Project Number: 1567

Project Acronym: ISFERALDA

Project title: Improving Soil FERtility in Arid and semi-arid regions using Local organic DAte palm residues

D5.1 EXPERIMENTAL SETUP

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Summary

The aim of this deliverable is to provide a reference document describing the experiments to be conducted at the different study sites in field or in laboratory so that similar methodologies can be used to collect comparable data from all sites. This does not forbid additional experiments from being conducted.

The objective of the laboratory and field experiments is to gather reference data on the effect of innovative organic amendments on soil properties and quality and on winter cereal crops, barley being selected as the model crop. With these results, technical sheets can be drafted to help farmers and other stakeholders to make relevant choices according to their priorities.

To these purposes, five study sites have been selected in different contexts (pedo-climatic conditions, watering practices, oasian and non-oasian systems), in order to adapt the practices. The amendments used for the experiments at all sites and in laboratory experiments include:

- Compost: always produced from date-palm residues supplemented with manure,
- Biochar: given that biochar alone does not supply plant nutrients (nitrogen, phosphorus, potassium), biochar can be activated with mineral fertilizers or mixed with compost in different proportions.

The quantities of organic amendment to be applied are estimated according to the needs of the crops for a given yield. Other products (manure, mineral compounds such as sand, bentonite) will be used at specific sites but will not be included in the inter-site comparisons.

Contents

1 Task 5-1 Soil-product interactions (Leader: UB)

1.1 Carbon and nitrogen mineralization dynamics under laboratory conditions

1.1.1 Objectives

The objective of this experiment of soil incubations under controlled conditions is to evaluate the nitrogen (N) fertilizing value of date palm residue compost and to study its interactions with biochar. Respirometric and enzymatic measurements are also used to evaluate the carbon (C) mineralization of the soil organic matter and the biological activity of the soil.

The specific objectives are to evaluate:

- the N mineralization rate;
- the compost and biochar chemical stability;
- the role of biochar in sequestering organic compounds from compost
- the "priming effect" with biochar and/or compost addition in soil
- select a mix adapted to the context of oasian agrosystems

1.1.2 Method

Different mixtures of organic products (biochar and/or compost) will be applied to 2 sandy soils from South Tunisia, representative of the arid regions of northern Sahara.

Experiments will be performed in triplicates with the following treatments:

- control soil
- soil + biochar (1% weight/weight)
- soil + compost (2% weight/weight)
- soil + mix biochar-compost (25-75%)
- soil + mix biochar-compost (50-50%)

The kinetics of C and N mineralization under optimal conditions will be studied. Soil water content (2/3 of soil field capacity) and temperature (28 °C) will be kept constant during the experiment.

All experimental trials will be conducted in 500 mL pots with approximatively 250 g of soil. CO_2 emissions and mineral N (NH_4^+ and NO_3^-) content from each trial will be measured 10 times during incubation experiment (90 days). CO_2 emissions will be captured by a NaOH trap and then analysed by a titration method. NH_4^+ and NO_3^- concentrations in each sample of soil will be analysed by a titration/distillation method.

Other parameters will be measured at the beginning and at the end of the experiment: organic C content, soil pH, electrical conductivity, P content, CEC, initial soil and compost mineral N quantity, C:N ratio, C and N microbial biomass, dehydrogenase enzymatic activity.

1.2 Adsorption/desorption of elements (N, P, K, Ca, Mg, Na) in amended soil using batch-adsorption techniques

1.2.1 Objectives

Chemical analysis of water irrigation from different study sites of ISFERALDA project shows moderate salinity with an Electrical Conductivity (EC) around 6 $dS.m^{-1}$, which have a predominantly chlorinated-sodium content. Sodium adsorption ratio (SAR) value is approximatively 5, thus these waters are suitable for irrigation but cause a danger of alkalinisation of the soil.

This assay aims to (i) investigate the capacity of date palm biochar and compost mix to reduce the sodicity of irrigation water; and (ii) study the effect of organic amendments on sorption/desorption of nitrate (NO_3^-), ammonium (NH_4^+), phosphate (PO_4^{3-}) and potassium (K^+) in a loamy sandy soil.

1.2.2 Method

1st experiment:

The first step is to create a simulated irrigation water in the lab, based on the Na, Ca, Mg, K, SO_4, HCO_3, and Cl concentrations in irrigation waters obtained from the different sites of ISFERALDA project. The simulated irrigation water consisted of 205, 384, 165, 34, 1866, 997 and 104 mg.L^{-1} of Ca, Na, Mg, K, Cl, SO_4 and HCO_3, respectively.

