. Genetic plant varieties and field management processes recommended by the decision support models are tested in experimental plots, results are used for fine-tuning of the models. The centralized political system of China supports the efforts to build nationwide monitoring networks and to restructure agricultural systems on a nationwide scale. The country's government has more than tripled its agricultural research investment between in the first decade of the new century.

Farmers everywhere in the world, who are perfectly aware of the unique natural context of their fields, are practicing experimentalists who can be and must be involved in innovation efforts. To support bottom-up innovation, the EU launched the European Innovation Partnership for Agricultural Productivity and Sustainability (EIP-AGRI). It aims to promote joint research and development projects by linking farmers, researchers, businesses and other stakeholders into groups looking for solutions to shared problems and disseminating the results.

Collective learning, knowledge sharing, and bottom-up initiatives are critical factors of innovations' diffusion. Botanicalls, created by a grassroots project of technologists and artists, is a do-it-yourself kit with a sensor was developed that goes a flowerpot to measure moisture in it. When it gets too dry, the sensor sends an alert to the owner's mobile phone, and its sends a grateful "thank you" when the plant gets watered. The number of users grew very fast, and techno-gardening hobbyist started to build more sophisticated automated gardening systems by the help of small, simple, and cheap microcontrollers[25] like the Arduino[26] developed in Italy. This easy-to-use device may receive signals from many sensors and may control lights, motors, etc. It is built on an open-source electronics platform, so a complete development platform is available. Similar projects, and tools like the Botanicalls kit may teach many people how to

[25] Microcontrollers are small computers on a single integrated circuit board with programmable input/output peripherals.
[26] *Szilágyi and Toth (2015)* analyze Arduino's agricultural data collecting capabilities.

connect a plant to the internet-of-things, how a sensorsy system works, and how to build a closed control loop, plus they get a deeper understanding of the economics of smart systems.

Fast diffusion of innovations and intensive knowledge sharing may require new knowledge management approaches and institutions. Besides top-down advisory services, many industry observers highlight the importance of horizontal networks, social learning and participative solutions *(Busse 2014; Nemes, High 2013; European Union 2014, p. 45).*

6. Summary and conclusions

Due to world population trends and the rise of a new middle class, demand for agricultural products is continuously growing. Obtaining bigger yields with limited resources and without destroying the natural environment, exploiting soil, polluting air and water is a challenge everywhere in the world. Agriculture of the future must be efficient and sustainable, problems of intensive yet environmentally safe production must be solved.

Digital mastery managed to raise efficiency, productivity, and profitability in many industries. From this perspective, agriculture appears to be a laggard because of a few reasons. However, the sector's digital transformation started decades ago, as precision agriculture, an information-intensive management system emerged in the 1980s thanks to the advent of such technologies as computers and global navigation satellite systems. Information-based site-specific solutions were used for optimizing fertilizer distribution and irrigation to varying soil and weather conditions, i.e. to apply the right treatment in the right place at the right time.

Together with other innovations, precision agriculture put the industry on a new development trajectory, pushing ahead efficiency and productivity thresholds. It highlighted that gains in yields will depend ever more on innovating in context, datafication of key factors, statistical analysis and decision-support algorithms.

Although the technical revolution of precision agriculture appears to be unfinished and its market penetration is low in many parts of the world, fast technological innovation opens up new opportunities. New hardware and software tools, combined or supported by innovative service solutions appear everywhere, revolutionize complete industries and sectors. Among others, exponentially increasing computing capacity and speed, general connectivity, the internet-of-things, mobile tools, sensor technology, automation and robotics, drones, imaging satellites, machine learning, artificial intelligence, parallel processing of Big Data, cloud computing, miniaturization, nanotechnology, progress in machine-human interface, optical pattern recognition, software as a service, etc. open a new entrepreneurial space. Large companies, small ventures and other stakeholders are looking for competitive and profitable positions in this new arena. The complexity of many problems to be solved requires an all-embracing approach, intensive cooperation and the emergence of complete innovation ecosystems.

The new technologies and tools mentioned above will influence directly and indirectly the development of agriculture. Many stakeholders, large and small companies, research and development centers realize the opportunity and contribute to the digital development of the sector. The number of developers and users is growing, experience and knowledge is accumulating, there are many promising cases and results, but further research is needed to decide where the new potential efficiency and productivity thresholds are, what can be the realistic yield and profit expectations, what kind of factors will influence diffusion and adoption patterns, what will be the intended and the unintended consequences, how the environmental footprint of agriculture is changing.

One thing is sure: besides digital tools, leadership capabilities are also essential to initiate and support this transformation. Technology develops rapidly, fascinating new tools have appeared, but adaptation depends on farmers and managers.

Don’t worry, software will not eat your food, but it is highly possible that together with sensors, robots, drones, satellites, and other digital tools software will transform agriculture radically. Crop fields may look low tech from a bird’s-eye view, but the digital systems guiding and controlling them from planting to harvest get more and more sophisticated. Smart agriculture’s main promise is to produce more food with less resources and less harmful environmental impacts. The sector must climb higher on the ladder of digital mastery.

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