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Enhancing NY State on-farm experimentation with digital agronomy

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Abstract.

Agriculture is putting pressure on the ecosystems and practices need to evolve towards a more sustainable way of producing food. Farmers are doing this by conducting on-farm experimentation with their own objectives and with experimental designs at the scale of production. A survey conducted in Australia found that 90% of farmers are engaged in on-farm experimentation. Scientists have not been involved in this farmer-centric process, and this is changing with the advent of digital agronomy. Indeed, the digital agronomy toolbox offers possibilities to enhance the farmer-centric on-farm experimentation process by three main components: (1) collecting contextualization data on top of experimental data, (2) pooling data from multiple farms conducting similar experimentation, and (3) analyzing that data with machine learning. Using the digital agronomy toolbox requires specialist skills that scientists have, which opens the door for a co-creation process that will accelerate the pace towards sustainable production. This project consists in conducting interviews among NY State farmers in order to better understand their endogenous experimentation process. The interviews conducted over 10 field crops farmers provided insights on how farmers conduct their experiment to progress in their crop management practices. More specifically, it was possible to better understand how farmers benefit from the outcomes of their experiment for decision making without necessarily having to record, organize and analyze data. It seems like this remains a slow process, possibly related to the limited use of contextualization data that would allow a better understanding even when results of experimentation are not clear. Yet, farmers are careful in laying down their experiments, accounting for soil variability when the information is available for instance. Overall, interviews have allowed to verify that a large majority of farmers conduct on-farm experimentation and that there is potential for improvement using digital agronomy. Further research will be needed to provide a quantitative assessment of the current state of on-farm experimentation in NY State and to clearly identify where and how digital agronomy can be employed to enhance this process and accelerate the transition towards sustainable crop production.

Keywords.
on-farm experimentation, digital agronomy, semi-structured interviews, farm digitalization

Introduction

Agriculture is a key sector in which to address great planetary challenges such as climate change, large-scale nitrogen- and phosphorus-induced environmental change, and accelerating biodiversity loss (Rockström 2009). The complexity of these challenges, and their potential solutions, mandates novel and multidisciplinary efforts (Chaplot 2021). Moreover, the rapid evolution of environmental degradation and rate of technological advances require a continuous learning process in order to provide adapted, efficient, and timely solutions. Farmers and agriculture stakeholders are at the forefront of solution implementation because they live the consequences of each decision made on their farm. Solving these pressing environmental issues is a high stakes game and requires bold, new approaches that include the farmers.

Farmers conduct on-farm experimentation and the value of this research and development effort is estimated to about 20B USD (MacMillan and Benton 2014). Despite such an important investment, this R&D effort does not contribute to common scientific knowledge such as is the case for governmental and private research. Moreover, this R&D is de-centralized and tackles practical questions that are dear enough to farmers that they invest their own money to conduct it. With digital technologies, we can now consider integrating this effort into the scientific knowledge, and this may accelerate the transition towards a sustainable food production system.

In an effort to make evidence-based management decisions, farmers currently use science-based information derived from generic small plot experiments as well as farm-specific field scale experiments. While the science-based data provides thorough understanding of the phenomenon at stakes, it does not embrace the scale of agroecological variability existing on farms, which often surpasses the treatment effect (Laurent et al. 2019). In counterpart, field scale experimentation often lacks replication and context documentation and may be difficult to interpret unless compared treatments yield drastically different outcomes. In both cases, the consequence is a slow process for adopting new cropping practices and an inefficacy for adapting to ever changing conditions. As (Hagmann et al. 1997) put it:

> "*The existing paths for information coming from research centers via extensionists to farmers (and, ideally, back to the scientists again) are too slow, and farmers' priorities get lost along the way*."

With rapidly changing climate conditions, it is imperative to find new ways to enhance the efforts of farmers' practices to adapt and mitigate climate change in order to maintain food security (Whitfield et al. 2018). The advent and democratization of digital agronomy opens new perspectives for decentralized research working together with conventional research to accelerate innovation and slow the pace of environmental degradation associated to food production. With the complexification of agriculture and on-farm experimentation comes the complexification of the skill set required. A transdisciplinary approach to agricultural research involving farmers, experts, and students has the potential to unlock new possibilities, help embrace complexity existing in the field, and form the next generation of workers that will have to deal with change (Francis et al. 2008).