Triplicate biochar samples are also tested for oxidation-reduction potential (ORP) over a 1-week period by adding 30 mL of deionized water to 1 g of biochar in a 50 mL beaker, allowing to sit lightly covered with parafilm at room temperature, and measuring ORP over time. A deionized water control is also used. Finally, after oven drying at 105 °C for 12 h, biochar organic functional groups are characterized using Fourier transform infrared spectroscopy (FTIR).

An initial batch sorption experiment using a constant biochar and simulated irrigation water quantities is performed. 0.5 g of biochar or compost is put in contact with 25 mL simulated irrigation water in triplicate 50 mL centrifuge tubes. The tubes are allowed to sit undisturbed for different times before measurement with a pH meter. Following each time period, tubes are destructively sampled by centrifuging for 10 min, the liquid filtered through Whatman #1 filter paper, and then the solutions are analysed for Na, Ca, K, and Mg concentrations via inductivity coupled plasma-optical emission spectroscopy (ICP-OES). Data from the biochar adsorption experiment over time is analysed using kinetics models, with sorption kinetics typically used to determine sorption capacity.

A second adsorbent-dose batch experiment is carried out with different quantities of biochar with 25 mL of simulated irrigation water. The time required to achieve the steady-state concentration is determined by the first experiment described above.

Others adsorbent-dose batch experiment are conducted with soil alone and compost alone, as well as different mix described below (§ 3. Treatments).

2nd experiment:

For the determination of organic amendments capacity to retain mineral nitrogen, 0.1 g of biochar is mixed with 50 mL of 34.4 mg L^{-1} nitrate and 10.0 mg L^{-1} ammonium solution or 30.8 mg L^{-1} phosphate solution. A control is made without either biochar or nutrient elements. The mixtures are shaken and then filtered through 0.22 µm filters. In addition to pH, concentrations of nitrate in the supernatants were determined using an ion chromatograph. Concentrations of ammonium and phosphate in the supernatants were measured using the phenate method and the ascorbic acid method, respectively, using a UV/VIS spectrophotometer (Yao et al., 2012).

Additional adsorbent-dose batch experiment is conducted with soil alone and compost alone, as well as different mix described below (§ 3. Treatments).

1.2.3 Treatments

1st experiment:

All the following treatments are conducted in triplicates:

- biochar (0.5g) + 25 mL simulated irrigation water at different durations
- 0.25, 0.50, 1, 1.5, 2 g biochar + 25 mL simulated irrigation water
- compost (0.5g) + 25 mL simulated irrigation water at different durations
- loamy sandy soil (0.5g) + 25 mL simulated irrigation water at different durations
- loamy sandy soil (0.3g) + biochar (0.1g) + compost (0.1g) + 25 mL simulated irrigation water

2nd experiment:

All the following treatments are conducted in triplicates:

- biochar + nutrients
- compost + nutrients
- mix compost/biochar + nutrients
- soil + nutrients

- soil + mix compost/biochar + nutrients

2 Task 5-2 Laboratory experiments: Pot cultivation experiments (Leader: UB)

These experiments will be conducted using the organic amendments (OAs) products obtained from palm grove residues, i.e. compost and biochar, in order to evaluate their efficiency of on soil properties (fertility, water and nutrient retention, structure…) and on plant development.

2.1 UB-UMKB experiments on Algerian soils

Different combinations of biochar, compost and chemical fertilizers will be tested in a pot-cultivation experiment. It will be conducted using barley as test-plant, under a glass shelter. The different treatments will be fully randomized, and three replicates will be performed.

2.1.1 UB experiments

Soil from the experimental fields of the Institute of Agronomy, University of Batna, is used in those experiments. Soil samples were collected at 20 cm depth. From earlier studies, characteristics of the Batna soil are presented in Table 1. Further analyses are in progress.

Table 1 : Properties of the soil of the Institute of Agronomy, University of Batna

pH	7.98
Electric conductivity	0.175 ds/m
Organic carbon	1.67%
Total nitrogen	0.24%
Total limestone	40.5%
Active limestone	15%
CEC	25 meq/100g
Exchangeable Potassium	2.4 meq/100g
Exchangeable Sodium	3.66 meq/100 g
Calcium	34.4 meq/100 g
Magnesium	2.4 meq/100 g
Phosphorus (Olsen)	19.70 ppm

The treatments are listed below and will include a single dose of fertilizer (according to the results of the first field experiments of ISFERALDA). The applied doses of biochar (65% C) will range from zero to 20 ton/ha (7.5, 10.5, 13.5, 17, 20 ton/ha), corresponding to a soil C content ranging from 0.1% (initial) to 1.3%. Biochar will be activated by compost or chemical fertilizer applied to the pots before sowing. The doses of compost and mineral fertilizers will be the same as those of the field trials, as determined to cover the crop requirements in N, P and K.

