Climate-KIC is supported by the EIT, a body of the European Union

Friendly Fruit Outcomes :

Environment-friendly innovations in strawberry production

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.

Credits:

Project coordination : François Laurens, Monique Varlet, Aude Alaphilippe

Booklet design and creation : Blandine Chieze

Booklet editing : Blandine Chieze, Aude Alaphilippe, François Laurens, Monique Varlet

Leaflets editing : Marion Casagrande, Aude Alaphilippe, (+ see leaflets for their respective authors)

Table of contents

Friendly Fruit

A 3-YEAR PROJECT

Fruit production — like all agricultural practices — must adapt to climate change. Fruit supply chains are already experiencing the negative impact of a warming climate and environmental degradation. Early and erratic crop flowering, the reduction of 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 3 years (2018-2020) and coordinated by INRAE, the Friendly Fruit project aimed to address some of these challenges in strawberry and apple fruit production. Its objective was threefold: to (i) test practices, (ii) evaluate their impacts, and (iii) 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 the environment 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 on apple and strawberry in various environments to test their efficiency and estimate their agronomical, environmental, and financial impacts.

Main applications of the project results

After three years of experimentation, important outputs had been reached.

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 fertilization 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 enabled 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 (i.e. a synthetic 2 pages) describes **the practice, the conditions for its implementations and its performances, and provides a summary 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 the farm 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 fertilization

Water management

Plant material

Other practices

Leaflets titles and topic associated

Biocontrol and Pesticide reduction

Innovative sprayer reducing pesticide use in strawberry fields	**n°1**
N fertilization 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 fertilization

Optimization of the mineral nutrition of strawberry crops: Monitoring using a theoretical fertilization 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

Optimization of the irrigation of strawberry field crops: Monitoring based on tensiometers	**n°7**

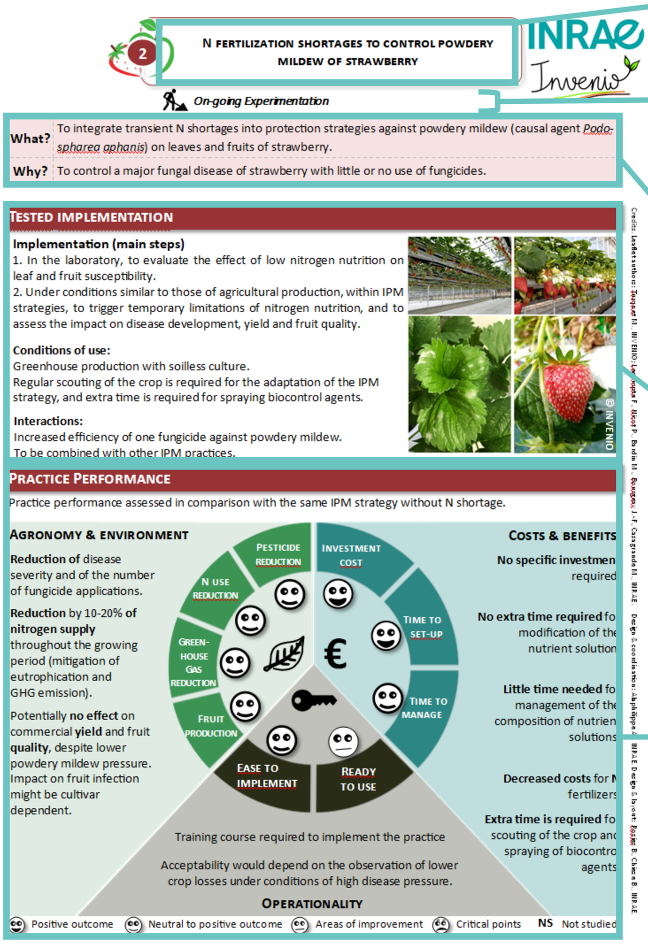
Plant material

Identifying resilient strawberry cultivars to increase crop pedoclimatic adaptation	**n°8**
Knowing plant plasticity to optimize strawberry yield using architecture analysis	**n°9**

Other practices

Pumping solar system in strawberry production	**n°10**

How to read a leaflet



N FERTILIZATION SHORTAGES TO CONTROL POWDERY MILDEW OF STRAWBERRY

On-going 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

Training course required to implement the practice

Acceptability would depend on the observation of lower crop losses under conditions of high disease pressure.

OPERATIONALITY

Positive outcome | Neutral to positive outcome | Areas of improvement | Critical points | NS Not studied

Contents 1/3

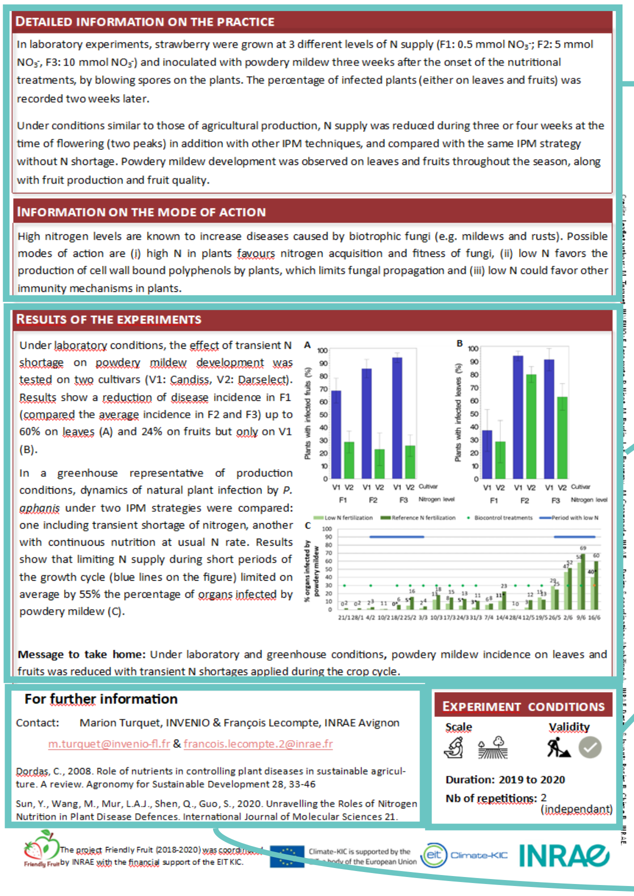
Title of the environment-friendly practices.

Status of the new practice or innovation:
ready to use, promising but need to be confirmed, on-going experimentation, exploratory research.

Short description of the purpose and the reason of the study.

Operationality aspects:
condition of implementation, condition of use and possible interactions with other practices.

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



DETAILED INFORMATION ON THE PRACTICE

In laboratory experiments, strawberry were grown at 3 different levels of N supply (F1: 0.5 mmol NO_3^-; F2: 5 mmol NO_3^-, F3: 10 mmol NO_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 and fruits) was recorded two weeks later.

Under conditions similar to those of agricultural production, N supply was reduced during three or four weeks at the time of flowering (two peaks) in addition with 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 favors the production of cell wall bound polyphenols by plants, which limits fungal propagation and (iii) low N could favor 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 *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 further information

Contact: Marion Turquet, INVENIO & François Lecompte, INRAE Avignon
m.turquet@invenio-fl.fr & francois.lecompte.2@inrae.fr

Dordas, C., 2008. Role of nutrients in controlling plant diseases in sustainable agriculture. A review. Agronomy for Sustainable Development 28, 33-46

Sun, Y., Wang, M., Mur, L.A.J., Shen, Q., Guo, S., 2020. Unravelling the Roles of Nitrogen Nutrition in Plant Disease Defences. International Journal of Molecular Sciences 21.

EXPERIMENT CONDITIONS

Scale | Validity

Duration: 2019 to 2020

Nb of repetitions: 2 (independant)

The project Friendly Fruit (2018-2020) was coordinated by INRAE with the financial support of the EIT KIC. Climate-KIC is supported by the EIT, a body of the European Union

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

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

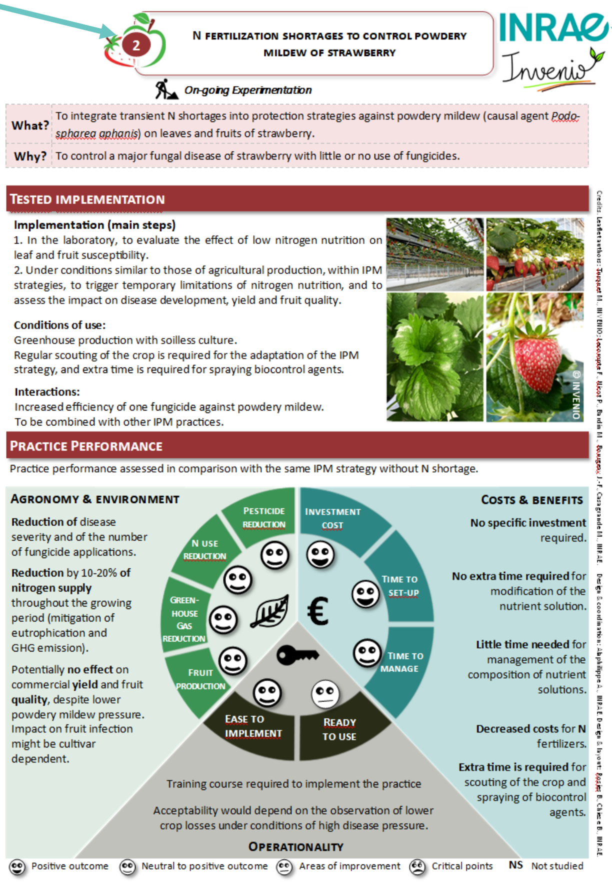
Synthesis of the experimental conditions:
Scale (on laboratory or on field) and its validity (on going or ready to use (see status description on front page))
Duration of the experimentation and the number of repetitions of the experiment in the same year.

