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D1-8 ISFERALDA guidelines

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Summary

The production of organic amendments from date palm residues in Algeria and Tunisia remains underdeveloped, with limited compost production and almost nonexistent biochar production. Despite the availability of raw materials, only a few composting units operate in both countries. Surveys indicate strong potential for compost use in agriculture if supported by policies and incentives. Biochar production remains minimal, but its wider adoption could be encouraged through awareness campaigns and scientific research.

Compost from date palm residues generally contains high mineral matter (>60%), high salinity and varies in organic composition. Some analyses revealed a wide diversity of characteristics among studied composts, some showing OM close to fresh plant material, some being more mature. To improve compost quality, recommendations include reducing mineral contamination, lowering salinity, preventing nutrient loss, and investing in cost-effective equipment. These recommendations are developed in this report.

Biochar production presents challenges, notably the risk of soil salinization after application. Rinsing biochar before application reduces salinity but results in nutrient loss, particularly potassium. Sodium adsorption by biochar remains low across tested pyrolysis conditions. Experiments demonstrated that biochar significantly enhances soil water retention. To optimize biochar quality, recommendations were made in this deliverable to balance porosity, stability, and water retention while using appropriate pyrolyzers.

Artisanal pyrolyzers could improve the greenhouse gas (GHG) balance by utilizing date palm residues as a heat source. Further refinement of biochar production techniques is needed to maximize its agricultural benefits. With proper optimization, both compost and biochar could play a crucial role in sustainable agriculture, benefiting farmers in oasis regions economically and environmentally.

The results from pot and field experiments demonstrate that compost provides nitrogen and phosphorus essential to the soil, leading to a significant increase in grain and straw yields (30% to 140% higher compared to the control). Compost's effect on plant nutrition, especially nitrogen, is most noticeable in the first few months after application but declines rapidly thereafter, even though only 17% of the nitrogen undergoes gross mineralization over a four-month period. In contrast, the release of phosphorus from compost is more sustained.

While the benefits of using compost are obvious, there are some notable drawbacks, particularly regarding its mineral content. The high mineral content reduces the organic matter supply, which in turn limits the availability of nutrients. Efforts will be needed to lower this mineral content in

composts. Furthermore, the high salinity of compost increases the risk of soil salinization, which could eventually hamper soil fertility.

In flood irrigation systems, nitrogen loss from compost, mainly as nitrate, occurs due to the leaching of excess irrigation water. This nitrogen loss means that optimal plant growth requires an additional nitrogen source, such as urea, during the grain-filling phase to ensure both satisfactory yield and high grain quality. Alternatively, improving irrigation systems—such as switching to drip irrigation—would save water and extend the fertilizing effects of date palm compost by reducing nitrate leaching.

According to the ISFERALDA project, biochar proved to be more effective than compost in improving soil water retention, particularly in soils with higher sand content. This finding indicates that coarse-textured soils, like those in the Sahara desert, could greatly benefit from the application of biochar derived from date palm residues, enhancing their water retention properties. When applied on a larger scale, such practices could contribute to optimizing irrigation and therefore save water.

Due to biochar's low density, it is recommended to incorporate it into the surface horizon of soil to prevent the biochar particles from being blown away by wind during sandstorms or carried away by water during flood irrigation events.

In pot experiments, using biochar alone without rinsing did not improve barley yields compared to the control. However, combining date palm compost with biochar—by mixing them two weeks before field application—proved more effective. This combination enriches the biochar with nutrients and microorganisms from the compost, enhancing soil water retention (thanks to biochar) and supplying necessary nutrients (nitrogen, phosphorus, potassium) for crop growth while also reducing pathogens and weeds. The result is better yields, and biochar also contributes to sustainable carbon storage in the soil.

Both materials of this combination, biochar and compost, have high salinity levels, presenting a clear risk of soil salinization. Since nitrogen from compost is primarily available early in the crop cycle, as with the application of compost alone, additional nitrogen will be needed during the grain-filling phase to achieve a high-quality yield with a good protein content. A potential solution, as with using compost or biochar alone, is to implement more water-efficient irrigation systems, such as drip irrigation. This method would retain more water due to biochar’s properties, reduce nitrate leaching compared to flood irrigation, and may eliminate the need for additional nitrogen during the grain-filling phase.

