# Computational agroecology: should we bet the microfarm on it?

DAVID COLLIAUX, Sony CSL Paris
JONATHAN MINCHIN, Ecological Interaction
SEBASTIEN GOELZER, Vergers Urbains
PETER HANAPPE, Sony CSL Paris

Current imaginaries for the future of food production are often set on two opposite sides, either digital technologies enabling higher productivity at a large scale, or small-scale diversified farming that minimizes the use of digital technology. However, computational agroecology is starting to explore the space for digital technologies that are adapted to complex agroecosystems. In this paper, we define a specific scale (microfarms) and farming practice (the French Method) on which these tools can be developed and tested. We show how the age old French Method, with its set of constraints, leads to original technologies and we illustrate this with some of the tools we developed. We discuss in particular three aspects: Tools, Plants, and People where computation can interact with farming practices. We also discuss the consequences of introducing digital technologies in microfarms, including potentially harmful ones.

CCS Concepts: • **Human-centered computing** → **Human computer interaction (HCI)**.

Additional Key Words and Phrases: agriculture, robotics, design

**ACM Reference Format:**
David Colliaux, Jonathan Minchin, Sebastien Goelzer, and Peter Hanappe. 2022. Computational agroecology: should we bet the microfarm on it?. 1, 1 (May 2022), 9 pages. https://doi.org/XXXXXXX.XXXXXXX

## 1 INTRODUCTION

Our actions are guided by our imaginary. Today's ecological transition is calling for a new imaginary that is adapted to the challenges we are facing. Considering the future food system, several scenarii have been proposed and compared [Food et al. 2021; Thompson 2018], and those are often split around two positions: farming systems that heavily rely on digital technologies and systems that rely on low-tech tools.

This view has been challenged, for example in the LIMITS workshops [Hendry 2021], and computational agroecology has been proposed as a framework to develop digital tools for sustainable farming [Hanappe et al. 2016; Raghavan et al. 2016]. Sustainable production of food is easier to implement on small farms [De Schutter 2014] and it is thus interesting to develop an imaginary and computational tools specifically for the farmers working at this scale [1]. In this paper, we present the tools developed for microfarms that cultivate vegetables using the French Intensive Method [2].

After a description of the microfarm imaginary, we review the arguments against the use of computation in sustainable food production systems. We then claim that computational tools should be developed for microfarms and we illustrate this with some of our work organized around three poles: Tools, Plant, and People. An example of Tools is a robot, operating autonomously along a line of crops to remove weeds in a precise manner. The Plant example is a crop monitoring system which may be used for farm management. The People example is a knowledge base we want to build using french gardening manuals from the 19th century.

We hope some guidelines can be picked up from our experience for developing technologies for farmers at this microscale and that this work contributes to the debate on the role of technologies in developing a sustainable food system [3].

## 2 THE FRENCH METHOD IN THE 19TH AND 20TH CENTURIES

### 2.1 Paris: from the 19th Century to its recent re-introduction

The age-old techniques used in market gardening in Paris were first formalized in the 17th century in the writings of Royal Gardeners (Olivier de Serres and Jean-Baptiste de la Quintinie). Starting in the mid 1800s, many books and periodicals were published on the topic until the end of the second world war [Roy 1998]. From the 60s onwards, the method slowly disappeared in the Parisian region because of urban expansion and because market gardeners switched to tractor and irrigation-based farming on larger fields. However, around that same time, starting in the 60's until the 2000's, Alan Chadwick[Martin 2022] and John Jeavons [Jeavons 2001] experimented with the French Intensive Method to show that it could be very productive on small plots of land. The method was also later popularized among market gardeners to grow vegetables out of season, in particularl by Eliot Coleman [Coleman 2009].

In France, since 2010, we see renewal of market gardening [Morel and Léger 2016] and urban [Aubry and Daniel 2017] microfarms inspired by the methods of 19th century market gardeners from Paris and adapting their practices to include the knowledge from movements of the 20th century

[1] The scale at which a farm is called a microfarms depends greatly on the region, in a Parisian context we refer to farms that are less than 10,000m² (typically 1000m²).

[2] Some of this work was done in the European project ROMI: Robotics for microfarms.

[3] see the panel discussion "Sustainable Agriculture, reconnecting with nature and engineering a better future" @Maker Faire Rome 2021 https://www.youtube.com/watch?v=akaI1fyxsXQ.

Authors' addresses: David Colliaux, koddda@gmail.com, Sony CSL Paris; Jonathan Minchin, Ecological Interaction; Sebastien Goelzer, Vergers Urbains; Peter Hanappe, Sony CSL Paris.

2022. XXXX-XXXX/2022/5-ART $15.00
https://doi.org/XXXXXXX.XXXXXXX

for sustainable farming like agroecology [Wezel et al. 2009] and permaculture [Ferguson and Lovell 2014]. In parallel at the same period, urban and peri-urban agriculture projects flourished in the Paris Area.

### 2.2 Cultivation methods

The French Method can be summarized as "Cultivate the smallest garden, as well as possible". It has been popularized recently worldwide with books in English language [Coleman 2009; Fortier and Bilodeau 2014; Hervé-Gruyer and Hervé-Gruyer 2016] published on the topic. Cultivating in microfarms involves very technical skills and well-designed tools. For example, to produce out of season, Parisian market gardeners built the soil through an intensive use of horse manure and used innovations like glass jars to create a microclimate around plants. The Permaculture approach inspired farmers to work with Nature. However, the old manuals on the French Method mention that they consciously work against Nature by using elaborate techniques to grow vegetables out of season in order to produce throughout the year.

The crops are very diversified and are organized according to rotation plans to fit up to seven cultivation cycles in one year. Intercropping is further increasing the complexity of the planning by associating plants on a same culture bed. Although there are sometimes biological reasons (allopathy) for these associations, most are made based on the complementarity of the plant's architectures and growth dynamics, or simply to fill as much space as possible.