To further the understanding of the innovation trial, these are the main contacts or references.

How to read a leaflet

Leaflet number

Logo of the institutions involved in the experimentation.



N FERTILIZATION SHORTAGES TO CONTROL POWDERY MILDEW OF STRAWBERRY

On-going Experimentation

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

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

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PRACTICE PERFORMANCE

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

AGRONOMY & ENVIRONMENT

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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.

Training course required to implement the practice

Acceptability would depend on the observation of lower crop losses under conditions of high disease pressure.

OPERATIONALITY

Positive outcome | Neutral to positive outcome | Areas of improvement | Critical points | NS Not studied

Credits. Leaflet authors: Turquet M., INVENIO; Lecompte F., Nicot P., Bardin M., Bourgeay J.-F., Casagrande M., INRAE. Design & coordination: Alaphilippe A., INRAE. Design & layout: Rosies B., Chieze B., INRAE.

Author: leaflet writer(s)
- *the person(s) in charge of the data collation*
- *together with the leaflet coordinator and designers.*

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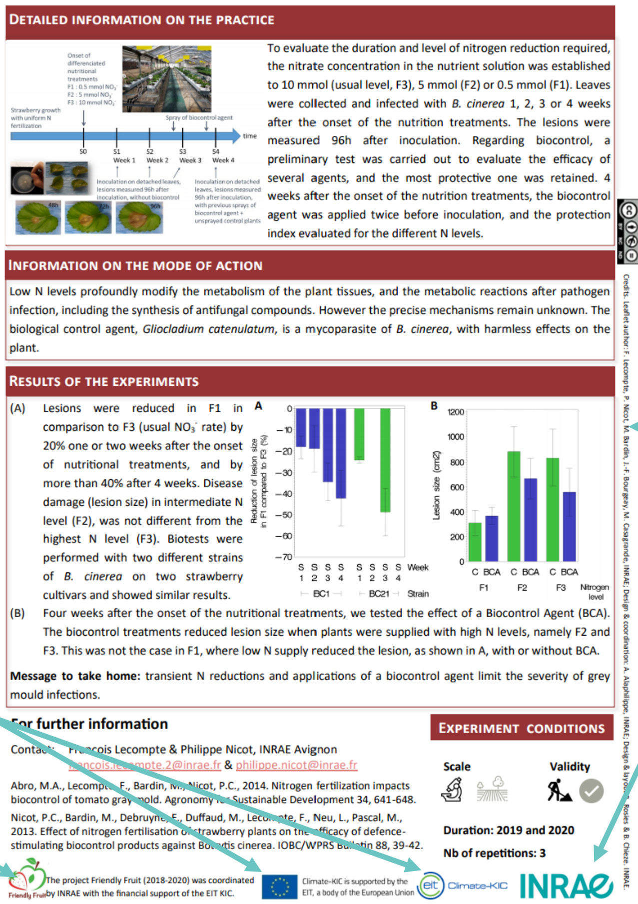

DETAILED INFORMATION ON THE PRACTICE

To evaluate the duration and level of nitrogen reduction required, the nitrate concentration in the nutrient solution was established to 10 mmol (usual level, F3), 5 mmol (F2) or 0.5 mmol (F1). Leaves were collected and infected with *B. cinerea* 1, 2, 3 or 4 weeks after the onset of the nutrition treatments. The lesions were measured 96h after inoculation. Regarding biocontrol, a preliminary test was carried out to evaluate the efficacy of several agents, and the most protective one was retained. 4 weeks after the onset of the nutrition treatments, the biocontrol agent was applied twice before inoculation, and the protection index evaluated for the different N levels.

INFORMATION ON THE MODE OF ACTION

Low N levels profoundly modify the metabolism of the plant tissues, and 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.

RESULTS OF THE EXPERIMENTS

(A) Lesions were reduced in F1 in comparison to F3 (usual NO_3^- 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 further information

Contact: François Lecompte & Philippe Nicot, INRAE Avignon
francois.lecompte.2@inrae.fr & philippe.nicot@inrae.fr

Abro, M.A., Lecompte, F., Bardin, M., Nicot, P.C., 2014. Nitrogen fertilization impacts biocontrol of tomato gray mold. Agronomy for Sustainable Development 34, 641-648.

Nicot, P.C., Bardin, M., Debruyne, F., Duffaud, M., Lecompte, F., Neu, L., Pascal, M., 2013. Effect of nitrogen fertilisation of strawberry plants on the efficacy of defence-stimulating biocontrol products against Botrytis cinerea. IOBC/WPRS Bulletin 88, 39-42.

EXPERIMENT CONDITIONS

Scale | Validity

Duration: 2019 and 2020

Nb of repetitions: 3

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

Climate-KIC is supported by the EIT, a body of the European Union

Credits. Leaflet author: F. Lecompte, P. Nicot, M. Bardin, J.-F. Bourgeay, M. Casagrande, INRAE; Design & coordination: A. Alaphilippe, INRAE; Design & layout: B. Rosies & B. Chieze, INRAE.

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Authors

Logo of the coordinator/ editor of the leaflets

Financial support

Project logo

How to read a leaflet

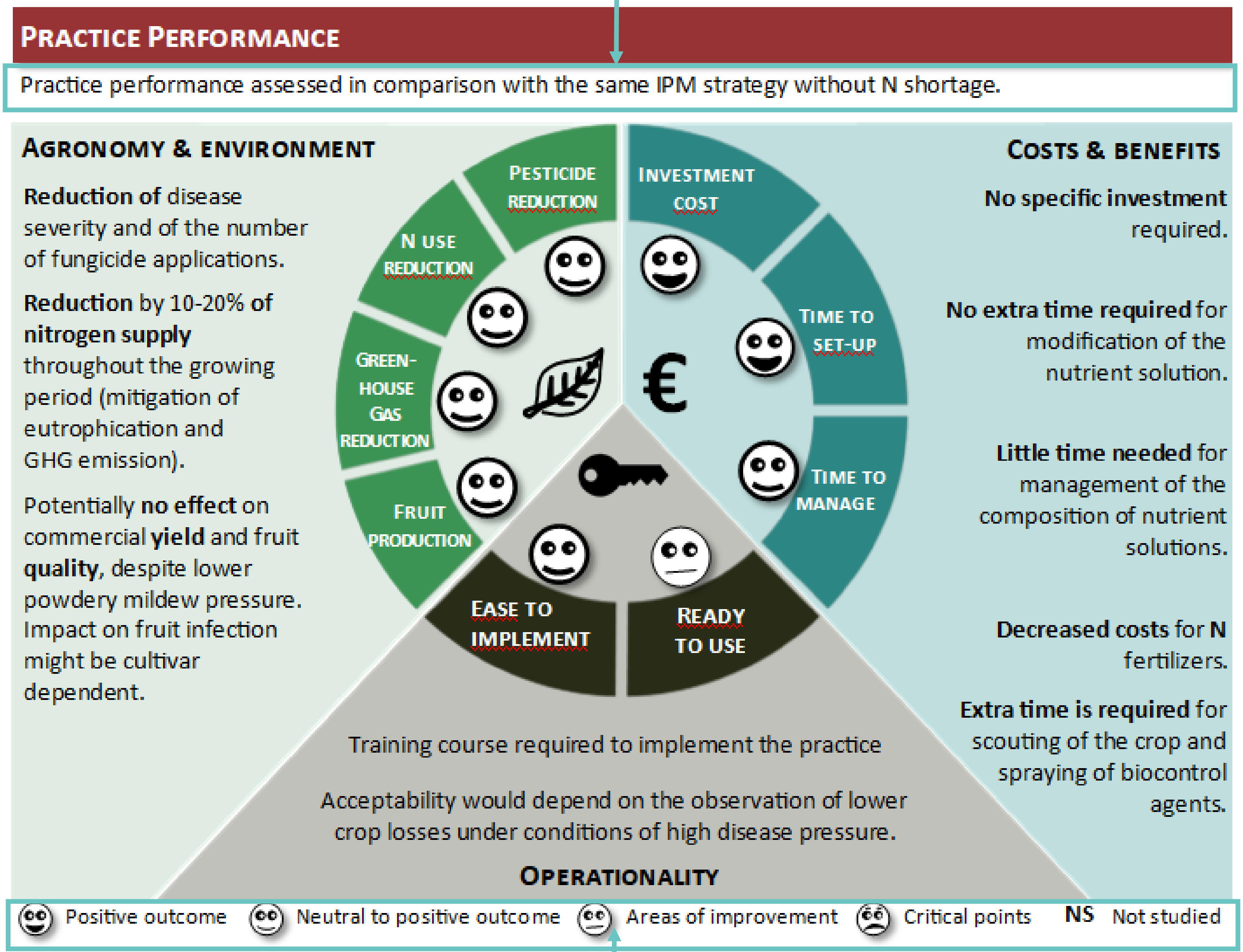
Practice Performance Evaluation 3/3

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 outcome, (ii) neutral to positive outcome, (iii) areas of improvement, (iv) critical points.

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 referent 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.