A combination of date palm biochar and urea with a complement of chemical fertilizers would enhance the benefits of biochar by providing the necessary nutrients for crop development. Biochar would help improve soil water retention and nitrogen from urea and other nutrients from chemical fertilizers would ensure a consistent supply of essential nutrients throughout the plant’s growth stages. This combination would support optimal yield and grain quality by staggering nitrogen release. However, this method relies on expensive chemical fertilizers and does not align with circular economy principles, which emphasize the sustainable use of local resources.

Date palm residues alone cannot sustain biochar or compost production at the required rates for continuous soil amendment. Biochar application at 10 tonnes per hectare would need waste collection from an area 12–20 times larger annually. Compost production yields only 1.7–2.7 tonnes per hectare per year, requiring 13–21 years for full application on the same land. This highlights the need for additional biomass sources or external residue inputs. Despite these limitations, using date palm residues improves soil fertility and supports circular economy principles.

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1 Introduction

The use of organic amendments based on date palm residues in agriculture could play a crucial role in enhancing soil fertility, improving water retention, and promoting sustainable farming practices. In Algeria and Tunisia, date palm residues present a valuable yet underutilized resource for the production of organic amendments such as compost and biochar. Despite the availability of raw materials, compost production remains limited, and biochar production is almost nonexistent, facing several technical, economic, and logistical challenges.

This report synthetizes the current state of organic amendment production in these two countries, highlighting the potential benefits, challenges, and strategies for improvement. The findings from the ISFERALDA project provide valuable insights into optimizing compost and biochar production from date palm residues, as well as their agronomic effects and contributions to the circular economy. By addressing key obstacles—such as equipment shortages, high production costs, and lack of awareness—this study outlines recommendations for increasing the adoption of these sustainable practices, ultimately benefiting farmers and contributing to environmental conservation.

2 Date palm organic amendment production

2.1.1 Organic Amendments production in Algeria and Tunisia

The production of organic amendments in Algeria and Tunisia remains underdeveloped, particularly in the case of compost and almost nonexistent for biochar. Despite the availability of raw materials and technical feasibility, compost production from date palm residues is still limited, with only a few operational units across both countries. The profitability of date palm compost remains moderate due to rising production costs, especially in Algeria, where taxes and competition from both established producers of other types of compost and imported compost create significant market challenges. In Tunisia, compost is more competitively priced but would benefit from increased production and improved distribution.

Encouraging compost adoption requires raising farmer awareness, increasing production, diversifying products, and reducing costs to enhance affordability. Survey findings indicate promising potential for compost use in agriculture, provided that appropriate policies and support programs facilitate its adoption and growth.

From a technical perspective, the lack of appropriate equipment, such as grinders, and limited expertise in composting techniques are major obstacles. Economically, high production costs restrict farmers' access to these organic amendments. Furthermore, limited awareness among both producers and users contributes to weak local demand, despite the proven benefits, such as improved soil fertility and reduced production costs for some farmers.

Biochar production from date palm residues is nearly absent in Algeria and remains limited in Tunisia. Despite investments in high-capacity furnaces, production levels remain low. However, biochar is a profitable venture for Tunisian producers due to low production and distribution costs, as well as a lack of competition, giving them a market monopoly.

The wider adoption of biochar could be promoted through awareness campaigns, communication efforts, and scientific studies showcasing its agronomical, ecological and economic benefits. Additionally, supportive agricultural policies and programs could help accelerate its use, enabling significant growth in the coming years.

Nonetheless, the outlook for development is encouraging. A strategic approach combining awareness campaigns, training programs, product diversification, and cost reduction could lead to broader adoption. Supportive agricultural policies—including subsidies, infrastructure improvements, and practical initiatives such as pilot plots—would be crucial to accelerating this transition.

In conclusion, with targeted and coordinated efforts, the valorization of date palm residues could not only promote more sustainable agriculture but also generate significant economic benefits for farmers in oasis regions.

