Training in agricultural technologies: a new prerequisite for smart farming

Simon Ritz[1*], Davide Rizzo[1 2], Jérôme Dantan[2], Michel Dubois[2], Fatma Fourati[2], Alexis Belloy[1], Anne Combaud[2]

[1] Chaire Agro-Machinisme et Nouvelles Technologies, UniLaSalle, Beauvais, FRA
[2] InTerACT research unit, UniLaSalle, Beauvais-Rouen, FRA
* Corresponding author. Email: simon.ritz@unilasalle.fr

Abstract

Most of the technological innovations in agriculture enter the farm through agricultural equipment, to ease farmers' decision-making processes. The ultimate goal of smart farming is to make a better use of natural resources to reduce farming trade-offs, thus meeting the society's expectations for sustainable development. The continuously growing number of agricultural technologies aims to contribute to achieving this goal, yet deeply changing the human-machine interactions. This opens new opportunities and challenges for both equipment manufacturers and farmers. They are therefore required to expand their knowledge to master smart farming tools, currently underused. Two complementary questions shall then be answered: first, what are the available tools for farmers with limited time, variable education level and when decision-making occurs in a context of bounded rationality and framed capacity for action? Second, on a more prospective note, which direction should take initial and vocational trainings about AgTech in view of the above? This paper uses the French example to discuss available tools within the education ecosystem and propose some recommendations to facilitate deployment of smart farming, with a focus on the need to reconnect education and training about technological solutions and their use on the farm. Altogether, we discuss how the deployment of smart farming requires positive, inventive and integrated vision for the appropriate use of all technical and scientific means, promoting an open collaboration between all actors, with a culture of innovation and entrepreneurship.

Keywords: Sustainable agriculture, agricultural equipment, vocational training, farmer education, precision farming, agronomy

1. Introduction

Leading to what is called a Third Green Revolution, Smart Farming represents the application of modern Information and Communication Technologies (ICT) into agriculture. Smart farming is strongly related to three interconnected technology fields: management information systems, precision agriculture, and agricultural automation and robotics (Kernecker *et al*., 2016). The link between technologies and agriculture is important. Bellon Maurel & Huyghe (2017) used agroecology to demonstrate the complementarity between practices and resources: agroecology is a set of practices which are not stabilized and need more knowledge about the ecosystems and their use for production (Berthet, 2014), while farming equipment and AgTech (agricultural technologies: precision agriculture tools, automation and robotics) are a set of resources to be mobilized, to achieve the agroecological objectives of the farmer. Smart farming becomes then one of the possible ways to sustainable agriculture, using AgTech to shift from intuitive to fact-based farming practices.

From this perspective, farm equipment is a vector for technological innovation in agriculture towards sustainability, AgTech a tool for implementation of smart farming practices. For example: produce more with less inputs through precision farming; use of sensors, information transfer and data processing as decision support tools; robots or specialized machines to manage soil cover and weeds. The list of technological answers to the new needs in agriculture gets longer every day and the pace of technology evolution is improving. One of the indicators is the number of proposals for using new technologies in agriculture, which is quickly growing (Brun & Haezebrouck, 2017; Wolfert *et al*., 2017; Janssen *et al*., 2017).

Seeing beyond immediate solutions and benefits, it is likely that external factors such as regulatory framework, insurance, or market expectations (traceability) will induce mandatory use of AgTech in some areas, in the near future, forcing their mass adoption by farmers.

As such, "agriculture is challenged by breakthrough changes that require farmers to expand their knowledge to be able to master recent farming innovations such as digital machine control, embedded sensors, big data management, etc. Thanks to the lowering cost and miniaturization of advanced technologies, farmers are pushed and eager to shift from intuitive to fact-based farming practices: chemical inputs, genetic responses and environmental condition can finally be controlled and accounted for at the intra-field level (Aqeel-ur-Rehman *et al*. 2014; Bencini *et al*. 2012). The increased data collection and monitoring capacities are indeed answering the need for a better use of natural resources to reduce farming trade-offs, thus meeting the society expectations for sustainable development." (Dantan *et al.*, 2018)

However, many researches focused on low diffusion or appropriation of new technologies (timing of adoption by some farmers), as adoption levels of AgTech are generally found low (Barnes *et al.*, 2019). Among other possible negative factors for adoption, Bellon Maurel & Huyghe (2017) identified deficit of the demand from farmers and the complexity − either real or perceived − of innovative equipment; Barnes *et al.* (2019) found economic cost barrier to adoption, behavioral component, impact of subsidy and taxation framework, industry bias perceived by farmers; Zhang *et al.* (2002) identified the lack of development of agronomic and ecological principles for optimized recommendations for inputs at the localized level. Synthesizing 10 studies on the matter, Tey & Brindal (2012) identified eventually 34 factors influencing adoption of precisions technologies, notably pointing that the implementation of AgTech require substantial technological and informationally driven analytical skills and knowledge-based interpretation.

This questions the required skill set of farmers in order to integrate innovative technologies in their farming practices (from adoption to adaptation and appropriation, Orlikowski, 2000; Carroll *et al.* 2003) for smart farming deployment, knowing that formal education and age have been found to be "common indicators of innovative behavior for most studies of technology adoption and seem to support the notion that younger and formally educated farmers are more likely to adopt precision agricultural technologies. This is further evidenced by the lack of training and technical support perceived as an adoption constraint to uptake of precision agricultural technologies." (Barnes *et al.*, 2019)

Farmers' education and tools for training becomes a key element of analysis, object of this paper: education to innovation is a component of both attitude towards innovative technologies and their appropriation on the farm (Barnes *et al.*, 2019; Knight *et al.*, 2010). Two complementary questions shall then be answered: first, what are the available tools for farmers with limited time, variable education level and when decision-making occurs in a context of bounded rationality and framed capacity for action? Second, on a more prospective note, which direction should take initial and vocational trainings about AgTech in view of the above?

