Friendly Fruit Outcomes:

Environment-friendly innovations in strawberry production

The performance of agronomic practices tested and implemented in the project.
Acknowledgement:

We wish to thank all our financial partners, outside partners, trial collaborators, numerous leaflets’ authors and leaflets’ reviewers who contributed to making this project a success. These contributions implied international collaboration, skills and expertise from various sectors, including private companies and public institutions. We are using a Creative Commons licence.

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Like all agricultural practices, fruit production must adapt to climate change. Fruit supply chains are already experiencing the negative impacts of a warming climate and environmental degradation. Early and erratic crop flowering, a reduction in fruit quality, the emergence of new diseases and water supply issues, as well as rising demand for inputs to sustain production, all present unique challenges.

Funded by EIT Climate-KIC for a period of three years (2018-2020) and coordinated by INRAE, the Friendly Fruit project was designed to address some of these challenges in strawberry and apple fruit production. Its objective was threefold: (i) to test practices, (ii) to evaluate their impacts, and (iii) to implement and disseminate environment-friendly agricultural practices in various areas of the fruit industry.

Friendly Fruit brought together a network of experts from research institutes, universities, industrial organisations and experimental stations in France, Italy, the Netherlands, Spain and Morocco.

The project focused on some key targets which have the biggest impacts on environmental and human health: water use efficiency, soil quality and biodiversity, phytosanitary control, use of new energies, and mitigation of global warming effects. During the three years of the project, 19 practices were tested in apple and strawberry in various environments to test their efficacy and estimate their agronomical, environmental, and financial impacts.
Main applications of the project results

After three years of experimentation, important outputs had been reached. The most significant outputs on strawberry are described here.

In strawberry farm labs in Morocco, the use of sensors for water management proved to be extremely efficient, with more than 40% of water saved. In addition, the use of soil indicators and plant nutritional status allowed for a significant reduction of nitrogen (-54%), potassium (-15%), phosphorus (-88%) inputs.

Prototypes of photovoltaic panels on the ground proved to be a cheap and efficient way to feed a pump to lift water from wells. This technology will be experimented with in more areas.

New disease-resistant hybrids created in France and Italy were tested in Morocco. There are at least seven new promising elite hybrids which show yields and quality that are as good as or better than the varieties currently grown in this region. One more year of experimentation is needed to confirm results and make a final selection.

A new sprayer designed and developed under the project has met all expectations: the quality of protection equals that of existing tools while reducing the doses by 60%. Additionally, it has significantly reduced the risk of exposure for the applicator.

The IPM experiments performed in the lab and in greenhouse confirm that N fertilisation can be used as a tactical and additional tool to manage powdery mildew and Botrytis cinerea in soilless strawberry production and certainly also on other pests and diseases.

Pre-plant soil disinfection tested in Friendly Fruit also showed encouraging results which offer alternative practices to chemical soil disinfection and are harmless for the grower, consumers, and soil biodiversity.

Remarkably interesting research on plant architecture performed in Friendly Fruit showed a strong link between the quality of the young strawberry plant and the yield. However, further studies would be necessary to better understand the mechanisms and propose precise recommendations for growers.

The project included an active dissemination and training policy to empower farmers with key knowledge to enable a practical change towards more sustainable farming and adaptation to Climate Change.

As final outputs, the Friendly Fruit project made it possible to develop standalone leaflets dedicated to farmers and stakeholders to disseminate the Friendly Fruit practices. For each practice experimented within the project (about 10 per crop), a leaflet (a two-page summary) describes the practice, the conditions for its implementations, details of its performance, and provides an overview of the experimentation. Our goal with this booklet/compilation of leaflets is to provide synthetic and sufficient relevant information to encourage the adoption of practices that best suit a farm’s particular constraints and material capacities.
Friendly Fruit

Map of environment-friendly practices tested within the project per topic
2018-2020

Biocontrol and pesticide reduction
Soil management and fertilisation
Water management
Plant material
Other climate mitigation practices
# Leaflets titles and topics

## Biocontrol and Pesticide reduction
- Innovative sprayer reducing pesticide use in strawberry fields  
  - n°1
- N fertilisation shortages to control powdery mildew of strawberry  
  - n°2
- Innovative strategies for the control of grey mould on strawberry leaves  
  - n°3

## Soil management and fertilisation
- Optimisation of the mineral nutrition of strawberry crops: Monitoring using a theoretical fertilisation schedule and soil bioavailability tests  
  - n°4
- Non-chemical soil fumigation in strawberry: the BIOFUMIGATION method  
  - n°5
- Non-chemical soil fumigation in strawberry: the ASD (Anaerobic Soil Disinfestation) method  
  - n°6

## Water management
- Optimisation of the irrigation of strawberry field crops: Monitoring based on tensiometers  
  - n°7

## Plant material
- Identifying resilient strawberry cultivars to increase crop pedoclimatic adaptation  
  - n°8
- Knowing plant plasticity to optimise strawberry yield using architecture analysis  
  - n°9

## Other climate mitigation practices
- Pumping solar system in strawberry production  
  - n°10
How to read a leaflet 1/2

Title of the environment-friendly practice. And leaflet number

Status of the new practice or innovation:
Ready to use, promising but needs to be confirmed, ongoing experimentation, exploratory research.

