


Reducing

the use of mineral fertilisers
and agro-chemicals by

recycling treated organic waste

as compost and bio-char

www.fertiplus.eu

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EDITORIAL

A vast quantity of organic waste is produced annually within the EU. Agriculture is the biggest contributor in organic residues, followed by yard and forestry waste, sludge waste from water treatment plants, food processing waste, and an organic fraction in municipal waste. Urban and farm organic residues are a large source of nutrients and today not used to its full potential.

Biochar, compost and biochar-compost blend are products that have a potential to be used commercially in agriculture as an alternative or partial substitution to synthetic fertilizers. FERTIPLUS has taken up the challenge to identify innovative processing technologies and strategies to convert urban and farm organic waste into valuable and safe products for use in agriculture and horticulture.

We have focused on compost and biochar and a blend of both products. The most attractive options have been tested in lab and field trials. Based on our experiments we provide science based information on use, quality and safety of these products. This should allow industries to further develop these products.

We have concluded and communicated with EU policy makers on the options for regulation and revision of the fertilizer legislation to enhance safe use of these recycled products in agriculture.

Waste processing considered in FERTIPLUS included biological treatment, composting, or pyrolysis resulting in biochar and combinations of such products including anaerobic digestion.

We have suggestions on what characteristics make a good biochar and what functionality biochar would add to sustain and enhance soil properties and soil quality once applied to soils. And we have tested how biochar can be used in combination with composting or added to compost or in combination with anaerobic digestion to enhance the nutrient retention and nutrient use efficiency.

Our website at www.fertiplus.eu provides focused dissemination and communication with brochures and reports and findings from meetings on innovations with our stakeholders, farmers and extension services.

FERTIPLUS has worked with 14 partners and it has been a great pleasure to work together and the support from the EU FP7 programme and other funding has been greatly appreciated by all of us.

PETER KUIKMAN

Fertiplus is coordinated by Dr. Peter Kuikman at ALTERRA at Wageningen University and Research Center.

THE JOINT ROLE OF BIOCHAR AND COMPOST IN A EUROPEAN FERTILIZER MARKET

Daniel Meyer-Kohlstock (Bauhaus-Universität Weimar) and Peter Kuikman (ALTERRA)

A potential replacement of synthetic fertilizers via compost and biochar depends strongly on two questions. 1) How much nutrients can they provide and 2) How much can they increase nutrient efficiency?

The answer to the first question can be found in Figure 1. Given that only one third of the bio-waste (Figure 2) and only one half of the waste water sludge is currently used as compost and bio solid, the replacement of synthetic fertilizers could be increased, but the potential altogether seems to be marginal. The same applies to biochar from woody bio-waste.

Much more nutrients are available in agricultural manure. However, since most of it is already applied in agriculture, it can hardly replace synthetic fertilizers, except for surplus manure from regions with dense livestock holding (see Figure 3).

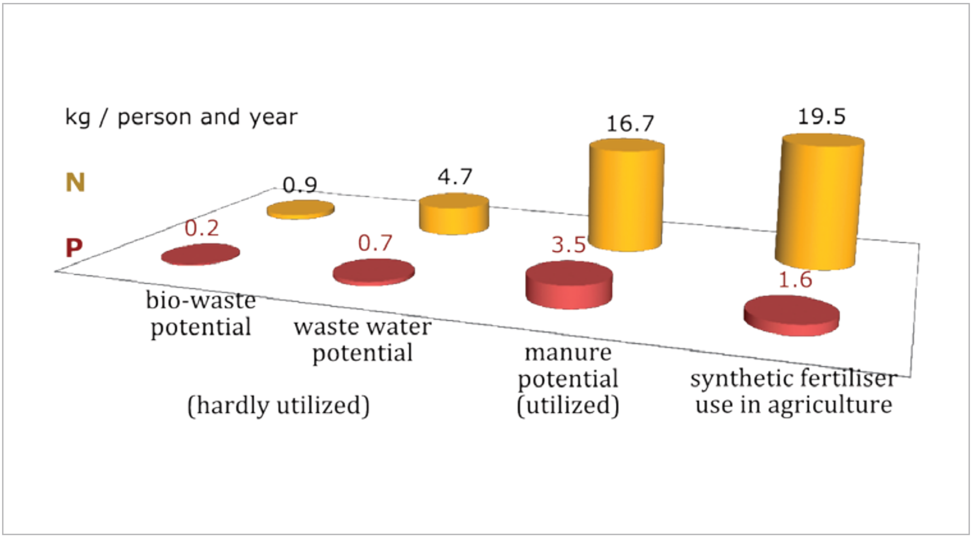


Figure 1. Nitrogen (N) and Phosphorus (P) potential and utilization per person and year in the EU

The answer to the second question is less precise, yet more important. While some research showed even greater agricultural yields than possible with synthetic fertilizers, it is difficult to analyze the complex relations between biochar, compost, and soil. However, they point to a possible role of biochar-compost substrates in the fertilizer market, i.e. to the reduction of applied nutrients by improving the nutrient efficiency, for organic as well as for synthetic fertilizers.