Or, to sum it up, how to support today and tomorrow's farmers and agricultural equipment manufacturers to realize their new technological and digital transition? This paper uses the French example to discuss available tools within the education ecosystem and propose some recommendations to facilitate deployment of smart farming.

2. Materials and Methods

2.1. Panorama of initial trainings promoted by farmers with an AgTech component in France

Identification of AgTech oriented training courses is the linchpin for assessing available tools for deployment of smart farming. In France, most of the training courses in agriculture are under the supervision of the Ministry of Agriculture. They are carried by 824 either public or private institutions which are spread over the whole country (Fig. 1): 806 educational institutions from French level 3 to level 5 (high schools) and 18 higher education institutions of levels 6 and 7. Higher education in agriculture includes a short cycle leading to level 5 and a longer cycle leading to level 7. The 80 degrees of levels 3 to 5 (Tab. 1) are also supervised by the National Education Ministry (distinct from the Ministry of Higher Education and Research). The reattachment of training courses to the Ministry of Agriculture is dictated by the following principles:

- They are directly connected with changes in both agricultural/rural areas and agricultural/rural professional qualifications;
- The exercises of the missions defined by the 8th book of the rural and sea fishing code are federated in the educational institution project, in particular to contribute to development, experimentation and innovation activities linked with agriculture and agribusiness.

The link between agricultural trainings and the Ministry of Agriculture is thus supposed to guarantee the adequacy between education and the professional sector.

A few training courses of level 5 to 8 in both universities and IUT (French Institutes of technologies) are supervised only by the Ministry of Higher Education and Research. Indistinctively from the supervising Ministry, only some training courses are recognized as conferring the "CPA" ("Capacité Professionnelle Agricole" in French i.e. Agricultural Professional Capacity), required legally for starting a farm as farmer and benefit from start-up loans and start-up allowance. The CPA is accessible from Level 4.

Training courses conferring the CPA have been studied more particularly, in order to:

- Identify the main training courses followed by farmers or agricultural employees (Tab. 1);
- Analyze the frequency of themes linked to smart farming in those courses (Tab 2 and 3).

The final purpose is to assess the farmers' preparation for smart farming.

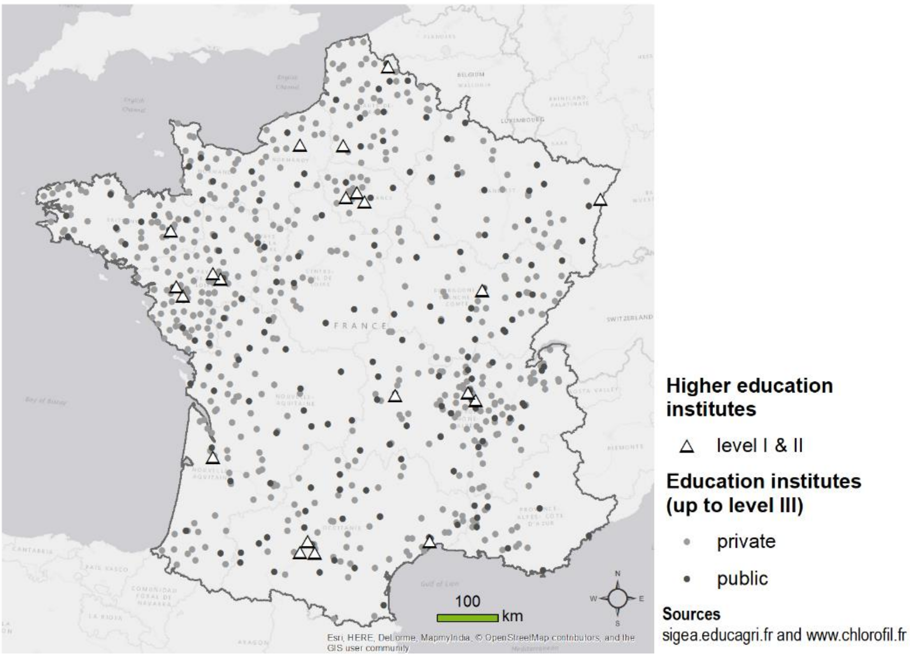

Figure 1: map of French agricultural education institutes

Table 1: Number of degrees available per French education level (international standard classification (ISCED 2011) between brackets).

	French (international) educational level					Source
	3 (4)	4 (3)	5 (5)	6 (6)	7 (7)	
Ministry of HE	NA	NA	NC	NC	NC	A
Of which delivering CPA			2	2	5	A
Ministry of agriculture	35	29	16	1	*18* §	B
Of which delivering CPA	/	15	16	1	*16* §	A
Professional integration* (% of graduated per year)		64 to 83	40 to 60	NA	4,2	C, D, E

* as a farmer and farm worker
§ number of institutes (instead of number of degrees)
A http://daaf.reunion.agriculture.gouv.fr/IMG/pdf/Arrete_CPA_29-10-2012_LISTE_DES_DIPLOMES_cle01badf-1.pdf
B http://www.chlorofil.fr/diplomes-et-referentiels.html
C http://www.chlorofil.fr/fileadmin/user_upload/stats/statea/statea-2017-05-insertion-bacpro-2012.pdf
D http://www.chlorofil.fr/fileadmin/user_upload/stats/statea/statea-devenir-btsa-scol-2007.pdf
E http://www.chlorofil.fr/fileadmin/user_upload/stats/statea/statea-2018-02-esavp.pdf

Note: for Levels 6 & 7, number of institutes are indicated in italics, instead of number of degrees.

The frequency of themes linked to smart farming in the programs is studied by a search of keywords in the degree references and RNCP (Répertoire National des Certifications Professionnelles in French i.e. National Register of Professional Certifications) sheets for both levels 4 and 5 degrees. Keywords searched aim to characterize agricultural technologies / smart farming: data, AgTech, new technologies, robots, AI (Agro-Industry), drone, PFT (Precision Farming Techniques), precision agriculture.