Because it is such a small surface, it is planted very densely and every unused space in the field is filled immediately. Microfarms require a lot of physical effort, for example manual weeding, and working in such densely packed crops demands a lot of precision that is hard to obtain with classical mechanical machines.

### 2.3 Socio-technical context of micro-farms

Rural and suburban microfarms that obtain their revenue solely from the sales of their produce rely on community supported agriculture schemes or sell to local restaurants. Other farms, especially in urban environments, have developed other activities (education, social integration...) as a complement to the sales or even as their main activity. Microfarms are thus multi-functional and are good places for social activities and technical experimentation.

Microfarms in rural areas may be reluctant to use mechanization in their first years of installation because it is a huge investment that would hinder their development. Lightweight mechanization only comes when the project is viable or it is used thanks to neighbors lending their equipment. In urban microfarms, on the contrary, projects include from the start a technological component to grow crops in interstitial spaces of the city, in line with the vision Kropotkin had of the Paris gardener [Kropotkin 1913] who defies the soil and "would grow the same crops on an asphalt pavement". This technological component is very strong in farming towers, for example, including all sorts of sensors, automation and control systems for the inputs (water, light, nutrients). On other spaces like rooftops, microfarms use low-tech instrumentation to grow food (drip irrigation, hydroponic towers, raised beds, ...).

Another interesting aspect of micro-farms, whether rural or urban, is that many of the people involved are not from the agricultural world, neither from family environment nor education. Many of them have a high level of education, sometimes coming from engineering or digital backgrounds.

## 3 IS COMPUTATION USEFUL FOR MICROFARMS?

Digital agriculture is full of promises that are yet to be fulfilled and it may currently be at the peak of its hype cycle. It aims to draw on sensors, robotics, imagery, and data mining to increase the profitability of farming [Sponchioni et al. 2019]. It is also assumed that it could make agriculture more sustainable, although this claim is yet to be demonstrated [Sacco et al. 2021]. For example, the environmental impact of an indoor vertical farm with LED grow lights is open for discussion [Streed et al. 2021].

Most of the digital systems for farming, unfolding the Agriculture 4.0 "revolution", are targeted at large scale farms. Some of these systems rely on heavy infrastructures, like satellites, for precise positioning of robots or tractors during their navigation or for the remote sensing of crops. This brings the cost of the digital tools out of the range for microfarms.

The digital agriculture developments are also designed for conventional farms that cultivate large monoculture fields. The agrosystem complexity of microfarms is much higher, which makes many of these tools irrelevant.

A major concern raised by critics is also that tools including a digital component, like robots, are difficult to apprehend and to build by farmers. This removes the possibility of farmers to engage in the creative process of building artifacts [Giotitsas 2019]. Moreover, the use of digital tools with an imposed framework may leave the farmer with a feeling of loss of control over her farm. A related issue is that when data is produced by those digital tools, it is not always clear how the data is shared and whether privacy is preserved.

A more general criticism is that digital agriculture is taking a solutionist approach that accumulates technological fixes whereas a radical change at the political level is needed to bring a long-term effective solution for the sustainable production of food.

Still, computation is useful to many domains in our daily life. Why would sustainable farming and microfarms be exempt from that? Computation can have an impact at a global scale and if digital technologies can help develop sustainable farming it may have a global impact. Therefore, we feel that it is worth studying the possibilities and limits of computational agroecology in the context of microfarms.

## 4 THE FRENCH METHOD IN THE 21ST CENTURY

Recent work at the Bec Hellouin farm [Guégan and Leger 2015] and by Carnavalet [de Carné-Carnavalet 2020] show that the method of the Parisian market-gardeners is as relevant today as it was a hundred years ago. Market gardeners in the past were quick to adopt available technologies to optimize their work. As they were close to cities, market-gardeners had easy access to various industries. One such example, given by Jean-Michel Roy, ethnographer specialized in the Parisian market farms, is the use of irrigation [4]. As the technology evolved, market farmers quickly evolved for pulling out water from a well with a bucket to horse-powered pumps, to electrical pumps.

So what are the technologies that we can offer today to microfarms? We propose the following:

- A light-weight autonomous electrical tractor/rover to assist with physical tasks such as weeding, planting out, or carrying loads.
- A crop monitoring system linked to a planning and modeling system to assist with the organization of the 700 sow-grow-harvest batches.
- A shared knowledge and data system to exchange the best practices and the collected statistics among cooperating market farmers.

It is well-known that market gardening is a physically challenging profession. 95% of the professional disorders in farming are musculoskeletal and have a high social and economic impact. Many young farmers entering the profession of organic farming quit after 5 years of intensive labor, because of exhaustion or muscular problems. Small-scale motorized tools seem more than justified to reduce the workload and many small farms happily use walk-behind motor tillers to prepare the culture beds or electric dumpers to transport compost or harvest. A number of these tasks can easily be linked to a planning system. For example, the French Method requires a steady flow of seedlings to assure the continuous occupation of all the space and to spread out the harvests over time. Preparing the sowing trays can be a relaxing activity but for those farmers that wish it, the activity can be left to an automatic sowing device that automatically plants the required number of seeds based on the calendar. Other operations can be automated, too, such as weeding. The rover can assist with planting out - a physically challenging task - by adapting the mechanism found in large planting equipment to the smaller rover. The farmer will still have to walk alongside the rover but avoids carrying seedlings and transplanting them on her knees.