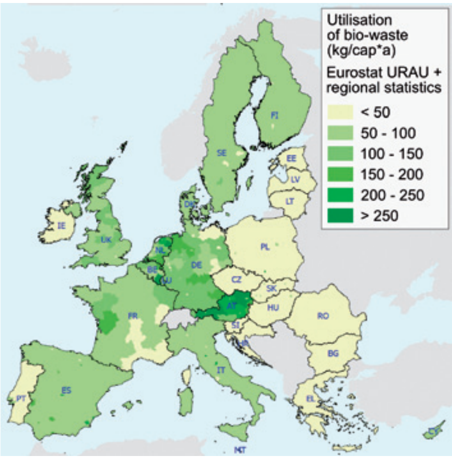


Figure 2. Bio-waste utilization in the European Union in kg per person and year
(source: doi:10.3390/resources4030457)

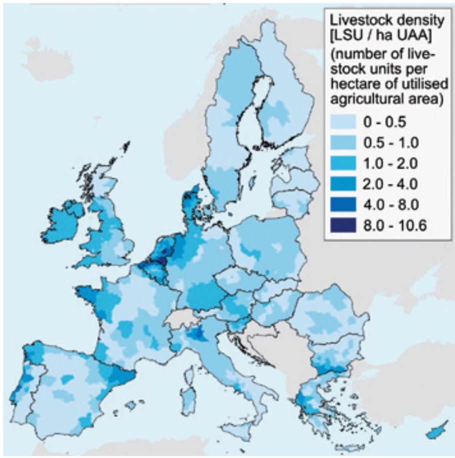


Figure 3. Livestock units (equivalent of a grazing adult dairy cow) per hectare agricultural land
(source: doi:10.3390/resources4030457)

BIOCHAR PRODUCTION AND ITS BENEFICIAL PROPERTIES FOR AGRICULTURAL USE

Andrew Ross (Univ. Leeds), Surjit Singh, (Univ. Leeds), Lydia Fryda (ECN) and Rian Visser (ECN)

The objective of this work has been to Explore feedstock, conversion technologies and modification towards functional biochar & hydrochar. The Hypothesis made is that 'No one size fits all biochar: There is a variation of soils and crops demand different types biochar' (Figure 4). Biochar characteristics are linked to (a) feedstock (b) process (c) modification (physical/ chemical activation) to improve adsorption capacity, Specific Surface Area, porosity Biochars vs. hydrochars show different physical and chemical properties; probably complementary reaction in.

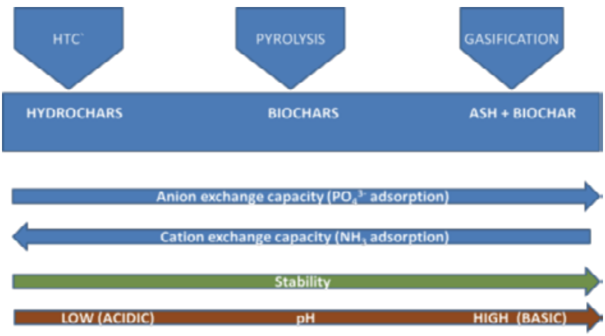


Figure 4. Biochar production routes, main properties and soil categories
(source: doi:10.3390/resources4030457)

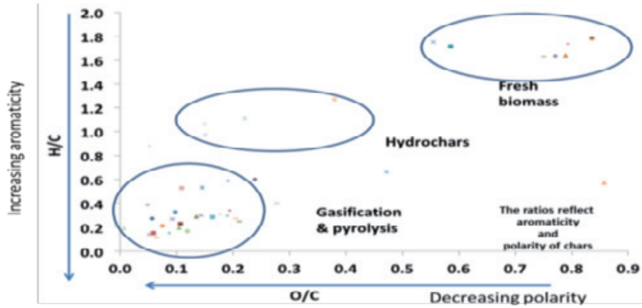


Figure 5. Van Krevelen diagram of the produced biochars

Biochar was produced at ECN , Univ. of Leeds and at the industrial partner Proininso, in an auger type slow pyrolyser at 400oC & 600oC (2) modified pilot fluidised bed gasifier, at 670oC & 750oC (continuous biochar production), (3) a hydrothermal carbonisation reactor, applying high pressure at 250 oC / 1 hr @ feed /water loading = 10 wt.% and a slow pyrolysis large scale unit. There is a clear distinction among the biochars produced in each reactor type, as shown in the Van Krevelen diagram in Figure 5. Figure 6 shows the measured PAHs according to EPA 16 PAH definition. Most biochars' are below the threshold proposed by IBI and EBC. The PAH content is mainly process related.

Furthermore the recalcitrance index, which is a measure of the lifetime of biochar in the soil, predicts that HTC hydrochars are less stable than pyrolysis biochars, as shown in Figure 7, as Class B chars (0.50 ≤ R50 < 0.70, pyrolysis biochars) are more recalcitrant than Class C chars (R50 < 0.50, HTC biochars).