Table 2: Terms identified linked to keywords per education level

	French (international) educational level	
	4 (3)	5 (5)
Keywords found (translated)	DSS, GPS, digital technologies, innovative technologies, new on-board technologies	New technologies, technological innovations

It shall be noted that the program sheets listed in the RNCP for Level 4 are either recent (2017) or in the process of consultation for an implementation in September 2019. This update follows the overall reform of the baccalaureate in France. The BTSA ("Brevet de Technicien Supérieur Agricole" technician certificate) sheets, which are relatively old with regard to the mutation of agriculture (2009 to 2014) should logically be updated too. Adaptations of programs with inclusion of AgTech components can thus be expected in the coming years.

Concerning Levels 6 and 7 diplomas, the titles of specializations courses taught in the engineering schools, as well as the master's degrees approved by the Conférence des Grandes Ecoles (CGE) have been studied, to draft a panorama of Levels 6 & 7 trainings related to AgTech. Such trainings may have two dominant features: one is more agricultural machinery-oriented, which is generally associated with technical trainings in agricultural equipment such as professional baccalaureate or technician certificate, the other is oriented more on data processing (computer and statistics), usually associated with higher education trainings. Thus, we provide higher education courses in connection with the AgTech taught by main engineering schools (Tab. 3).

Table 3: French higher education courses with an AgTech component

a. Level 6

Educational institute/ University, city	Course title	Degree / duration / opening
Bourgogne University / Agrosup Dijon	Agronomie spécialité agriculture, nouvelles technologies, durabilité (Agronomy specialty agriculture, new technologies, sustainability)	Bachelor / 1 year
ISA, Lille	Numérique et Biologie (Digital and biology)	Bachelor / 3 years / 2019

b. Level 7

Educational institute/ University, city	Course title	Degree / duration / opening
AgroCampus Ouest, Rennes	Mathématiques appliquées, statistiques - Parcours Data science pour la biologie (Applied Mathematics, Statistics - Data Science for biology)	Master 2 / 1 year
	Ingénieur agronome, Option Statistiques appliquées - Sciences des données (Agricultural Engineer, Applied Statistics - Data Science course)	Engineer / 1 year
Agrosup, Dijon	Gestion des Entreprises et Technologies Innovantes pour l'Agroéquipement - GETIA (Enterprise Management and Innovative Technologies for Agro-equipment)	Master / 2 years
	Sciences et Techniques des Equipements agricoles (Agroequipment)	Engineer / 1 year
ESA, Angers – in partnership with ESEO	AgTech : Innovation numérique et connectée pour la création de valeur en agriculture et agroalimentaire (AgTech: digital and connected innovation)	Master / 15 months / 2019
Montpellier Sup Agro, Montpellier	Ingénieur agronome, Option - AgroTIC (AgroICT) - Data sciences pour l'agronomie et l'agroalimentaire (Agricultural Engineer, AgroTIC and data science course)	Engineer / 1 year
Bordeaux Sciences Agro, Bordeaux – in partnership with Montpellier	Ingénieur agronome, Option AgroTIC (Agricultural Engineer, AgroTIC course)	Engineer / 1 year
UniLaSalle, Beauvais or Rouen	Ingénieur agronome, Option Agroéquipements et nouvelles technologies (Agricultural Engineer, agro-equipment and new technologies course)	Engineer / 2 years
UniLaSalle Rouen	Master of Science Agricultural and Food data Management	Master of Science / oct 2018
ISA Lille – YNCREA, Lille	Ingénieur agronome, Option Agriculture durable & Smart Farming (Agricultural Engineer, sustainable agriculture and smart farming course)	Engineer / 1 year
ENSAT, Toulouse	Ingénieur agronome, Option Agrogéomatique (Agricultural Engineer, GIS course)	Engineer / 1 year

Complementary to initial training, in vocational training (or lifelong learning), the skills related to AgTech (both machinery and digital) are increasingly necessary with the digital transition as well as more and more complex machines in agriculture. Actors of the supply chain are asking for lifelong learning. An analysis of the complete offer in this sector should be carried out to add a new dimension to the present article. Yet, researches are made difficult by the multiplication of actors involved and the subjectivity that would generate a partial analysis. However, we can mention the Certificates of professional qualification (e.g. those delivered by AXEMA), promoted by the private sector for the targeted topics which are covered, also in connection with the French chambers of agriculture network. There are also short courses on mechanization dedicated to farmers proposed by agricultural organizations such as technical institutes like Arvalis, training organizations in agriculture such as Résolia and manufacturers such as AGCO. Finally, some short courses in statistics and data processing are proposed by peripheral actors of the farming equipment supply chain; these generally require solid foundations in both mathematics and computer science (e.g. statistics courses proposed by both Idele breeding institute and French Modelling and Data Analysis for Agriculture Network).

2.2. Current impact of skills and knowledges in AgTech acquired in initial training in France

In absence of a detailed analysis of the offer and impacts of lifelong learning in AgTech fields, it is interesting to assess potentiality of diffusion of AgTech in the current farming population, based on education level of farmers and age. As highlighted above, trainings in smart farming are recent in France, and limited to higher education: it can thus be expected that initial education including references to smart farming have only been accessible to a small number of students and a very limited number of professionals yet. Crossed indicators to verify this are the level of education of the farming population and its age, keeping in mind that the French farming population is aging, quickly: from an average age of 49 years old in 2000, the farming population went to 52.5 years old average in 2016 (Agreste, 2018).

France is among the best ratios in Europe for the initial training of farmers. In line with other sectors, the overall education level of farmers rose significantly in the last 20 years, with the democratization of education and the modernization of farms. In 2016, more than 50% of the farmers possess a secondary education degree. The main variation factor among the farming population is the age: 20% of farmers above 60 years old only have a primary education level, while 85% of the farmers under 40 years old have at least a secondary education degree. Education of young farmers has made a significant jump in the last 15 years: the proportion of farmers under 40 years old with a secondary education degree went from 45% in 2000 to 85% in 2016 (Agreste, 2018).