Following the recommendations of Carnavalet, the 1000 $m^2$ farm can be organized into 48 permanent beds of 16 m long and 1.3 m wide [**??**] with passage ways of 30 cm, of which 10 to 20% is generally covered by polytunnels. Such a relatively small surface can easily be covered by a camera that moves over the field using a cable-system, a "cablebot", to collect daily images of the crops. Following the old practices, the annual planning is split into two parts: from August to December, and from January to July. The goal is to produce weekly baskets throughout the year. This involves weekly harvests, but also weekly sowing and transplanting. The planning of the varieties, their location, and their quantities quickly becomes complicated, hence the blackboards with the huge calendar and long task list found in most farms. The more the planting schedule is spread out, the more the harvests can be spread out over different baskets compositions. The expected germination and harvest dates are often based on the indications given by the seed producers. There is usually a large interval of times where these operations can be executed. And in some cases the dates and durations dont even match [5]. The provided dates cannot take into account the variations that exist between farms and even within the same farm (ex. the difference between being planted in the field or in the polytunnel). The crop monitoring can help collect growth statistics over time for a given farm, location, and variety to help improve the estimates of the harvest times. Light-weight plant growth modeling that uses temperature-hours and sun-hours as an input can improve the estimates. These can help the market farmer predict the basket compositions and avoid, for example, that all tomatoes are ready for harvest in August when all her customers are on holiday. The farmers of the old days had accumulated many years of experience with planting patterns that they fine-tuned from one year to the next. However, for market farmers that are starting today, such a help in planning may be a welcome support to get into the rhythm, or to adapt a given calendar to local conditions. The planning can be used to make non-trivial optimisation, such as trying to group all crops that will be harvested on a given date in the same bed.

There are many projects and ongoing discussions on sharing know-how and best practices between like-minded farmers. Sharing information seems obvious but the absence of an existing open system that is widely adopted is proof that building a convenient system is non-trivial. The sharing of YouTube videos is perhaps the most effective but has the shortcoming that information is hard to validate and aggregate into a more comprehensive knowledge database. Projects that use a more structured approach, using ontologies for example, often don't reach the required ease of use for farmers. It's very challenging to ask farmers to enter information or observations at the end of a long day of work. Accessing and entering information in the field is even more awkward with the sunlight making the screen unreadable and wet fingers making the touch interface unusable. The use of speech-to-text and natural language processing tools may help in accessing, structuring, and combining farming information.

## 5 COMPUTATION FOR MICROFARMS: EXAMPLE APPLICATIONS

What could be the role of computation for microfarms? And what specific aspects of the French Method should guide the

[4]Personnal communication

[5]For example, a variety that can be sowed in the nursery in February, that takes three months to harvest, but should be transplanted mid-May.

design of this computational system? We consider three poles around which computation can be organized: Tools, Plants, and People. For each of these poles, we present an example that we developed and present guidelines that could be drawn from our experience.

## 5.1 Tools

A first remark is that it is important that tools in which computations are embedded are well suited for microfarms and the sociotechnical context in which they are set. We will illustrate this with the ROMI rover for weeding.

*5.1.1 The ROMI Rover for precision weeding.* The ROMI rover [Colliaux and Hanappe 2017] is a lightweight robot whose primary task currently is the precision weeding of crops (both inter and intra-rows). A camera at the top of the robot takes a picture of the workspace underneath the rover and the imaging pipeline detects the cultivated plants. A robotic arm equipped with a rotating hoe will then scratch the surface of the soil that is not occupied by cultivated plants to prevent small weeds from taking root. The hardware components include Arduino microcontrollers, standard motor drivers, two wheelchair motors, an Open Hardware CNC machine [6] for the robotic arm. The frame can be welded or built using the principles of XYZ cargo bikes [7]. The robot was designed so that it is easy to build in a workshop with off-the-shelf components. The design and the software are shared in an Open Hardware and Open Source manner[8].

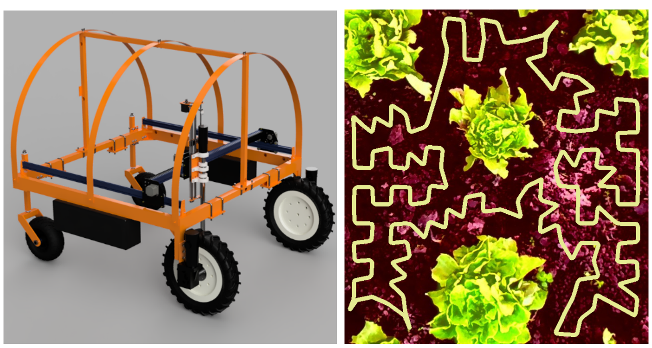

Fig. 1. (Left) The ROMI Rover for precision weeding. (Right) Sample path for the weeding tool covering the soil while avoiding salads.

In polytunnels, a simple classifier (like a support vector machine on RGB values) can be used to detect the plants but, in open fields, there are strong variations in luminosity (shades and overexposure) which is better managed using deep neural networks to distinguish between soil, weeds, and cultivated plants. The rover can thus be run on a light single board computer (like a Raspberry Pi) when operating in polytunnels but a computer with GPU is needed when used in open fields. The rover can navigate along a crop bed by following the row of plants using the top camera. The U-turn to switch between a culture bed and the next one still has to be performed by a human operator, for now.

The robot can be extended with a tool carrier so that it can pull various harrows commonly used by market gardeners. The frame width can be adapted to fit the size of the culture bed. During a workshop, the frame of the ROMI rover was repurposed to make a greens harvester [9]. Further extensions can be envisioned, making the rover a light-weight, versatile, autonomous, electrical tractor that is useful for both precise and physical tasks.

*5.1.2 Guidelines.* The design of tools embedding computation for microfarms should be flexible enough to take into account the specific layout of the farm. In particular, it should be adapted to dense and diverse crops planted in a precise manner. It should be lightweight to navigate in a crowded environment and to avoid soil compaction. It should be appropriate technology [Schumacher 1973] and adapted to the constraints of the microfarms. For example, it can be questioned whether using a satellite network to have a small machine navigate a 30m x 30m area is appropriate.