In order to measure the effect of biochar on the water retention capacity, the humidity of the pots would be rigorously monitored and maintained at 2/3 of the soil retention capacity. The following parameters will be rigorously monitored :

- The plant biomass produced,
- The main nutrients (N, P and K of the plant) according to the vegetation stages,
- Plant-available elements before and after the start of the cultivation,

- Water retention capacity,
- Electric conductivity,
- Soil aggregate distribution (Mean Weight Diameter) and structural stability.

Treatments for the experiments

The doses of biochar selected for this experiment represent consecutive inputs of the quantity of biochar that can be produced yearly on a palm grove of 1 ha:

- Treatment 0 (control): 0.1% soil C (untreated soil, no plant)
- Treatment 1: 0.1% soil C (untreated soil, with plant)
- Treatment 2: 0.1% soil C (soil with fertilizer)
- Treatment 3: compost 27 ton/ha
- Treatment 4: 0.5% soil C (activated biochar, OA 7.5 ton/ha)
- Treatment 5: 0.7% soil C (activated biochar, OA 10.5 ton/ha)
- Treatment 6: 0.9% soil C (activated biochar, OA 13.5 ton/ha)
- Treatment 7: 1.1% soil C (activated biochar, OA 17 ton/ha)
- Treatment 8: 1.3% soil C (activated biochar, OA 20 ton/ha)

2.1.2 UMKB experiments

Soils from the experimental field of the Institute of Agronomy, University of Biskra (two soil types: sandy and clayey) are used in those experiments.

2.2 URCA-Ecotron pot experiments on Spanish soil

Objective: effects of organic amendments combined with urea on winter barley growth.

In complement to the experiments conducted in the Universities of Batna and Biskra, pot experiments will also be performed in the University of Reims Champagne-Ardenne. They will include an isotopically labelled N source in order to monitor its fate in the plant-soil system.

2.2.1 Objectives

The purpose of this experiment in pots is to evaluate the effects of various organic amendments (biochar and compost based on palm residues) on the biological functioning of the soils with certain conditions similar to the natural conditions (identical amendments, similar quality of irrigation water and soils). We also want to assess the effects of the amendments on plant productivity and on the availability of certain elements (Na^+, nitrogen, phosphorus, K^+ and trace elements).

2.2.2 Method

The experiments take place in a growth chamber with abiotic conditions as follows :

- temperature: 20 °C day, 15 °C night,
- power of the lamp: ≈ 400 W/m^2,
- photoperiod: 12 hours day, 12 hours night,
- air relative humidity: ≈ 50%.

Soil collected in Spain (Cañada de Gallego) will be used for this experiment. Organic amendments and organic fertilizer quantities to add are not determined yet. They will be based from the incubation studies with Tunisian soils and field experiments assays.

Soils analysis will be conducted before the beginning of this experiment. Soil moisture content will be maintained at two-thirds of its field capacity during the growth of plants. Water quality used is based on the water irrigation quality of study sites in North Africa (high electrical conductivity EC).

Analysis of exchangeable cations are conducted before and post-harvest, as well as mineral nitrogen, pH, cation exchange capacity (CEC) and EC in soils. Determination of quantities of plant elements (Na, N, P, K, Cl and trace elements) will be made after harvest.

Morphological parameters (number of tillers, height) will be quantify at different stages of plants development. Post-harvest aerial and root biomass will be determined too.

Regarding the biological parameters, quantitative PCR (Polymerase Chain Reaction) will be performed to measure the activity of genes involved in the nitrification and denitrification process, as well as microbial biomass, taxonomic diversity and community structure of soil microorganisms by pyrosequencing techniques.

Leachate recovery will be used to quantify total and dissolved organic carbon, as well as dissolved nitrogen. Measurement of nitrogen in plants allows to compare different Nitrogen use efficiency (NUE) between all treatments. After adding ^{15}N-Urea, stable isotope analysis of soil nitrogen by Isotope ratio mass spectrometer (IRMS) allows to calculate mineralization and immobilization rate of nitrogen with and without biochar. Stable isotope analysis of plants nitrogen is used to quantify the source of the source of the nitrogen taken from the plant (soil vs. organic fertilizer).