The level of education of farmers is thus rising, also induced in part by subsidies programs (CPA as referred above) targeting young farmers, requiring a minimal initial secondary education level validated to benefit from the start-up aid scheme (start-up loans for young farmers and start-up allowance). Proportion of higher education degrees among the farmers' population grows in the same proportion, although for a smaller number.

Indeed, in 2016, the proportion of farmers who possessed a higher education degree of all types falls at 24% (11% in 2000), and only at 14% with a specialization in agriculture. Once again, age is predominant factor of variation: 43% of farmers under 40 years old have a higher education diploma while only 14% of farmers above 60 years old have one, which demonstrate a great potential for developing smart farming in the future.

However, for the time being, the limited number of farmers with a higher education degree and the aging farming population complexifies deployment of smart farming, whose adoption by farmers can be associated to many factors.

2.3. Relation of farmers to AgTech and innovation

In the literature, various factors have been identified to describe how farmers relate to AgTech and innovation. For instance, the review by Tey & Brindal (2012) identified 34 significant factors to explain the adoptive decision making of precision agriculture technologies (PATs), further grouped in seven categories: socio-economic factors, agro-ecological factors, institutional factors, informational factors, farmer perception, behavioral factors and technological factors. The authors finally pointed out some levers to bridge the information gap, which emerged among the key limiting factors in the adoption of PATs. Knight *et al.* (2010) demonstrated that farmers' education encourages innovation. In their recent study Barnes *et al.* (2019) highlighted that the educational status is not a clear predictor of adoption of PATs. However, education, advisory services and other information mechanisms might help changing how farmers relate to AgTech and their inclination towards innovation and the shift towards information intensive technologies.

In this regard, connections and infrastructures emerge as underpinning factors influencing the information mechanisms, especially in rural areas within a context of digitalization of information. Unfortunately, few data exist on the real access and use of web-related devices. A remarkable exception is the Agrinautes survey for France (Boiteau *et al.*, 2018), last edition of which reached 1210 equipped farmers. Weather and banking services, as well as classified advertising and farm data were the main reason of connection for almost all the respondents, 85% of which use internet at least once a day. Regarding social networks, 60% of them use social networks, the most used being Facebook and Youtube, including to view tutorials related to their daily work. Of notice, the farmers having at least a connected equipment almost doubled in a couple of years: respectively 24.7% in 2016 and 39.4% in 2018. These figures suggest that the population of connected farmers is already using information technologies in the day-to-day farm management, eventually shifting towards the adoption of AgTech devices. In this vein, the connection availability widens the opportunities to explore innovation and filling the information needs. This endogenous interest of the profession is illustrated below with the analysis of the recent orientation of professional events toward AgTech and the multiplication of experimentation sites.

2.4. Multiplication of professional initiatives to facilitate new technologies diffusion / appropriation

Several factors can illustrate the interest of a sector to facilitate diffusion / appropriation of a specific topic: orientation of professional events, number of experimentation structures involving users (i.e. the topic does not interest only innovation actors but generates interest of the end-users in view of a possible adoption), or multiplication of training sessions or informative communications for end-users (specialized press), etc. The research of the current paper is focused on the first two factors.

First, an extensive research has been carried out to list all professional events involving a specific dimension in agricultural technologies / smart farming in most recent years, from 2014 to 2018. Keywords used were: data, AgTech, new technologies, robots, AI, drone, PFT, precision agriculture. However, the team faced a lack of indexing for events which occurred more than two years before date of research: for recurring events, pages were updated to the last or coming version of the event, and for one-time events, websites were missing, or at best present with partial information. A shift was made towards social networks and their records to identify the said events. Altogether we identified 79 events between 2016 and 2018, unevenly distributed (Fig. 2).

The following points can be listed after reviewing the data:

(1) All main agricultural professional events in France (>30 000 visitors) developed an orientation towards AgTech. For example, the Paris International Show increased five-fold the area dedicated to AgTech in 3 shows. Additionally, events dedicated specifically to AgTech begin to appear (FIRA, LFDay, e-Day, CoFarming Fest).

(2) Unbalanced distribution at the scale of the country, benefiting to the north-western half, concentration of events around research poles: out of 46 location identified, Paris, Montpellier, Beauvais, Angers and Toulouse concentrate 38% of the events, highlighting a possible impact of research centers in the dynamism of the regions.

(3) Events in Paris emphasize the interest generated by AgTech of peripheral actors: several events non-specific to agricultural topics (data, finance, technology) had an orientation towards AgTech, representing a link with technological/financial sectors which identify agriculture as an opportunity for development.

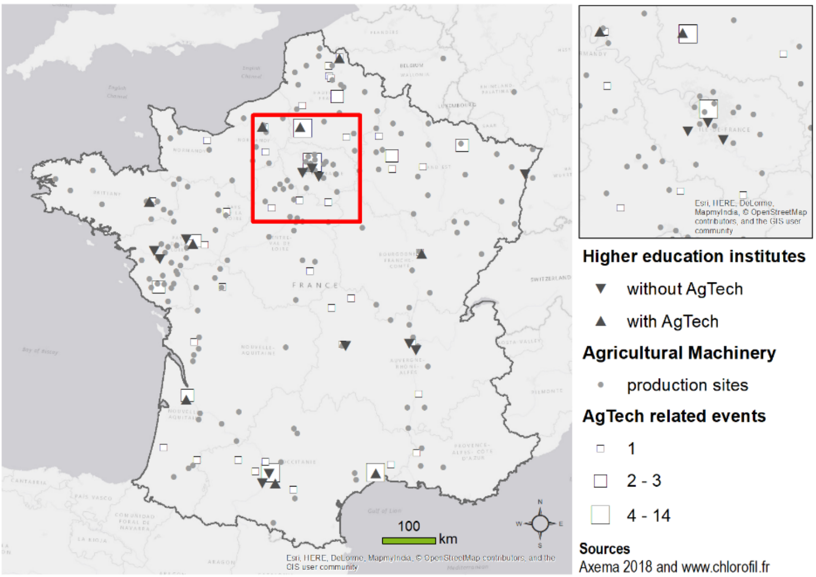

Figure 2. Spatial distribution in France of professional events with an AgTech orientation compared to higher education institutes and farm equipment manufacturers

(4) Link between AgTech and FoodTech: AgTech is very often associated to FoodTech, which seem to place AgTech as one of the possible links from field (the farmer) to fork (the consumer), useful for traceability of agricultural products concerns, consumers' education and positive reinforcement of farmers' image.