Many microfarms choose to use a minimum mechanization at the installation because it would weigh heavily on the finance so the technologies for microfarms have to be low-cost. One way to alleviate this problem is to share the machines among several farmers. The robot would then need to be able to adapt to each specific farm, which may have different culture bed widths for example.

Finally, it is important for the tools to not alienate the users. For this, we consider that it should be easy to repair, modify and extend. Those changes can be shared among the community of users through digital platforms in an open manner. The design may thus be shared globally, each machine being manufactured locally, in a manner adapted to the local needs.

The guidelines for the tools for microfarms to be adaptable, appropriate, accessible and open-source can be summarized by the term convivial technologies [Pantazis and Meyer 2020; Vetter 2018]. An example of such a tool, at a scale even smaller than the microfarm, is the Farmbot [10], where tools mounted on a large CNC machine are managing a culture bed in an automated fashion. Another example of a robot designed specifically for smallholder farms, is the Di-wheel [Sukkarieh 2017] for crop monitoring, which uses a smartphone as a sensor. There are also communities promoting the development of convivial tools like Atelier Paysan in France, Farmhacks in the USA and Tzoumakers in Greece for example.

## 5.2 Plants

The relation of computation to plants, through collected data and models, should be adapted to the small scale and diverse setting of the microfarms. We illustrate this with the Farmer's Dashboard for precise crop monitoring.

[6] https://www.inventables.com/technologies/x-carve
[7] http://www.xyzcargo.com
[8] https://docs.romi-project.eu/Rover
[9] https://github.com/romi/HarvesterOnWheels
[10] https://farm.bot

*5.2.1 The Farmer's Dashboard for farm management.* The Farmer's Dashboard is a crop monitoring and modeling tool to assist in the management of the farm. It was tested on a single culture bed equipped with a cable bot for image acquisition [Sollazzo et al. 2020]. The camera takes a sequence of images along the culture bed regularly (for example once a day). Images are then stitched together to form a map of the field and are then registered to be put in a common frame of reference. On each map, every plant is identified and plants are matched on pairs of successive images. The area occupied by each plant is measured (projected leaf area). The growth curve can thus be obtained for each individual plant and statistics aggregated for the population. Data can be visualized at the level of the farm, of the culture bed or of the individual plant.

In parallel to the development of the Farmer's Dashboard, a digital ledger was set up to allow farmers to report observations and view records whilst in the field. Various methods were explored over three years at the Valldaura Labs research facility and ROMI test site in Catalonia. Over eighty crops were grown annually through a six stage rotation system between thirty plant beds of 130cm width. Each bed was designed with principles of companion planting and intercropping to maximize space used on each plant bed and to provide an abundant range of diverse produce. The garden was created to provide a practical example of complex polyculture for research purposes, as well as supply the kitchens and local restaurant. In particular the management of this microfarm brought about two main challenges; firstly was the detailed planning and optimisation of plant layouts themselves, projecting this through the rotation system into the future. A second challenge was to accurately and rapidly communicate detailed location based information between distinct groups of practitioners over long planning periods.

In our organic model it would take upto five years to build up a rich soil base following the rotation system, more specifically this meant planting families of associated crops in a particular spot and in sequence. This would match the nutrient absorption rates of distinct crop groups to the nutrient availability of the soil, planting in this way would either feed the crops or use the crops to replenish soil nutrients. The rotation system was detailed for the location of individual plants rather than plant beds which is the norm. This associative and sequential complexity in plant layouts was compounded by differences in growth rates, exemplified by cabbages growing slowly and lettuces being fast to develop. This highlights the importance of transmitting location and time based information to and from farmers in the field.

The crop planning was initially drawn out and mapped using CAD software including Inkscape [11] and Rhino 3D [12]. This mapping and modeling is drawn in a digital sandbox that can be quickly edited and updated. The vector based drawing not only provides a digital overview, but it is a reference that farmers can zoom into for ever more detail without loss of quality. Some planting layouts could be made parametric in this way. ie. Customisable according to numerical inputs. This also afforded a great potential for generating planting layouts and for modeling an optimal use of space. This ultimately could be performed in conjunction with near real-time monitoring data provided by the cablebot, rover or aerial monitoring tools such as drones. The main objective is to explore methods to capture and transmit observational information coming from the farmers in the field and translate their tacit and situated knowledge into a digital medium. This can then contribute to relational databases containing the computational analysis of the Farmer's Dashboard, meaning that farmers field observations and digital monitoring of the same crops are compounded.

The gardeners at Valldaura were transient and in many cases would not meet each other from season to season. Facilitating 'knowledge transfer' between farmers was vital, in particular concerning planting tables and harvest schedules, task management and spatial distribution. The farm FarmOS application provided a simple way to designate and visualize data in geolocated areas. The plant layout sandbox sketches could be loaded and viewed here, and tasks assigned to a plot or person could also be linked to a calendar, with text notations or other visual references. The FarmOS API allowed us to contribute data gathered through mobile apps and online forms. Google forms were used to input planting, transplanting, harvest quantities and weights were noted alongside growth observations, anomalies and pest identifications. Other information about plants such as common predators or ailments were stored in spreadsheets and could be loaded into a plot areas by reading .csv files.

