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Agro-physiological traits as biological factors to optimize organic and inorganic amendments for date palm cultivation

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Abstract
The date palm (*Phoenix dactylifera* L.) is the most important fruit crop in the oasis ecosystems due to its different ecological and socio-economic roles. However, this crop is confronted with environmental stresses such as soil poverty in organic and mineral matter. This research aimed at how local compost and/or phosphate sludge (PS) can affect the agro-physiological parameters of date palm over time in a greenhouse environment. The results showed that the factor time (period) presented a positive effect in the improvement of the physiology (stomatal conductance and chlorophyll fluorescence) and the growth (number of leaves, shoot height, and leaf area) of date palm seedlings treated with compost and PS + Compost in the periods P4-P9 and P8-P9, respectively, compared to the control. In addition, this study revealed the effectiveness of compost alone or combined with PS to boost the growth performances and physiology of date palm seedlings from the second month of the experiment with an apparent difference after four months of compost and PS application. It is clear from this study that the application of compost and its combination with PS could be a biological tool to improve date palm development under poor soil.

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Introduction

In recent years, the globe has become very cognizant of environmental issues affecting food security and productivity, human nutrition, and welfare (Smith et al., 2020). The primary limiting factor, which negatively affects crop production in the tropics, is soil nutrient shortage due to soil degradation, affecting plant growth as well nutrient availability, and absorption (Ait-El-Mokhtar et al., 2019; Fattahi et al., 2021). Some approaches, such as soil fertilization, can be used to restore the productive capacity of soils. Fertilizers are generally defined as any organic or inorganic substances of biological origin applied to soil to offer one or more plant nutrients required for its development (Tao et al., 2015). Because synthetic chemicals are considered pollutants, toxic, and expensive, so researchers are working hard to

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produce natural fertilizers that are less hazardous, less expensive, and more readily available (Rouphael et al., 2020). Agricultural growth techniques have shifted toward organic, ecological, or environment-friendly strategies (Petropoulos et al., 2020; Turan et al., 2021). Modern agriculture involves decreased use of chemical fertilizers, while maintaining crop production and quality.

Phosphorus (P) seems to be a mineral macronutrient necessary for plant development and the metabolism of molecules. Plant roots also absorb P in the form of orthophosphates, either $H_2PO_4^-$ or HPO_4^{2-}, although their concentrations in soil are in the micromolar range (Etesami and Maheshwari, 2018). This is because of P complicated dynamics in the soil; this nutrient has a distinct feature as it is highly fixable in soil. Mineral P can be present in soil linked with the interface of iron or aluminum oxides, rendering its low solubility and hence, inaccessible for plant development (Audette et al., 2020). These factors contribute to the utilization of chemical P fertilizers and animal manure applied to farmlands, which now has resulted in severe environmental degradation in recent decades, such as the input of cadmium and radioactive elements into the soil from polluted fertilizer application (Conrad et al., 2019; Li et al., 2021).

The demand for P in croplands is predicted to rise by up to 80% (Mogollón et al., 2018). This indicates that there will be an utter scarcity of P supply from industrialized fertilizer manufacturers in the future, exacerbated by the depletion of P existing in croplands due to erosion (Conrad et al., 2019; Alewell et al., 2020). As a result, P is gaining more attention as a nonrenewable natural resource (Cordell et al., 2009; Amiri et al., 2020). Plant P uptake and utilization must be improved for environmental and economic reasons by valorizing industrial and agricultural waste using a biological process like composting (Meddich et al., 2016; Ait-El-Mokhtar et al., 2020a; Sayara et al., 2020; Mobaligh et al., 2021).

Green waste compost or phospho-compost can be used as a partial component of the growth medium (El Gabardi et al., 2020; Ait Rahou et al., 2021). Furthermore, some studies have demonstrated a possible beneficial influence on plant growth and vigor by increasing mineral nutrient absorption and photosynthetic activity (Ben-Laouane et al., 2021; Boutasknit et al., 2021; Haouas et al., 2021a). Previous researches have shown that organic fertilizers may be used to restore damaged soils (Libutti and Rivelli, 2021). Compost is mineralized when mixed into soil, giving plants a steady release of accessible mineral nutrients, thereby enhancing soil fertility (Lahbouki et al., 2021; Malesani et al., 2021; Zafar-ul-Hye et al., 2021). Compost improves the physical and chemical characteristics of soils, such as pH neutrality, and boosts organic matter and nutrient availability, resulting in increased growth and yield of plants (Bello et al., 2021; Zafar-ul-Hye et al., 2021). Moreover, using compost made from organic waste and phosphate sludge is a promising technique for generating crops with high quality and yield (Anli et al., 2021a; Boutasknit et al., 2021a).