Second, also represented on the map, the team observed since 2015 the set-up of 20 distinct experimental structures, aiming to support the development of AgTech. With some differences in the type of organization and functioning, all of them carry the mission to contribute, often on a learning-by-doing approach, to the adoption of AgTech by farmers.

Noticeably, the network Digifermes (Arvalis) uses existing 13 farms to deploy AgTech, by placing the farmers at the center of the development of projects with high technical readiness levels. The Ferme 3.0 (Chambre d'Agriculture Hauts-de-France), the oldest of those experimental structures oriented towards AgTech, describes itself as a living lab for agronomic, technological and robotic solutions. AgriLab (UniLaSalle), on the other end, places open innovation as a prerequisite for the farmers who want to develop an innovative project.

Eventually, all those initiatives target explicitly the end-users (the farmers) and are distinguishable from profit-oriented enterprises, illustrating the genuine interest of the sector for the diffusion of AgTech.

3. Results and Discussion

3.1. The rising need of an AgTech learning ecosystem

As demonstrated above, AgTech notions beyond initiation are taught only in higher education courses in France, despites efforts of the profession for diffusing technologies. This is favorable to the deployment of AgTech in the future when linked to the raise of education level of farmers. However, the raise of education level of farmers faces a structural standstill with the lack of accessible options within the French education system for farming-oriented higher education level diploma for future farmers. Until today, the vast majority of farmers-to-be choose the levels 4 & 5 degree path, which are dead-end paths in the education ecosystem and only allow few continuations. There is no obvious link between those 2-years courses and further studies at license / master level. The education system should allow the future farmers to reach easily any level and facilitate transfers from a level to the next one. This missing link between technically-oriented trainings, largely endorsed by farmers-to-be, and masters' level degree has to be created to allow a deeper mastering of AgTech, before usage on farms. Higher education institutions should have the legislative capacity to build those bridges and to develop them with the idea of valuating technical assets of the students, while providing them with the required technological and informationally driven analytical skills and knowledge-based interpretation capacities.

In terms of content, it is necessary to value agricultural technologies as a tool, in the context of agronomy. Training courses should be designed with this distinction and avoid nowadays trends: in most of the training courses referenced above, the AgTech orientation of the trainings is made at the expense of agronomy, leading to AgTech as a precept being opposed to historical fields of agronomy.

Modality of training in AgTech are important: a support farm and a technological workshop are required as support tools for pedagogy and experimentations, in line with the French Ministry of Agriculture recommendations. The overall objective is eventually to set up a full ecosystem dedicated to train future farmers and existing farmers in AgTech:

- License and master degrees accessible from technical training courses,
- Facilitate the articulation between agronomy and AgTech in all level of training with the support of:
    - A dedicated farm for field experimentation,
    - A technological workshop conceived with the purpose of designing farming tools using AgTech, based on a project-based learning approach.

Eventually, based on the learners' profiles and aspirations, training courses and their content should be tailored and proportion in agronomy / AgTech balanced in view of specific objectives. Links with technological training course should be envisaged and mobilized upon need with the option to graduate with two diplomas jointly, from several institutions if need be. Same approach should be used for vocational training for farmers' or other professionals: the connection between technological solutions and their use on the farm should be in the heart of the training with an appropriate mix of pedagogical modalities.

3.2. Vocational education and training of smart farming: the need of an active learning approach

Farmers constantly take complex decisions that needs to account for multiple variables. For the greatest share of these decisions, they must face the uncertainty alone and in a short lapse of time. As so, they learn by doing and continuously observing the results of their decisions (e.g. Casagrande *et al.*, 2012). Therefore, vocational education and training programs aiming to unlock the appropriation of smart farming technologies will benefit from an active learning approach. The active learning implies learners to engage in meaning-making inquiry, action, and personal reflection (Lima *et al.*, 2017), thus in a similar mood of the typical farmer's decision-making process. More in general, this follows the experiential learning cycle that relates concrete experience and abstract conceptualization as modes of grasping experience, then transformed through either reflective observation and/or active experimentation (Kolb 2014, p. 51).

The active learning may take various complementary forms, such as (1) the project-based learning, (2) the dual vocational training and apprenticeship, (3) the makerspaces and similar. The project-based learning targets a self-directed learning processes starting from sound and realistic problems, thus including the uncertainty of the real-life decision-making process (Abbey *et al.*, 2016). In this sense, project-based learning generally provides an interface between academia and practitioners, so facilitating the hybridization of knowledge. This might help to build trust in smart farming technologies, as these are for the most coming from a non-agricultural background. In the same vein, the vocational education and training in smart farming could also be developed through the dual learning or apprenticeship programs. These combine on-the-job training and academic instruction, with the learners spending alternatively their time in a hosting enterprise and in the academia (cf. Mulder 2018). Finally, the training in agricultural technologies could specifically benefit from the makerspaces and similar. Makerspaces are inspired by the do-it-yourself approach, thus supporting an informal creative ecosystem equipped with a variety of rapid prototyping and low-tech tools and a meeting space for design teams. This approach was further formalized by the Fab Lab foundation (an outreach project from MIT's Center for Bits and Atoms) that federate an open and collaborative global network of places sharing a common set of tools and processes (http://www.fabfoundation.org/). For instance, in France recently opened AgriLab®, a makerspace entirely dedicated to agriculture and drawn upon the three Fab Lab pillars: doing, sharing, and learning. This platform promotes the culture of open innovation and knowledge sharing by and for farmers about agricultural equipment and new technologies for a more sustainable agriculture. It already hosted a couple of intensive workshops for farmers and students in agronomy to identify relevant technologies to support their field observations (Dantan *et al.*, 2018).