2.1.2 Results and recommendations

Based on the results obtained in the ISFERALDA project, areas for improving production processes have been identified.

2.1.2.1 Evaluation and optimization of date palm compost

The quality of date palm compost was evaluated using four different mixtures: date palm residues combined with sheep manure (SM), poultry manure (PM), sewage sludge (SS), and landfill leachate (LL). Among these, SM compost had the best overall balance, characterized by a low Corg/N ratio, high stability, and nutrient richness, making it particularly suitable for sustainable agriculture. PM compost had high potassium content but low germination rate, indicating potential phytotoxicity. SS compost showed maturity but lacked potassium, while LL compost showed slower degradation and stability. All composts had high electrical conductivity (EC), raising concerns about salinity due to mineralization of organic matter and water used in composting. Given its superior performance, sheep manure compost was selected for further studies.

A comparative analysis of 2 date palm composts produced by the Association for the Preservation of the Chenini Oasis (ASOC, Tunisia) and a compost produced by Palm Compost (Algeria) showed that the different composts all had a very high mineral matter content (>60%), a high salinity (EC>9.2 $mS.cm^{-1}$) and properties with significant differences from one compost to another. In particular, the Rock-Eval analysis highlighted substantial variations in the composition of organic matter: the ASOC compost was very similar to fresh plant matter, while the Palm Compost showed greater maturity, coming closer to the compost data found in the literature. The analysis of all these results provided valuable information to optimize the production process.

Recommendations for producing better quality compost

- <u>Reducing mineral content:</u>

Placing windrows on a concrete platform, inside concrete bins, or even on protective tarps rather than directly on the natural soil would minimize contamination by mineral particles.

Covering the windrows could reduce the input of mineral particles carried by the wind.

- <u>Reducing salinity for better compost quality.</u>

Keeping the salt content of the compost as low as possible is crucial for two reasons.

1. It optimizes the maturation process by avoiding any interference with microbial activity.

2. It prevents excessive salt accumulation in soils, which is particularly important in arid and semi-arid regions.

To reduce the salt content of composts, here are the recommendations.

- Covering the compost piles, either with a permanent roof or with temporary tarps, could help retain moisture by reducing evaporation. This would reduce the poor-quality water input to the compost and limit the accumulation of soluble salts in the compost due to water evaporation.

- Using local water sources with the lowest possible salt content. In areas where well water salinity fluctuates seasonally (typically higher in summer, reaching several $g.L^{-1}$), compost production should be scheduled when water quality is optimal.

- Prevent nutrient loss

Avoiding excessive water application to windrows reduces the risk of leaching, thus avoiding the loss of valuable fertilizing compounds.

- Cost-effective equipment investment

Expensive equipment, such as date palm waste grinders, would be more financially viable if shared among farmer groups, making composting more accessible.

By implementing these measures, date palm compost production can be optimized to improve both its agronomic value and environmental sustainability.

2.1.2.2 Evaluation and optimization of date palm biochar

The biochars studied were produced from date palm residues at temperatures of 450°C. Different oxygen contents during pyrolysis were tested to know the influence of this parameter. The biochars studied release significant amounts of cations (calcium, potassium, magnesium and sodium (Na)) upon contact with water and stabilize after five rinses. To minimize these initial cation releases, it is recommended to rinse the biochar before application to the soil. However, Rinsing results in the loss of nutrients such as potassium present in the biochar. Producers must therefore determine whether or not to rinse the biochar based on their customers' expectations.

Sodium retention by the biochar remained systematically low (15-20%), regardless of the oxygen contents tested during pyrolysis. While the biochar produced with oxygen retained slightly more sodium than the biochar produced without oxygen under nitrogen flow, the difference was not significant. This suggests that the presence of oxygen during pyrolysis has a limited influence on sodium adsorption, especially when Na concentrations in solution are high. Furthermore, increasing the specific surface area of biochars produced with oxygen during pyrolysis did not significantly improve Na retention, indicating that other factors, such as porosity and surface functional groups, play an important role. The low sodium retention capacity of the studied biochars limits their overall effectiveness in mitigating soil salinization, however studies with biochars produced at different temperatures could be performed to determine the potential of other types of biochars to limit soil salinization. These results show that precise control of anoxia levels in the pyrolysis chamber is not a major concern, provided that combustion of the feedstock is avoided. This is particularly relevant since regulating oxygen levels with artisanal or even industrial pyrolysis methods remains challenging.