Short description of the purpose and reason for the study.

Operationality aspects:
Conditions for implementation, conditions for use and possible interactions with other practices.

Practice performance evaluation:
Smileys correspond to the level of performance of the practice in comparison with a reference system. See page 8 for more information.

Details on the experimental conditions and the understanding of the environment-friendly practice (mode of action).

License. With no commercial use.

A key-result from the experimentation:
Graph and explanation, and a take-home message.

Summary of the experimental conditions:
Scale (laboratory or field) and validity (ongoing or ready to use (see status description on front page)). Duration of the experimentation and the number of repetitions of the experiment in the same year.

To further readers’ understanding of the innovation trial, these are the main contacts or references.
How to read a leaflet 2/2

Practice Performance

Each practice is evaluated in relation to three axes: agronomy & environment, costs & benefits and operationality.

Each axis has two to four indicators evaluated on a four-level scale: (i) positive effect, (ii) neutral to positive effect, (iii) room for improvement, (iv) bottleneck.

For each indicator a short explanation is given and for each axis a synthesis on the strength and weakness of the practice is given.

The performance is evaluated in comparison to a reference system described at the top of the section.

Legend: each of the four smileys corresponds to one of the 4 qualitative classes. The description of each class for each indicator is given on the following page.
### INDICATORS

<table>
<thead>
<tr>
<th>Agronomy &amp; environment</th>
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#### Pesticide reduction
- All pesticides eliminated
- Some pesticides eliminated
- No pesticide reduction but risk of pullulation of pests is limited
- Not currently known

#### Greenhouse gas reduction
- 2 items below: reduced input use (pesticides or mineral N), reduced energy use (machinery, warming or cooling), carbon sequestered (increased soil organic matter), and/or green
- 1 item below: reduced input use (pesticides or mineral N), reduced energy use (machinery, warming or cooling), carbon sequestered (increased soil organic matter), and/or green energy production
- No increase in input or energy use, no carbon sequestration or green energy production
- 1 item or more below: increased input use (pesticides or mineral N), increased energy use, and/or GHG emitted

#### Fruit production
- Increase fruit production quantity OR quality
- No effect on quantity and quality
- Not known or contradictory effect (i.e. quality improves but quantity decreases or reverse)
- Reduce fruit production quantity and/or quality

### OPTIONAL INDICATORS

<table>
<thead>
<tr>
<th>N, Water or Energy use</th>
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<tbody>
<tr>
<td>Large decrease in quantity (&gt;20%)</td>
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<tr>
<td>Small decrease in quantity (10-20%)</td>
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<tr>
<td>Identical to the standard use</td>
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<tr>
<td>Increased use</td>
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</table>

### Costs & benefits

<table>
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<th>INDICATORS</th>
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#### Investment cost
- No extra cost
- Low or possible to build
- Investment needed
- Large investment needed

#### Time to set up
- None
- Low
- Labour intensive
- Labour intensive and at a peak period

#### Time to manage
- None
- Low
- Labour intensive
- Labour intensive and at a peak period

### Operationality

<table>
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<th>INDICATORS</th>
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#### Ease of implementation
- No specific knowledge or skills needed OR easy to implement
- Training course needed to implement
- Complex to implement
- Not ready to implement

#### Availability
- Available and widespread practice
- Practice being disseminated
- Validated on-station
- Ongoing experimentation
**Tested Implementation**

Implementation (main steps):
1. Use of the sprayer requires:
   - Either a towed device with a common binding
   - Or an independent motorisation allowing automation of a remote-control system.
2. Timing and mixing products are the same as “traditional” atomization but with lower volumes.

**Condition of use**
The practice is suitable for strawberry fields, as a substitute to traditional machine treatment.

**Interactions:**
Optimisation of the biocontrol efficiency or plant elicitor sprayed thanks to improved distribution on plants.

**Practice Performance**
Practice performance assessed in comparison with traditional treatment machine (lance).

**Agronomy & Environment**
- 60% pesticide reduction.
- No change of the fertilizer amount and the energy used.
- Same yields.
- Reduction of the impact of pesticides on the environment and of residues on fruits with lower spray volumes and less active compounds.

**Costs & Benefits**
- Low cost and self-construction would be possible.
- No extra time for implementation.
- No extra time for its use.
- Valorisation of the production with reduced pesticide impacts on users and consumers, and with reduced input costs (water and pesticides).

**Operationality**
- Practice is easy to use and allows for better protection for the user but still needs to be tested on farm.

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**Status: promising but needs to be confirmed**

**What?**
Developing a sprayer adapted to strawberry production which only sprays the necessary amount of product by mixing air with the product during the treatment in addition to fine atomization.

**Why?**
Improving treatment efficiency, reducing phytopharmaceutical product quantity and reducing risks for the user.
The sprayer developed includes a treatment module with a protection box to avoid treatment deviations and to protect the user. An impeller on the top and an air release allows a shuffling of leaves. Nozzles are on the top and on the sides for a homogeneous and sufficient application. In the experiment, the device is a trolley pushed by the applicator. Mean speed of the device is at least 3 km/h, that is, 5 ha per day.