Morocco is a global leader in the phosphate-based products business, represented by the Office Chérifien du Phosphate (OCP). Phosphate ore from Morocco is processed using a series of enrichment procedures that include crushing, screening and washingwell as flotation (Boujlel et al., 2019). Phosphate sludge (PS) is produced in enormous amounts during the washing and flotation processes, with 28 million metric tons produced per year that contains about 20% of phosphorus (P_2O_5) (Haouas et al., 2021b). PS is a huge economic and environmental problem that has resulted in the loss of recycled waste, the formation of dikes, the disfigurement of the landscape, and the reduction of arable areas as a result of its accumulation (Haouas et al., 2020). Until now, little research has tried to establish acceptable methods for PS valorisation, such as composting (Haouas et al., 2021b; Mobaligh et al., 2021). PS as a phosphate rock by-product has the potential to be a long-term, low-cost, and always-available substrate for rehabilitating deficient soils. This opens up new pathways for its circular economy integration. Moreover, recycling PS for land application can minimize disposal costs while also providing a source of mineral nutrients for a variety of crops (Anli et al., 2021a; Boutasknit et al., 2021a; Haouas et al., 2021a).

In oasis ecosystems in arid and semi-arid climates, date palm is a primary agricultural fruit crop, which has important socio-economic and ecological values (Hanieh et al., 2020). The date palm is a multifunctional tree inextricably tied to the inhabitants of the Arabian Peninsula's lives and heritage. It offers food, shelter, and lumber, and all parts of the palm may be used in various ways (Arias et al., 2016; Elsadig et al., 2017). Compared to other fruits, the date fruit is extremely high in dietary nutrients and calories due to its high sugar content, giving the user immediate energy (Salomon-Torres et al., 2017; Salomón-Torres et al., 2021). Despite its essential importance, date palm cultivation is still faced with various environmental constraints. Among these constraints, the poverty of soils in organic matter and nutrients, drought, and salinity are the major problems of the oasis environment (Jonoobi et al., 2019; Ait-El-Mokhtar et al., 2020b; Anli et al., 2020).

To address these problems, the critical originality of this study is that it compares the positive effect of compost from green waste and/or phosphate sludge (PS) on the agro-physiological characteristics of date palm seedlings grown in a greenhouse. This study summarizes the results of experiments and analyses of agro-physiological characteristics carried out on compost and/or PS to identify the optimal period for these amendments to influence date palm development; it also offers some recommendations for their application and dosages to be used for achieving optimal date palm growth and yield.

Materials and Methods

Plant material, and preparation and application of compost and phosphate sludge

Before germination in plastic basins with a sandy substrate wetted with sterile distilled water, *Phoenix dactylifera* seeds (Cv. Jihel) were disinfected with sodium hypochlorite:water (1:2 v:v) followed by washing three times with sterile distilled water. The seeds were then incubated for three weeks at 38 °C in an oven. Once the seedlings were two month old (one-leaf stage), they were transplanted into plastic bags containing 2.2 kg of soil that had been sterilized at 180 °C for 3 h and mixed with compost (5%) and/or PS (5%).

The compost utilized in this study was made from grass waste, according to Meddich et al. (2016). The compost physicochemical characteristics were: pH, 7.9; electrical conductivity, 7.1 mS cm^{-1}; Olsen available phosphorus, 300 mg kg^{-1}; total organic carbon, 30.6%; total nitrogen, 2.2%; C/N ratio 14, and NH_4^+/NO_3^-, 0.4. The phosphate sludge utilized in this study was from the Cherifian Phosphate Office's El Youssoufia Station in Morocco. The PS physicochemical characteristics were: pH, 7.7; electrical conductivity, 0.7 mS cm^{-1}; Olsen available phosphorus, 21.4 mg kg^{-1}; total organic carbon, 0.38%; total nitrogen, 0.07%, and C/N ratio 5.43.