2.2.3 Treatments

- control loamy sandy soil
- control clayey soil
- loamy sandy soil + plants
- clayey soil + plants
- loamy sandy soil + compost
- loamy sandy soil + biochar + ^{15}N-Urea
- loamy sandy soil + ^{15}N-Urea
- loamy sandy soil + mix biochar-compost
- clayey sandy soil + compost
- clayey sandy soil + biochar + ^{15}N-Urea
- clayey sandy soil + ^{15}N-Urea
- clayey sandy soil + mix biochar-compost
- loamy sandy soil + compost + plants
- loamy sandy soil + biochar + ^{15}N-Urea + plants
- loamy sandy soil + ^{15}N-Urea + plants
- loamy sandy soil + mix biochar-compost + plants
- clayey sandy soil + compost + plants
- clayey sandy soil + biochar + ^{15}N-Urea + plants
- clayey sandy soil + ^{15}N-Urea + plants
- clayey sandy soil + mix biochar-compost + plants

All treatments are conducted in triplicates which makes a total of 60 pots.

3 Task 5-3 laboratory experiments: Soil water retention (replacing rainfall simulations, leader: URCA)

Rainfall simulations have been included in the ISFERALDA proposal. However, further investigation of the site and soil characteristics lead the partners to the conclusion that they are not relevant for the project.

We should have studied the risks of runoff, erosion and changes in soil surface conditions based on rainfall simulations. However, these risks do not appear to be significant in the context of the study.

Indeed, soil erosion in these regions is predominantly wind erosion. Water erosion is much less important. The land studied is rather flat and not very prone to surface runoff. The soil is mostly sandy with little change in soil surface conditions.

Task 5-3 does not therefore seem relevant to us, as things stand. This is why, in agreement with the project officer, we change it. As organic amendments have a proven influence on soil water retention, we propose to dedicate this task to quantifying the influence of the AOs selected in the project on soil water retention properties. The name of this task would be: Task5-3 Laboratory experiments: soil water retention measurements.

3.1 Objectives

The aim of this experiment is to quantify the effects of organic amendments on soil water-retention. Two soils with different characteristics will be used to assess their properties after addition of biochar and/or compost mixtures at different application rates.

3.2 Method

An increase of available water content (AWC) of sandy soils using biochar in combination with compost was found by Liu et al. (2012). These results can be explained by the high porosity and surface area of biochars. Pore size distribution of date palm biochar will be determined by scanning electron microscopy (SEM) and mercury porosimetry, whereas surface area of biochar and compost will be measured by BET (Brunauer, Emmett and Teller) method.

The experiments are carried out on topsoil samples (0-20 cm deep) from south Spain (province of Alicante). These soils have been selected based on their properties similar to soils of experimental sites in Algeria and Tunisia. Sand was added to these soils in order to study the water retention of sandier soils. Water retention is measured at different water potentials and notably the field capacity (FC) and permanent wilting point (PWP). The measuring device consists of low and high extraction chambers pressure. Samples are placed in rubber rings, then arranged on porous ceramic plates previously saturated in water.

Soil samples are slowly saturated by adding water in rings before being placed in the extraction chambers. During the experiment, the samples are kept in the extraction chamber for several days until equilibrium between pressure force and water retention force in soil samples is reached. Water masses retained by samples are then measured by weighing their masses before and after drying at 105 °C for 24 hours.

3.3 Treatments

The soil water retention is measured at different matric potentials on two soils:

- sandy loam soil, called A (53.5% sand, 11.6% clay)
- silt loam soil, called B (18.4% sand, 18.5% clay)

To get sandier soils, we added 1/3 and 2/3 sand to each of the initial soils. This resulted in four new soils:

- based on soil A, a sandy loam soil, called A1 (69% sand, 7.7% clay)
- based on soil A, a sandy loam soil, called A2 (84% sand, 3.9% clay
- based on soil B, a loam soil, called B1 (45.6% sand, 12.3% clay)
- based on soil B, a sandy loam soil, called B2 (72.8% sand, 6.2% clay)

On these 6 soils, we tested 4 treatments:

- soil without amendment,
- soil + compost (3% weight),
- soil + biochar (3% weight),
- soil + compost (1.5% weight) + biochar (1.5% weight)

This makes a total of 24 soil treatments.

4 Task 5-4 Field experiments: plot scale (Leader INRAA)

This task has been merged with Task 5-5 (field scale).

5 Task 5-5 Field experiments: field scale (Leader IRA)

The objectives are to study the impact of organic amendments on the fertility and edaphic properties of soils, on barley yields and on the productivity of oases. A common experimental protocol is applied on the five project sites in order to obtain comparable results.