The vent system and airflow direction allow for: (i) a **finer spray** which reduces product amounts, and (ii) a **better shuffling of plants** for a homogeneous distribution of the product on old and young leaves, spikes and heart of plants, in laboratory. Efficacy on pests is the same compared to the control but with a dose of 210 L/ha, meaning a **reduction of 60 % of the control volume**. Concentrations of products are the same, which means that **active compounds are reduced by 60%** as well.

Thanks to spraying quality optimisation associated with the direction of nozzles with airflow, the experimented device showed that it is possible to obtain the same plant protection as with convention methods and to reduce the amount of inputs (about 60 %). The percentage of plants with aphids is comparable to the control. The results were conducted with the sanitary conditions of the years 2019 and 2020. This device also allows one to reduce the risk of exposure of the applicator thanks to confined and more localized treatment on plants.

**Message to take home:** The device reduces the product volume sprayed and the amount of the active compounds by 60 % with the same efficacy on pests and the same yields.

For more information

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          & François Lecompte (INRAE Avignon)
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          & francois.lecompte.2@inrae.fr

**Experiment conditions**

- **Scale**
- **Validity**
- **Duration:** 07/2019 to 06/2020
- **Nb of repetitions:** 1
**N Fertilisation Shortages to Control Powdery Mildew of Strawberry**

**Status:** Ongoing experimentation

**What?** To integrate transient N shortages into protection strategies against powdery mildew (causal agent *Podosphaera aphanis*) on leaves and fruits of strawberry.

**Why?** To control a major fungal disease of strawberry with little or no use of fungicides.

### Tested implementation

**Implementation (main steps)**

1. In the laboratory, to evaluate the effect of low nitrogen nutrition on leaf and fruit susceptibility.
2. Under conditions similar to those of agricultural production, within IPM strategies, to trigger temporary limitations of nitrogen nutrition, and to assess the impact on disease development, yield and fruit quality.

**Conditions of use:**
- Greenhouse production with soilless culture.
- Regular scouting of the crop is required for the adaptation of the IPM strategy, and extra time is required for spraying biocontrol agents.

**Interactions:**
- Increased efficiency of one fungicide against powdery mildew.
- To be combined with other IPM practices.

### Practice performance

Practice performance assessed in comparison with the same IPM strategy without N shortage.

#### Agronomy & Environment

- **Reduction of** disease severity and of the number of fungicide applications.
- **Reduction by** 10-20% of nitrogen supply throughout the growing period (mitigation of eutrophication and GHG emission).
- Potentially **no effect** on commercial yield and fruit quality, despite lower powdery mildew pressure. Impact on fruit infection might be cultivar dependent.

#### Costs & Benefits

- **No specific investment required.**
- **No extra time required** for modification of the nutrient solution.
- **Little time needed** for management of the composition of nutrient solutions.
- **Decreased costs** for N fertilizers.
- **Extra time is required** for scouting of the crop and spraying of biocontrol agents.

#### Operationality

- **Positive effect**
- **Neutral to positive effect**
- **Room for improvement**
- **Bottleneck**

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Detailed information on the practice

In laboratory experiments, strawberries were grown at 3 different levels of N supply (F1: 0.5 mmol NO\textsubscript{3}; F2: 5 mmol NO\textsubscript{3}; F3: 10 mmol NO\textsubscript{3}) and inoculated with powdery mildew three weeks after the onset of the nutritional treatments, by blowing spores on the plants. The percentage of infected plants (either on leaves or on fruits) was recorded two weeks later.

Under conditions similar to those of agricultural production, N supply was reduced for three or four weeks at the time of flowering (two peaks) in addition to other IPM techniques, and compared with the same IPM strategy without N shortage. Powdery mildew development was observed on leaves and fruits throughout the season, along with fruit production and fruit quality.

Information on the mode of action

High nitrogen levels are known to increase diseases caused by biotrophic fungi (e.g. mildews and rusts). Possible modes of action are: (i) high N in plants favours nitrogen acquisition and fitness of fungi, (ii) low N favours the production of cell wall bound polyphenols by plants, which limits fungal propagation and (iii) low N could favour other immunity mechanisms in plants.

Results of the experiments

Under laboratory conditions, the effect of transient N shortage on powdery mildew development was tested on two cultivars (V1: Candiss, V2: Darselect). Results show a reduction of disease incidence in F1 (compared the average incidence in F2 and F3) up to 60% on leaves (A) and 24% on fruits but only on V1 (B).

In a greenhouse representative of production conditions, dynamics of natural plant infection by \textit{P. aphanis} under two IPM strategies were compared: one including transient shortage of nitrogen, another with continuous nutrition at usual N rate. Results show that limiting N supply during short periods of the growth cycle (blue lines on the figure) limited on average by 55% the percentage of organs infected by powdery mildew (C). 

Message to take home: Under laboratory and greenhouse conditions, powdery mildew incidence on leaves and fruits was reduced with transient N shortages applied during the crop cycle.

For more information

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Experiment conditions

Scale

Validity

Duration: 2019 to 2020

Nb of repetitions: 2
Tested implementation

Implementation (main steps)
Under experimental conditions, first reduce N supply, then evaluate every week after the onset of nitrogen shortage, the leaf susceptibility to *B. cinerea* (grey mould). Finally, evaluate the synergy with a biocontrol agent.