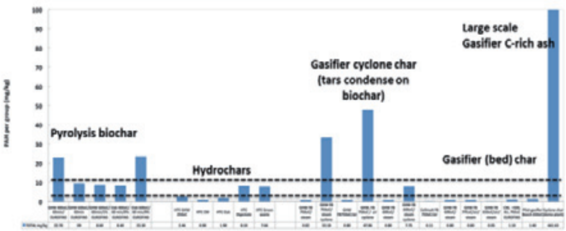


Figure 6. EPA 16 PAH concentration in biochar

Feedstock	HTC 250	Pyrolysis 400	Pyrolysis 600
Holm Oak	0.49	0.50	0.54
CellMatt	0.44	0.47	0.52
Presscake	0.41	0.48	0.50
Paprika waste	0.44	0.47	0.49
Green waste	0.40	0.49	0.49
Pig manure	0.44	0.49	0.49

Figure 7. Recalcitrance index of biochars

Finally, in the pyrolysis & gasification biochars an increase in macronutrients, micronutrients and heavy metals was noted, which is feedstock related while in the HTC chars the increase in some macronutrients (Ca, P) and micronutrients (Fe, Mn and Zn) is process related, the balances confirm elements in the effluent water.

WHAT DOES LIFE CYCLE ANALYSIS CONTRIBUTE TO THE ENVIRONMENTAL IMPACT OF USING BIOCHAR IN AGRICULTURE?

Nataša Sikirica (Alterra), Tom Oldfield (Renetech), Guadalupe López (Tecnova)

FertiPlus project applies Life Cycle Analysis (LCA) in order to achieve the goals of its Working Package 5 (WP5). LCA is a tool which serves to analyse the environmental aspects and potential impacts throughout a product's life-cycle. It allows a systematic comparison of environmental performance of products, from 'cradle to grave', i.e. from raw material until the end of life.

Below Figure 8 gives an example of life-cycle of biochar, modelled with "GaBi" model, an LCA model.

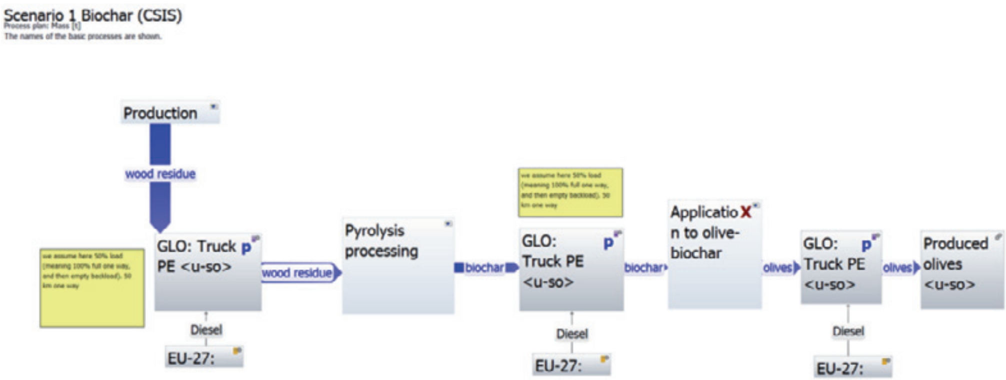


Figure 8. Life-cycle of biochar, modelled with "GaBi" model, an LCA model

The aims of the WP5 are: 1) to assess the environmental performance of recovering nutrients from various waste streams via the production of biochar and their subsequent application in agriculture; 2) to assess the environmental performance of producing and using compost and biochar-compost blend against biochar. The analysis is still ongoing; however, the results will answer questions such as: a) Does - and how - biochar addition to compost benefit the environment?; b) Is biochar better (looking at the environment) than compost?; c) Where are 'hotspots' in supply chain? With LCA a wide range of environmental impacts can be captured, for instance, global warming potential, eutrophication, acidification, etc. Below Figure 9 shows an example of environmental impacts of biochar, via only several chosen impact categories.

The Figure 9 serves here only as an example, thus, it does not present the results of the assessment.

Figure 9. Example of environmental impacts of biochar

As conclusion: LCA helps to establish (organic) waste treatment hierarchy; it helps understand environmental consequences of decisions farmers make; and it supports creation of science-based policies that focus on minimal environmental impact.

INTERACTION OF BIOCHAR AND COMPOST WITH PLANT HEALTH, YIELD AND SOIL QUALITY: BALANCING RISKS AND OPPORTUNITIES!

Bart Vandecasteele (ILVO), Jane Debode (ILVO), Tommy D'Hose (ILVO), Nicole Viaene (ILVO), Tania Sinicco (CRA), Claudio Mondini (CRA) and Miguel Ángel Sánchez-Monedero (CSIC)

Biochar can be applied as a pure soil amendment, but can also be processed with other biomass before being added to the soil. We tested the effect of adding biochar during or after composting or ensiling (Figure 10). This was tested for compost based on the organic fraction of municipal solid waste mixed with green waste, and for silages of vegetable crop residues and maize straw. We observed that biochar may alleviate suboptimal processes, both for silage and for composting.