Agronomy & environment

INDICATORS				
Pesticide reduction	All pesticides eliminated	Some pesticides eliminated	No pesticides eliminated but risk of pullulation of pests is limited	Not known today
Greenhouse gas reduction	2 items below: decrease input use (pesticides or mineral N), decrease energy use (for machinery, warming or cooling), sequester carbon (increase soil organic matter), and/or produce green energy	1 item below: decrease input use (pesticides or mineral N), decrease energy use (for machinery, warming or cooling), sequester carbon (increase soil organic matter), and/or produce green energy	No increase in input or energy use, no carbon sequestration or green energy production	1 item or more below: increase input use (pesticides or mineral N), increase energy use, and/or emit GHG
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				
N, Water or Energy use	Large decrease in quantity (>20%)	Small decrease in quantity (10-20%)	Identical to the standard use	Increase use

Costs & benefits

INDICATORS				
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

INDICATORS				
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
Ready to use	Available and widespread practice	Practice being disseminated	Validated on-station	On-going experimentation

1 Innovative sprayer reducing pesticide use in strawberry fields

INRAE Invenio

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.

Tested implementation

Implementation (main steps):

1. Use of the sprayer requires:
   - Either a towed device with a common binding
   - Or an independent motorisation allowing automatization or 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:

Optimization 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).

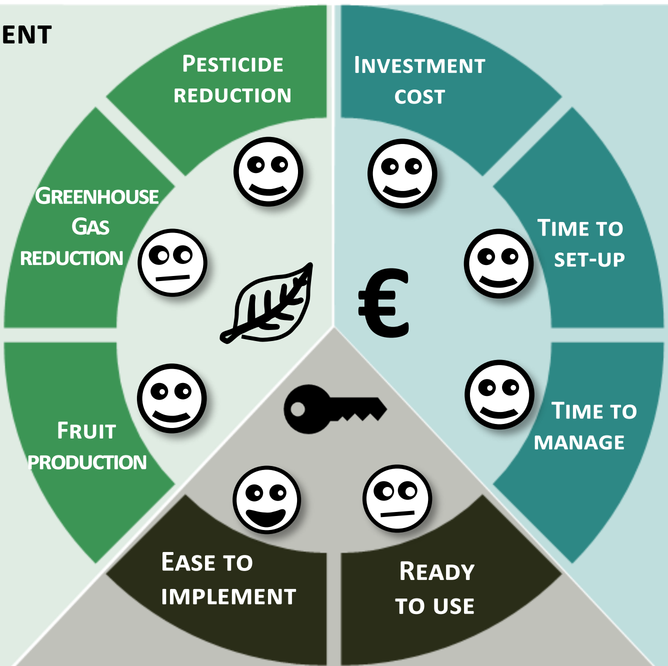
Agronomy & environment

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).

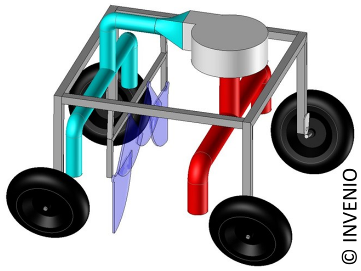
Practice is **easy to use** and allows for better protection for the user but still needs to be tested on farm.

Operationality

Positive outcome | Neutral to positive outcome | Areas of improvement | Critical points | **NS** Not studied

Credits. Leaflet authors: Thiery F., Cavaignac S., INVENIO; Lecompte F., Casagrande M., INRAE. Design & coordination: Alaphilippe A., INRAE. Design & layout: Rosies B., Chieze B., INRAE.

Detailed information on the practice

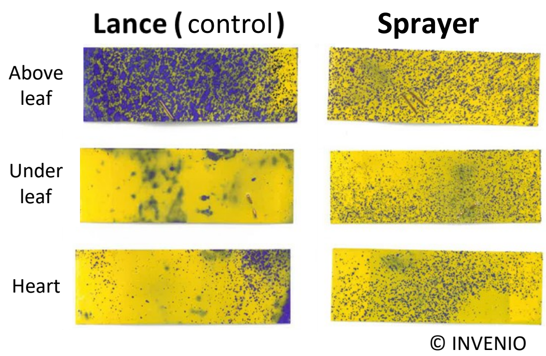


The sprayer developed includes a treatment module with a protection box to avoid treatment deviations and to protect the user. An impeller on the top and an air release allows a shuffling of leaves.

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.

Information on the mode of action

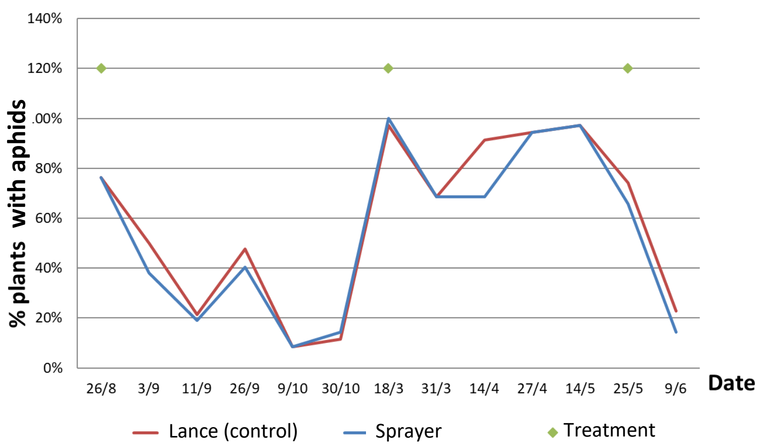
The vent system and airflow direction allow for: (i) a **finer spray** which reduces product amounts, and (ii) a **better shuffling of plants** for a homogeneous distribution of the product on old and young leaves, spikes and heart of plants, in laboratory. Efficacy on pests is the same compared to the 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.



Results of the experiments

Thanks to spraying quality optimization 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 further information

Contact: Fanny Thiery, Sébastien Cavaignac (INVENIO) & François Lecompte (INRAE Avignon)
f.thiery@invenio-fl.fr, s.cavaignac@invenio-fl.fr
& francois.lecompte.2@inrae.fr

Experiment conditions

Scale **Validity**

Duration: 07/2019 to 06/2020

Nb of repetitions: 1

Credits. Leaflet authors : Thiery F., Cavaignac S., INVENIO; Lecompte F., Casagrande M., INRAE. Design & coordination: Alaphilippe A., INRAE. Design & layout: Rosies B., Chieze B., INRAE.

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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

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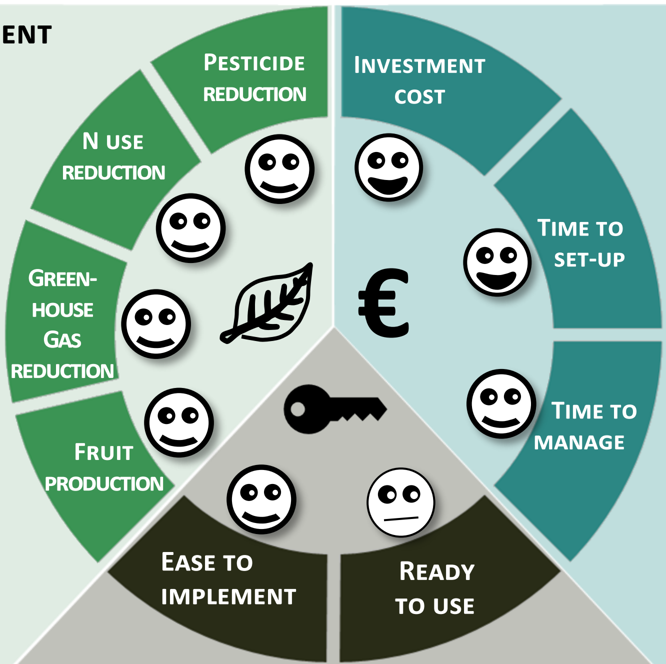

Costs & benefits

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

Training course required to implement the practice

Acceptability would depend on the observation of lower crop losses under conditions of high disease pressure.

Positive outcome | Neutral to positive outcome | Areas of improvement | Critical points | **NS** Not studied

Credits. Leaflet authors: Turquet M., INVENIO; Lecompte F., Nicot P., Bardin M., Bourgeay J.-F., Casagrande M., INRAE. Design & coordination: Alaphilippe A., INRAE. Design & layout: Rosies B., Chieze B., INRAE.

Detailed information on the practice

In laboratory experiments, strawberries were grown at 3 different levels of N supply (F1: 0.5 mmol NO_3^-; F2: 5 mmol NO_3^-, F3: 10 mmol NO_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.

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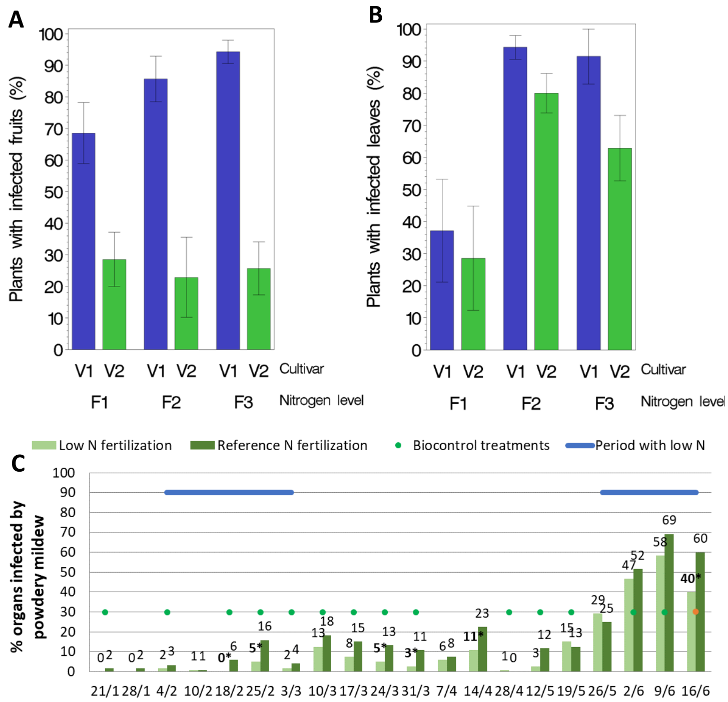
Results of the experiments

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 *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 further information

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Dordas, C., 2008. Role of nutrients in controlling plant diseases in sustainable agriculture. A review. Agronomy for Sustainable Development 28, 33-46

Sun, Y., Wang, M., Mur, L.A.J., Shen, Q., Guo, S., 2020. Unravelling the Roles of Nitrogen Nutrition in Plant Disease Defences. International Journal of Molecular Sciences 21.