Date palm seedlings were grown in a greenhouse at 25.5 ◦C (16/8 h light/dark) with average relative humidity of 68.5% and fluorescent light (500 µmol m^{-2} s^{-1}) during 20 weeks. The study used a fully randomized design with 5 biological replicates for each treatment, and all plants were arranged in the greenhouse randomly. Four treatments were applied: i) Control without any amendment, ii) Compost (soil amendment with 5% of compost), iii) PS (phosphate sludge at 5%), and iv) PS + Compost (combined treatment: soil amendment with 5% compost and 5% PS).

Data collection and statistical analyses

After 15 days of transplantation, the first measurement of growth and physiology of the seedlings was recorded. Each measurement was delayed by 15 days, which was considered as one period for growth and physiological parameters evaluation. During the experiment, nine measurements (P1 to P9) were carried out and corresponded to nine periods (P).

Growth performance

During the experiment, growth traits, such as number of leaves (NL), shoot height (SH), and leaf area (LA) were evaluated 9 times (periods) with an interval of 15 days between two consecutive measurements. These parameters were assessed to evaluate the date palm seedlings' growth performance subjected to different applied treatments.

Physiological parameters evaluation

To monitor physiological characteristics of date palm seedlings, stomatal conductance and quantum yield of photosystem II (F_v/F_m) were assessed. Between 11:00 AM and 01:00 PM, a porometer (CI-340, Handheld Photosynthesis System, WA USA) was used to measure stomatal conductance (g_s) at two youngest fully developed date palm leaves, as described by Harley et al. (1992). A fluorometer was used to estimate the fluorescence of PSII (F_v/F_m) (OPTI-SCIENCE, OS30p). By obscuring the upper edge of the second fully grown leaf for 30 minutes, dark adaptation was achieved. Transmission at 650 nm on a leaf area of 12.5 mm^2 was used to assess this parameter. At a 10 µs acquisition speed, the fluorescence signal was recorded for a second (Baker, 2008).

Table 1. Effect of a period on evaluated parameters under different applied treatments during nine periods in greenhouse conditions using analysis of variance (ANOVA)

Parameters/treatments	Control	Compost	PS	PS+Compost
F_v/F_m	***	***	***	***
g_s	***	***	***	***
NL	***	***	***	***
SH	***	***	***	***
LA	***	***	***	***

F_v/F_m : chlorophyll fluorescence; g_s: stomatal conductance; LA: leaf area; NL: number of leaves; SH: shoot height, PS: phosphate sludge. ***: significant difference at the 0.001 level.

Statistical analyses

The effects of compost and phosphate sludge (PS) application on agro-physiological traits of date palm seedlings were statistically analyzed with the multivariate analysis (MANOVA) using IBM SPSS23. Period (P) and treatment (T) were, respectively, used as first and second factors. Five replicates per treatment were used for all evaluated agro-physiological traits. The significance of differences between treatments and factor interactions were assessed at the 5% probability level. Tukey's (HSD) post-hoc test at $P < 0.05$ was computed to compare the means.

Results

Effect of the period (P), treatment (T), and period x treatment (P-T)

Effect of period (P)

Regardless of the ANOVA test, there was a significant difference on the different evaluated parameters according to the period variable for each treatment. Generally, period and treatment factors presented a substantial effect on the evaluated parameters (**Table 1**).

The homogeneity of variance tests allowed separating the studied parameters into two groups (**Table 2**). The first group included chlorophyll fluorescence (F_v/F_m), number of leaves (NL), and shoot height (SH), which did not differ significantly ($P > 0.05$). As for the second group, there were stomatal conductance (g_s) and leaf area (LA) that recorded a highly significant difference ($P < 0.001$) according to the period factor. Therefore, the first group was statistically analyzed according to Tukey's test (parametric test) since there was an equality of variance, and the second one according to Games-Howell (non-parametric test) since there was no variance equality (**Table 2**).