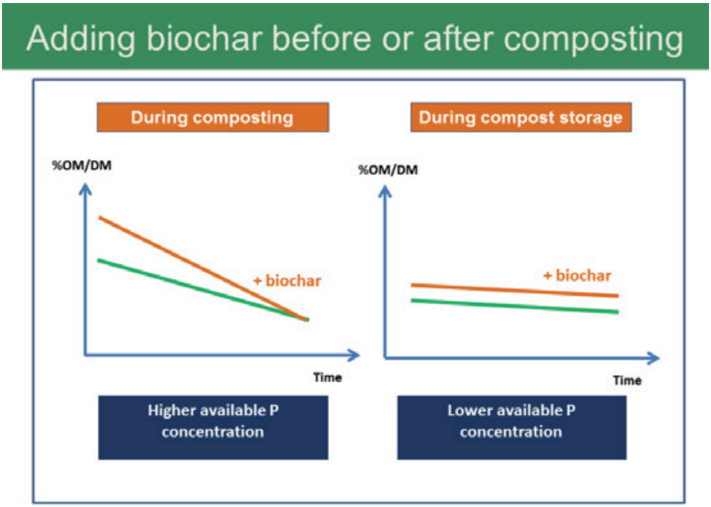


Figure 10. Adding biochar before or after composting

Besides assessing the effect on the process and on the product quality, these products were also tested as soil amendments in bioassays and field trials, allowing to study the effects on plant and soil quality as well. Bioassays with lettuce-basal rot, strawberry-gray mold and potato-cyst nematodes were executed to quantify the effects of biochar, compost and biochar-blended compost on different agronomical aspects related to plant and soil health.

The effect on disease suppression (Figure 11) dependes on the plant-pathogen-soil/substrate system tested and product-specific responses were associated with significant shifts in rhizosphere microbiology.

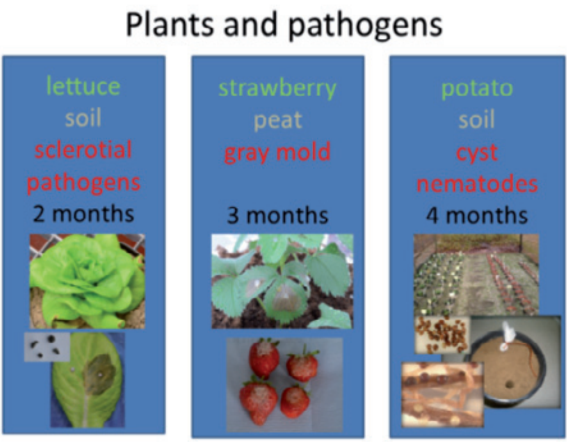


Figure 11. Plants and Pathogens

We assessed the effect of compost, biochar and their mixture on soil organic C content, chemical, physical and biological soil quality in field trials, and compared this with the effect of other soil and crop management practices. In the first field trial, the effect of biochar is compared with compost and biochar-blended compost at a single rate of 10.9 t C ha^{-1}, in a crop rotation with cereals, leek and ryegrass. In a second field trial, the effect of a yearly compost dose at a rate of 2 t C ha^{-1} was assessed.

We tackled the question whether the effects on soil quality are generic or rather depending on climatic conditions, soil type, type of compost applied and crop rotation. Single application of biochar/compost in field soils with high nutrient status resulted in an increase of pH and C content, while the repeated application of compost also led to higher disease resistance and higher soil biodiversity without inducing higher nutrient losses.

SOIL PROPERTIES AND DESIRED AGRONOMICAL VALUE OF BIOCHAR IN COMBINATION WITH COMPOST APPLICATION

Guadalupe López (TECNOVA) and Carolina Martínez (TECNOVA)

Information about farmers requirement has been collected during FERTIPLUS project by making questionnaires and organizing a workshop (Figure 12) to introduce biochar properties and to solve their Questions and doubts.

Only few farmers were aware of biochar product and the characteristics and benefits that can get to the soil. They are receptive to the incorporation of new organic amendments to the soil, however, they demand specific information on nutritional composition, expected improve of fruit yield and quality. The price of the final product and the security of the product are the main concerns of farmers.

Figure 12. Fertiplus Farmers Workshop. Almería (Spain)

Some identified key points to help biochar acceptation by large farming system are:

- **Standardisation** of properties and characteristics to provide
- **Tailor made** biochars
- Fundings for **price reduction**
- **Compost: combinations** in final product or in the composting process

The agronomical results of field trials in FERTIPLUS project are not conclusive, and need further research on the long –term effects of its application in soil. Some conclusions are:

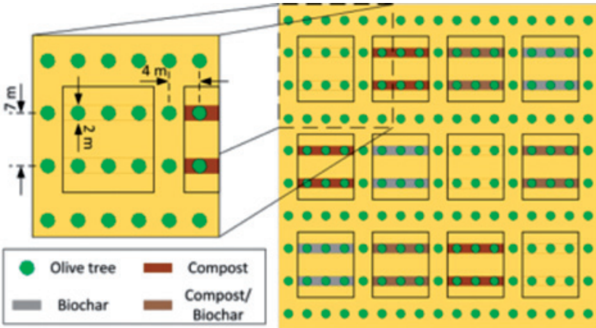
- **WHEN** soil presents a limiting factor (pH, nutrients deffiency, organic carbon, water holding capacity…) Biochar, compost or Biochar blended compost can help in alleviating limiting factors for crop yields and crop health.
- **NO** effects observed in Yields
- **NO** effects observed in nutritional status of plant
- **SOME POSITIVE** effects observed in fruit quality parameters (tomato)
- **SOME POSITIVE** effects observed in natural strength of plants and soils (tested on pot experiments in strawberry)
- **BIOCHAR** has a great potential to offset climate change