Experiment conditions

Scale **Validity**

Duration: 2019 to 2020

Nb of repetitions: 2 (independant)

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

Climate-KIC is supported by the EIT, a body of the European Union

Credits. Leaflet authors: Turquet M., INVENIO; Lecompte F., Nicot P., Bardin M., Bourgeay J.-F., Casagrande M., INRAE. Design & coordination: Alaphilippe A., INRAE. Design & layout: Rosies B., Chieze B., INRAE.

3 INNOVATIVE STRATEGIES FOR THE CONTROL OF GREY MOULD ON STRAWBERRY LEAVES

Promising but needs to be confirmed

What? Decrease leaf susceptibility to the agent of grey mould *Botrytis cinerea* by transient reductions of nitrogen supply and release of biocontrol agents.

Why? To control an important fungal disease of strawberry with little or no use of fungicide.

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 2.5hours/ha).

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

PRACTICE PERFORMANCE

Practice performance assessed in comparison with continuous and usual N supply in production (10 mmol NO_3^-).

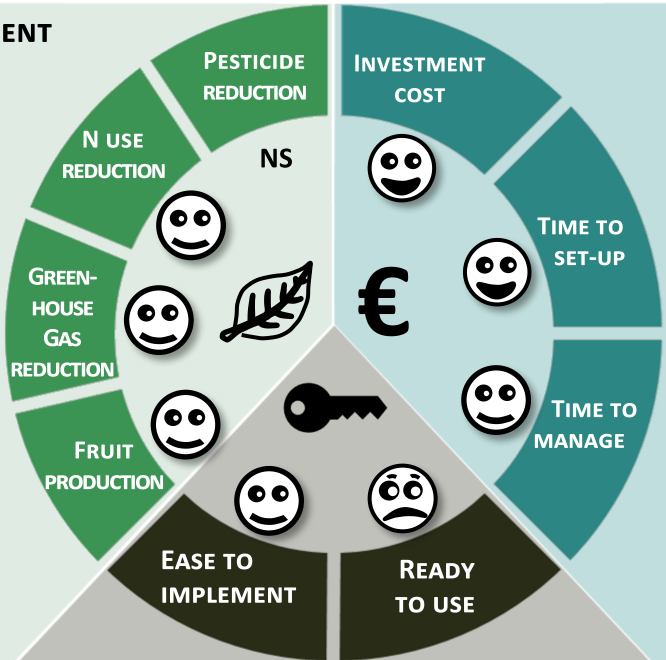
AGRONOMY & ENVIRONMENT

Pesticide reduction effect not known yet.

Reduction of nitrogen use (mitigation of eutrophication and/or Greenhouse Gas emission).

Potentially **no effect** on **yield** and fruit **quality**.

Possible positive or negative effects on post-harvest diseases and **potential reduction of fungicides** but to be tested in real production conditions.



COSTS & BENEFITS

No specific investment required.

No extra time required for setting-up of the practice.

Little time needed for management of the composition of nutrient solutions.

Decreased costs for **N** fertilizers but **additional costs** for the purchase of the **biocontrol product**. **Extra time needed** to spray the biocontrol product.

The practice would require a training course to be implemented

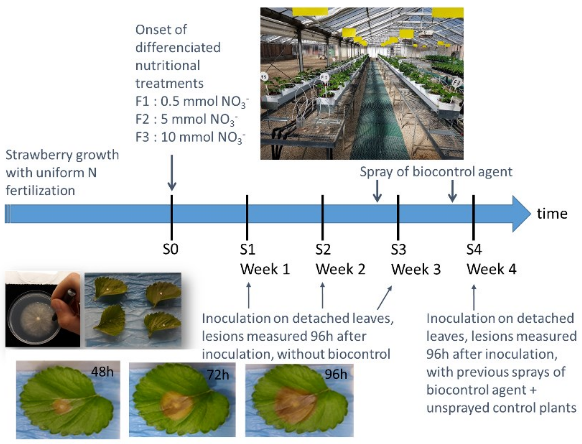
Additional information on farm trials is required before implementation

OPERATIONALITY

Positive outcome | Neutral to positive outcome | Areas of improvement | Critical points | **NS** Not studied

Credits. Leaflet authors: Lecompte F., Nicot P., Bardin M., Bourgeay J.-F., Casagrande M., INRAE. Design & coordination: Alaphilippe A., INRAE. Design & layout: Rosies B., Chieze B., INRAE.

Detailed information on the practice



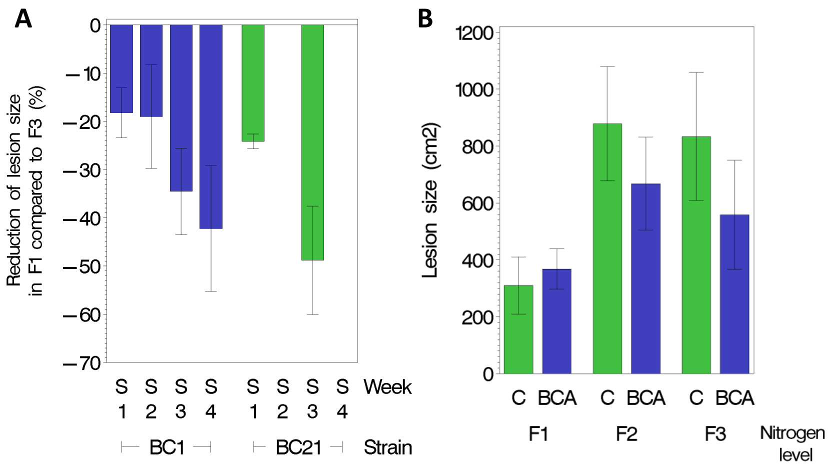
To evaluate the duration and level of nitrogen reduction required, the nitrate concentration in the nutrient solution was set at 10 mmol (usual level, F3), 5 mmol (F2) or 0.5 mmol (F1). Leaves were collected and infected with *B. cinerea* 1, 2, 3 or 4 weeks after the onset of the nutrition treatments. The lesions were measured 96h after inoculation. Regarding biocontrol, a preliminary test was carried out to evaluate the efficacy of several agents, and the most protective one was retained. 4 weeks after the onset of the nutrition treatments, the biocontrol agent was applied twice before inoculation, and the protection index evaluated for the different N levels.

Information on the mode of action

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.

Results of the experiments

(A) Lesions were reduced in F1 in comparison to F3 (usual NO_3^- 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 further information

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Abro, M.A., Lecompte, F., Bardin, M., Nicot, P.C., 2014. Nitrogen fertilization impacts biocontrol of tomato gray mold. Agronomy for Sustainable Development 34, 641-648.

Nicot, P.C., Bardin, M., Debruyne, F., Duffaud, M., Lecompte, F., Neu, L., Pascal, M., 2013. Effect of nitrogen fertilisation of strawberry plants on the efficacy of defence-stimulating biocontrol products against Botrytis cinerea. IOBC/WPRS Bulletin 88, 39-42.

Experiment conditions

Scale **Validity**

Duration: 2019 and 2020

Nb of repetitions: 3

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

Climate-KIC is supported by the EIT, a body of the European Union

Credits. Leaflet authors: Lecompte F., Nicot P., Bardin M., Bourgeay J.-F., Casagrande M., INRAE. Design & coordination: Alaphilippe A., INRAE. Design & layout: Rosies B., Chieze B., INRAE.

Optimization of the mineral nutrition of strawberry crops: Monitoring using a theoretical fertilization schedule and soil bioavailability tests

Promising but needs to be confirmed

What? Monitor the fertilization of strawberry field crops based on: (i) a theoretical fertilization 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 **fertilization 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.

Nitrate concentration in soil solution (mg/l)	Multiplier Coefficient
< 100	1,5
100-150	1
150-200	0.8
C > 200	0.5

Practice Performance

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

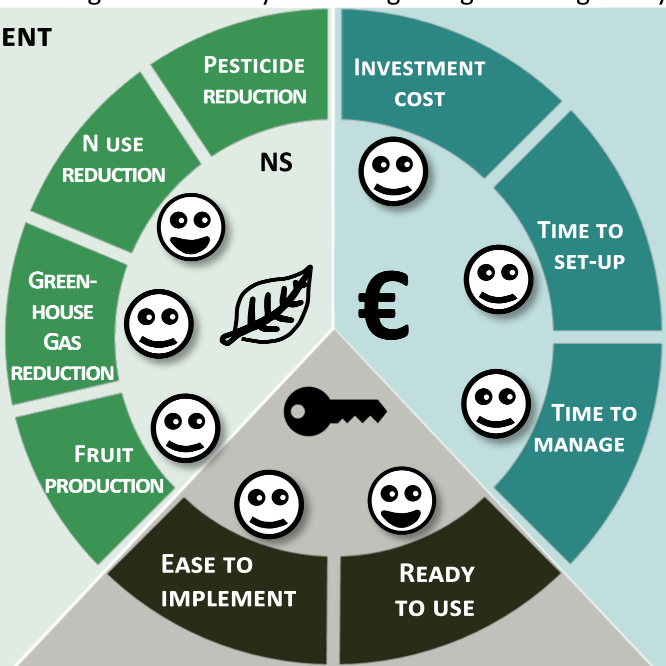
Agronomy & environment

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.