As for the ANOVA results, they showed a great significant difference ($P < 0.001$) in F_v/F_m , g_s, and LA, while no significant difference was recorded for NL and SH (**Table 3**). A significant positive correlation was recorded in g_s, NL, SH, and LA with the factor period. However, F_v/F_m showed no significant difference in considering the period factor. These results could be explained by the fact that g_s, NL, SH, and LA were closely impacted by the time. Moreover, the growth parameters changed linearly over time during the experiment (**Figure 1**). The physiological traits, especially F_v/F_m (**Figure 2A**) and g_s (**Figure 2B**) functioned in a non-linear way during the same period. However, it can be observed that all parameters execution in time was significant according to the different applied treatments (**Table 1**).

Treatment effect

All parameters changed in a highly significant way with time except for $F_v/F_{m.}$ Moreover, it is interesting to note that the correlations between different parameters (g_s, NL, SH, and LA) recorded very high values compared to the values between F_v/F_m and the other parameters (**Table 4**). In addition, the compost application alone and in combination with PS recorded a positive effect in improving all studied parameters. The correlation of the studied parameters with all treatments showed a significant difference except for F_v/F_m as a period function (**Table 5**). The control treatment recorded a low correlation coefficient (0.073) for F_v/F_m with a significant change of the other parameters with time. The F_v/F_m and the other parameters showed an essential development with time for the date palm seedlings treated with compost with a correlation coefficient around 0.507. However, the PS treatment showed a very low correlation coefficient (-0.236) for F_v/F_m with a significant alteration of the other parameters as a function of time. In addition, the PS + Compost treatment provided a significant time-dependent change with a decrease in the correlation coefficient (0.440) for F_v/F_m compared to the compost treatment (0.507). To understand the treatments' effect on date palm seedlings, Compost and PS+Compost treatments were compared with control and PS treatments. The obtained results showed no significant difference between the control and PS treatments and Compost and PS+Compost in all evaluated parameters. However, the compost application in the absence or the presence of PS significantly improved $F_v/F_{m,}$ g_s, and LA compared to the control and PS treatments (**Table 6**).

Table 2. Homogeneity of variances test based on the average of different traits evaluated on date palm during nine periods under greenhouse conditions.

Parameters	Levene's statistics	ddl1	Ddl2	Significance
F_v/F_m	0.335	3	176	0.800ns
g_s	16.012	3	176	0.000***
NL	0.276	3	176	0.843ns
SH	0.406	3	176	0.749ns
LA	10.915	3	176	0.000***

F_v/F_m : chlorophyll fluorescence; g_s: stomatal conductance; LA: leaf area; NL: number of leaves; SH: shoot height

Table 3. ANOVA test on date palm seedlings during nine periods under greenhouse conditions.

		Square sum	dl	Medium square	F	Significance
F_v/F_m	Intergroups	0.036	3	0.012	70.908	0.000***
g_s	Intergroups	17531.837	3	5843.946	26.261	0.000***
NL	Intergroups	0.267	3	0.089	0.204	0.893ns
SH	Intergroups	67.165	3	22.388	1.799	0.149ns
LA	Intergroups	1034.905	3	344.968	8.521	0.000***

F_v/F_m : chlorophyll fluorescence; g_s: stomatal conductance; LA: leaf area; NL: number of leaves; SH: shoot height

Table 4. Pearson correlation between period (days) and evaluated parameters on date palm seedlings during nine periods under greenhouse conditions

	Period (days)	F_v/F_m	g_s	NL	SH	LA
Period (days)	1.0	0.145 ns	0.649**	0.883**	0.912**	0.871**
F_v/F_m	0.145 ns	1.0	0.517**	0.156*	0.272**	0.453**
g_s	0.649**	0.517**	1.0	0.635**	0.738**	0.827**
NL	0.883**	0.156*	0.635**	1.0	0.857**	0.791**
SH	0.912**	0.272**	0.738**	0.857**	1.0	0.911**
LA	0.871**	0.453**	0.827**	0.791**	0.911**	1.00

F_v/F_m : chlorophyll fluorescence; g_s: stomatal conductance; LA: leaf area; NL: number of leaves; SH: shoot height. ** and *: Correlation is significant at the 0.01 and 0.05 levels, respectively, and ns: non-significant