As previously mentioned farmers with wet and muddy hands find data input difficult, especially at the end of the day. Photographic observations commonly replaced text as they were easier and faster to produce and handle. Some researchers used their smartphones to contribute observations made through i-naturalist or Natusfera (local to Catalonia), both are species recognition apps. Communities of farm workers often make use of community chat groups using Telegram and Whatsapp. This provides them a direct communication and a historic record of tasks and notes. The Oxalis chatbot [13] was used to connect to the FarmOS database and deliver geo-referenced search results back into a Telegram chatgroup or conversely to upload notations and observations to the common databases. Meaning that the Telegram group was used to communicate and retrieve analytical, graphic, geo-referenced as well as tacit and situated knowledge to the group and provided a way of reporting, recording and synthesizing data derived from multiples of different sources.

The experience of both analogue and digital planning tools formed a basis to conceive of and propose computational applications. A knowledge base that combines and relates direct

[11] https://inkscape.org
[12] https://www.rhino3d.com/
[13] developed by Kevin Lim at Valldaura Labs

observations and experiential knowledge from communities of farmers in the field with statistical and analytical data born of computer vision has significance both for annotating and classifying machine learning data, and for producing in-situ prediction models, decision support systems over long time frames. One application may be to identify plant growth traits, assigning and communicating tasks in support of individual crops. Another may be to follow a 'farm to fork' strategy and optimize harvests and distribution operations by linking growers directly with market consumers by calculating custom and exact harvests of individual crops for bespoke and on-demand markets. Moreover, from the growth curves, we build phenomenological models for the dynamics of the crops [14] and this enables to compute and model optimal polycropping layouts in a dynamic context, based on long term strategies of plant associations, soil nutrient replenishment and plant growth characteristics. This will help farmers predict the harvest and to design and manage the farm by choosing the best plant association and crop rotations. Making that information readily available, editable and finally computable in the field is also an example of a convivial and appropriate technology.

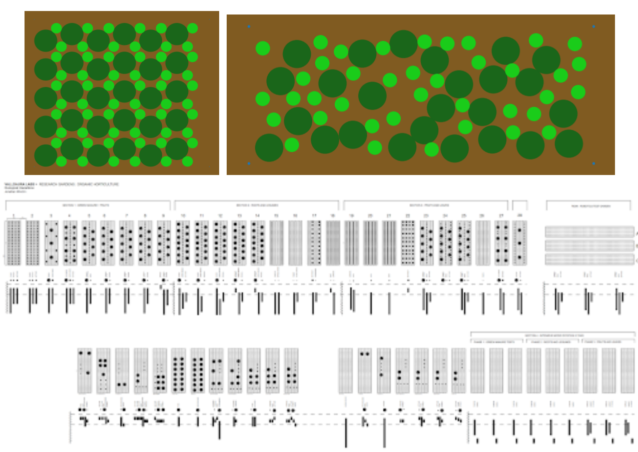

Fig. 2. (Top) Example planting patterns for intercropped lettuces and cabbages optimizing the occupation of space.(Bottom) Example of a CAD 'sketchpad' depicting cropping layouts, rotations with planting and harvest schedules.

*5.2.2 Guidelines.* On microfarms, it is possible to gather data with extreme details, up to the plant level, and the computer vision algorithms processing the images, for the segmentation of each plant for example, should be able to cope with multiple plant species cultivated together, as it is practiced in the French Method. A challenging task is to match the map of a culture bed from one time of acquisition to the next because the plants are changing in aspect or even the ground may be modified by external conditions (if it has been raining for example). To ease the registration of consecutive maps of the culture bed, we can use fiducial markers. Adding these markers would be difficult on a large scale farm whereas it is relatively easy to do on a microfarm. This is an example where working with a small scale setup is a strength.

The trend in digital agriculture is to acquire a lot of data, to upload it on a remote server where it will be processed and analyzed by specialists. In this case, it is not always clear to the farmer how the data will be used as the data is aggregated with data from other farms to feed models with long time scale of development[Duncan et al. 2021]. We think there is a clear interest in data aggregation from multiple farms and that farmers should be able to contribute to the construction of such models in an open science manner if they are willing to but we also think that it should be clear that the data can be kept on the farm with computations performed locally. It is thus interesting to find application cases where the data is directly useful to the farmer in the management of the farm without requiring the use of a cloud service.

A microfarm cultivating according to the French Method is a complex agroecosystem mixing many time scales and interactions among the plants. For the design of a farming system [Martin et al. 2013], it is possible to use an optimization framework in simple scenarii [Brulard et al. 2019], for example in microfarms we optimize space, but a simulation framework is more appropriate given the complexity of microfarms. Traditional modeling methods using detailed principles of the physiology of plants, as crop models used in agronomy, will be both hard to simulate and to analyze in this context. Innovative models, taking inspiration from complex systems, are thus needed to capture the dynamics or yields on the farm with as little parameters as possible. Apart from agronomy and ecology, models from remote disciplines, like finance or statistical physics, can bring new insights to the data [Paut et al. 2019]. It is important that these models include variability in external conditions (weather,...) and in the yields.

Although the development of crop monitoring technologies for plant phenotyping and modeling of complex agroecosystems is directly useful for breeders [Deery and Jones 2021] and agronomists, it has yet to be proven that those will bring value to farmers. Still experimentation is an intrinsic part of the farmer's activity [Hansson 2019] and there is interest in the agronomy community to have on-farms experiments [Lacoste et al. 2022]. Shall the tools based on data analysis be conceived with all farmers as potential users or shall we introduce a new profession, farmer-researcher, who would earn compensation for the time they spend doing task with no short-term profitability, like building models for example.

Also, farmers are already using farm management tools with a precise calendar for their crop rotations, for example in the form of spreadsheets. Should we integrate the acquired data and simulated models in those tools or would this make the tools too heavy to use on a daily basis? Or would it be that those tools are mostly useful in the settling of the microfarm while the farmer is learning how to manage the farm? The greatest benefits of those technologies will come

[14] a simulation of the model is available here https://github.com/SonyCSLParis/lettuces_and_cabbages

from sharing the data with other farmers and researchers but there may be a resistance from farmers to share this data as it is personal data. How much should we incentivize farmers to share their data?