Field and pot experiments demonstrated that biochar is highly porous (73%) and hydrophilic. The porosity of date palm residues increases significantly during pyrolysis, and plays a key role in the water retention capacity of soils. The pyrolysis temperature (450°C) is well suited to create pores in a size range that optimizes water availability for plants. In addition, the biochar did not show hydrophobicity and its functional groups responsible for the cation exchange capacity, essential for nutrient retention, were preserved at this moderate temperature.

Recommendations for biochar production

- <u>Having a good balance between porosity, chemical stability and water retention</u>

Set the pyrolysis temperature to around 450°C.

- <u>Using an industrial or artisanal pyrolyzer</u>

Atmosphere during pyrolysis can contain a few % of oxygen. A pure nitrogen flow is not mandatory to obtain quality biochar.

- <u>Optimizing the quality of biochar</u>

Optionally rinse the biochar several times to leach out soluble salts. On the other hand, rinsing leads to loss of nutrients such as potassium. Priorities must be identified by producers and end-users before rinsing biochar.

- <u>Improve carbon footprint</u>

For artisanal or industrial production, the use of fossil fuels as a heat source have a negative impact on the greenhouse gas (GHG) balance. However, well-designed, low-tech pyrolyzers could improve this balance by using part of the date palm residues to initiate the heating and by capturing the syngas to use them as a heat source once the process is underway. In addition, this would prevent the release of toxic or environmentally harmful compounds, such as carbon monoxide, combustible gases (carbon monoxide, dihydrogen, hydrocarbons) and powerful GHGs (methane).

The results of the ISFERALDA project show that the tested biochar significantly improves the water retention capacities of sandy soils. Biochar could have the potential to mitigate soil salinization, but further optimization is needed to improve its retention capacity and reduce the risks of salinity. It will therefore be necessary to refine production techniques and improve its physical and chemical properties to maximize its benefits in sustainable agriculture.

3 Agronomic effects of organic amendments

3.1 Date palm compost

3.1.1 Farmers' opinions and feelings

Concerning date palm compost use, farmers identified key obstacles to date palm compost use. They include insufficient equipment (50%), absence of demonstration plots (30%), lack of technical knowledge (10%), and limited availability of quality manure (10%). Despite these challenges, 90% perceive compost use as environmentally beneficial, while 70% report reduced production costs and half observe improved yields and crop quality. However, 50% have yet to see significant agronomic impacts.

To promote compost use, farmers recommend awareness campaigns (40%), pilot plots for training, subsidized collective grinders, and practical guides. Nearly all current users plan to continue using compost, and 60% of non-users intend to adopt it soon.

Barriers include the complexity of the composting process (40%), long maturation times, and the need for regular monitoring. Additionally, 20% of farmers highlight the high cost of production as a significant limitation. Training and financial support are essential to overcome these challenges and encourage widespread adoption.

3.1.2 Agronomic aspect

The quality of date palm compost depends on the nitrogen source added to date palm residues. A study conducted in the ISFERALDA project showed that the addition of sheep manure allows to obtain the best quality compost. However, additional results must confirm these data.

The use of date palm compost allows, thanks to the increase in temperature during the composting process, to eliminate pathogens and weed seeds present in the initial products.

Compost enhances the development of microbial communities involved in nitrogen mineralization, mineralization and denitrification.

The results obtained during pot and field experiments showed that the compost provides nitrogen and phosphorus to the soil. This contribution leads to a significant increase in grain and straw yield (+30 to 140% compared to the control). The impact of compost on plant nutrition, particularly through nitrogen supply, is evident in the first few months after application but declines rapidly thereafter (despite an estimated gross mineralization of only 17% over four months of incubation). In contrast, phosphorus release from compost is more sustained. By the second year after application, the effect of compost is still present, though grain yield is only about 15% higher than in unfertilized plots.