5.1 Study sites

Field experiments are conducted in 5 study sites located in Algeria and in Tunisia. The descriptions of these study sites are presented in the deliverables D3-1 and D3-3.

5.2 Field trial planning

5.2.1 Experimental design

Within each study site, plots should have a minimum area of 2 m² (larger areas possible if space is available) and a minimum of 3 replicates for each treatment with randomization (Figure 1). Organic amendments are applied manually to the soil surface in the plots and incorporated to a depth of 20 cm. During flood irrigation, the biochar tends to float to the surface so care should be taken to export the biochar outside the plot.

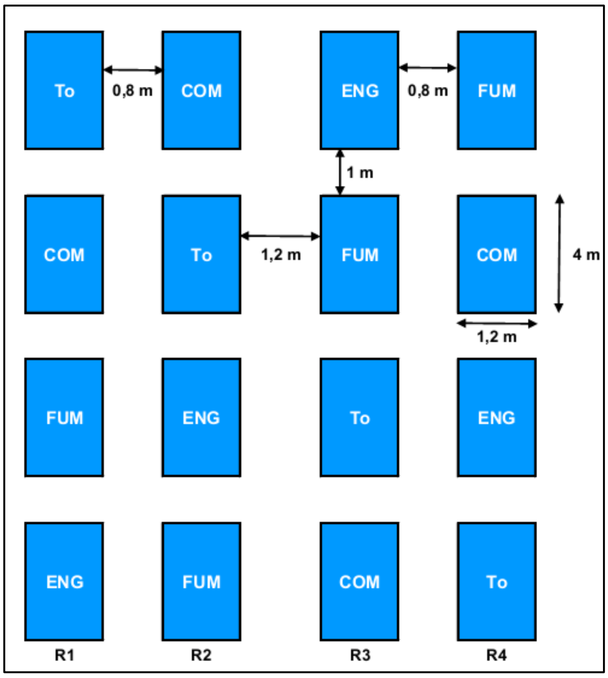

Figure 1: example of an experimental randomized design set at INRAA and comprising 4 replicates of To (control, unfertilized culture), COM (compost), FUM (bovine manure) and ENG (mineral fertilizer).

5.2.2 Technical itinerary

Winter barley is the model plant used for these trials. The barley varieties used are Saida in Algeria and Ardhaoui in Tunisia. The crops are sown in rows 20 cm apart. The sowing density on all sites is 160 kg/ha.

The sowing date is between October and December depending on the favorable conditions at each study site.

5.2.3 Tested treatments

The field experiments are conducted over three cropping seasons from 2021 to 2024, during which different conditions were tested. In all three cropping seasons, only plots that had not received any organic fertilizer in a previous experiment were used.

In 2021-2022, two conditions were tested:

Trials without any amendments (Control);

Use of compost alone at a common rate per country.

These two conditions were tested on all 5 study sites. In addition, other treatments more specific to certain sites were tested. Manure was applied on some study sites and chemical fertilizers were applied on the Algerian sites in order to estimate the maximum yield of barley (Figure 1).

In the 2022-2023 and 2023-2024 cropping seasons, three additional conditions are to be carried out based on the results of WP4, including developments in biochar production and characterization of its nutrient retention properties. The five treatments are:

- Trials without any amendments (Control);
- Use of compost alone at a common rate per country;
- Use of a mixture of biochar and compost (see below);
- Use of biochar activated with mineral fertilizers (see below);
- Use of fertilizers with an optimal yield objective (plethora trial): be careful how to disseminate the results to the farmers. This modality should not be preferred to organic amendments, even if it seems to guarantee the maximum yield.

No treatment with biochar alone is used.

As for the first cropping season, some additional conditions can be carried out in the different study sites.

5.3 Biochar production and activation

5.3.1 Biochar production

Artisanal pyrolysis will use the whole leaf (petiole + rachis + leaflets). For laboratory production, it is possible to use only the petiole and rachis. These residues are coarsely ground (particles < 1 cm) and sun-dried for a period of 3-5 days.

Pyrolysis should last between 4 and 5 hours (heating time). It should be slow, i.e. with a gradual increase in temperature. It is preferable not to exceed a temperature of 600 °C during pyrolysis. In order to estimate the yield of biochar production, all dried residues are weighed before and after the pyrolysis process.

If petrol, oil or other fuels are used, it is necessary to quantify the mass of these products used to produce a batch of biochar.