Table 5. Pearson correlation between period (days) and applied treatments evaluated on date palm seedlings during nine periods under greenhouse conditions. A: Control, B: Compost, C: PS, and D: PS+Compost treatments

		Period (Days)	F_v/F_m	g_s	NL	SH	LA
Treatments	**Period**	1	0.073	0.847**	0.891**	0.920**	0.968**
Control	F_v/F_m	0.073	1	0.287	0.117	0.230	0.127
	g_s	0.847**	0.287	1	0.791**	0.799**	0.822**
	NL	0.891**	0.117	0.791**	1	0.859**	0.856**
	SH	0.920**	0.230	0.799**	0.859**	1	0.951**
	LA	0.968**	0.127	0.822**	0.856**	0.951**	1
Compost	Period	1	0.507**	0.878**	0.904**	0.961**	0.974**
	F_v/F_m	0.507**	1	0.444**	0.335*	0.458**	0.493**
	g_s	0.878**	0.444**	1	0.872**	0.917**	0.892**
	NL	0.904**	0.335*	0.872**	1	0.897**	0.877**
	SH	0.961**	0.458**	0.917**	0.897**	1	0.965**
	LA	0.974**	0.493**	0.892**	0.877**	0.965**	1
PS	Period	1	-0.236	0.768**	0.840**	0.889**	0.940**
	F_v/F_m	-0.236	1	-0.457**	-0.342*	-0.300*	-0.128
	g_s	0.768**	-0.457**	1	0.667**	0.775**	0.653**
	NL	0.840**	-0.342*	0.667**	1	0.829**	0.850**
	SH	0.889**	-0.300*	0.775**	0.829**	1	0.890**
	LA	0.940**	-0.128	0.653**	0.850**	0.890**	1
PS+Compost	Period	1	0.440**	0.785**	0.904**	0.939**	0.965**
	F_v/F_m	0.440**	1	0.318*	0.523**	0.423**	0.483**
	g_s	0.785**	0.318*	1	0.723**	0.740**	0.782**
	NL	0.904**	0.523**	0.723**	1	0.874**	0.839**
	SH	0.939**	0.423**	0.740**	0.874**	1	0.940**
	LA	0.965**	0.483**	0.782**	0.839**	0.940**	1

** and *. The correlation is significant at the 0.01 and 0.05 levels, respectively

Effect of period-treatment (P-T)

The obtained results showed that F_v/F_m, g_s, SH and LA had significant differences (P < 0.01) except NL, which showed no significant difference (P > 0.05) (**Table 7**). This interaction suggested that the treated date palm seedlings were able to improve photosynthetic activity and consequently enhanced growth performances, including LA and SH as an effect of period and applied treatments. As for NL, these results can be explained because whatever the treatment was used in the function of time (period), this parameter did not change, and this may have been the result of the date palm's slow growth to form new leaves as well as the short period of the experiment (135 days). In addition, the MANOVA analysis showed that F_v/F_m, g_s, SH and LA had significant differences (P < 0.01) following the treatment (T) and the period (P) factors and their interaction (T*P). In contrast, NL showed only a significant difference (P < 0.001) under the P factor (**Table 7**).

Table 6: Effects of applied treatments on evaluated parameters on date palm seedlings during nine periods under greenhouse conditions. Each period corresponds to 15 days.

	Chlorophyll fluorescence	
Treatments	Group A	Group B
PS	0.75 b	-
Control	0.76 b	-
PS+Compost	-	0.78 a
Compost	-	0.79 a
Sig.	Ns	Ns
Treatments	**Stomatal conductance**	
Control	34.48 b	-
PS	35.32 b	-
Compost	-	52.01 a
PS+Compost	-	56.70 a
Sig.	Ns	Ns
Treatments	**Number of leaves**	
PS	1.73 a	-
Control	1.82 a	-
Compost	1.82 a	-
PS+Compost	1.82 a	-
Sig.	Ns	-
Treatments	**Shoot height**	
Control	17.10 a	-
PS	17.42 a	-
Compost	18.22 a	-
PS+Compost	18.63 a	-
Sig.	Ns	-
Treatments	**Leaf area**	
Control	13.46 b	-
PS	13.74 b	-
Compost	-	17.89 a
PS+Compost	-	18.81 a
Sig.	Ns	ns

Table 7. Multiple analysis of variance (MANOVA): interactions between period and treatments factors on date palm seedlings evaluated parameters during nine periods under greenhouse conditions. Each period corresponds to 15 days.