The advantages of using it are very clear, however there are also disadvantages, particularly in relation to certain properties of compost presented above. Obviously, the high mineral content reduces the supply of organic matter and therefore nutrients. An effort will have to be made to reduce this high mineral content in composts.

In addition, the high salinity of composts leads to a risk of soil salinization and therefore of reducing its fertility.

In flood irrigation systems, significant nitrogen loss from compost, primarily as nitrate, occurs due to the leaching of excess irrigation water. Under these conditions, due to the nitrogen loss, optimal plant growth requires an additional nitrogen source, such as urea, during the grain-filling stage to achieve both a satisfactory yield and high grain quality. Another solution could be to improve irrigation systems. Improving irrigation methods, with a drip irrigation for instance, would not only save water but also extend the fertilizing effect of organic amendments over time and reduce nitrate leaching in shallow aquifers.

3.2 Date palm biochar

Even if that was not studied in the ISFERALDA project, biochar users need to pay attention to the pyrolysis temperatures. Biochar properties will differ greatly depending on this.

The results obtained in the ISFERALDA project showed that biochar was more effective in improving soil water retention than compost. Moreover, the higher the sand content, the more pronounced the effect of organic amendments on water retention. The available water capacity was increased by up to +80% in the most favorable case (a sandy loam soil enriched with 2/3 sand and amended with biochar), compared to the unamended soil. This demonstrated that the sand content influences the effect of OA application. Thus, coarse-textured soils such as those in the Sahara desert regions could greatly benefit from the application of biochar from date palm residues, with a significant improvement in their water retention properties. Applied on a larger scale, such practices could play a role in optimizing irrigation.

Due to the low density of biochar (0.34), it is advisable to incorporate biochar into the first few centimeters of soil. This will prevent the biochar particles from being blown away by wind during sandstorms and during flood irrigation episodes. In fact, since biochar has a lower density than water, its particles can be easily carried away by free water on the surface.

Since the carbon in biochar is stable, its use allows carbon to be stored in the soil and therefore helps combat global warming.

As specified in section 2.1.2.2, rinsing the biochar with water can be carried out before application to the soil. Indeed, studies from the ISFERALDA project have shown that biochars studied release significant amounts of cations, particularly sodium. There is therefore a risk of soil salinization when using this product. One way to reduce this risk is to rinse the biochar with water. In the study carried out, 5 rinses with water were necessary to stabilize these releases. However, it should be noted that rinsing the biochar also leads to the loss of nutrients such as potassium, present in significant quantities in the biochars studied.

In pots experiments, the use of biochar alone and without rinsing did not improve barley yields compared to control.

3.3 Combining date palm compost with date palm biochar

The combination of compost and date palm biochar could combine the advantages of the 2 organic amendments thanks to their complementarity.

The methodology consists of a mixture of biochar and compost 2 weeks before application to the field in order to enrich the biochar with the nutrients and micro-organisms present in the compost. As for biochar and compost, this mixture should be incorporated into the surface horizon of the soil so that it is less subject to wind or water erosion than on the surface.

This combination has the advantage of improving soil water retention thanks to biochar, providing the nutrients necessary for crop growth (N, P, K) and eliminating pathogens and weeds from the initial products.

These improvements lead to better yields and the use of biochar allows for sustainable carbon storage in the soil.

However, the combination of these 2 organic amendments has disadvantages. It requires work and monitoring before application to the field. Since both biochar and compost have high salinities, the risk of soil salinization is clear. Finally, since nitrogen is provided by compost and is only available at the beginning of the crop, a nitrogen supply at the grain filling stage is necessary to have a good quality yield with a good protein content in the grains. A complementary solution, as for the use of compost or biochar alone, would be to use a different, more water-efficient irrigation system, such as drip irrigation. It would save water thanks to the improved water retention of the biochar and would reduce nitrate leaching compared to flood irrigation. It would then perhaps not be necessary to resort to a supplementary nitrogen supply during the crop at the grain filling stage.