There is no need to clean the biochar with water. The ash contains nutrients such as P and K.

The biochar is then packed in a bag before being crushed by a heavy machine.

Once ground, the biochar should be sieved to 5 mm. The mass of the <1 mm, 1-2 mm and 2-5 mm classes should be measured to get an idea of the particle size distribution. No biochar particles larger than 5 mm will be used in the field trials.

5.3.2 Biochar activation

5.3.2.1 Activation with fertilizers

The biochar will be enriched with a nutrient solution before incorporation into the soil of the experimental plots. The proposed enrichment method is a post-pyrolysis method, by contact with mineral fertilizers in solution (Ndoung et al., 2021). The biochar dose will be 10 $t.ha^{-1}$ (or 1 kg/m²).

The quantity of water to be used for the nutrient solution is based on the measurement of the biochar's water retention capacity. For example, for the date-palm biochar produced by URCA, , the water retention capacity is 2.7 L/kg.

1) Determine the mass of biochar that will be used and prepare the corresponding amount of fertilizer solution (see below). In this example : 3 L of solution for 1 kg of biochar.

2) Mix the biochar and the solution for activation ; contact time 10 days in open air. Mix occasionally.

3) Let the biochar air-dry until the water content decreases by half (in the example, 1.5 L of water / kg of biochar.

4) Apply the biochar to the soil while wet and incorporate homogenously on the soil surface. Incorporate manually to a depth of ~20 cm.

The dose of fertilizers to use is calculated depending on the requirements of barley at the target yield in qt/ha. Phosphate will be supplied as mono-ammonium-phosphate (MAP), with a quantity determined to cover the P needs and the quantity of N also supplied deduced from the N requirements. Only 1/3 of the N required will be added to the nutrient solution, with urea complementing the N from the MAP. A 2nd application of urea (1/3 of the required N) and a third application of sulfazote (1/3 of the required N) will be performed.

5.3.2.2 Activation with compost

The mixing of biochar and mature compost should be done two weeks before field application in order to enrich the biochar with the nutrients and microorganisms present in the compost.

The doses of biochar and compost remain the same for all treatments (see below). The biochar is added to the compost and the mixture is moistened to a paste. The mixture is kept well moistened during 2 weeks for optimal activation. During this time, the mixture is stirred at least twice.

In Algeria, for 1 m² of cultivated soil: 1 kg biochar + 2.7 kg fresh compost (equivalent dry matter has to be calculated).

In Tunisia, for 1m² : 1 kg biochar + 3.5 kg of compost in dry matter equivalent, i.e. 5.2 kg of fresh compost.

Important:
- Re-evaluate the humidity of the compost each year to readjust the quantity to add.

- Do a total nitrogen analysis to check that the nitrogen content is close from one year to the next for each batch of compost applied.

5.4 Determination of the doses of amendments to be applied

5.4.1 General principles

Wherever relevant, target yields for barley will be 5 ton/ha (or 50 qt/ha) of grains and 5 ton/ha (or 50 qt/ha) of straw. The N,P and K content in barley grown locally as well as the N balance in the soil at the time of sowing have to be taken into account.

For the treatments with compost alone as well as those with compost + biochar, the quantity of compost to apply is determined based on its composition (and more precisely, its N content) and on the N requirements of barley. It is hypothesized that if compost supplies the right amount of N, the plant requirements for phosphorus and potassium will also be fulfilled. If it is not possible to use the same compost for the 2022-2023 trials as for the 2021-2022 trials, the amount of compost used has to be calculated again based on the composition of the compost used.

For mineral fertilizers, the quantities of N, P and K are also based on the requirements of barley, but all three compounds are taken into account because they are supplied separately. The amount of each individual fertilizer has to be adapted based on its content in N, P and K. For example, N can be supplied as urea, sulfazote and together with P as mono-ammonium sulphate (MAP). K can be supplied as potassium sulfate (K_2SO_4).