Parameters	Treatment (T)	Period (P)	T*P
F_v/F_m	***	***	***
g_s	***	***	***
NL	ns	***	ns
SH	***	***	**
LA	***	***	***

Dendrogram (hierarchical classification: clusters)

According to the Ward's method, the results of the hierarchical classification classified the different applied treatments based on the periods into three distinct groups (clusters) (**Figures 3A**). In addition, the CART (Classification and Regression Tree) decision tree using the SPSS program was used to understand the characteristics of each group. The period variable was found to be the first discriminating variable among the three groups, followed by the treatment variable. On the other hand, regardless of the treatment, we may conclude that group 1 (Node 1) was defined by the periods P1, P2, and P3. The samples of the control and PS treatments were included in group 2 (Node 3) for a period more than or equal to 5. Group 3 (Node 4) contained samples from the compost and PS + Compost treatments for periods above 4. In other words, this decision tree showed three distinct behaviors in our experiment: 1) a behavior that confused the applied treatments with the periods P1, P2, and P3; 2) a behavior that discriminated the Compost and PS + Compost treatments from the control and PS treatments; and 3) a behavior that distinguished the separation of Compost and PS + Compost treatments (**Figure 3B**). These results suggest that the change in the development of date palm seedlings after transplanting began to be apparent from the second month (P4). Indeed, after two months of cultivation, the application of compost alone or combined with PS showed a significant change in development than that by the control and PS treatments. This can be explained by a good adaptation of the date palm and better absorption of mineral elements in the substrate amended by the compost.

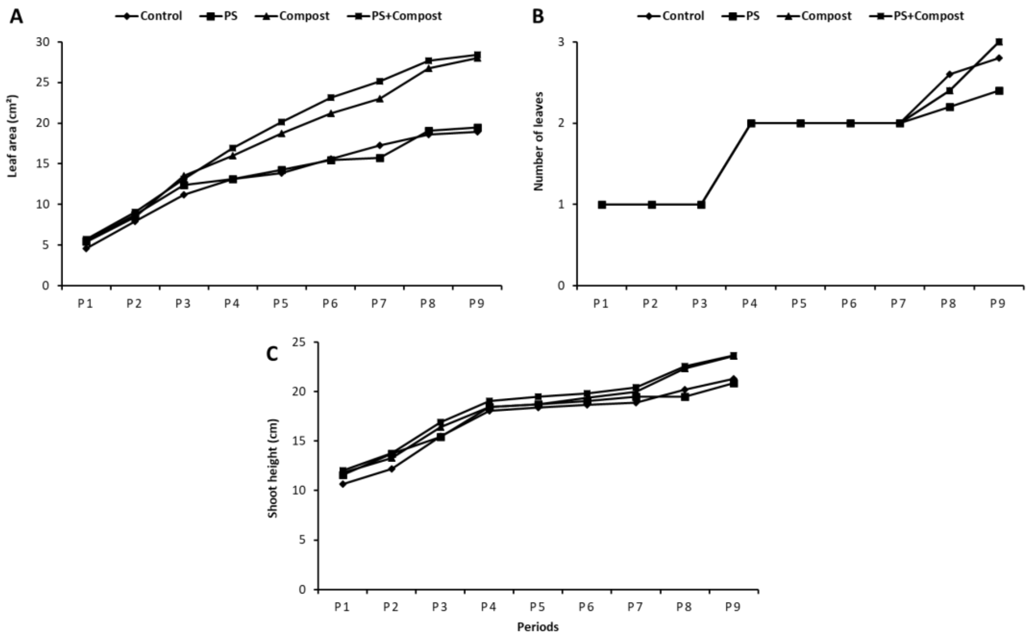

Figure 1. Leaf area (A), number of leaves (B), and shoot height (C) of date palm seedlings subjected to control, PS (Phosphate sludge), compost, and PS + Compost treatments during nine periods (P1 to P9) of the experiment under greenhouse conditions. Each period corresponds to 15 days.