3.4 Combine date palm biochar with urea and mineral fertilizer

The combination of date palm biochar and urea would complement the benefits of biochar with a supply of nitrogen necessary for crop development.

The proposed method is a post-pyrolysis method, by contact between the biochar and the mineral fertilizers in solution. The wet mixture must be incorporated into the soil in the surface horizon for the same reasons as those developed previously. Nitrogen is provided in the form of urea and the other nutrients are provided in the form of chemical fertilizers, such as mono-ammonium phosphate and potassium sulphates. Only 1/3 of the necessary nitrogen is applied in the initial mixture. The 2nd and 3rd thirds of urea will be applied in the open field later depending on the phenological stages of the barley.

This blend offers the advantage of enhancing soil water retention due to the biochar while supplying essential nutrients to crops through both chemical and organic fertilizers. Additionally, although not demonstrated in this project, biochar may contribute to improved nutrient absorption over time, enhancing soil fertility in the medium term. Another benefit of this mixture is its ability to stagger nitrogen supply, ensuring a consistent supply throughout different plant growth stages, which supports optimal yield and grain quality.

However, this mixture also has disadvantages. It requires work and monitoring before application to the fields. This method relies on the use of expensive chemical fertilizers and does not align with the principles of the circular economy, which promotes the sustainable use of local resources.

4 Contribution to the circular economy

Application of biochar or compost derived from date palm residues supports the circular economy.

Annual date palm residue production is estimated at 1.5–2.4 tonnes per hectare, yielding approximately 0.5–0.8 tonnes of biochar per hectare based on experimental results. At an application rate of 10 tonnes per hectare, biochar production from a given area would require collecting and processing waste from an area 12 to 20 times larger within a year. Conversely, if biochar were produced solely from the waste of a single plot, it would take 12 to 20 years to accumulate enough for full application. This indicates that date palm residues alone cannot sustain a biochar supply of 10 tonnes per hectare every 3–5 years on the same plot, necessitating the inclusion of other biomass sources or the use of residues from additional plots.

Laboratory and field studies have demonstrated that biochar consists predominantly of highly stable organic matter, which decomposes minimally in soil. The carbon content (62%, equivalent to 6.2 tonnes per hectare) can thus be considered sequestered in the long term. However, our experiments did not assess potential biochar losses due to wind erosion or runoff, which could necessitate reapplication. To prevent such losses, proper incorporation into the soil is essential, reducing the risk of particles being dispersed by wind or irrigation water.

Compost production from date palm residues requires a 70:30 ratio of residues to manure. Accounting for a 20% mass loss during composting, annual residue production allows for compost yields of 1.7–2.7 tonnes per hectare, provided manure is available in sufficient quantities and at a reasonable cost. Even if the rate depends on the nitrogen content of compost, if we consider a recommended compost application rate of 36 tonnes per hectare (based on pot and field trials), a purely local recycling approach would require 13 to 21 years to generate enough compost for full application on a given area. This timeline closely mirrors that of biochar production, despite biochar's longer persistence in soil. Thus, date palm residues alone are insufficient to meet soil organic amendment needs. Supplementary biomass sources and fertilizers are necessary, or residues must be sourced from other plots, potentially to their detriment.

Nonetheless, even if these agricultural residues are not sufficient to provide crop nutrition alone, incorporating organic amendments based on date palm residues significantly enhances soil properties and fertility.

5 Conclusion

From a technical point of view, the lack of suitable equipment, such as grinders, and the poor mastery of composting techniques constitute major obstacles. From an economic point of view, high production costs limit farmers' access to these organic amendments. In addition, the lack of awareness among producers and users contributes to a still timid local demand, despite the observed benefits, such as improved soil fertility and reduced production costs for some farmers.

However, the development prospects are encouraging. A strategy combining awareness, training, product diversification and production costs reduction could allow for wider adoption.

Supporting agricultural policies, through subsidies and adapted infrastructure, as well as concrete actions such as the creation of pilot plots, would be crucial to accelerate this transition.

In short, with targeted and coordinated efforts, the valorization of date palm residues could not only contribute to more sustainable agriculture, but also offer significant economic gains to farmers in oasis regions and producers of organic amendments.