5.4.2 Compost

The dose of compost to be applied are calculated according to the nitrogen (N) requirement of the selected crop for the desired yield per hectare. In each cultural situation, the direct effect of an organic fertilizer applied on a winter crop is equal to:

$$\boldsymbol{N_{mineral\ from\ compost}} + \boldsymbol{organic\ N_{mineralized}}\ \text{between application and the end of the N absorption period} - \boldsymbol{N\ losses_{by\ volatilization\ lixiviation}}$$

This effect can be estimated via the Apparent Fertilizer Recovery (AFR) for organic fertilizer:

$$AFR_{org} = \frac{\text{N absorbed by the fertilized crop} - \text{N absorbed by the unfertilized crop}}{\text{Total N supplied by the fertilizer}}$$

This coefficient is used to calculate the quantities of fertilizer to be applied at the beginning of the growing season via a mass balance:

$$\boldsymbol{b \times Y + PHN = ISN + MIN_{soil} + MIN_{res} + N_{irr} + AFR \times X_{org}}$$

with:

Y = yield objective in quintal of grains/ha,
b = N requirement in kg per quintal of grains produced,
PHN = post-harvest N in the soil (in kg of N/ha),
ISN = initial soil mineral N content (in kg of N/ha),
MIN_{soil} = supply of N through mineralization of soil stable organic matter (in kg of N/ha),
MIN_{res} = supply of N through mineralization of residues of crops of the previous season (in kg of N/ha),
N_{irr} = supply of N by the irrigation water
AFR = apparent fertilizer recovery of the organic fertilizer
X_{org} = total N content of the organic fertilizer (in kg of N/ha).

These parameters will be measured throughout the growing seasons and during the laboratory incubation experiments, particularly the rates of nitrogen mineralization of the compost and soil.

For the 2021-2022 season, the compost rates provided were determined as follows:

- Definition of the barley yield objectives
- Estimation of the crop N exports (grains + straw)
- Use of the compost chemical analysis and estimated N mineralization rate to estimate the necessary compost supply.

<u>Example of calculation for the Tunisian compost:</u>

- Yield objective: 50 qt/ha;
- Barley N exports: 1.5 kg_N/qt of grains and 0.65 kg_N/qt of straws, which represent in total 2.15 kg_N/qt (reference);
- N content of the compost: 15.5 g/kg (analyses performed in October 2021)
- Estimation of the rate compost mineralization: 20% over the first year;
- Compost dry matter content: 67%

➔ Calculation of the quantity of compost dry matter to apply:

$$dry\ matter\ of\ compost = \frac{2150}{15{,}5 \times 50} = 6{,}935\ t.ha^{-1}$$

That corresponds to 10.35 $t.ha^{-1}$ of fresh compost.

Considering an organic N mineralization rate of 20%, the necessary amount of fresh compost is 10,35 / 0,2 = 57.9 $t.ha^{-1}$. That represents a dose of 38.8 $t.ha^{-1}$ of compost dry matter. This calculation neglects the mineralization of soil organic matter N.

In Algeria, the higher N content in the compost (3.18 $g.100g^{-1}$ of N) leads to lower doses of compost (27 $t.ha^{-1}$).

5.4.3 Biochar

Biochar is a carbonaceous material that is very stable over time and its fertilizing value, if applied alone, is very limited. The quantities of biochar to be applied are determined in relation to a target value of the organic matter content of the soil. Biochar is not applied for the first cropping season (2021-2022) because no homogeneous and well-characterised product was available in time. It will be included in the experiments from the 2022-2023 cropping season.

Based on the results of the Nissaf Karbout (IRA) pot crops, the biochar application rate will be 10 t dry matter/ha or 1 kg/m². The dry biochar is weighed before application to the soil in order to respect this application rate. An application of 10 t/ha of biochar leads to an increase in soil organic carbon stocks of about 50% in the two Tunisian sites, and of 115% in the Ouargla site.

5.4.4 Optimum yield trial

The barley modality grown with fertilizer is replicated under the same conditions as for the 2021-2022 season in Algeria. The amount of fertilizer is provided in the form of mono-ammonium phosphate (MAP), potassium sulfate (K_2SO_4) and urea, equivalent to an input of 55 kg(N)/ha, 80 kg(P)/ha and 116 kg(K)/ha.

For 1 m², it is necessary to prepare:
- 15.4 g MAP (N-P-K 12-52-0),
- 22.9 g of K_2SO_4 (N-P-K 0-0-51),
- 7.9 g urea (N 46%).

Fertilizers are applied between the cultivated rows.

5.4.5 Timing of fertilizer application

Compost and biochar are added to the soil before sowing. Minerals fertilizers are supplied in a fractionated manner: P and K are supplied at the start of the cultivation experiment, but N is supplied at three time points, at start of the experiment and at two steps determined by the plant development.

5.5 Measurements of soil properties and agronomic parameters

5.5.1 Initial physical-chemical characterization of the soils

Soil initial characterization is conducted at each site before application of the organic products (Table 2). Two depths are investigated: 0-20 cm and 20-40 cm. Composite soil samples are created by five-point sampling (in a Z scheme) and then analyzed in triplicate (Figure 2).