Farmer-centric on-farm experimentation (OFE) is a process enhanced by digital agronomy and enabled by experts to help farmers achieve their objectives of sustainable crop production faster (Lacoste et al. 2022). Tapping into this wealth of de-centralized research can accelerate the way we learn about agriculture and help overcome major challenges related to food production (MacMillan 2018; MacMillan and Benton 2014). It can also accelerate impacts on the ground by fast-tracking technology transfer, extension, and vulgarization activities because the user is involved in the creation process. Several examples of farmer-centric OFE enhanced by digital technologies exist around the world (Lacoste et al. 2022), and there is an opportunity to integrate this new approach into the national system of land-grant colleges and universities so that it benefits farmers, students, researchers, and society as a whole. Learning how to bridge science-led (i.e., conventional research) and farmer-led (i.e., endogenous experimentation) experimentation is key to scale up farmer-centric OFE enhanced by digital technology and developing the science of OFE is yet to be done.

Farmer-centric OFE enhanced by digital agronomy is a fairly new approach and the first scientific conference on this topic took place in Montpellier in October 2021 (OFE2021). An international group of pioneers have published the first manifesto on this topic in January 2022 and have outlined the necessity for a paradigm shift and explained certain core principles of OFE, notably that it is (1) farmer-centric, (2) implemented in real systems, (3) evidence-driven, (4) specialist-enabled, (5) based on co-learning, and (6) scalable (Lacoste et al. 2022). The objective behind OFE is to bring farmers, scientists, and other stakeholders together around a mutually beneficial experimentation process that supports the farmers in their management decisions(Lacoste et al. 2022). The conventional scientific experimental method pioneered by Fisher in the 1920’s is well suited for analyzing the observations from small plot experiments and to establish causality(Fisher 1926, 1936). Likewise, the endogenous experimental process of farmers has allowed agriculture to evolve over thousands of years and has led to the agriculture that we know today (Röling and Wagemakers 1998). Until now, these distinct experimental processes have operated separately with the scientific experimentation method generating generic knowledge that is independent of local conditions and the endogenous experimental process adapting generic agronomic knowledge to their local conditions and testing new ideas by trial and error (MacMillan and Benton 2014). Both processes are rather slow with the scientific experimental method requiring replication over several seasons for a result that may or may not be positive and that requires local adaptation. Similarly, the endogenous experimentation method often wastes time with experimentation that produce unclear results that are hard to interpret because of the lack of context documentation and thus needs to be abandoned or repeated. Meanwhile, the emergency of unprecedented environmental degradation and a rapidly changing climate require new ways of conducting agricultural research in order to generate impact on the ground faster than the existing slow processes (Herrero et al. 2020). The solution may reside in inventing a hybrid research methodology that would enhance the endogenous learning processes with digital agronomy enabling observational research by providing ample data for contextualization of observations. This requires farmers’ current experimental process to be complemented by new metrics and by adapted experimental design, and for academic agriculture research to engage in observational research (Hansson 2019).

Scientists around the world are developing the science behind field-scale experimentation methodology and statistics enable the merging of endogenous experimentation and science. A team of agronomists and statisticians at Cornell University has developed a methodology based on a single-strip trial to enable evidence-based decision making that acknowledges the farm reality (Cho et al. 2021). Similarly, the group ADAS in the UK has coined the term “Agronōmics” to describe the wealth of data that can be collected and used for contextualizing observational data and for conducting robust statistical analysis (Kindred et al. 2016; Sylvester-Bradley et al. 2017). On other fronts, social scientists are studying how farmers are benefiting from and engaging in OFE (Cook et al. 2018; Reed et al. 2016).

The overall objective of this project consists in generating a base of information about the current state of OFE and communicating to farmers the potential benefits and the principles behind farmer-centric OFE enhanced by digital agronomy. The specific objectives are (1) to recruit field crop producers of NY State to discuss on-farm experimentation during an interview, and (2) to assess the state of OFE by conducting semi-structured interviews among field crop producer of NY State.