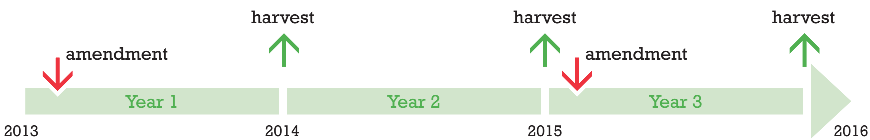
I. FIELD SCALE EXPERIMENT AT CSIC (SPAIN): OLIVE ORCHARD

Site description: SAT Casa Pareja 1870. Jumilla, Murcia (Spain)

- **Cultivar:** Olea europaea var. Arbequina, irrigated, organic farming, 20 years old tree in a framework of 4 x 7 m2.
- **Agroclimatic conditions:**
  - Semi-arid Mediterranean climate
  - Annual rainfall: 250 mm/year
  - High insolation rate (200 w/m2)
  - Mean daily maximum T: 20.7°C
  - Coordinates: 38°23' N 1°22' W
- **Soil:** Haplic Calcisol, 57% sand and 16% clay, 30% $CaCO_3$, pH of 8.01, 1.68% TOC
- **Soil amendments:** biochar, olive mill waste compost and a mixture compost/biochar (90/10). Dose: 20 ton/Ha

Experimental design and chronogram





Key findings

- Biochar and mixture treatments led to the highest and most persistent increase in TOC in soil, whereas compost significantly increased soluble C and N.
- Application of a compost/biochar mixture showed a synergistic effect, suggesting a boost on the microbial processes transforming N, without a parallel increase in N_2O emissions.
- Under this type of agro-ecosystem N_2O emissions are negligible and biochar would not play a significant role in N_2O mitigation.

II. FIELD SCALE EXPERIMENT AT CRA (ITALY): GRAPEYARDS

Sites description: S1: Lonzano (Gorizia) – S2: Buttrio, S3: Spessa (Udine) (Italy)

Cultivar: Vitis vinifer, non irrigated

S1: Pinot Blanc, 20 y, framework 2.7 x 0.7 m

S2: Ribolla gialla, 20 y, framework 2.4 x 0.9 m

S3: Sauvignon, 20 y, framework 2.0 x 0.8 m

Agroclimatic conditions:

- Warm Temperate climate (cfa - Koppen)
- Annual rainfall: 1450 mm/year
- Mean air humidity: 77.7%
- Mean daily T: 15.4 °C

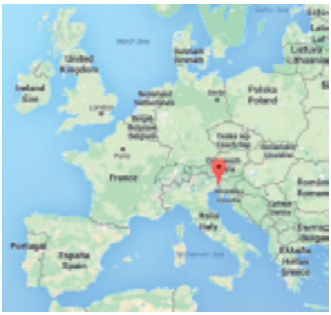
Coordinates:

S1: 46°01' N 13°29' E

S2: 46°03' N 13°26' E

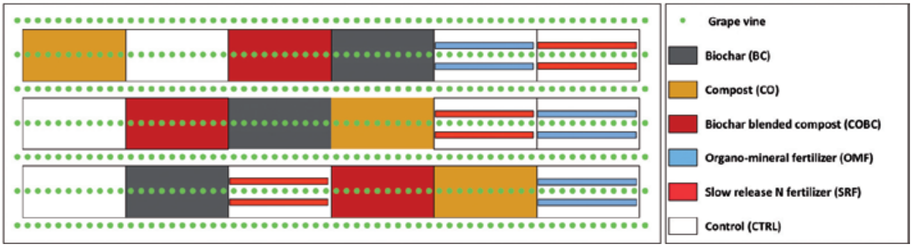
S3: 46°00' N 13°20' E

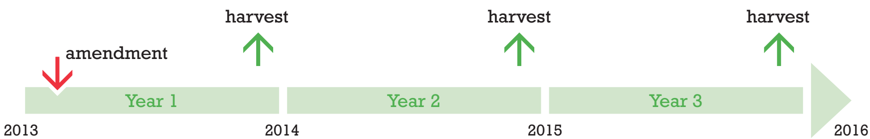
Soil amendments: biochar, biowaste compost and a mixture compost/biochar (90/10). Dose: 10.9 ton/Ha



Experimental design and chronogram

Randomized blocks (3 or 4 replicates), 10 plants for replicate Plot area (m^2) S1: 38.6, S2: 32.4, S3: 32