Conditions of use:
No extra time for the modification of the nutrient solution. For the spraying of a biocontrol agent, one or several sprayings (ca 2.5 hours/ha).

Interactions:
Possible synergy with genetic resistance and defense inducers (not evaluated).

Practice performance assessed in comparison with continuous and usual N supply in production (10 mmol NO$_3$).
Low N levels profoundly modify the metabolism of the plant tissues, as well as the metabolic reactions after pathogen infection, including the synthesis of antifungal compounds. However, the precise mechanisms remain unknown. The biological control agent, *Gliocladium catenulatum*, is a mycoparasite of *B. cinerea*, with harmless effects on the plant.

(A) Lesions were reduced in F1 in comparison to F3 (usual NO₃⁻ rate) by 20% one or two weeks after the onset of nutritional treatments, and by more than 40% after 4 weeks. Disease damage (lesion size) in intermediate N level (F2), was not different from the highest N level (F3). Biotests were performed with two different strains of *B. cinerea* on two strawberry cultivars and showed similar results.

(B) Four weeks after the onset of the nutritional treatments, we tested the effect of a Biocontrol Agent (BCA). The biocontrol treatments reduced lesion size when plants were supplied with high N levels, namely F2 and F3. This was not the case in F1, where low N supply reduced the lesion, as shown in A, with or without BCA.

**Message to take home:** transient N reductions and applications of a biocontrol agent limit the severity of grey mould infections.

For more information

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**Experiment conditions**

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Duration: 2019 and 2020

Nb of repetitions: 3
What? Monitor the fertilisation of strawberry field crops based on: (i) a theoretical fertilisation schedule, (ii) a P and K test at the beginning of the season and (iii) N tests during the cycle.

Why? To preserve nutrient resources and limit losses to the environment and pollution by adapting inputs to the crop’s needs while maintaining performance levels.

**TESTED IMPLEMENTATION**

Implementation (main steps):
1. Create a theoretical fertilisation schedule (N, P, K) based on the expected biomass and nutrient levels.
2. Obtain a maximum quantity to be provided per element which is fractionated into theoretical doses according to the development kinetics of the culture (see table).
3. These theoretical doses are adjusted according to an initial test for P and K in soil, and during the cycle for nitrogen using a portable reflectometer (Nitrachek®).

**Conditions of use:**
Practice adapted to field-grown strawberry plants. The nitrate test is performed with a soil sample and distilled water.

**PRACTICE PERFORMANCE**

Practice performance assessed in comparison with a fertilisation schedule established from the development stages of the crop, without considering bioavailability at the beginning or during the cycle.

**AGRONOMY & ENVIRONMENT**

**PESTICIDE & NUTRITION REDUCTION**

- **Pesticide reduction has not been studied.**
- **Reduction in the use of N and P (less GHGs) and energy related to the pump injecting the fertilizers.**
- **No loss of yield but the results have to be consolidated.**
- **Reduction in the consumption of fertilizers, and potentially their loss in the environment.**

**INVESTMENT COST**

- **A well-known alternative practice that has already proven success.**
- **Easy to set-up but requiring a short assistance for the tests’ handling and interpretation.**

**OPERATIONALITY**

- **Low investment cost and quickly amortized.**
- **Little time required to set up the schedule.**
- **Little time required for monitoring; distributed over the production period.**
- **Reduced fertilisation costs.**

**COSTS & BENEFITS**

- **Positive effect**
- **Neutral to positive effect**
- **Room for improvement**
- **Bottleneck**
- **Not studied**

**Table: Nitrate concentration in soil solution (mg/l)**

<table>
<thead>
<tr>
<th>Nitrate concentration in soil solution (mg/l)</th>
<th>Multiplier Coefficient</th>
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<tbody>
<tr>
<td>&lt; 100</td>
<td>1.5</td>
</tr>
<tr>
<td>100-150</td>
<td>1</td>
</tr>
<tr>
<td>150-200</td>
<td>0.8</td>
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<tr>
<td>C &gt; 200</td>
<td>0.5</td>
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**Detailed Information on the Practice**

The experiment was conducted in 5 farm labs in the area of the Gharb-Loukkos in Morocco on several strawberry varieties. Each farm was monitored with a programme based on data on soil and plant status and adjustment of fertilizer inputs (“low input” plots) in comparison to a “traditional” static fertilisation programme (“farm” plots). Nitrate concentration in soil, quantity of inputs used (N, P, K), yields and fruit quality were monitored on both plots compared (farm/low inputs). To obtain nitrate concentration: (i) Collect 8 soil samples on every ridge to make a mixed sample; (ii) Collect 100g of this last sample, add 100 mL of distilled water (or KCl), mix and strain; (iii) dip a strip in the filtrate and measure nitrate concentration (mg/L) using a mobile reflectometer (Nitrachek®).

**Information on the Mode of Action**

The creation of a theoretical fertilisation schedule (N, P, K) requires the potential needs of the crop to be defined in relation to quantitative nutrients and expected biomass. Taking into account effectiveness and fertilizer analysis, one obtains a maximum amount to apply per nutrient, which is divided into theoretical doses in relation to the crop growth kinetics. These theoretical doses are adjusted, based on an initial test for P and K, and throughout the nitrogen cycle (see example table).