Costs & benefits

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 fertilization costs.

Operationality

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.

Positive outcome | Neutral to positive outcome | Areas of improvement | Critical points | **NS** Not studied

Credits. Leaflet authors: Lecompte F., Bomel S., Casagrande M., INRAE; EL Mrini S., Hamim A., INRA Maroc; Lamrahi D., Essrifi H., Messem; Taleb A., Danone; Didicheikh A., GIZ. Design & coordination: Alaphilippe A., INRAE. Design & layout: Rosies B., Chieze B., INRAE.

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 fertilization 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

Example of the farm n°3 (February 2020)	
Theoretical dose/strawberry plant needs (kg/ha/wk)	6
Nitrate concentration in soil solution (ppm)	321
Coefficient to apply to the theoretical dose	0,5
Actual dose for the "low input" plot (kg/ha/wk)	3
Actual dose for the "farm" plot (kg/ha/wk)	6

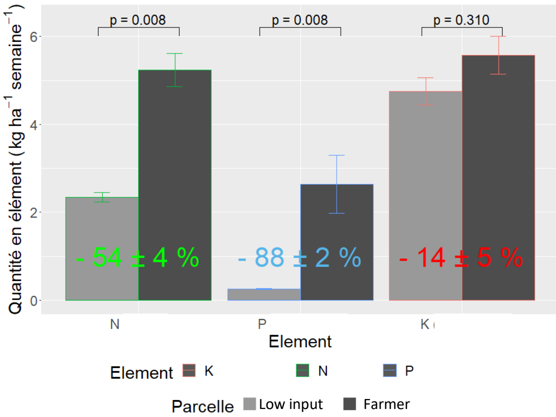
The creation of a **theoretical fertilization schedule** (N, P, K) requires the potential needs of the crop to be defined in relation to quantitative nutrients and expected biomass. Taking into account effectiveness and fertilizer analysis, one obtains a maximum amount to apply per nutrient, which is 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 fertilization planning and bioavailability tests makes it possible to reduce fertilizer consumption, maintain yields and limit environmental pollution.

Values over 6 months	Low inputs	Farmer
Nitrogen (kg/ha)	54.2 ± 5.2	127.1 ± 8.1
Phosphorus (kg/ha)	5.7 ± 0.3	63.3 ± 14.8
Potassium (kg/ha)	108.4 ± 5.7	135.2 ± 8.3
Marketable yield (g/plant)	379 ± 63	392 ± 63



For further information

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Thibault, C, Lecompte, F. 2018, Gestion de la fertilité des sols en culture légumières et maraîchères. GIS Piclég.

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

Experiment conditions

Scale **Validity**

Duration: 1 year (early season 2020)

Nb of repetitions: 5

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

Climate-KIC is supported by the EIT, a body of the European Union

Credits. Leaflet authors: Lecompte F., Bomel S., Casagrande M., INRAE; EL Mrini S., Hamim A., INRA Maroc; Lamrahi D., Essrifi H., Messem; Taleb A., Danone; Didicheikh A., GIZ. Design & coordination: Alaphilippe A., INRAE. Design & layout: Rosies B., Chieze B., INRAE.

NON-CHEMICAL SOIL FUMIGATION IN STRAWBERRY : THE BIOFUMIGATION METHOD

5

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.

Step 2. Soil Incorporation of 'Biofence' pellets to a 25-30 cm soil depth

Step 3. Irrigation to activate 'Biofence' hydrolysis

Conditions of use: Applicable in areas where strawberry is cultivated.

PRACTICE PERFORMANCE

Practice performance assessed in comparison with chemical fumigation.

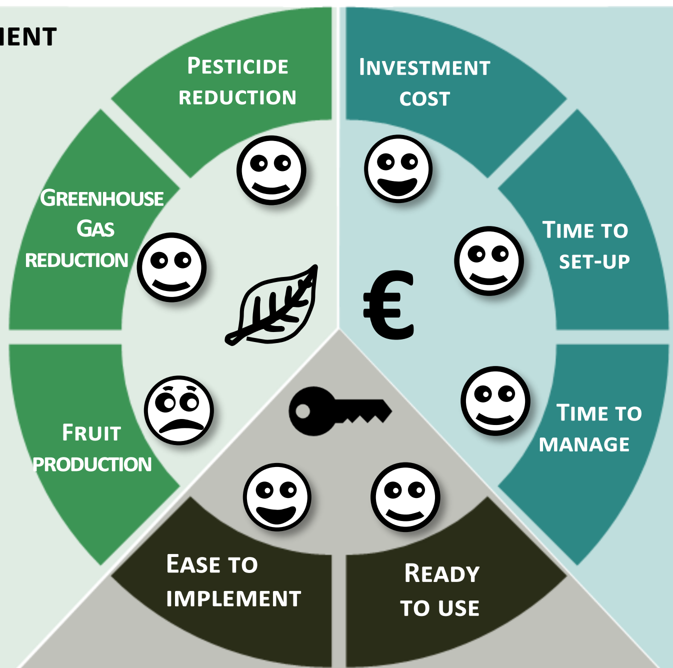
AGRONOMY & ENVIRONMENT

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.

No specific skills or knowledge are required.

It is a **promising alternative** to chemical soil fumigation, with **no harm to operators and environment**

OPERATIONALITY

Positive outcome | Neutral to positive outcome | Areas of improvement | Critical points | **NS** Not studied

Credits. Leaflet authors: Giovannini D., Baruzzi G., CREA; Casagrande M., INRAE. Design & coordination: Alaphilippe A., INRAE. Design & layout: Rosies B., Chieze B., INRAE.

Detailed information on the practice

On 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).

Multispan tunnel (35 m x 5 m; 2.2 m top height) used for the trial and typical of protected strawberry growing in Southern Italy

Information on the mode of action

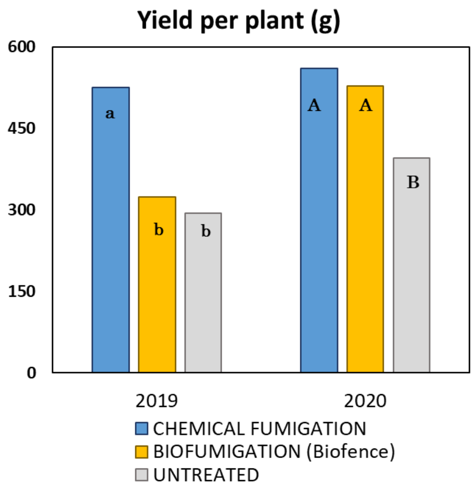
Pre-planting soil fumigation is a necessary practice to minimize replanting syndromes impacting yield quantity and quality of strawberry. The Biofumigation natural system was developed as an alternative to chemical fumigation to break down soilborne pests and pathogens. The **soil is wet** after the 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**.

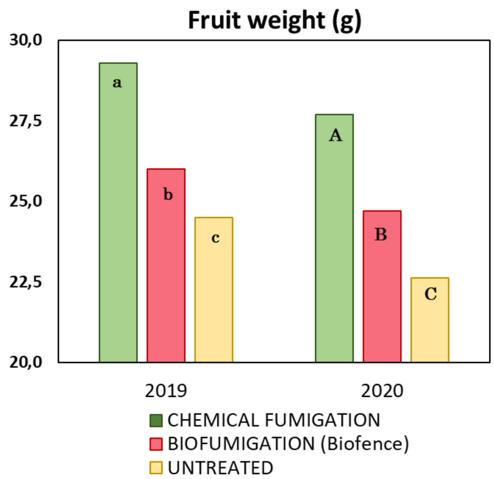
Results of the experiments

Biofumigation as compared to untreated plots allowed some improvements in terms of plant growth, yield and fruit weight. As compared to chemical fumigation, a significant yield reduction was observed in 2019 but not in the 2020 harvest seasons. Some fruit weight reduction was also observed in both years. Optimization of the application conditions is still needed to improve the performance of this technique and allow profitable strawberry cultivation in monoculture.

Message to take home:

Biofumigation with defatted seed meals of Brassicaceae (commercial product: Biofence®, Nutrien Italia S.p.A) shows potential as an eco-friendly alternative to conventional soil chemical fumigation on strawberry that would require additional experimentation.





For further information

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Mocali S., et al., 2015. Resilience of soil microbial and nematode communities after biofumigant treatment with defatted seed meals. Industrial Crops and Products, Volume 75, Part A, pp 79-90; Clarkson J., Michel V. and Neilson R. Mini-paper - Biofumigation for the control of soil-borne diseases.https://ec.europa.eu/eip/agriculture/sites/agri-eip/files/9_eip_sbd_mp_biofumigation_final_0.pdf

Experiment conditions

Scale **Validity**

Duration: 2 years

Nb of repetitions: 4 per year

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

Climate-KIC is supported by the EIT, a body of the European Union

Credits. Leaflet authors: Giovannini D., Baruzzi G., CREA; Casagrande M., INRAE. Design & coordination: Alaphilippe A., INRAE. Design & layout: Rosies B., Chieze B., INRAE.

NON-CHEMICAL SOIL FUMIGATION IN STRAWBERRY: THE ASD (ANAEROBIC SOIL DISINFESTATION) METHOD

6

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):

In the time interval between previous crop removal and new strawberry planting:

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.

Alternative implementation (avoiding steps 4 & 5): Could be combined with raised beds preparation if using a double (TIF and black) mulching film. Soil irrigation through the drip lines under the mulch could initiate product decomposition.

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.