## 5.3 People

The final aspect where digital tools could be useful is in making accessible the knowledge of farmers about cultivation in microfarms. There is a lack of scientific literature on market gardening so this knowledge is spread across various less formal sources (books, forums, videos, social networks,...) which make it difficult to navigate or compare the pieces of advice found there. The aim is thus to organize these documents and extract knowledge from them. It would also enable tracking changes in farming practices over time.

*5.3.1 Mining old manuals.* Because the French Intensive Farming method is historically grounded, we considered starting our analysis with French gardening manuals from the 19th century, often written by people who were market gardeners themselves. We decided to study more specifically the verbs appearing in these books since our focus is on farming practices.

We collected 7 books [15], dating from 1802 to 1881, and performed optical character recognition (OCR) on it. Due to the scanning conditions of the books, the result of OCR is not perfect and some words are transformed. To clean the dataset, we checked whether each word is in standard references for the French language (the corpus Frantext or the Wiktionary). When not present in these references, we looked for words within a small edit distance. Some of the words could not be recovered this way, this is for example, the case for the verb "contre-planter" (which means planting a crop in between the rows of another plant) which is crucial for the French Intensive Farming cultivation method.

After selecting the verbs, we counted their frequency of occurrence and we compared it to the frequency of occurrence in a standard corpus for the French language (Frantext). The most specific verbs of our corpus were then selected to draw the word cloud nas shown in Fig. 3. We could also draw a map of the verbs in the corpus using a Word2Vec embedding [Mikolov et al. 2013] and localize the part of the map specific to market gardening.

The texts all show similar structure in their content. For example, it almost always includes a calendar section as well as a list of sections detailing for each crop its characteristics and the varieties, a very technical crop management sequence for cultivating this crop and other aspects, like the soil and weather suitable for this crop. Furthermore, it is fascinating to see how these manuals contain scientific knowledge which could be tested experimentally. For example in one manual, it is claimed that pouring cold water when the weather is hot on salad, late in their growth, will result in mottling at the heart

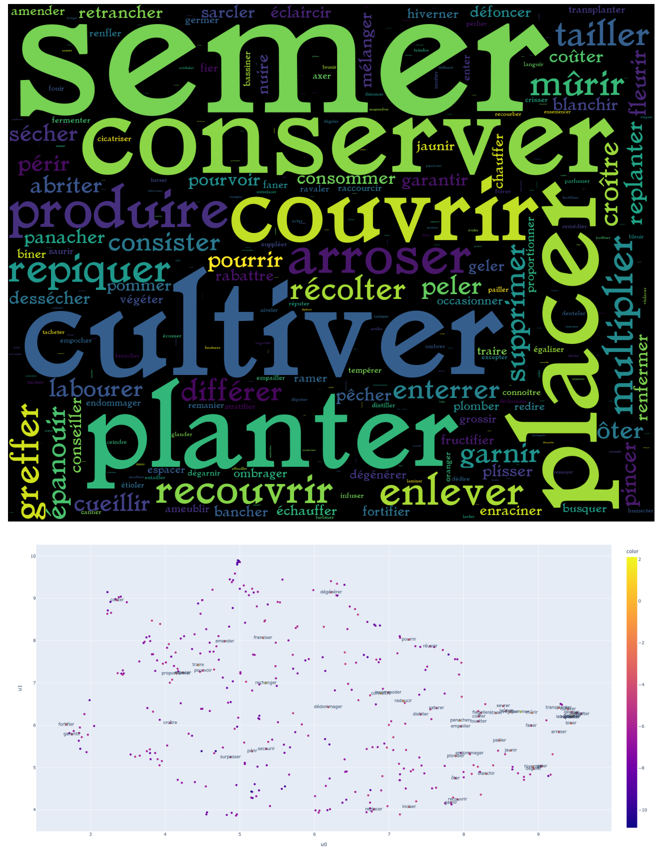


Fig. 3. (Top) 300 most specific verbs in the 19th c. manuals with the size denoting their frequency of occurrence. (Bottom) Projection of the embeddings of the verbs representations. Only verbs with the highest specificity are written, showing that the right part of the map is mostly specific to market gardening.

of the salad. Many of these elements of scientific knowledge may be extracted automatically by detecting patterns related to causation.

*5.3.2 Guidelines.* A first observation is that the commonly used ontologies for agriculture (like AGROVOC [Caracciolo et al. 2013]) may not be suited for the diversified crops found in microfarms. Specific ontologies, on top of which we can build knowledge graphs, adapted to complex crop management sequences should be developed according to the FAIR [16] principles [Darnala et al. 2021]. Another thing to take into account is that farming practices are as much concerned with know-how than with knowledge, which makes the encoding in language or knowledge graph more difficult. A possible way around this would be to generate drawings or animations illustrating the textual descriptions for sequences of instructions. It is important that old and newly produced knowledge

[15] Those books (retrieved from Google Books or from the Gallica website) and the results of the analysis can be found here: https://github.com/SonyCSLParis/good_old_gardening_manuals

[16] Findable, Accessible, Interoperable and Reusable

can be easily shared online. Social platforms should thus integrate elements for the representation of farming practices like calendar describing the crop rotations and maps describing the spatial configurations of crops [Norton et al. 2019]. The knowledge gained from these platforms should open the possibility for open science [Calvet-Mir et al. 2018].

## 6 PERSPECTIVE AND CONCLUSION

In all aspects we explored, Tools, Plants and People, community is crucial for computation in microfarms. The community enables support for the cost of technological equipment. It brings more data about the plants for building better models. And finally, it enables discussions and sharing of knowledge about farming practices. The ideal configuration for microfarms would be to have a group of such farms gathered together in a similar fashion to the 'lotissements' [17] of market gardeners as found in the Paris area in the 19th century. It would also help on another aspect we didn't discuss fully here which is the supply and distribution circuit to reach customers.