**Results of the Experiments**

In Morocco, with the pedoclimatic conditions and farming practices of the farms studied, this practice allows an average significant reduction of 88% for Phosphorus and 54% for Nitrogen over the first 6 months of the crop season, with low variability between farms. Results on K nutrients are encouraging and could be improved thanks to foliar tests on ongoing crops. Likewise, nitrogen foliar tests allow potential plant stress to be verified. The efficiency of each nutrient input is improved because the decrease of inputs does not impact marketable yields. It is necessary to redo the experiment over a complete season, with a farm sample exploring a diversity of pedoclimatic contexts. Theoretical doses could be refined, depending on varieties.

**Message to take home:** Monitoring with the help of theoretical fertilisation planning and bioavailability tests makes it possible to reduce fertilizer consumption, maintain yields and limit environmental pollution.

**For more information**

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The project partners thank the 5 volunteering farmers that collaborated to the experiment in Morocco.

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**Experiment Conditions**

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Duration: 1 year (early season 2020)

Nb of repetitions: 5
**Non-chemical soil fumigation in strawberry: the Biofumigation method**

**Status:** promising but needs to be confirmed

**What?**
Pre-planting incorporation of defatted seed meals of Brassicaceae plants into the soil (commercial product: 'BioFence' pellets, Nutrien Italia S.p.A.).

**Why?**
To contain soilborne pests and pathogens of previous strawberry crops and minimize the replanting syndrome without using chemical fumigants.

**Tested implementation**

**Implementation (main steps):**
In the time interval between previous crop removal and new strawberry planting:
1. Soil tillage;
2. Incorporation of 'BioFence' pellets (2.5-3.0 t/ha) at a 0-30 cm soil depth;
3. Irrigation (10-15 mm) to activate hydrolysis of glucosinolates;
4. Preparation of raised beds containing only the treated soil, mulching with black polyethylene film;
5. Planting

**Interaction with other cultural operations:**
Irrigate after the incorporation of the pellets. Plant 7 days after irrigation to avoid phytotoxic effects.

**Practice performance**
Practice performance assessed in comparison with chemical fumigation.

**Agronomy & environment**
- Pesticide reduction by substituting chemical fumigation.
- Decrease in machinery use due to chemical fumigation application.
- Compared to chemical fumigation, it might moderately decrease yield and fruit weight.
- Alternative to chemical fumigation to contain pests and pathogens harmful to the crop.

**Costs & benefits**
- No extra investment in comparison to chemical fumigation.
- Little time needed to set up.
- Little time needed to manage.
- Cheaper practice than chemical fumigation.
- Compatible with organic farming.
- Can add commercial value to the crop yield.

**Operationality**
- No specific skills or knowledge are required.
- It is a promising alternative to chemical soil fumigation, with no harm to operators and environment.
Pre-planting soil fumigation is a necessary practice to minimize replanting syndromes impacting yield quantity and quality of strawberry. The Biofumigation natural system was developed as an alternative to chemical fumigation to break down soilborne pests and pathogens. The soil is wet after the incorporation of ‘Biofence’ pellets, i.e. defatted seed meals derived from Brassicaceae plants particularly rich in glucosinolates. This process activates the hydrolysis of glucosinolates by the endogenous enzyme myrosinase, which in turn initiates the production of a series of break-down products, mainly isothiocyanates, allowing some pathogens to be contained and nematodes and weeds to be disturbed.
**Non-chemical soil fumigation in strawberry: the ASD (Anaerobic Soil Disinfestation) method**

**Status:** promising but needs to be confirmed

**What?**
Addition of protein-rich organic matter to the soil before planting (commercial product: 'Soil Resetting', granular, Thatchtec, NL).

**Why?**
To contain soilborne pests and pathogens of previous strawberry planting and minimize replanting syndrome with no use of chemical fumigants.

**Tested Implementation**

**Implementation (main steps):**

1. Soil tillage;
2. Incorporation of 'Soil Resetting' (8 t/ha) to a 0-30 cm soil depth;
3. Irrigation (10-15 mm) to enhance product decomposition;
4. Sealing the treated soil with totally impermeable film (TIF);
5. TIF removal after no less than 3 weeks;
6. Preparation of raised beds containing only the treated soil, mulching with black polyethylene film;
7. Planting.

**Conditions of use:** Applicable in areas where strawberry is cultivated (soil T°>17°C seems preferable).

**Practice Performance**

Practice performance assessed in comparison with chemical fumigation.

**Agronomy & Environment**

- **Pesticide reduction** by substituting chemical fumigation.
- Decrease in machinery use due to no chemical fumigation applications.
- Compared to chemical fumigation, it might slightly decrease fruit production.
- Alternative to chemical fumigation to contain pests and pathogens harmful to the crop.

**Costs & Benefits**

- **No extra investment** in comparison to chemical fumigation.
- Little time needed to set up.
- Little time needed to manage.
- Same costs or slightly higher than chemical fumigation.
- Compatible with organic farming.
- Can add commercial value to the crop yield.