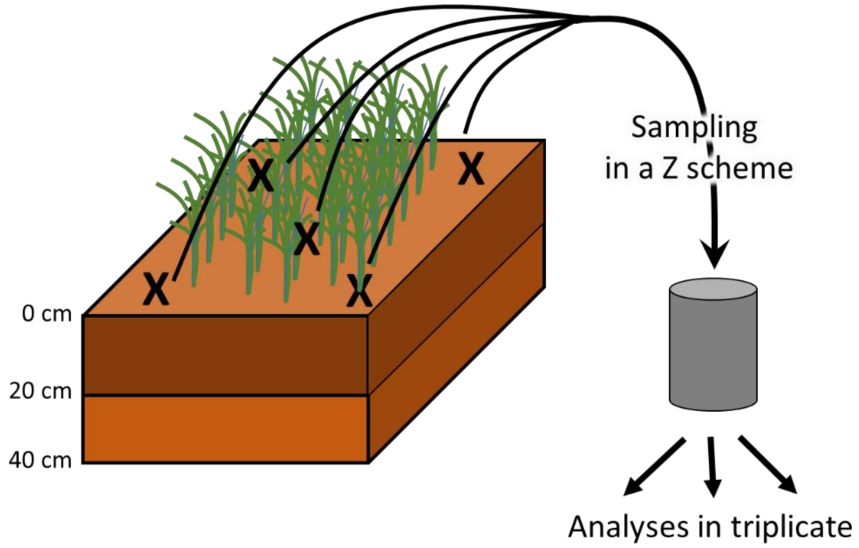

Figure 2: Schema for composite sample in a plot

Table 2: Physical-chemical parameters measured and methods used

Parameter measured	Method(s) used	Sites
Granulometry	Robinson pipette / laser granulometer (URCA)	All sites
Granulometry after decarbonatation	Robinson pipette / laser granulometer (URCA)	All sites
pH	pH-meter Ratio 1:5	All sites
Organic carbon	Walkley and Black / dry burning (URCA)	All sites
Total limestone	Bernard calcimeter	All sites
Active limestone	Drouineau-Galet method (URCA)	All sites
Total nitrogen	Kjeldahl method	All sites
Mineral nitrogen	NitraCheck	All sites

Exchangeable phosphorus	Olsen (IRA) / Joret-Hébert (ITDAS)	All sites
Exchangeable sodium, magnesium, calcium and potassium	Extraction with ammonium acetate	All sites
Sodium adsoption ratio	Atomic absorption (IRA) / Extraction with ammonium acetate (ITDAS)	All sites
Gypsum	Hot digestion of soil samples by sodium carbonate solution (IRA) / Acetone (ITDAS)	All sites
Electric conductivity	Saturated paste extract (IRA) / Conductivimeter (INRAA) / Ratio 1:5 (ITDAS)	All sites
Apparent density	Cylinder method	All sites
Microbial biomass	Fumigation-extraction	Tunisian sites
Enzyme activity	Enzymatic assay	Tunisian sites

5.5.2 Soil monitoring during the cultural season

In addition to the initial characterizations, the following parameters will be analyzed at three stages of plant development, tillering, heading and post-harvest, with the same method as in the Table 2:

- pH and electric conductivity
- total and mineral Nitrogen content,
- Sodium adsoption ratio ,
- microbial biomass and enzyme activity.

5.5.3 Plant characterization

The plant morphological description will be conducted at development stages: germination, tillering, heading and maturity. Different parameters will be monitored (Table 3):

- percent of germination,
- plant density (nb/m²),
- number of tills per plant,
- mean plant height.

In addition, plant biomass harvested at maturity will be characterized:

- aerial biomass,
- if possible, root biomass,
- grain yield,
- N, P and K content in the grains and straw.

Plant height is measured from the soil surface to the summit of the average ear layer (barbs not included).

The grain yield is estimated according to the weight of the collected sample’s grains and to the experimental plots’ harvest.

Table 3: Measured parameters to monitor vegetation (a cross means that the measurement have to be done at this stage)

Parameter	**Unit**	**Sampling frequency**				**Method**
		Germination	Tillering	heading	maturity	
germination	%	x				
Plant density	Plant/m²	x				
Tills per plant	Number				x	
Mean plant height	Meter	x	x	x	x	
Aerial biomass	g				x	Fresh wt / dry wt
Root biomass					(x)	Fresh wt / dry wt
Grain yield	g/m²				x	
N, P and K content in the grains					x	
N, P and K content in straw					x	

Bibliography

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