Whether it is to relieve from physically demanding tasks or to help in the design and management of the farm, there is a risk for digital tools to alienate the farmer. She would loose her sense of autonomy and agency if automation goes too far for her. This can happen when there is a lock-in system where committing to using one tool forces you to use a whole series of other tools. The same problem appears about data ownership where data export to cloud services for later use in decision support systems may result in the feeling of not owning the data and not being in control of the farm. Then, the digital tools should be flexible enough to let the farmer choose the level of automation and the data sharing policy according to her preferences.

Because we believe farming practices are deeply rooted in their geographical context, we focused here on the Paris region. Still, we are aware that other contexts in the world have farming methods specifically adapted to microfarms, for example in China [Chan and Gill 1977]. We are focused here on market gardening in Paris but urban agriculture has in many other cities, like New-York example. We are interested in how digital technologies inspired by the French method would be adapted or whether new suggestions would be inspired by these different contexts.

We showed that microfarms cultivating vegetables using the French Intensive Farming method is a powerful imaginary to develop computation in agriculture combining high levels of agrosystem complexity and labor automation. Today's vertical and smart farms found in cities can echo the technical innovations about market gardening in Paris 19th century although we doubt that this is a path towards a sustainable food system. We rather described how computation can be brought to microfarms in polyculture needing very precise and complex crop management. We showed how we built robots for precise weeding, developed crop monitoring and modeling tools for helping in farm design and management and analyzed old gardening manuals for organizing knowledge about farming practices. The experience during these projects showed us how many opportunities of application may open by scaling the field down. We propose as a target for computational agroecology to make farming on small surfaces viable, fostering the settlement of farmers in urban or peri-urban environment while reducing the reliance of agriculture on petroleum-based inputs.

[17]French word meaning parceling.

## 7 ACKNOWLEDGMENTS

The work presented here was done in part in the projects ROMI and CENTRINNO. These project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreements No 773875 and 869595. D.C. thanks Martina Galetti and Aliénor Lahlou for their comments after reading the first version draft.

## REFERENCES

Christine Aubry and Anne-Cécile Daniel. 2017. Innovative commercial urban agriculture in the Paris metropolitan area. In *Toward Sustainable Relations Between Agriculture and the City*. Springer, 147–162.

Nicolas Brulard, Van-Dat Cung, Nicolas Catusse, and Cyril Dutrieux. 2019. An integrated sizing and planning problem in designing diverse vegetable farming systems. *International Journal of Production Research* 57, 4 (2019), 1018–1036.

Laura Calvet-Mir, Petra Benyei, Laura Aceituno-Mata, Manuel Pardo-de Santayana, Daniel López-García, María Carrascosa-García, Antonio Perdomo-Molina, and Victoria Reyes-García. 2018. The contribution of traditional agroecological knowledge as a digital commons to agroecological transitions: The case of the CONECT-e platform. *Sustainability* 10, 9 (2018), 3214.

Caterina Caracciolo, Armando Stellato, Ahsan Morshed, Gudrun Johannsen, Sachit Rajbhandari, Yves Jaques, and Johannes Keizer. 2013. The AGROVOC linked dataset. *Semantic Web* 4, 3 (2013), 341–348.

Peter Chan and Spencer Gill. 1977. *Better Vegetable Gardens the Chinese Way: Peter Chan's Raised-bed System.* Graphic Arts Center Publishing Company.

Eliot Coleman. 2009. *The winter harvest handbook: Year-round vegetable production using deep-organic techniques and unheated greenhouses.* Chelsea Green Publishing.

David Colliaux and Peter Hanappe. 2017. LettuceThink: A open and versatile robotic platform for weeding and crop monitoring on microfarms. In *2017 EFITA WCCA CONGRESS*. 171.

Baptiste Darnala, Florence Amardeilh, Catherine Roussey, and Clement Jonquet. 2021. Crop Planning and Production Process Ontology (C3PO), a new model to assist diversified crop production. In *Integrated Food Ontology Workshop (IFOW'21) at the 12th International Conference on Biomedical Ontologies (ICBO).*

C. de Carné-Carnavalet. 2020. *Le maraîchage sur petite surface: La French Method : une agriculture urbaine ou périurbaine.* Editions de Terran. https://books.google.fr/books?id=ph31zQEACAAJ

Olivier De Schutter. 2014. UN Special Rapporteur on the right to food. *Report on agroecology and the right to food* (2014).

David M Deery and Hamlyn G Jones. 2021. Field phenomics: will it enable crop improvement? *Plant Phenomics* 2021 (2021).

Emily Duncan, Alesandros Glaros, Dennis Z Ross, and Eric Nost. 2021. New but for whom? Discourses of innovation in precision agriculture. *Agriculture and Human Values* 38, 4 (2021), 1181–1199.

Rafter Sass Ferguson and Sarah Taylor Lovell. 2014. Permaculture for agroecology: design, movement, practice, and worldview. A review. *Agronomy for sustainable development* 34, 2 (2014), 251–274.