**Operationality**

No specific skills or knowledge are required.

It is an almost ready-to-use alternative to chemical soil fumigation, with no harm to operators and environment.

**Credits**

Leaflet authors: Giovannini D., Baruzzi G., CREA; Casagrande M., INRAE.
**Detailed Information on the Practice**

In a commercial farm in Southern Italy, under multi-span tunnels, ‘Sabrosa’ cv. bare-roots plants were planted at a density of 72,000 plants Ha\(^{-1}\). There were 4 replicates, i.e. 4 double-row beds x treatment x year.

During the growing season, plants were sampled to measure fresh and dry weight. Data recorded or calculated: single picking yield, total yield, fruit weight and quality (Brix, titratable acidity and flesh firmness).

**Information on the Mode of Action**

Pre-planting soil fumigation is a necessary practice to minimize the replanting syndrome impacting yield quantity and strawberry quality. The ASD practice was developed as an alternative to chemical fumigation to break down soilborne pests and pathogens. The mode of action is still not fully understood. It seems that soil irrigation and sealing (hampering the air exchange) after the incorporation of the ‘Soil Resetting’ granules facilitates the establishment of an anaerobic environment, where the anaerobic microflora thrive. The secondary metabolites (i.e. organic acids and toxic volatile compounds) generated by such anaerobic decomposition can contain a broad range of pathogens, nematodes and some weeds.

**Results of the Experiments**

ASD as compared to untreated plots allowed significant improvements in terms of plant growth, yield and fruit weight. As compared to chemical fumigation, some yield reduction was observed in 2019 but not in the 2020 harvest season. Some optimisation of the application conditions is still needed to reduce the remaining performance gap between this alternative technique and chemical fumigation, and in turn allow profitable strawberry cultivation in monoculture.

**Message to take home:**

Pre-planting anaerobic soil disinfestation (commercial product: Soilresetting®, Thatchtec, NL) is an almost ready-to-use eco-friendly alternative to soil chemical fumigation on strawberry.

**For more information**

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The project Friendly Fruit (2018-2020) was coordinated by INRAE with the financial support of the EIT KIC.

**Experiment Conditions**

- **Scale**: 
  - ![Climate KIC](https://example.com/climate-kic-icon)
  - ![INRAE](https://example.com/inrae-icon)

- **Validity**: ✔

- **Duration**: 2 years

- **Nb of repetitions**: 4 per year
Irrigation management based on sensors which measure soil water tension, a component of the water potential, in strawberry field crops.

To preserve water resources by adjusting irrigation to the crop’s needs while maintaining yield level.

**TESTED IMPLEMENTATION**

Implementation (main steps):
1. **Install 3 to 5 pairs of sensors** of 2 depths (10 & 30 cm) on each homogeneous area. A homogeneous area is monitored identically (irrigation, variety) and has similar soil features.
2. Fractionate irrigation inputs to **maintain soil water tension between 10-15 cbar** which reflects water status of the soil, subsurface and in-depth.
3. **Check sensors at least once a week** during the growing season (manual or automatic).

**Conditions of use:**
- Practice adapted to field-grown strawberry plants.

**Interactions:**
- In a fertigation system, irrigation interacts with fertilisation.

**PRACTICE PERFORMANCE**

Practice performance assessed in comparison with an irrigation schedule based on an empirical estimation of crop needs and soil water status.

**AGRONOMY & ENVIRONMENT**

- **Pesticide reduction has not been studied.**
- **Reduction in the use of water quantity and energy linked to water pumping.**
- **No loss of yield** but results to be consolidated.
- **Reduction in irrigation inputs**, and potentially of fertilizers lixiviation GHG release.

**PESTICIDE REDUCTION**

**INVESTMENT COST**

- **Low investment** cost, and quickly amortized.
- **Little time** required to set up and remove the sensors.
- **Little time** required for monitoring, distributed over the production period.
- **Reduced consumption** of energy and water and its associated costs, which might increase.

A **well-known** alternative practice that already has **proven success**. **Fairly easy to set up** but requiring a **short training** for the users.

**OPERATIONALITY**
Detailed information on the practice

Trials were conducted on 5 farm labs in the Gharb-Loukkos region (Morocco) and one experimental site in Dordogne (France). On each site, monitoring was carried out with tensiometer sensors on a “low input” plot, compared to regular practices “farmer” plot.

The aim was to divide irrigation up, with many shorts and numerous irrigations triggered when the subsurface sensor exceeded 15cbar, and doses adjusted by means of in-depth sensors (see table). Monitored parameters during test process are soil water tension, total water supply quantity, strawberry yields and fruit quality on both plots.

Information on the mode of action

Soil water tension is the force that has to be deployed to extract it. Zero tension represents a saturation of soil water, which is drained freely. By contrast, high tension limits plant absorption and induces water stress. The goal is to maintain a moderate tension allowing for an adequate water supply and avoiding excessive drain. The senor produces an electric signal, depending on water quantity, in tension (cbar or kPa). Subsurface sensor tension allows irrigation needs (input frequency) to be defined, whereas the in-depth sensor informs on water movements and helps to define irrigation timing needs (input dose).