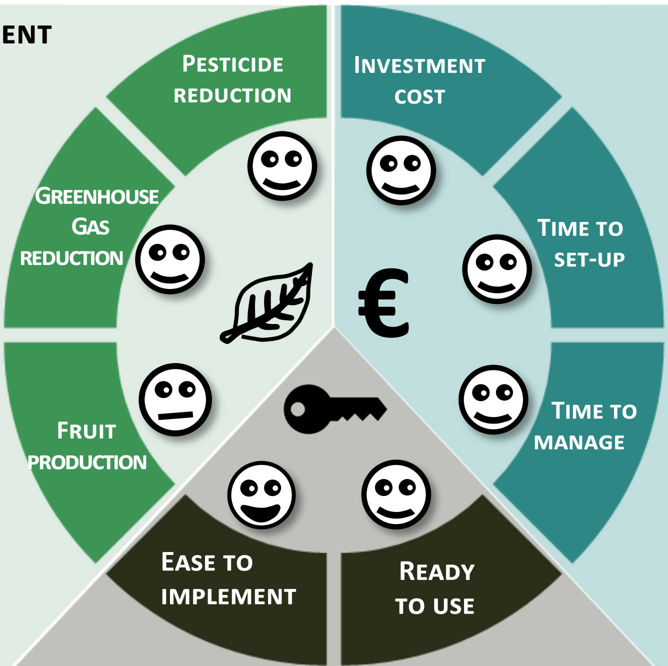
AGRONOMY & ENVIRONMENT

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.**

Positive outcome · Neutral to positive outcome · Areas of improvement · Critical points · **NS** Not studied

Credits. Leaflet authors: Giovannini D., Baruzzi G., CREA; Casagrande M., INRAE. Design & coordination: Alaphilippe A., INRAE. Design & layout: Rosies B., Chieze B., 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

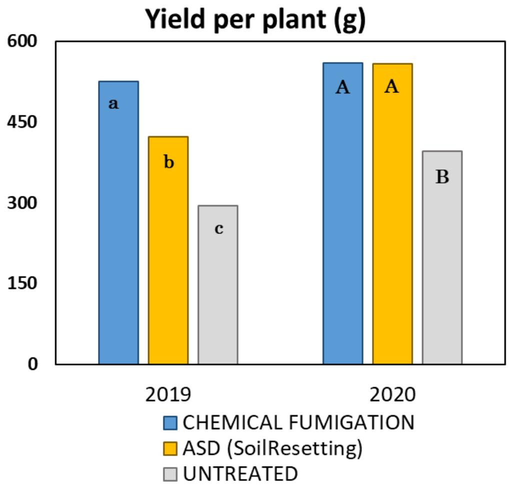
Pre-planting soil fumigation is a necessary practice to minimize the replanting syndrome impacting yield quantity and strawberry quality. The ASD practice was developed as an alternative to chemical fumigation to break down soilborne pests and pathogens. The mode of action is still not fully understood. 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.

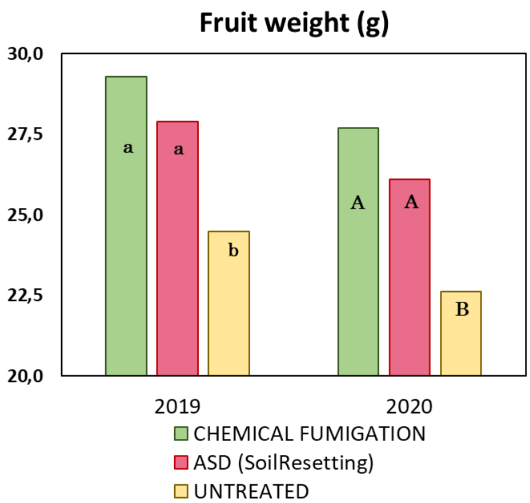
Results of the experiments

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®, Thatcthec, NL) is an almost ready-to-use eco-friendly alternative to soil chemical fumigation on strawberry.





For further information

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Shennan, C., Muramoto, J., Lamers, J., Mazzola, M., Rosskopf, E.N., Kokalis-Burelle, N., Momma, N., Butler, D.M. and Kobara, Y. 2014. Anaerobic soil disinfestation for soil borne disease control in strawberry and vegetable systems: current knowledge and future directions. Acta Hortic. 1044, 165-175

Strauss L. and Kluepfel D.A. 2015. Anaerobic soil disinfestation: A chemical-independent approach to pre-plant control of plant pathogens, Journal of Integrative Agriculture, 14(11):2309-2318.

Experiment conditions

Scale | **Validity**

Duration: 2 years

Nb of repetitions: 4 per year

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

Climate-KIC is supported by the EIT, a body of the European Union

Credits. Leaflet authors: Giovannini D., Baruzzi G., CREA; Casagrande M., INRAE. Design & coordination: Alaphilippe A., INRAE. Design & layout: Rosies B., Chieze B., INRAE.

Optimization of the irrigation of strawberry field crops: Monitoring based on tensiometers

Promising but needs to be confirmed

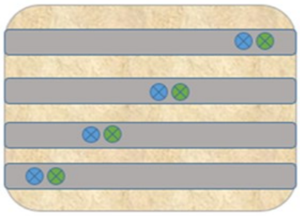
What? Irrigation management based on sensors which measure soil water tension, a component of the water potential, in strawberry field crops.

Why? 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 fertilization.

Practice Performance

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

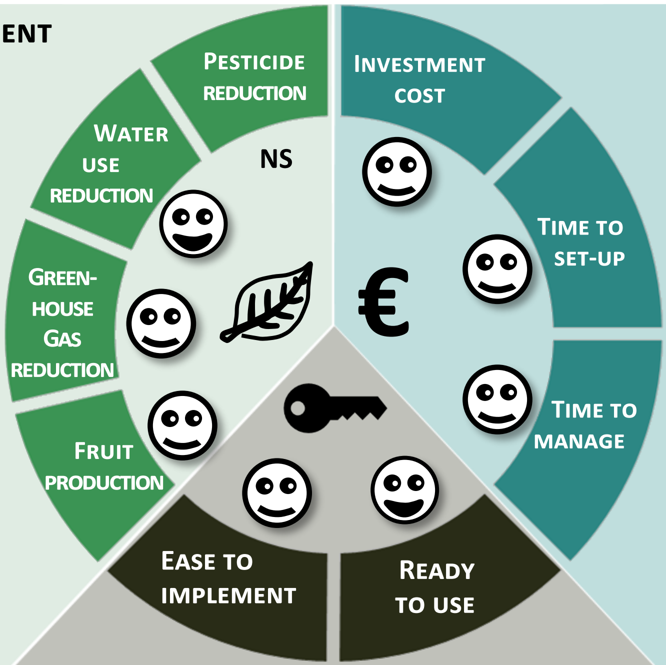
Agronomy & environment

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.



Costs & benefits

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**.**

Operationality

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

Positive outcome | Neutral to positive outcome | Areas of improvement | Critical points | **NS** Not studied

Credits. Leaflet authors: Lecompte F., Bomel S., Casagrande M., INRAE; Thiery F. (INVENIO); EL Mrini S., Hamim A., INRA Maroc; Lamrahli D., Essrifi H., Messem; Taleb A., Danone; Didicheikh A., GIZ. Design & coordination: Alaphilippe A., INRAE. Design & layout: Rosies B., Chieze B., INRAE.

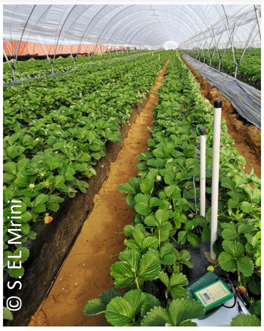
Detailed information on the practice

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.

Lower soil water tension	Water supply
0 - 10 cbar	Decrease the dose
10 - 15 cbar	No change
> 15 cbar	Increase the dose

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

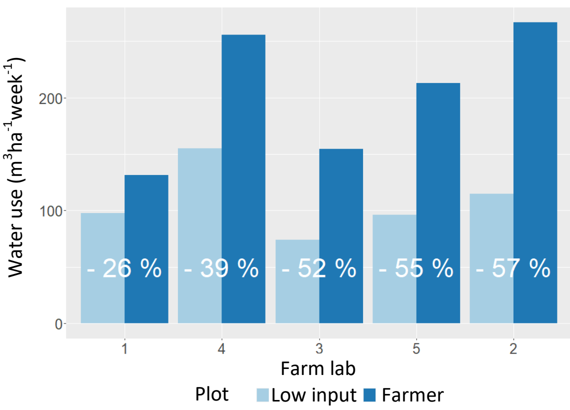
In Morocco, with the pedoclimatic conditions and regarding farming practices of the followed farms, this practice allows an average significant reduction of 46 ± 6 % of water consumption during the first 6 months of cultivation (p-value = 0,032). Median is 52 % and reductions ranged from 26 % to 57 %. 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.

	Low inputs	Farmer
Irrigation	2,889 ± 380 m^3/ha	5,451 ± 705 m^3/ha
Efficiency	0.13 ± 0.01	0.07 ± 0.01



For further information

Contact: François Lecompte, INRAE Avignon
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Ricard, S, Lecompte, F. 2015, Pilotage de l'irrigation en cultures légumières : enquêtes sur les outils et les pratiques. GIS PICLég.

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

Experiment conditions

Scale **Validity**

Duration: one year (early season)

Nb of repetitions: 6

Friendly Fruit
The project Friendly Fruit (2018-2020) was coordinated by INRAE with the financial support of the EIT KIC.
Climate-KIC is supported by the EIT, a body of the European Union
Climate-KIC
INRAE

Credits. Leaflet authors: Lecompte F., Bomel S., Casagrande M., INRAE; Thiery F. (INVENIO); EL Mrini S., Hamim A., INRA Maroc; Lamrahi D., Essrifi H., Messem; Taleb A., Danone; Didicheikh A., GIZ. Design & coordination: Alaphilippe A., INRAE. Design & layout: Rosies B., Chieze B., INRAE.