Materials and Methods

Recruiting farmers

This step will be done by working with Cornell Cooperative Extension Specialists for field crops production. This involves reaching out to farmers directly, explaining the concept of on-farm experimentation briefly, and asking for their participation and availability. The concept of on-farm experimentation was explained as follows:

> "*Farmer-centric on-farm experimentation refers to all experimentation mainly planned and funded by the farmer at the scale of decision making to support their own data-driven management decisions. It is different from "industry-initiated" and "researcher-initiated" experimentation which are planned by the industry and researchers respectively and conducted on farmers' fields with their assistance for crop management and data collection*."

Three Cornell Cooperative Extension Specialists from three field crop production regions of NY were involved. The first region comprised Wayne, Ontario, and Seneca counties which are part of both Central NY and Finger Lakes regions, and where large non-dairy grain production are located. The second region was the Mohawk Valley comprised of Ostego and Scholarie Counties located south of the Adirondacks. This region is hilly and intersected with woodland and contains smaller farms that often conduct dairy and forage production. The third region is the North Country within which is located the Jefferson County. This region contains some of the largest dairy concentrated animal feeding operations (CAFO) farms of the state and most large farms tend to have enough land to supply feed and spread the manure generated by their herd. These regions thus contain an array of different field crop production farms within NY State. In addition to this range of operations, farmers were contacted based on their level of "digitalization" (i.e., their familiarity with digital technologies and data collection, organization and use). This allowed for the evaluation of the range existing in the capacity of farmers to collect, organize, and use their farm data.

Conducting Semi-Structured Interviews for Needfinding

Needfinding is the process of studying people to identify needs with the objective of developing a product or service that will best meet those needs (Blindheim et al. 2016). One component of needfinding involves conducting semi-structured interviews. Semi-structured interviews often consist of preparing open-ended questions and follow up with specific questions exploring further certain aspects of the interviewee's response that is deemed interesting or important (Adams 2015). This process thus contains initial questions; however, it is impossible for the interviewer to formulate all the questions ahead of time because these will be formulated during the interview based on the interviewee's response. The format of the interviews included an opening that explains the objective of the information-gathering, a set of questions about on-farm experimentation, and a set of background questions on the farmer and the farm.

Below is the interview protocol containing the initial questions asked to the farmer in the semi-structured interview process.

> *Opening*
>
> "Thanks for agreeing to do this interview. I want to go with you over our informed consent so that you understand how we will use information from this interview and what your rights are. [Go over informed consent form, gain written or verbal consent as required.] Great! Now I want to start by explaining what I mean when I say farmer-centric on-farm experimentation because it can mean different things to different people. In this study, we say that:
>
> Farmer-centric on-farm experimentation refers to all experimentation mainly planned and funded by the farmer at the scale of decision making to support their own data-driven management decisions. It is different from "industry-initiated" and

"researcher-initiated" experimentation which are planned by the industry and researchers respectively and conducted on farmers' fields with their assistance for crop management and data collection.

Do you have any questions about that definition? [Answer if yes.] Now I'm going to ask a few questions about your experience with farmer-centric on-farm experimentation and then a few demographic questions about you and your farm."

Interview Questions for On-Farm Experimentation Study

Are you conducting experimentation on your farm?

If YES:

1. Who is or was the initiator of the experimentation?
   a. When you are the initiator, what are your motivations?
2. How much of your farm in terms of acreage is dedicated to on-farm experimentation?
   a. What percentage of your overall acreage is that?
3. What is the goal of your experimentation?
   a. What is the subject (nutrition, genetics, practices, novelties,...)?
   b. How do you determine the subject?
4. How do you determine if the experimentation is valuable?
   a. To what extent do you feel that you have been achieving this value?
      i. [if answer is low] To what extent do you feel you will achieve this value and how long will it be before you do?

What technology do you use in conducting your experimentation?

   a. For each technology mentioned:
      i. What is the purpose of the technology?
      ii. If it collects or analyzes data, what data does it work with?
      iii. How well does this technology help you achieve your goals?
      iv. In what ways might this technology be improved to help you achieve your goals?
   b. What technology, if any, has been a real game-changer for you in your experimentation?
      i. How so?

6. If your experimentation data was shared, would you want it to be anonymized? Why or why not?
7. Beyond what has been mentioned so far, what missing data could enhance the outcome of your experimentation?
   a. If you had access to the resources (time, equipment, input,...) what would you like to experiment with on your farm that you have not experimented with yet?