Results of the experiments

In Morocco, with the pedoclimatic conditions and regarding farming practices of the followed farms, this practice allows an average significant reduction of 46 ± 6 % of water consumption during the first 6 months of cultivation (p-value = 0.032). Median is 52 % and reductions ranged from 26 % to 57 %. Average increased water use efficiency (final yield/water quantity input) is 85 ± 17 %.

In France, results complement results in Morocco.

In Morocco, the trial extended over an incomplete season. Water savings and yields should be for an entire season. Furthermore, thresholds could be marginally refined depending on the soil.

Message to take home: Tensiometric sensors and fractionated irrigation allow for water consumption reduction and increase water use efficiency, while keeping yields high.

For more information

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The project partners thank the 5 volunteering farmers that collaborated to the experiment in Morocco.

Experiment conditions

Scale

Validity

Duration: one year (early sea-

Nb of repetitions: 6
**Identifying Resilient Strawberry Cultivars to Increase Crop Pedoclimatic Adaptation**

*Status: promising but needs to be confirmed*

**What?**
Assessing new breeding lines for identifying strawberry cultivars with increased resilience combined with fruit quality.

**Why?**
Identify new cultivars adapted for southern conditions, in order to reduce water use, reduce pest and disease incidence and increase fruit quality.

**Tested Implementation**

**Implementation (main steps)**

1. Identify genetic material from breeding programmes with improved plant rusticity (better water-use efficiency (i.e. ratio between yield and water used), and higher tolerance to diseases) and fruit quality.
2. Choose the cultivars to be tested and breed homogeneous bare root plants in a nursery.
3. Plant 100 plants of each cultivar in the pedoclimatic conditions to be tested, with a full irrigation treatment and a water regime reduced by one third.
4. Choose genotypes with the best adaptation to these conditions, i.e. with the best yield and fruit parameters.

**Conditions of use:**
This practice could be useful for nurseries and/or farmers.

**Practice Performance**

Practice performance assessed in comparison with current commercialized cultivars in the Mediterranean area (e.g. ‘Florida Fortuna’).

**Agronomy & Environment**

- **Pesticide reduction** from 10 to 30%.
- **Water use reduction** from 10 to 30%.
- **N and energy use reduction** (mitigation of eutrophication and/or Greenhouse Gas emissions).
- **Improved fruit quality** (sweetness) and similar yield.

**Costs & Benefits**

- **No specific investment** required (water meters monitoring the two water regimes used).
- **No extra time needed** for setting up of the practice.
- **No extra time needed** for management.
- **Decreased costs** for N, pesticides and water fertilizers.
- **Additional income** thanks to the increased fruit quality.

- **No specific skills required** if preliminary step characterizing water-use efficiency is done.

If results from the running trials are confirmed the most interesting breeding cultivars can be transferred to the

**Operationality**

- **Ease to implement**
- **Ready to use**
- **Investment cost**
- **Time to set-up**
- **Time to manage**
- **Pesticide reduction**
- **Water use reduction**
- **Greenhouse gas reduction**
- **Fruit production**
- **Increased sustainability, reduction of water, N and pesticide use, and increased fruit quality.**

Interactions: Effect of limiting the irrigation regime on plants.
Detailed Information on the Practice

UNIVPM, INVENI and CREA identified 15 strawberry breeding selections from their breeding programmes. After testing them in Italy and Spain, they were selected and bred in a nursery to set up a joint larger trial in Morocco. Yield and fruit quality parameters were collected in 2019 and 2020, with the following experimental trial:

- Each of 15 selections and Florida Fortuna, as the control cultivar, were tested with 100 plants, divided into 4 plots of 25 plants.
- With this experimental scheme, 2 trials were set up: (1) standard irrigation system; (2) reduced irrigation water restitution = 70%.

Information on the Mode of Action

All genotypes were tested by using the standard growing conditions used in the Mediterranean areas but with a specific monitoring of plant response to standard and reduced water conditions. The trial was aimed to identify genotypes with higher plant rusticity (requiring less water and nitrogen), tolerance to major soil and fruit diseases, and increased fruit quality, in particular firmness and shelf life, and sweetness (*°Brix*).

Results of the Experiments

- Fifteen new breeding selections were identified from trials carried out from UNIVPM, INVENIO and CREA, at different locations (Italy, France and Spain). They were tested on a joint trial in Morocco, to compare their response to southern growing conditions, even at a reduced water restitution.
- Data from the large trial carried out in Morocco showed a different response of the genotypes, and several showed a better performance compared to the ‘Florida Fortuna’ control. This difference was detected for both standards and reduced irrigation regimes.
- Most of the genotypes showing higher commercial yields in both trials also showed a reduced proportion of unmarketable fruit, with less deformed and rotten fruit.

Message to take home: AN13,13,55, Dina (UNIVPM), EXP118, EXP801, EXP121 (INVENIO) and Lam18 and Pircein (CREA) were identified as being of interest for the commercial yield, reduced discarded fruit and better fruit quality. These new genotypes can be proposed to growers as new resilient cultivars for more sustainable strawberry cultivation in the south.

For more information

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Experiment Conditions

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Duration: 2018-2021

Nb of repetitions: 3 repetitions in 3 field trials.
**What?**
Carrying out architecture analysis to studying strawberry plasticity, i.e. plant’s capacity to present different phenotypes according to environment.