Institut National de la Recherche Agronomique

Invenio

8

Identifying resilient strawberry cultivars to increase crop pedoclimatic adaptation

UNIVERSITÀ POLITECNICA DELLE MARCHE

crea Consiglio per la ricerca in agricoltura e l'analisi dell'economia agraria

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.

Interactions: Effect of limiting the irrigation regime on plants.

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

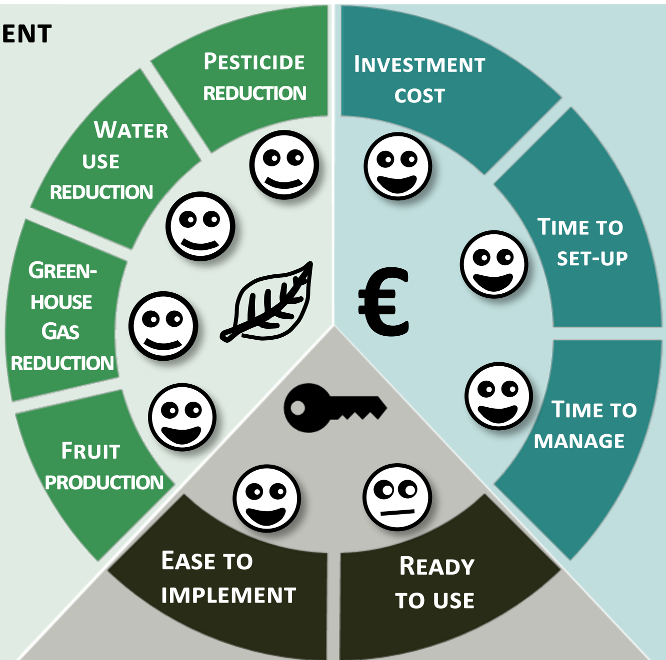
Pesticide reduction from 10 to 30%.

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.

Increased sustainability, reduction of water, N and pesticide use, and increased fruit quality.



Costs & benefits

No specific investment required (water meters monitoring the two water regimes used).

No extra time required 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.

Operationality

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**

Positive outcome | Neutral to positive outcome | Areas of improvement | Critical points | **NS** Not studied

Credits. Leaflet authors: Mezzetti B., UNIVPM, Baruzzi G., CREA, Chartier P., INVENIO, Hamim A., INRA Marocco, Casagrande M., INRAE. Design & coordination: Alaphilippe A., INRAE. Design & layout: Rosies B., Chieze B., INRAE.

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:

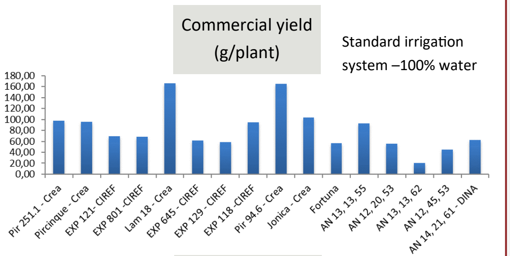
- Each of 15 selections and Florida Fortuna, as the control cultivar, were tested with 100 plants, divided into 4 plots of 25 plants.
- With this experimental scheme, 2 trials were set up: (1) standard irrigation system; (2) reduced irrigation water restitution = 70%.

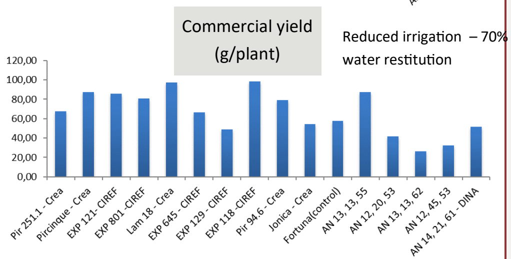
Information on the mode of action

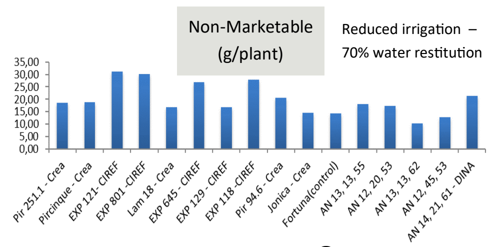
All genotypes were tested by using the standard growing conditions used in the Mediterranean areas but with a specific monitoring of plant response to standard and reduced water conditions. The trial was aimed to identify genotypes with higher plant rusticity (requiring less water and nitrogen), tolerance 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.







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Message to take home: AN13,13,55, Dina (UNIVPM), EXP118, EXP801, EXP121 (INVENIO) and Lam18 and Pircinque (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.

Experiment conditions

Scale **Validity**

Duration: 2018-2021

Nb of repetitions: 3 repetitions in 3 field trials.

For further information

Contact: B. Mezzetti (UNIVPM), G. Baruzzi (CREA), P. Chartier (INVENIO) & Ahlam Hamim (INRA Marocco)

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

Climate-KIC is supported by the EIT, a body of the European Union

Credits. Leaflet authors: Mezzetti B., UNIVPM, Baruzzi G., CREA, Chartier P., INVENIO, Hamim A., INRA Marocco, Casagrande M., INRAE. Design & coordination: Alaphilippe A., INRAE. Design & layout: Rosies B., Chieze B., INRAE.

9 KNOWING PLANT PLASTICITY TO OPTIMIZE STRAWBERRY YIELD USING ARCHITECTURE ANALYSIS

Ready-to-use

What? Carrying out architecture analysis to studying strawberry plasticity, i.e. plant's capacity to present different phenotypes according to environment.

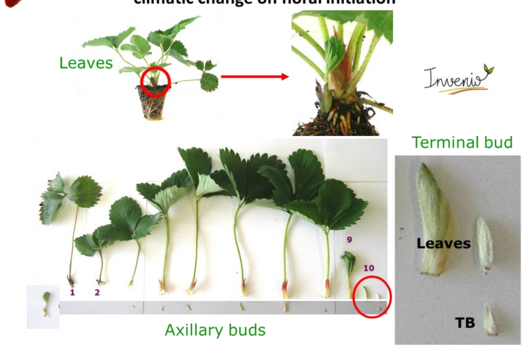
Why? To improve knowledge on variability of tray plants according to the origin of their plant-bearing runners. Ultimately, to develop a more resilient yield.

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.

Plant architecture and modelling for studying the impact of climatic change on floral initiation



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.

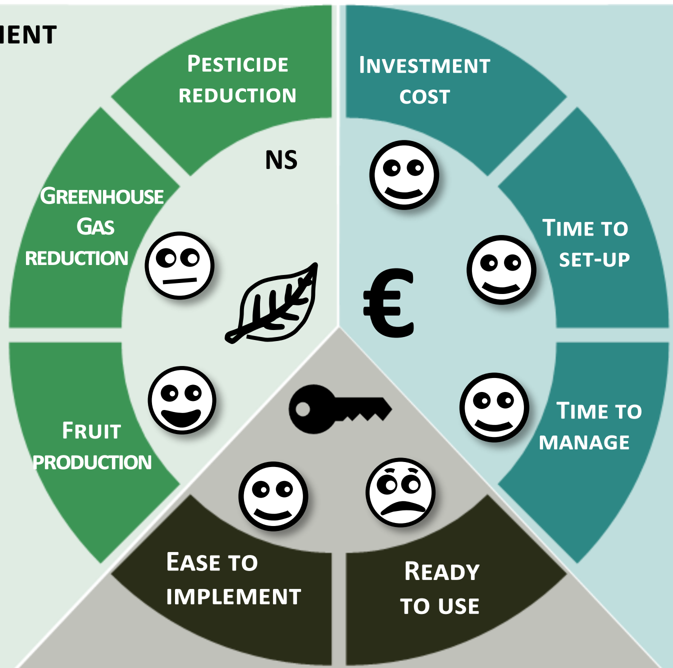
AGRONOMY & ENVIRONMENT

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.

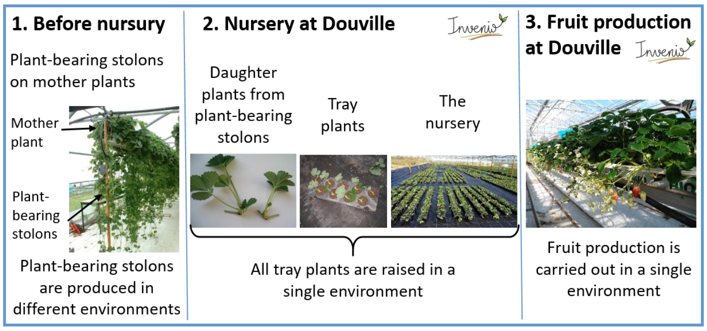
Positive outcome | Neutral to positive outcome | Areas of improvement | Critical points | NS Not studied

Credits. Leaflet authors: Denoyes B., Abadie M., Casagrande M., INRAE, Déméné M.-N., Guy K., INVENIO. Design & coordination: Alaphilippe A., INRAE. Design & layout: Rosies B., Chieze B., INRAE.

Detailed information on the practice

Studying the Gariguette variety from nursery to fruit production at INVENIO Douville:

1. **one year assay with 11 origins of plant-bearing runners** from mother plants grown in Europe and Morocco.
2. **Plant architecture in nursery** to evaluate the plant development, floral initiation and the potential yield.
3. For each plant-bearing stolon origins, sampling of 12 plants (4 replicates of 3 plants) for **architecture throughout the plant's development in nursery** (Douville).