If NO:

1. Why are you not engaging in experimentation on your farm?
2. Have you tried on-farm experimentation in the past and abandoned it?
3. What would motivate you to engage or re-engage in on-farm experimentation?

Other questions:

1. When you have a question about your farming practices, where do you look for information? Blogs, YouTube, Google?
2. Do you consider farming as competitive or collaborative?

Questions about You and Your Farm

If you don't mind sharing, I would like to ask some questions now about you and your farm to help us understand, for example, if answers to our questions thus far might vary by farm size or other aspects.

1. What is your age?
   a. Sex?
   b. Race?
2. What is the portrait of your farm in terms of acreage and crops (what rotations on what acreage)?
3. What crops do you grow?
4. Do you have animal production?
5. How long have you been growing these crops on this farm?
6. How long have you been a farmer?
7. What is the biggest challenge you face in farming?
   a. To what extent and in what ways do you think on-farm experimentation might help you now or in the future with this challenge?

Based on the semi-structured interview format, all the questions above stand as a starting point for a conversation to learn more about on-farm experimentation and to find what the needs are to complement this process with digital agriculture technologies. Interview were audio recorded using a laptop computer connected to a Zoom (e.g., Zoom Video Communication, San Jose, CA) meeting with "*Recording*" activated. This was done to provide remote access of the conversation in real time to project members who were not attending the interview. Indeed, a group of only 2 to 3 team members met with the farmers during the interview to avoid overwhelming the interviewee. Recording the meeting with Zoom also allowed for automatic transcription of the interview. In addition, a Zoom H2N Handy Recorder (Zoom Corp, Hauppauge, NY) was used for high quality recording of the interview. This allowed for ensuring that no part of the conversation was lost due to the poor microphone of the laptop computer used during the interview or if the Zoom recording stopped inadvertently. In addition, pictures were taken throughout the interview when farmers were producing pieces of interest (e.g., paper notepad where crop management records are documented). Results of the interviews were interpreted in a qualitative way and will serve to inform a survey that will enable more quantitative results. Therefore, results presented here may be considered as anecdotal because they do not pretend to represent the population, but rather to provide a range of considerations for how on-farm experimentation takes place in NY State.

Results and Discussion

A set of ten interviews were conducted across NY State and on farms with different cropping systems and acreage (Table 1.). All interviews except for one were conducted in the farm's office with the farm owner. We observed low diversity in the interviewees, all of them being white males above 45 years old. In one farm the successor was the owner's daughter, and she was present and involved in the interview. This lack of diversity is consistent with the low diversity of field crops farmers in NY State (DiNapoli 2019). Three interviewees had a dairy operation on their farm, and all three were subject to Concentrated Animal Feeding Operation (CAFO) regulation due to their size. Only one farm was accredited by USDA Organic for organic production, and it was for forage crops dedicated to off-farm dairy production. All farms, but one, were growing maize as silage and/or grain. It was interesting to note that only 6 farms out of 10 had access to a yield monitoring system. Yield mapping is a significant enabler of on-farm experimentation. Other means can also provide accurate information on yield; for instance, Farm 3 did not have a yield monitoring system on their combine harvester but had a calibrated truck scale with which they were weighting and recording all harvested loads. Farms that had neither a yield mapping system or a truck scale were either consuming all their harvest on-site with their dairy operation and/or were measuring their yield in terms of units (e.g., number of bails) or volume (e.g., amount in the bunker). Interestingly, farm 10 was employing a service that used a drone to estimate the volume of silage in the bunkers. This has the advantage of providing accurate yield records at the farm scale, however, it may not be accurate enough to provide yield outcomes for on-farm experimentation. The original goal was to interview 15-20 field crop producers. However, due to COVID-19 incidences and severe weather events (i.e., a set of three interviews were cancelled due to a snowstorm), only 10 field crop producers were interviewed. Overall, the pool of interviewees, though smaller than originally planned, was representative of the diversity of field crop operations of NY State in terms of size and location.

Table 1. Descriptive information about the farming operation of the interviewees.