**Why?**
To improve knowledge on variability of tray plants according to the origin of their plant-bearing runners. Ultimately, to develop a more resilient yield.

## Tested Implementation

### Implementation (main steps)

1. **Make a preliminary request** to a specialized laboratory (e.g. Invenio) to set the conditions of sampling, shipment and price;
2. In nursery or in production, **take a sample of 10 plants** representative of a batch. A batch of a single variety represents plants that have the same mother plant origin, which were transplanted on the same date and in the same place with a single technical culture.
3. **Send the plants** to the laboratory with their roots, to avoid any drying out of the plant.

### Conditions of use:
The practice is suitable for nurseries and/or farmers.
This approach is fully adapted to any cropping system, including those in Mediterranean areas.

## Practice Performance

Practice performance assessed with architecture analysis compared with no information on plant development.

### Agronomy & Environment

**Pesticide reduction**
- Effect not known yet.
- More efficient energy use.
- Increase in fruit production (yield).

The objective is to select a plant well balanced between vegetative and floral development for **yield resilience** and resistance to pathogens and pests.

### Costs & Benefits

- **Extra cost** for plant architecture analyses.
- **Little time needed** for contracting and planning with a specialized enterprise.
- **Few hours** for preparing plant samples in nurseries or fruit production and for sending them (1 to 4 samplings).
- **A few days to obtain architecture results.**

**Benefit for optimizing production management** (e.g. environmental controls, plant development, etc.).

### Operationality

The practice would require a training course to be implemented and architecture analyses.

On-station architecture approach show plasticity of plants that could be used for improving crop management.

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For more information

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Have a look at invenio website: https://www.invenio-fl.fr/


EXPERIMENT CONDITIONS

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Duration: 2018

Nb of repetitions: 4
Use of photovoltaic system to produce electricity to support strawberry cultivation and eventually post-harvest operations. It is suitable for dry and hot weather and isolated areas, and requires little space.

To reduce high environmental cost (CO2eq) of energy from fossil fuels. Strawberry farming demands high volumes of water in hot and dry climates and requires pumping from wells or ponds.

**Implementation (main steps)**
1. Water intake and energy need evaluation;
2. Context analysis (irradiation);
3. Choice of different solutions (conventional system, dual sides, with reflection panels, solar trackers);
4. Sizing and design;
5. System placement;
6. Performance monitoring and maintenance.

**Conditions of use:** This system fits for southern European or North African climates. If energy/water needs are satisfied, electricity can be led into the power grid (multi-functional farm). Low maintenance (<5h/ha*year).

**Agronomy & Environment**
- **Pesticide reduction** effect not expected.
- **Substitution of fossil fuel with renewable energy and stand-alone electricity production** (mitigation of Greenhouse Gas emissions).
- **No effect** on yield and fruit quality.
- **Replacement of non-renewable resources.** Greenhouse Gas emission reduction. No impact on the agronomic practice.

**Costs & Benefits**
- **Initial investment** required.
- Little time required for setting-up of the practice.
- No extra time required for management.
- Maintenance costs are very low. Service life at least 12 years. The cost is less than 5c€/kg strawberry.

**Operationality**
- Sustainable and effective energy solution for southern-European & north-African context.
**DETAILED INFORMATION ON THE PRACTICE**

Solar pumps are low-cost systems that increase the sustainability and the use of remote areas with high sun irradiance. The main goal of the practice is to identify the optimal position for the photovoltaic system and materials/panels to enhance the energy production. The photovoltaic system has two reflecting panels attached to the sides. Reflecting material could enhance the electricity production. These panels also serve as a lid to protect the photovoltaic system when not in use. Within the scope of the project, a lab-scale model of an integrated photovoltaic panel with support for reflective elements was developed, and evaluated energy performance instantaneously and over time.

**INFORMATION ON THE MODE OF ACTION**

Photovoltaic panel converts sunlight into electricity. This form of energy powers a motorized pump for lifting water from wells. Water can be used directly for irrigation or stored in tanks. In order to increase energy productivity, a lateral reflection system has been considered. It is also possible to use the same reflection system to cover the photovoltaic panels during a period of inactivity, to prevent deterioration.

**RESULTS OF THE EXPERIMENTS**

The use of energy from renewable sources supports and enhances the environmental sustainability, both CO2eq and fossil resource saving, of strawberry production. It is crucial for the transition from fossil to renewable energy. In terms of CO2eq it is possible to save more than 200 gCO2eq for 1 kg of strawberry, especially in hot climates context, where water needs are very high.

The electricity produced by a solar pump with 50 m2 photovoltaic panels makes available the quantity of water required throughout the season to produce one hectare of strawberries.

**Message to take home:** the use of renewable energy is currently an essential element to make plantations environmentally friendly and to ensure accessibility to a key production factor such as water.

**For more information**

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Study On Photovoltaic Modules On Greenhouse Roof For Energy And Strawberry Production, ICAEER 2019, https://doi.org/10.1051/e3sconf/201911803049

**Experiment conditions**

- **Scale**: inapplicable
- **Validity**: ✔
- **Duration**: 2018-2021
- **Nb of repetitions**: inapplicable

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