In conclusion, it is also important to consider that farmers entrust their peers as the ultimate reference to legitimate new knowledge acquired through direct or learning experiences, even against the availability of other references such as extension services, agricultural research and other media (Phillips *et al.*, 2018). Hence, the vocational education and training approaches in agricultural technologies will be more effective if developed within a learning community, as claimed for instance in agroecology (Francis *et al.*, 2011) and livestock innovative education (Sewell *et al.*, 2017).

3.3. Training centers: a possible interface between top-down and bottom-up innovations?

Eventually, and to go beyond the farmer-targeted approach, mostly promoting the diffusion of top-down innovation, training solutions should be conceived allowing and promoting the expression of bottom-up innovation, endogenously vouching for a better adoption, appropriation and eventually adaptation of AgTech and smart farming practices. This raises the question of the interface required for the expression of bottom up innovation and its valorization, or more generally of the missing link between bottom-up and top down innovations. The disconnection between bottom-up movement and top-down movement, in technology innovation, is not a fact which can be easily modified. It is the consequence of a fundamental dissymmetry.

A top-down organization, inside a company but also at the level of the society, is built on presumptions, rightly or wrongly, that knowledge is produced at top level, through research by scientists; then knowledge is transformed in formalized know-how by the engineers, and finally it is taught to farmers by specific teachers and consultants. It is a consequence of a classic vision in Western Culture coming from Francis Bacon (1561-1626) and René Descartes (1596-1650) with the aim that science should lead technique. No doubt that this new vision has changed and increased the rhythm of invention. This means that know-how is a consequence of knowledge, as research is divided in fundamental research and applied research. So, this logical hierarchy has easily transformed in a hierarchy of value. Even for action, it appeared that knowledge was a way to achieve dominance. And finally, a scientist does not want to discuss with a farmer who is supposed not to understand. The only possible relation is teaching. "As a result of these asymmetries, farmers' own particular needs and rights may be ignored, and inequalities are at risk of growing due to data-driven insights, rather than be reduced" (Kritikos, 2017).

Indeed, current solutions, such as service providers where data is retrieved by reselling companies either as decision support systems or to other companies for marketing / commercial purposes, are unsatisfactory to the farmers:

(1) Such solutions are based exclusively on technological advances, yet the farmers' participation in the innovation process and the technology customization on their needs appear to be quite limited.

(2) Farmers have generally to adapt to standard solutions suited for the greatest market share. Consequently, the proposed solutions do not fully suit the local heterogeneous agricultural needs. Even more, the customized solutions realized by businesses would be too expensive.

(3) The role of farmers in the innovation process is not clearly defined, or even denied. Proposed solutions (software, innovations, data involved, and decisions via a "black box") are often proprietary. The farmer is just considered as end-user more than an innovation actor, which would promote their autonomy.

(4) Farmers' collaboration/participatory control on hardware, data, knowledge sharing, and decision support is then low. Indeed, providers follow a general design which centralizes both data and "black box" decision tools, without collaboration between farmers of same regions.

Now, as the technical and cultural farmers' level is growing, also grow their awareness and concerns about the access to and the use of their farm data (American Farm Bureau Federation, 2018) and the related major shift in role and power relations.

On the other hand, a bottom-up organization is built on presumptions, rightly or wrongly, that know-how has its own autonomy and as innovation is always done at the level of know-how, the practitioners know what they need and so they ask to the scientists to answer to their questions. Fundamental research is thought as an activity to answer to questions of knowledge by the innovative farmers looking for a change of practice. This could look very naïve, but research has now shown that naivety is on the other size, when top-down is applied to complex social systems, such as healthcare or modern agriculture (Braithwaite *et al.*, 2018).

An interface is thus needed. The interface to build is conceptual, but not only. It needs that the scientists presume that the questions of farmers are legitimate. It needs also that the farmers accept or at least understand the different representations, proposed by the scientists, and assume the dual role of expert and learner. The research days in UniLaSalle, from which have been published two books (Dubois and Sauvee, 2016; Caroux *et al.*, 2018) are examples of possible interactions between practitioners, engineers, scientists and philosophers. Another example is to implement farmer-oriented innovation (e.g. Dantan *et al.*, 2018), through for example a chair fostering design and development of research, education and training in AgTech by acting at the interface between students, industry sector and farmers (Rizzo *et al.*, 2018). The Bec Hellouin organic farm is also a fine example of inventor farmer of precision tools for permaculture (Caroux *et al*., 2018, p. 59). The co-construction of new technical systems between farmers, research institutions and equipment manufacturers, is now valued in order to restore the creative and inventor role of the farmer (Caroux *et al*., 2018, p. 93). Finally, the start-up Agrifind develops a marketplace for the agricultural world, allowing the connection between farmers wishing to enhance their experience with other farmers seeking to acquire more knowledge and know-how. This web platform dedicated to the transfer of skills has been officially launched at the SIMA 2017. These examples, again, show that the farmers just need to be considered as inventors or co-inventors, involved in the local transformation of their activity.

Transforming agriculture into a complex adaptive system implies that a routine practice through a step-by-step model, from top to bottom, is less and less used. "Complexity science forces us to consider the dynamic properties of systems and the varying characteristics that are deeply enmeshed in social practices." (Braithwaite *et al.*, 2018). We have to learn by doing and "to accept that multiple forces, variables, and influences must be factored into any change process" and that "unpredictability and uncertainty are normal properties of multi-part, intricate systems."

4. Conclusions

Deployment of smart farming will only be possible with the combined inputs of initial training for tomorrow's farmers and vocational training for the current farming populations. Many drawbacks will slow down the process, but coordinated efforts of academics, private sector, peripheral actors of the supply chain and of the farmers themselves will eventually pay off, to avoid counter-productive accelerated concentration of farming capacities in large-scale farms at the expense of agricultural diversity.