Farm ID	NY Region	Nb. Cows	Area (Ha)	Cropping System*	Organic	Yield mapping
1	Finger Lakes	0	970	M-S-W	No	Yes
2	Finger Lakes	0	1210	M-S-W	No	Yes
3	Finger Lakes	0	690	H-M-S-W	No	No
4	Mohawk Valley	0	180	H-A	Yes	No
5	Mohawk Valley	225	240	M-A	No	No
6	Mohawk Valley	0	200	M-S	No	Yes
7	Central NY	0	1010	M-S-W	No	Yes
8	Central NY	0	690	M-S-W	No	Yes
9	North Country	1000	610	M-A	No	Yes
10	North Country	1000	810	M-A-H	No	No

*M: Maize; S: Soybean; W: Wheat, H: Hay, A: Alfalfa

Interpreting the responses from the interviewees

As mentioned above, the results of the interviews were obtained in a qualitative way. In a further analysis of the interview records, the project team will code and label the interview transcripts and then categorize the different labels to generate a more systematic and objective set of results. The interviews for the current publication were conducted in February and March 2022 and the transcripts are being labelled right now. Here, the results will be presented by lifting meaningful quotes from the transcripts and discussing the implications of each statement.

Quote 1	Q: "*Are you conducting experimentation on your farm?*" A: "*Oh yeah!*"

First and foremost, one major finding from the interview process is that **all interviewees mentioned that they were conducting on-farm experimentation for which they were the initiators** (Quote 1). This is major as it confirms that on-farm experimentation is an important process for NY State farmers to run their business successfully. This is consistent with a survey conducted in the Western Australia wheatbelt about on-farm experimentation, that found a large majority (>90%) of participants having conducted on-farm experimentation (personal communication, Lacoste & Cook 2019, unpublished results). It is fair to assume that most farmers in NY State conduct on-farm experimentation and is thus relevant to engage in learning more about this process in order to identify pains and gains related to on-farm experimentation. There are three aspects that will be discussed below, notably the data aspects, the time aspects, and the experimentation process.

The data aspects of OFE

Quote 2	"*we've always done a lot of different things in for experimenting somethings* […] *most of it hasn't been recorded per se*"
Quote 3	*"It is difficult for us to work with data and would prefer someone else doing the more complex data analysis."*
Quote 4	"*Last year we sprayed half of the soybean with fungicide from a crop duster and you can tell just by the color codes that the field did a little better.*"
Quote 5	*"We run side-by-side experiments and compare total yield using data coming out of the weight wagon."*
Quote 6	"*Going back to that pop up [i.e., starter fertilizer] scenario, where I run the three different products, that was a one-year deal. And maybe on a second or third year, maybe one of those other two would have really shined and maybe changed my mind. But in a situation like that, if there was even a* ***slightest yield advantage****, I would maybe have run it out another year. But when they both come right in [i.e., comparable yield], and it was a decent growing season, and it was not a good field, I didn't think that I needed to go any further*."

The quotes above seem to convey that the data recording and analysis conducted by farmers themselves is somewhat rudimentary (Quote 2, 3, 4, 5, and 6). The yield data are not always systematically recorded in order to generate a database that can be used for further analysis (Quote 2). This is consistent with the endogenous experimentation process being and integral part of decision making and therefore, results can translate directly into decisions without a need to revisit results in the future. It is important because, should farmers need to diligently collect, organize, and analyze data for their decision-making, experimentation for decision-making would not be accessible to many farmers as Quote 3 seems to suggest. Rather, experimentation results are analyzed succinctly, looking at major trends such as obvious color differences on a color-coded yield map (Quote 4) or simply comparing total yield across treatments (Quote 5). This is a major departure from conventional research where the statistical significance used for accepting or rejecting a hypothesis is extremely conservative (e.g., *p*-value of 0.05). Indeed, while interpreting on-farm experimentation results, farmers are interested by agronomic significance (e.g., 500 kg/Ha difference) and by general trends and seem to "accept the hypothesis" that the treatment or product experimented is beneficial with much less conservative decision criteria (e.g., “slightest yield advantage” in Quote 6). Overall, it seems like farmers do not have the time, skills or interest to proceed to more in-depth analysis of their results and could benefit from specialists to support them in this process.