Key findings

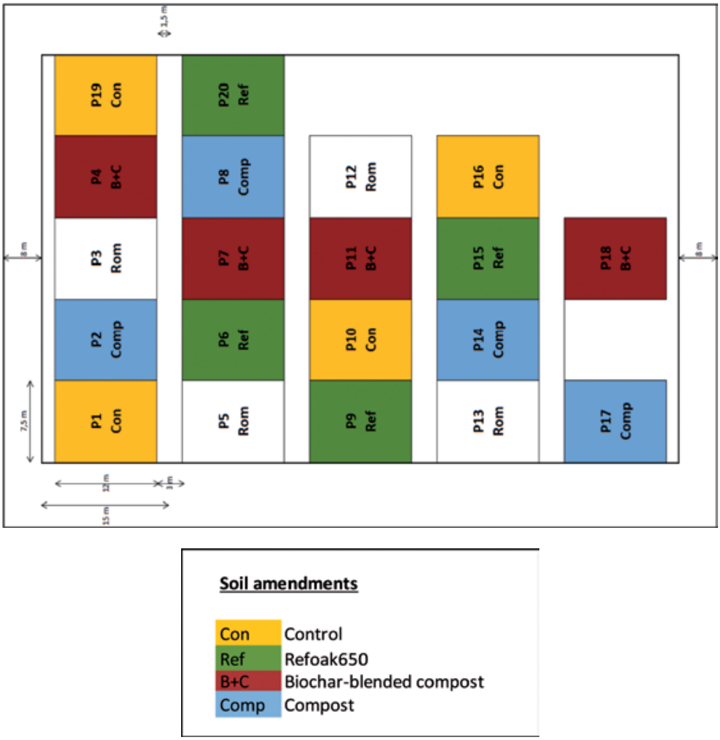
- Biochar and compost caused a significant increase in soil humidity and SOM content.
- Application of composts enhanced the content of extractable C, extractable and mineral N, available P, K and Fe and the amount and activity of soil microorganisms.
- Composts application also affected crop productivity and quality, causing an increase of grape production, N content in grapes and must acidity.
- Biochar and compost application to soil poses a low risk of heavy metal contamination provided that they were produced in accordance to QA schemes.
- Compost may represent a valuable substitute for chemical N fertilizers as they provide a low, but regular, N provision along all the growing season. This is important in soil characterized by low content of available N, but also to avoid excessive vegetative growth that would impair grape quality and the risk of N leaching.

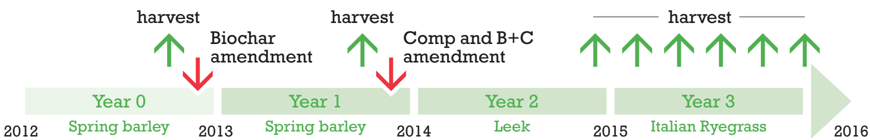
III. FIELD SCALE EXPERIMENTS AT ILVO (BELGIUM): ARABLE CROP ROTATION WITH VEGETABLES

Site description: BIOCHAR field trial, ILVO, Merelbeke (Belgium)

- **Crop rotation:** spring barley – spring barley -white mustard (cover crop) – leek – Italian ryegrass
- **Agroclimatic conditions:**
  - Fully humid temperate climate
  - Annual rainfall: 879 mm/year
  - Mean annual T: 10.7°C
- **Coordinates:** 50°58' N 3°46' E
- **Soil:** Haplic Luvisol, 59.9% sand, 34.7% silt and 5.4% clay, pH of 6.38, 0.85% TOC
- **Soil amendments:** biochar, compost and biochar-blended compost (90/10). Dose: 10.9 ton C (on a dry matter basis) per hectare

Experimental design and chronogram





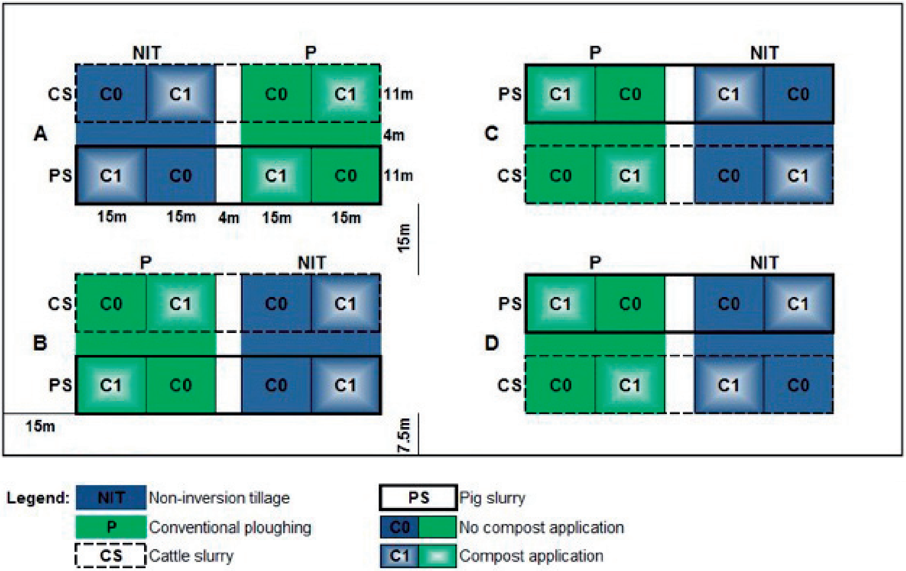
Key findings

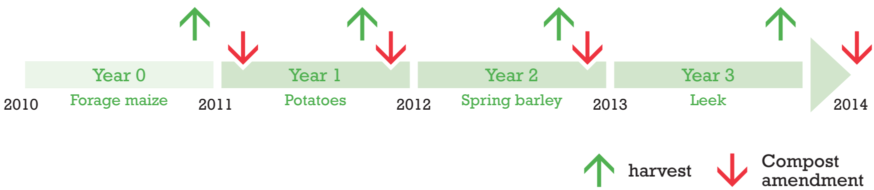
- The single application of biochar, compost and biochar-blended compost clearly increased the carbon content and the pH of the soil
- The microbial community and the disease suppressiveness of the soil remained unchanged after the addition of all three amendments
- Biochar showed no effect on crop yield