For the initial training, the involvement of the Ministry of Agriculture in supervising agricultural educational programs aim at this coordination of actors and overall guidance in including AgTech components within trainings, as seen with the last revision of program sheets of the National Register of Professional Certifications. Ongoing revision of short higher education programs should naturally reflect this trend as well. Same approach with the support of public institutions should be adopted to ensure consistency and limit dispersion of initiatives, especially for farmers-to-be in the framework of obtention of the Agricultural Professional Capacity.

However, mechanisms of dynamic update of training programs are required to adjust trainings to current usages. This requires resources: AgTech are constantly evolving, and the time required to build a consistent training program and identify academics with required skills to teach it often overpasses usages. One option for compensating differences in temporalities is that trainings in at higher education level in AgTech could be envisaged not focused on technologies, but on their usages, implication in agronomic programs, benefits, consequences on the cultural cycles, on the farms, on the supply chain. A clear focus of numerous students, whether technological, practical or organizational, would be detrimental to agronomy and would lead to a lack of hindsight when assessing technical, economical and sociological impacts on farming practices.

On the other end, useful project-oriented trainings for end-users, could promote this technological focus and provide to nowadays' farming population required skills for using, at least, before adapting, i.e. being part of the design or update of the technologies. Efforts shall be undertaken by the all supply chain to place farmers at the center of the innovation process. Moreiro (2016) and Hostiou *et al*. (2017) concluded their papers by highlighting the step of adapting the use of technologies to farmers' need and skills; or to a set of farming practices: "Significant research and development efforts will be needed to adapt such technologies to the particular requirements of farm machinery that will support the transition to agroecology" (Bellon Maurel & Huyghe, 2017). Equipment manufacturers have thus also a key role in leading farming innovations deployment by easing farmers' decision-making processes with the support of agricultural technologies.

Finally, the role of the peripheral actors of the farming equipment supply chain is a key for scalability of intervention: training of the whole farming population is neither required nor possible. However, ensuring that vocational trainings conferred benefit from a large impact by involving communication relays is a key aspect for successful development of smart farming.

Altogether, this new data intensive farming requires positive, inventive and integrated vision for the appropriate use of all technical and scientific means. Eventually, this vision of tomorrow's agriculture will allow for the emergence of digitally augmented farmers. This is the moment to undertake a technical revolution and to promote collaboration between farmers, engineering schools, students, farm equipment manufacturers and experts in agronomy, ICT, and research, with a culture of innovation and entrepreneurship.

Acknowledgements

This work has been supported by the *Chaire Agro-Machinisme et Nouvelles Technologies*, from UniLaSalle (Beauvais, France), with the financial support from the Michelin Corporate Foundation, AGCO, the Hauts-de-France Regional Council and the European Regional Development Fund (ERDF).

References

1. Abbey, Lord, Dowsett, E., Sullivan, J. 2017. *Use of problem-based learning in the teaching and learning of horticultural production*. The Journal of Agricultural Education and Extension, volume 23, n° 1. p. 61-78
2. Agreste, 2018. Population agricole, formation et recherche, GraphAgri, http://agreste.agriculture.gouv.fr/IMG/pdf/Graf1815_-_Formation_initiale.pdf
3. American Farm Bureau Federation. 2018. *Data Privacy*. https://www.fb.org/issues/technology/data-privacy/
4. Aqeel-ur-Rehman, Abbasi AZ, Islam N, Shaikh ZA, 2014, *A review of wireless sensors and networks' applications in agriculture*, Comput Stand Interfaces, 36: 263–270. https://doi.org/10.1016/j.csi.2011.03.004
5. Barnes A.P., Soto I., Eory V., Beck B., Balafoutis A., Sánchez B., Vangeyte J., Fountas S., van der Wal T., Gómez-Barbero M., 2019. *Exploring the adoption of precision agricultural technologies: A cross regional study of EU farmers*. Land Use Policy, Elsevier https://doi.org/10.1016/j.landusepol.2018.10.004
6. Bellon Maurel V, Huyghe C., 2017, *Putting agricultural equipment and digital technologies at the cutting edge of agroecolog*y. Oils and fats Crops Lipids, 24: D307. https://doi.org/10.1051/ocl/2017028
7. Bencini L, Maddio S, Collodi G, Palma DD, Manes G, Manes A., 2012, *Development of Wireless Sensor Networks for Agricultural Monitoring*, Smart Sensing Technology for Agriculture and Environmental Monitoring. Springer, Berlin, Heidelberg, pp. 157–186. https://doi.org/10.1007/978-3-642-27638-5_9
8. Berthet E., 2014. *Concevoir l'écosystème, un nouveau défi pour l'agriculture*. Presses des Mines. Paris
9. Boiteau P., Ménager M., Sauget N. (2018). Etude Agrinautes 2018 réalisée par BVA pour Terre-net Média et Hyltel.
10. Braithwaite J., Churruca K., Long J. C., Ellis L. A. and Herkes J. 2018. *When complexity science meets implementation science: a theoretical and empirical analysis of systems change*. BMC Medicine, 16:63. DOI: 10.1186/s12916-018-1057-z
10. Braun A-T, Colangelo E, Steckel T., 2018, *Farming in the Era of Industrie 4.0*, Procedia CIRP, 72: 979–984. https://doi.org/10.1016/j.procir.2018.03.176
11. Brun F. & Haezebrouck T.-P. AgTech – Digital *Agriculture Current development in France*. Conference Big Data and sustainability – Food and agriculture – September 20-21, 2017, Copenhagen, Denmark
12. Casagrande, M., Joly, N., Jeuffroy, M.-H., Bouchard, C., et David, C. 2012. *Evidence for weed quantity as the major information gathered by organic farmers for weed management. Agronomy for sustainable development*, volume 32, n° 3. p. 715–726
13. Caroux, D., Dubois, M. J. F., & Sauvée, L. (2018). *Evolution agro-technique contemporaine II. Transformations de l'agro-machinisme: fonction, puissance, information, invention*. Ed. UTBM Belfort, 252p.