Time aspects of OFE

Quote 7	“[…] *yeah, it's gonna take time, I mean, you know, just messing around, setting it up just right, or trying to figure it out*.”
Quote 8	*Q: “How long did it take you to transition to no-till?”* *A: “We are still transitioning after 17 years!”*

The Quotes 7 and 8 seem to indicate that experimenting is a slow process and requires sustained dedication from farmers. This slow learning process may be attributed to a lack of documentation and understanding of the external factors influencing the outcomes of experimentation. By relying on major trends and visual observations and by integrating the context in a more organic manner (e.g., “*it was a wet year*”) it is possible to influence decision making, however it is not possible to make systematic progress such as is allowed by the scientific methodology, and this may explain the slow pace of endogenous experimentation. In the current situation where a rapid transition towards sustainable food production is required, supporting farmers in their experimentation of sustainable cropping practices may be essential to achieve these ambitious goals in due time.

Experimentation process

Quote 9	*Q: “Can you talk to us about your protocols when you're doing experimentation?”* *A: “So typically it will be a kind of side-by-side thing […] you got soil or yield maps to go by, so you can kind of look at them to situate yourself to where […] the yields have been fairly consistent in that area, through your history, okay, that’s where you run your trial.”*
Quote 10	*“[…] we bought enough [PivotBio] for a couple of 100 acres. […] I will definitely take a field and split it. […] the standard is 180 units of applied nitrogen. But now on this side, I'm going to do 140 plus PivotBio, because it's supposed to give you 40 units. And then on the other side, 180 units plus PivotBio, see if I get a yield bump, and where PivotBio goes with 140 units, if I maintain that same level of yield as 180* […]“
Quote 11	*“[experimenting with no-till] that first year really told me a lot”*

Quotes 9, 10, and 11 demonstrate that farmers put some thought into the design of their experiments. For instance, with information about soil spatial variability, farmers can strategically lay their treatments to either avoid (Quote 9) or encompass soil variability. This allows for a better understanding of the experiment outcomes. For instance, a treatment may be beneficial in high productivity soil and not in low productivity soil. If soil productivity is ignored, this may yield outcomes that are difficult to interpret. Without a Geographic Information System to precisely locate the treatments, the farmer can only approximate the location of the experiment. As per Quote 9, this seems sufficient to obtain the desired information; however, it remains risky because of the inherent uncertainty associated to the lack of precision. Farmers are also clear about what they expect from their experiments. For instance, in Quote 10 the producer expects a similar yield from treatment 1 (i.e., reduction of 40 units of N plus biological agronomic product) and a yield increase from treatment 2 (i.e., maintaining N rate plus biological agronomic product). This way to frame the experiment's outcome is practical because it allows for fast decision making, each treatment being subject to a dichotomic outcome. The endogenous experimentation process can allow the farmers to quickly progress in the transition to new practices and product use (Quote 11). However, the lack of granularity in the outcomes (e.g., pass or fail as opposed to a better assessment of when it passes and when it fails) increases the risk of false positive and false negative, especially when conditions significantly depart from a long-term average, which is happening more frequently due to climate change. Therefore, without appropriate documentation of the experimental context, the endogenous experimentation process does not allow for systematic progress.

Conclusion or Summary

In summary, there is a pressing need to accelerate progress towards sustainable agriculture on the farms and enhancing the endogenous experimentation process of crop producers with digital agriculture techniques and technologies can potentially help achieve this goal. Semi-structured interviews conducted among a limited number of field crop producers in NY State has allowed to learn more about how farmers are experimenting and how digital agronomy can contribute to this process. All interviewees mentioned that they were conducting on-farm experimentation for which they were the initiators on their farm. Results of the interviews showed that the data collection, organization and use for on-farm experimentation is rudimentary and often non-existent, the relevant outcomes of experimentation being more visual or being observations of major trends in the numbers (e.g., comparing total yield across treatments). The endogenous experimentation process seems slow as expressed by farmers mentioning that "*it takes time trying to figure out*" and by a farmer stating that transition towards a new practice has been ongoing for 17 years. Nevertheless, farmers are thoughtful in their experimentation layout, accounting for soil variability when possible and using simple decision schemes that are consistent with limited data collection and conductive for efficient decision making. Overall, the results of the interviews confirm that on-farm experimentation is important and that it can be enhanced with digital agronomy. Further research will be needed to objectively quantify the results presented here and to identify specific techniques and technologies that can help farmers achieve their goals of sustainability faster.

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