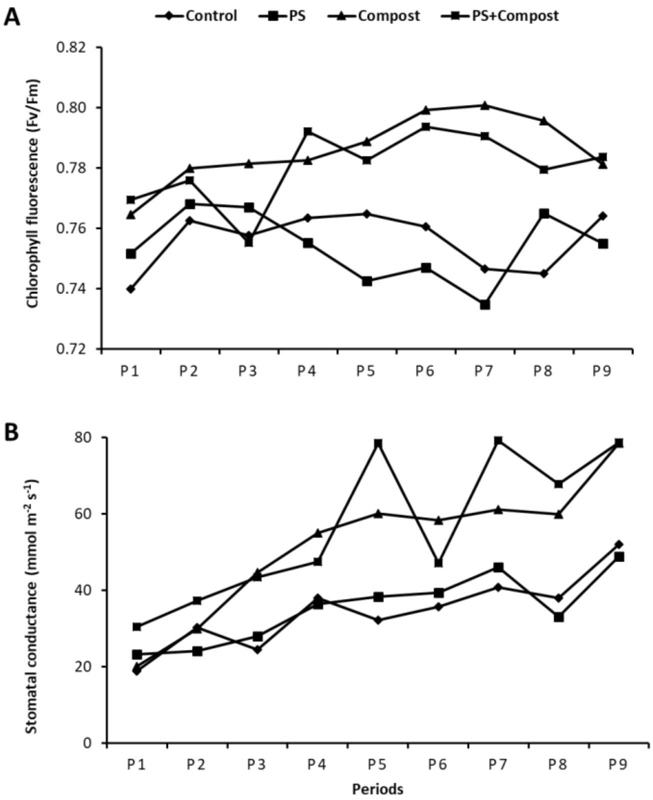

Figure 2. Chlorophyll fluorescence (A) and stomatal conductance (B) of date palm seedlings subjected to control, PS (Phosphate sludge), compost, and PS + Compost treatments during nine periods (P1 to P9) of the experiment under greenhouse conditions. Each period corresponds to 15 days.

Principal component analysis

Based on the results of the previous section (**Figure 3**), we noted three segments in terms of plant behaviors. To further explain the three behaviors while using growth and physiological parameters, we used the principal component analysis (PCA) tool. The mentioned analysis was performed on the SPSS software. It revealed 93% of the total variance of the parameters evaluated according to the treatments applied during different periods of the experiment. The PCA generated two graphical insights presented in **Figure 4**. The generated factorial map (**Figure 4A**) showed that the four variables (g_s, NL, SH and RL)