14. Carroll, J., Howard, S., Peck., J. and Murphy, J., 2003, *From adoption to use: the process of appropriating a mobile phone*, Australian Journal of Information Systems, 10:2, 38-38. http://dx.doi.org/10.3127/ajis.v10i2.151
15. Dantan J., Rizzo D., Fourati F., Dubois M., & Jaber M., 2018., *Farmer-Oriented Innovation: Outcomes from a First Bootcamp*, 3rd Abbé Grégoire Innovation Days International Conference. https://www.researchgate.net/publication/327269621_Farmers-oriented_innovation_outcomes_from_a_first_bootcamp
16. Dubois, M. J. F. & Sauvée L., 2016. *Evolution agro-technique contemporaine. Les transformations de la culture technique agricole*. Ed. UTBM Belfort, 235p.
17. Francis, C.A., Jordan, N., Porter, P., Breland, T.A., Lieblein, G., Salomonsson, L., Sriskandarajah, N., Wiedenhoeft, M., DeHaan, R., Braden, I., et Langer, V. 2011. *Innovative Education in Agroecology: Experiential Learning for a Sustainable Agriculture*. Critical Reviews in Plant Sciences, volume 30, n° 1-2. p. 226-237
18. Hostiou, N., Fagon, J., Chauvat, S., Turlot, A., Kling-Eveillard F., Boivin, X., Allain, C., 2017, *Impact of precision livestock farming on work and human animal interactions on dairy farms*. A review, Biotechnol. Agron. Soc. Environ, 21(4): 268-275. <hal-01563608>
19. Janssen S. J. C., Porter C. H., Moore A. D., Athanasiadis I. N., Foster I., Jones J.W., M. Antle J. M., 2017, *Towards a new generation of agricultural system data, models and knowledge products: Information and communication technology*, *Agricultural Systems*, 155: 200–212. https://doi.org/10.1016/j.agsy.2016.09.017
20. Kernecker, M., Knierim, A., Wurbs, A. (2016). *Report on farmer's needs, innovative ideas and interests*. Deliverable 2.2. Smart-AKIS https://www.smart-akis.com/wp-content/uploads/2017/02/D2.2.-Report-on-farmers-needs.pdf
21. Knight, J., Weir, S., Woldehanna, T. (2003) *The role of education in facilitating risk-taking and innovation in agriculture*, The Journal of Development Studies, 39:6, 1-22, DOI: 10.1080/00220380312331293567
22. Kolb, D.A. 2014. *Experiential Learning: Experience as the Source of Learning and Developmen*t. FT Press, 417 p. ISBN 978-0-13-389250-5.
23. Kritikos, M., 2017, *Precision agriculture in Europe. Legal, social and ethical considerations*. Report No.: PE 603.207. European Parliamentary Research Service. doi:10.2861/278
24. Le Méhaute, A., Raynal, S., Chédru, M., et Pormente, S. 2007. *L'acteur du projet « pour une économie de la connaissance »:* La Revue des Sciences de Gestion, volume 226-227, n° 4. p. 65-75
25. Lima, R.M., Andersson, P.H., Saalman, E.2017. *Active Learning in Engineering Education: a (re)introduction*. European Journal of Engineering Education, volume 42, n° 1. p. 1-4
26. Moreiro, L., 2016, *L'appropriation d'une technologie peut-elle entraîner le développement d'une compétence distribuée entre l'homme et la technologie ? Le cas de la viticulture de précisio*n. Thèse soutenue à l'Université Paris Sud. DOI: 10.3917/vse.202.0071
27. Mulder, M. 2018. *New investment in international vocational education research by the German federal government.* The Journal of Agricultural Education and Extension, volume 24, n° 2. p. 115-119
28. Orlokowski, W.J., 2000, *Using technology and constituting structures: A practice lens for studying technology in organizations*, Organization science, 11(4): 404-428. https://doi.org/10.1287/orsc.11.4.404.14600
29. Phillips, T., Klerkx, L., and McEntee, M. 2018. *An Investigation of Social Media's Roles in Knowledge Exchange by Farmers*. In 13th European IFSA Symposium. 1 Juillet 2018, Chania, Crete, Greece. p. 20.
30. Rizzo D., Fourati F., Ceapraz L., Ostapchuk M., Randrianasolo H., Combaud A. Ritz S., Jaber M., Dubois M., 2018. *Identifying the stakeholders' interactions within an agricultural innovation system towards sustainability*, SISA International Workshop, 3rd Edition, Riga
31. Rogers, E.M., 1995, *Diffusion of Innovations*, The Free Press, 3rd Edition, New York.
32. Sewell, A.M., Hartnett, M.K., Gray, D.I., Blair, H.T., Kemp, P.D., Kenyon, P.R., Morris, S.T., et Wood, B.A. 2017. *Using educational theory and research to refine agricultural extension: affordances and barriers for farmers' learning and practice change*. The Journal of Agricultural Education and Extension, volume 23, n° 4. p. 313-333
33. Sivertsson, O., & Tell, J., 2015, *Barriers to Business Model innovation in Swedish agriculture*, Sustainability, 7(2), 1957–1969. doi:10.3390u7021957.
34. Tey Y. & Brindal M. (2012). *Factors influencing the adoption of precision agricultural technologies: A review for policy implications*. Precision Agriculture. 13. 10.1007/s11119-012-9273-6.
35. Wolfert S., Ge L., Verdouw C., Marc-Jeroen Bogaardt M.-J., 2017, *Big Data in Smart Farming* – A review, Agricultural systems. 153:69–80. https://doi.org/10.1016/j.agsy.2017.01.023
36. Zhang N., Wang M., Wang N., 2002. *Precision agriculture – a worldwide overview*, Computers and Electronics in Agriculture, 36 (2–3): 113-132. https://doi.org/10.1016/S0168-1699(02)00096-0