Site description: BOPACT field trial, ILVO, Merelbeke (Belgium)

- **Crop rotation:** 4-year crop rotation of forage maize, potato (+ winter rye as a cover crop), spring barley (+ white mustard as a cover crop) and leek
- **Agroclimatic conditions:**
  - Fully humid temperate climate
  - Annual rainfall: 879 mm/year
  - Mean annual T: 10.7°C
- **Coordinates:** 50°59' N 3°46' E
- **Soil:** Bathylgleyic Cambisol, 57.0% sand, 37.7% silt and 5.3% clay, pH of 5.9, 0.81% TOC
- **Soil amendments:** animal slurry (i.e. pig and cattle slurry; dose: 170 kg N ha^{-1} y^{-1}) and compost (dose: 2 ton C (on a dry matter basis) h^{-1} y^{-1})

Experimental design and chronogram





Key findings

- The annual application of compost (i.e. 4 years) increases the topsoil carbon content without increasing the risk for N and P leaching
- Both compost application and non-inversion tillage enhance chemical, physical and biological soil quality
- Repeated compost application improves the disease suppressiveness of the soil
- No effects (compost) or no consistent effects (non-inversion tillage) on crop yields have been observed after a period of 5 years

IV. FIELD SCALE EXPERIMENT AT TECNOVA (SPAIN): INTENSIVE AGRICULTURE – TOMATO CULTIVATION IN GREENHOUSE

Site description: TECNOVA Experimental Centre, Viator, Almería (Spain)

- Cultivar: Lycopersicum esculentum cv. Ramyle, irrigated, conventional management, plant density 2 plants m-2
- Agroclimatic conditions:
  - Semi-arid Mediterranean climate
  - Annual rainfall: 200 mm year-1
  - High insolation rate: 3,600 sun hr year-1
  - Annual mean daily temperature: 18.7°C
- Coordinates: 36°53' N 2°22' W
- Soil: Imported soil with 3 layers: loamy soil (30 cm), manure (2-3 cm), sand (8-10 cm)
- Soil amendments: biochar and semi-dried sheep manure mixture. Dose: (0,100) (10, 90), (20/80), (40/60) ton Ha-1

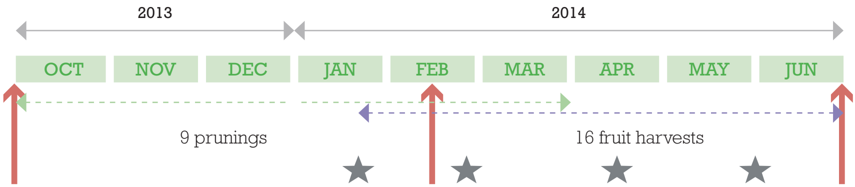
Experimental design and chronogram

T0 Conventional management and manure

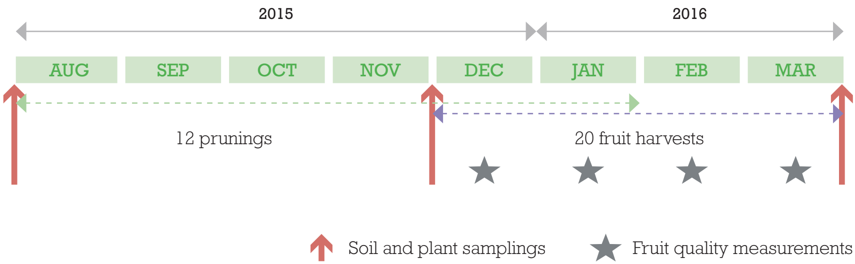
T1 Reduced management and manure

T2, T3, T4 Reduced management and biochar/ manure mixture

First field experiment



Second field experiment



Key findings

- Biochar applied in combination with semi-dried manure allowed to maintain soil fertility.
- Application of different biochar/manure mixtures showed similar and suitable biomass production and yield, and improved some fruit quality parameters.
- Higher amounts of nitrates in the root zone and higher N content in the crop were obtained in treatments with biochar.

V. POT TRIALS AT ILVO (BELGIUM): BIOLOGICAL, PHYSICOCHEMICAL AND PLANT HEALTH RESPONSES

Experimental set-up

Lettuce pot trials

- Cultivar: Lactuca sativa Alexandria
- Pathogen: Rhizoctonia solani (basal rot)
- Growth medium: sandy loam soil, 5.3% clay, 37.7% silt and 57.0% sand, pH of 5.77 and 0.86% TOC
- Agroclimatic conditions: growth chamber at 20 °C, 16 h/8 h day-night light regime and 80% RH
- Growth medium amendments: biochar at 1% and 3% (DW/DW), compost and biochar-blended compost at 1% (DW/DW)
- Growing time: 8 weeks