Information on the mode of action

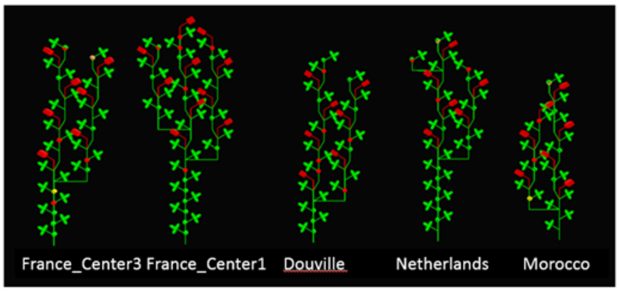
The architectural development of the cultivated strawberry determines the regularity of yield. Strawberry architecture is characterized by successive modules (*i.e.* axes of determinate growth) deriving one from another by sympodial branching and by the generation of runners which are specialized axes for spatially duplicating the whole plant structure.

Results of the experiments

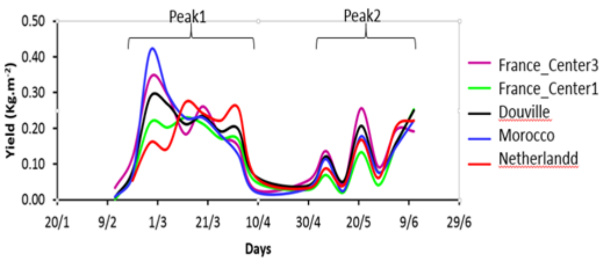
(A) In nursery: Plant-bearing runners from 5 origins were transplanted and raised at Douville INVENIO to produce tray plants. Depending on the plant-bearing stolon origin, plants developed more or less secondary axes. Plants from Morocco were less developed, while plants from Centre of France more developed.

(B) In fruit production: Large differences appeared in peak_1 of production while peak_2 was similar irrespective of the plant-bearing stolon origin. The peak_1 of fruit production is the consequence of floral initiation on orders 0 and 1 that took place in nursery (all tray plants were bred in Douville) but is influenced by plant-bearing stolon origin. Fruit production of peak_2 is due to floral initiation on orders 2, 3 and sometimes 4, which takes place after dormancy. In summary, the first peak is influenced by the environment of mother plants and of tray plants (nursery). Therefore, the environment of plant-bearing stolon production is very important for fruit production.

Message to take home: Plasticity of strawberry plants is observed in nursery with the effect of environment on mother plants that produce plant-bearing runners.



Representation of the central plant of each plant-bearing stolon origin (represented using MTG).



Weekly mean of yield production for plants issued from 5 different plant-bearing stolon origins (France, Netherlands, Morocco)

For further information

Contact: Béatrice Denoyes, (INRAE) & Marie-Noële Demené (INVENIO)
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Have a look at invenio website: https://www.invenio-fl.fr/

Labadie et al. Spatio-temporal analysis of the architecture of the perennial herbaceous strawberry species. In preparation.

Demene et al. Influence of environment on Gariguette in nursery. In preparation.

Experiment conditions

Scale **Validity**

Duration: 2018

Nb of repetitions: 4

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

Climate-KIC is supported by the EIT, a body of the European Union

Credits. Leaflet authors: Denoyes B., Abadie M., Casagrande M., INRAE, Déméné M.-N., Guy K., INVENIO. Design & coordination: Alaphilippe A., INRAE. Design & layout: Rosies B., Chieze B., INRAE.

10 Pumping solar system in strawberry production

Promising but needs to be confirmed

What? 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.

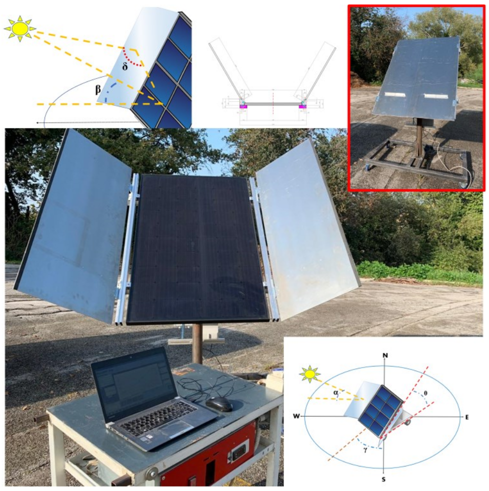
Why? To reduce high environmental cost (CO_2eq) of energy from fossil fuels. Strawberry farming demands high volumes of water in hot and dry climates and requires pumping from wells or ponds.

Tested implementation

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).



Practice Performance

Practice performance assessed in comparison with electricity provided from power grid or electrical generator that both use fossil fuel.

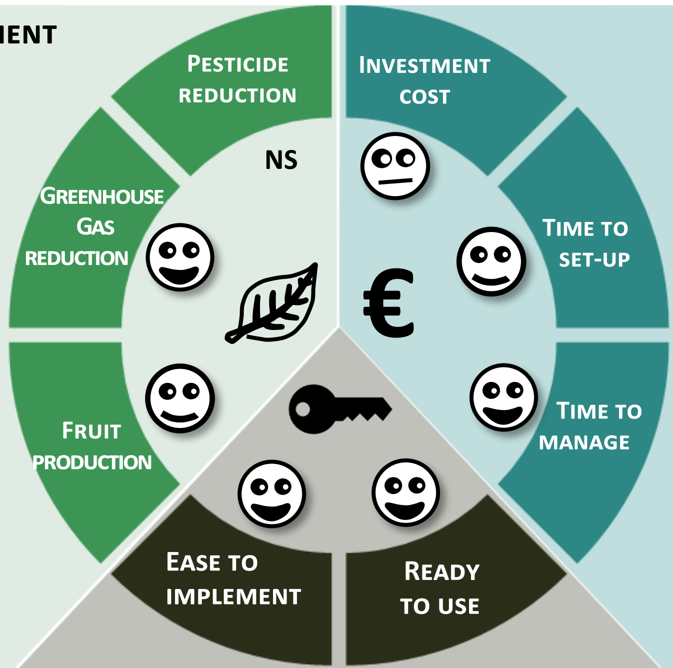
Agronomy & environment

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

The practice does not require highly skilled staff.

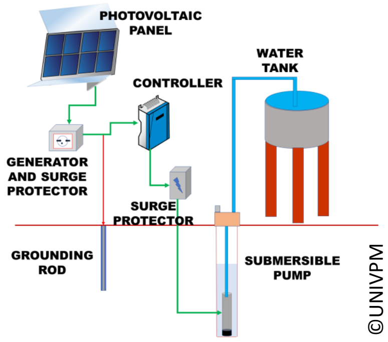
Sustainable and effective energy solution for southern-European & north-African context.

Positive outcome | Neutral to positive outcome | Areas of improvement | Critical points | NS Not studied

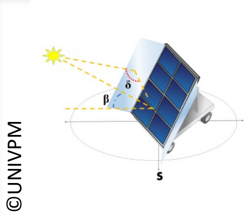
Credits. Leaflet authors: Toscano G., Fabrizi S., Duca D., UNIVPM, Casagrande M., INRAE. Design & coordination: Alaphilippe A., INRAE. Design & layout: Rosies B., Chieze B., INRAE.

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.



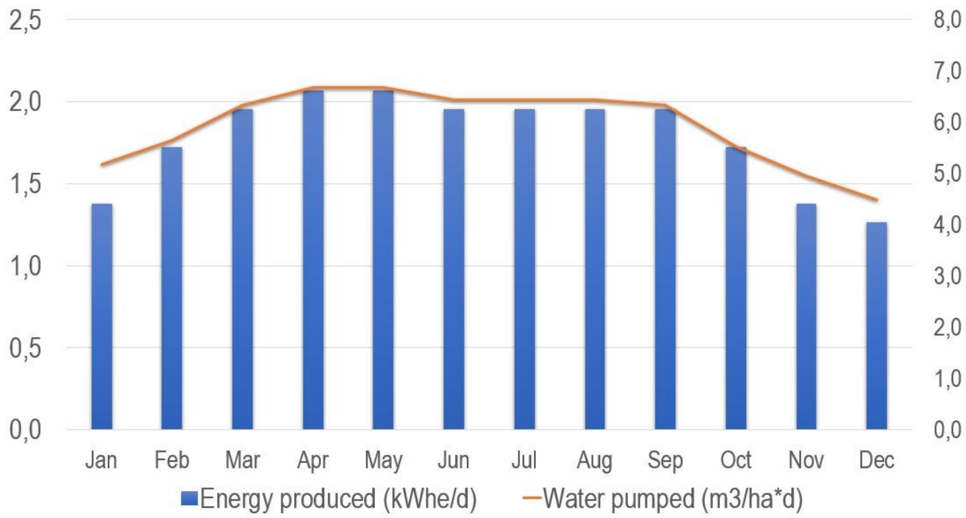
Information on the mode of action



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 further information

Contact: Giuseppe Toscano, Sara Fabrizi & Daniele Duca, UNIVPM
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d.duca@staff.univpm.it

Efficiency improvement of flat plate solar collector using reflector, Energy reports 3 (2017), https://doi.org/10.1016/j.egyr.2017.08.002.

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

Experiment conditions

Scale **Validity**

Duration: 2018-2021

Nb of repetitions: inapplicable

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

Climate-KIC is supported by the EIT, a body of the European Union

Credits: Leaflet authors: Toscano G., Fabrizi S., Duca D., UNIVPM, Casagrande M., INRAE. Design & coordination: Alaphilippe A., INRAE. Design & layout: Rosies B., Chieze B., INRAE.