IPES Food et al. 2021. A long food movement: transforming food systems by 2045. https://www.ipes-food.org/_img/upload/files/LFMExecSummaryEN.pdf

Jean-Martin Fortier and Marie Bilodeau. 2014. *The market gardener: a successful grower's handbook for small-scale organic farming.*

New Society Publishers.
Chris Giotitsas. 2019. *Open source agriculture: Grassroots technology in the digital era*. Springer.
Sacha Guégan and Francois Leger. 2015. *Maraîchage biologique permaculturel et performance économique*. Technical Report. INRA. 67 p. pages. https://hal.archives-ouvertes.fr/hal-01548676
Peter Hanappe, Rob Dunlop, Annemie Maes, Luc Steels, and Nicolas Duval. 2016. Agroecology: a fertile field for human computation. *Human Computation* 3, 1 (2016), 225–233.
Sven Ove Hansson. 2019. Farmers' experiments and scientific methodology. *European Journal for Philosophy of Science* 9, 3 (2019), 1–23.
David Hendry. 2021. Transition Discourse, Food, and Computing within Limits. *LIMITS Workshop on Computing within Limits* (06 2021). https://doi.org/10.21428/bf6fb269.244d268b
Perrine Hervé-Gruyer and Charles Hervé-Gruyer. 2016. *Miraculous abundance: One quarter acre, two French farmers, and enough food to feed the world*. Chelsea Green Publishing.
John C Jeavons. 2001. Biointensive sustainable mini-farming: II. Perspective, principles, techniques and history. *Journal of Sustainable Agriculture* 19, 2 (2001), 65–76.
Petr Alekseevich Kropotkin. 1913. *Fields, Factories and Workshops: Or, Industry Combined with Agriculture and Brain Work with Manual Work*. GP Putnam's Sons.
Myrtille Lacoste, Simon Cook, Matthew McNee, Danielle Gale, Julie Ingram, Véronique Bellon-Maurel, Tom MacMillan, Roger Sylvester-Bradley, Daniel Kindred, Rob Bramley, et al. 2022. On-Farm Experimentation to transform global agriculture. *Nature Food* 3, 1 (2022), 11–18.
Guillaume Martin, Roger Martin-Clouaire, and Michel Duru. 2013. Farming system design to feed the changing world. A review. *Agronomy for Sustainable Development* 33, 1 (2013), 131–149.
Orin Martin. accessed on the 09/01/2022. French Intensive Gardening: A Retrospective. https://agroecology.ucsc.edu/documents/for-the-gardener/French_Intensive.pdf
Tomas Mikolov, Ilya Sutskever, Kai Chen, Greg S Corrado, and Jeff Dean. 2013. Distributed representations of words and phrases and their compositionality. *Advances in neural information processing systems* 26 (2013).
Kevin Morel and François Léger. 2016. A conceptual framework for alternative farmers' strategic choices: the case of French organic market gardening microfarms. *Agroecology and Sustainable Food Systems* 40, 5 (2016), 466–492.
Juliet Norton, Birgit Penzenstadler, Samantha McDonald, Emily Kang, Nora Koirala, Rieko Konishi, Gabriela Pena Carmona, Jainee Shah, Sebastian Troncoso, and Bill Tomlinson. 2019. The SAGE Community Coordinator: A Demonstration. In *Proceedings of the Fifth Workshop on Computing within Limits*. 1–10.
Alekos Alexandros Pantazis and Morgan Meyer. 2020. Tools from below: Making agricultural machines convivial. *Επιθεώρηση Κοινωνικών Ερευνών* 155 (2020), 39–58.
Raphaël Paut, Rodolphe Sabatier, and Marc Tchamitchian. 2019. Reducing risk through crop diversification: An application of portfolio theory to diversified horticultural systems. *Agricultural systems* 168 (2019), 123–130.
Barath Raghavan, Bonnie Nardi, Sarah T Lovell, Juliet Norton, Bill Tomlinson, and Donald J Patterson. 2016. Computational agroecology: Sustainable food ecosystem design. In *Proceedings of the 2016 CHI Conference Extended Abstracts on Human Factors in Computing Systems*. 423–435.
Jean-Michel Roy. 1998. Les marchés alimentaires parisiens et l'espace urbain du XVIIe au XIXe siècle. *Histoire, économie et société* (1998), 693–710.
Pasqualina Sacco, Elena Rangoni Gargano, Alessia Cornella, Davide Don, and Fabrizio Mazzetto. 2021. Digital sustainability in smart agriculture. In *2021 IEEE International Workshop on Metrology for Agriculture and Forestry (MetroAgriFor)*. IEEE, 471–475.
E. F. Schumacher. 1973. *Small Is Beautiful: A Study of Economics As If People Mattered*. Blond Briggs.
Aldo Sollazzo, David Colliaux, Soroush Garivani, Jonathan Minchin, Lisa Garlanda, and Peter Hanappe. 2020. Automated vegetable growth analysis from outdoor images acquired with a cablebot.. In *Proceedings of the IEEE International Conference on Computer Vision Workshops*.
G Sponchioni, M Vezzoni, A Bacchetti, M Pavesi, and FM Renga. 2019. The 4.0 revolution in agriculture: A multi-perspective definition. In *Summer School F. Turco-Industrial Systems Engineering*. 143–149.
Adam Streed, Michael Kantar, Bill Tomlinson, and Barath Raghavan. 2021. How Sustainable is the Smart Farm? *LIMITS Workshop on Computing within Limits* (06 2021). https://doi.org/10.21428/bf6fb269.f2d0adaf
Salah Sukkarieh. 2017. Mobile on-farm digital technology for smallholder farmers. In *Proceedings of the Crawford Fund 2017 Annual Conference*.
Paul B Thompson. 2018. Four sociotechnical imaginaries for future food systems. In *Professionals in food chains*. Wageningen Academic Publishers, 189–211.
Andrea Vetter. 2018. The matrix of convivial technology–assessing technologies for degrowth. *Journal of Cleaner Production* 197 (2018), 1778–1786.
Alexander Wezel, Stéphane Bellon, Thierry Doré, Charles Francis, Dominique Vallod, and Christophe David. 2009. Agroecology as a science, a movement and a practice. A review. *Agronomy for sustainable development* 29, 4 (2009), 503–515.