Strawberry pot trials

- Cultivar: Fragaria x ananassar Elsanta
- Pathogen: Botrytis cinerea (gray mold)
- Growth medium: peat with and without 1.33g L-1 fertilizer and/or 3 g L-1 lime
- Agroclimatic conditions: greenhouse at 20°C
- Growth medium amendments: biochar at 1% and 3% (DW/DW)
- Growing time: 12 weeks

Potato pot trials

- Cultivar: Solanum tuberosum Bintje
- Pathogen: Globodera rostochiensis and G. pallida (potato cyst nematodes)
- Agroclimatic conditions: pots placed outside, exposed to prevailing weather conditions
- Growth medium: sandy loam soil, 5.3% clay, 37.7% silt and 57.0% sand, pH of 5.77 and 0.86% TOC
- Growth medium amendments: biochar at 0.3% and 1% (DW/DW), compost and biochar-blended compost at 1% (DW/DW)
- Growing time: 16 weeks

Key findings

Lettuce:

- Biochar had no effect on lettuce growth, on the susceptibly of the lettuce leaves against Rhizoctonia solani and on the lettuce rhizosphere microbiology.
- Compost and biochar-blended compost did increase lettuce fresh and dry weight, but had no effect on plant health and rhizosphere microbiology.
- Adding biochar to the mineral soil increased the carbon content, the pH and the nutrient availability, and reduced the water evaporation.

Strawberry:

- Addition of 3% biochar to peat resulted in a higher fresh and dry plant weight, a lower susceptibility to the fungal pathogen Botrytis cinerea and an increase of bacterial diversity of the rhizosphere microbiota.
- Fertilizer and lime added to the peat reduced these effects of biochar on the strawberry plants.
- Adding biochar to the unfertilized peat increased the nutrient availability, but had no effect on pH or water evaporation. Biochar acts as a fertilizer (higher biomass and strawberry yields) in unfertilized peat, but not in fertilized peat.

Potato:

- Biochar had no effect on potato yield and did not reduce the viability and reproduction of potato cysts nematodes (PCN).
- A significant increase in yield was observed in soil amended with compost and biochar-blended compost.
- Compost was suppressive for the PCN, but biochar-blended compost reduced this suppressing effect of compost.

FERTIPLUS PARTNERS IMPRESSIONS AND MESSAGES

Partner 2. BUW

During the project the experiences from former research on national recycling efforts could be used for and were strongly complemented by the European perspective. This provided many insights in solutions and barriers for the large-scale recycling of organic waste to compost and biochar. We (BUW) now better understand which measures are necessary to improve the overall recycling rates for organic waste in Europe. As a work package leader I value not only that this project led to new professional cooperations, but also to many long-lasting contacts on a personal level. A special success for me was the reduction of greenhouse gas emissions by attending all project meetings by train and ferry only, or respectively by video- or teleconference.

Partner 4. ILVO

We (ILVO) were able to test the effect of biochar in different processes at different scales, which gave us a good view on the specific interaction of biochar and the process, and what are the general principles behind the effect of biochar. This work was strongly connected with the work of other partners within Fertiplus, and this was a good experience for us.

The research on the effect of compost, biochar and biochar-blended compost on soil quality was based on the integrated assessment of soil chemical, physical and biological properties and effects on disease suppression. This approach was very valuable, and illustrated that the effect of biochar and/or compost is sometimes caused by highly specific interactions.

Partner 5. OWS

4 years ago OWS joined the Fertiplus consortium because we saw biochar as a possible opportunity for the anaerobic digestion process, mainly as a way of treating the final digestate.

Throughout the project, this shifted as our test showed that adding biochar to the AD process itself had a stabilizing effect when working with elevated nitrogen content and also seemed able to decrease the H2S levels, again improving process stability. So for OWS, the results are very interesting to have a non-chemical additive to remediate AD processes, which can end up in the digestate and even have a positive effect on the soil improving/fertilizer value of the digestate/compost.

We were hoping to also see opportunities for recuperating nitrogen from the process water, but tests were showing a large variability and overall a too low removal of N from the process water for being commercially feasible at this moment. Nevertheless, we saw promising results with modified biochars, so for OWS this is definitely a route that we would like to continue to work on in new projects.

Partner 7. CRA

For CRA, Fertiplus has been important because it gave us the possibility to perform studies and research on a relevant agronomical and environmental topic allowing us to contribute to the improvement of farmers and society at European level.

Moreover it allowed for the establishment of effective collaborations with other partners that could possibly have a follow up beyond the end of the project.

Personaly, Fertiplus means progress in my scientific formation by getting in touch with cutting-edge technologies and methods and high qualified and skilled researches from all Europe.

The main outcomes of the project:

- Characterization of biochar in relation to feedstock and process and functionalization of biochar according to its utilization
- Suitability of compost to reduce the utilization of mineral fertilizer and to improve soil fertility and quality
- Blending of biochar and compost as a promising option for both improvement of the composting process and of compost quality
- Valuable and effective synergy arising from the collaboration among research groups with different background, expertise and facilities

Partner 8. IDC

During these 4 years, Fertiplus has meant for IDC the opportunity to work with a really impressive group of people, their best on their field, to whom we have learnt and with whom we have work together to communicate and disseminate the project results that are aimed at developing new products that are friendly to the environment.

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