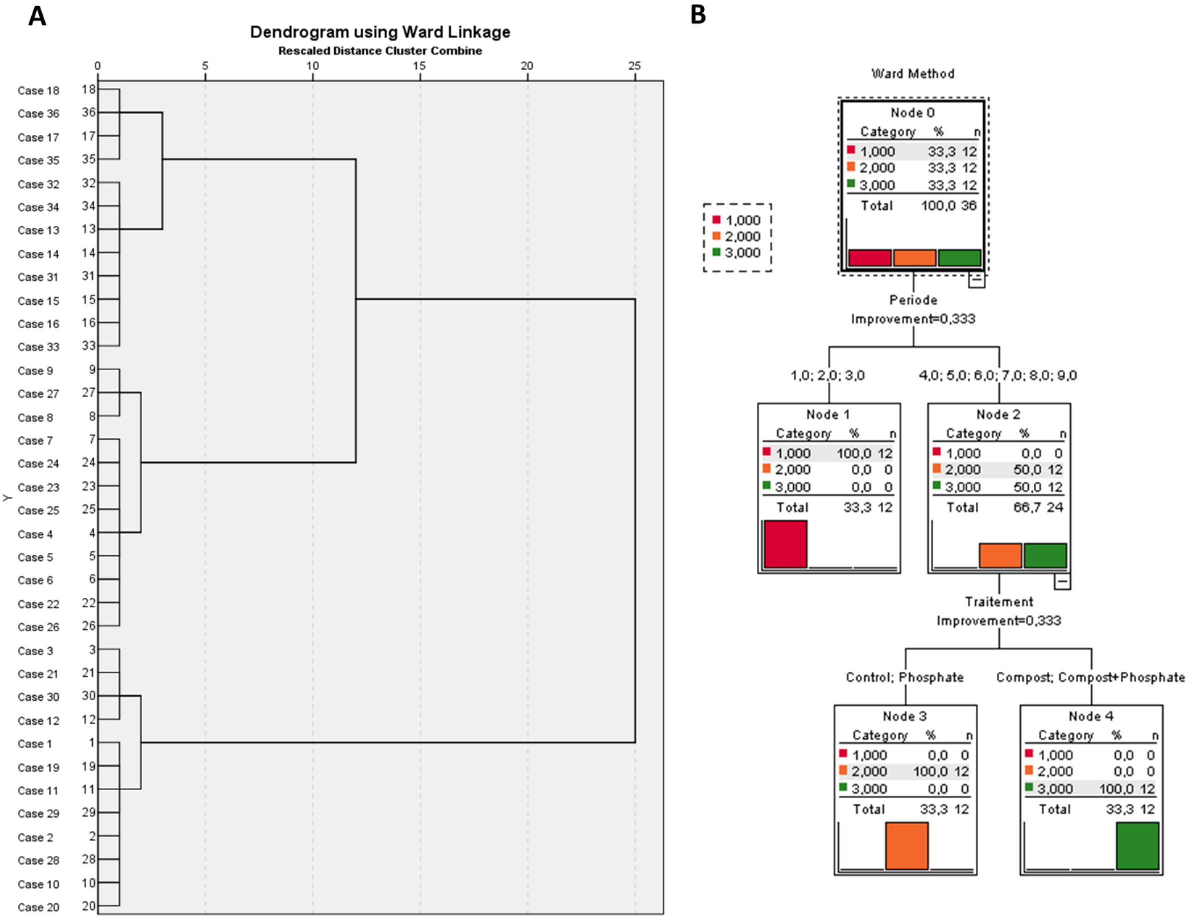

Figure 3. Hierarchical classification of different applied treatments based on nine periods. Each period corresponds to 15 days.

were perfectly correlated and provided the same information. However, the parameter FC (chlorophyll fluorescence) remained independent of the group of four parameters and brought a singular and different information. This allowed to give two main components (component 1 (75%) = morphological parameters and component 2 (18%) = physiological parameters). Moreover, the perceptual map (**Figure B**) allowed us to visualize the dispersion of our statistical individuals on the first map (**Figure 4A**) and particularly the three categories already obtained in **Figure 3**. We also observed a change over time resulted in changes in the oriented behaviors of FC and g_s for the compost and PS + Compost treatments. On the other hand, for control and PS treatments, the change in time had a tendency to decrease FC and g_s. These findings showed that the photosynthetic activity measured in terms of F_v/F_m was inhibited in the absence of compost (Control and PS treatments), however, the activity was maintained higher with compost supplementation in the presence or absence of PS. It might be related to the presence of PS in the soil, as well as a deficiency of mineral components required to photosynthesis in the lack of compost.

Discussion

According to the ANOVA analysis (**Table 1**), the obtained results showed significant impact on all evaluated traits based on period and applied treatments factors. This may have been due to changes occurred in plant growth and physiology with time. In addition, following the homogeneity test (**Table 2**), the findings revealed a significant difference in g_s and LA traits. At the same time, F_v/F_m, NL, and SH showed no significant difference during the study periods. The improvement in g_s and LA parameters could be explained by the fact that plants growth traits, especially leaf area, was correlated with the quantum yield of PSII (F_v/F_m), which might have happened with enhanced CO_2 uptake via stomata (Movahedi et al., 2021). However, the non-significant differences in F_v/F_m , as well as NL and SH of date palms, could be explained by the fact that date palm is a slow-growing plant and can maintain its photosynthetic activity under differing cultivation periods (Baslam et al., 2014; Anli et al., 2020).

As shown in **Table 3**, ANOVA analysis revealed an improvement of date palm seedling physiology (g_s and F_v/F_m) and growth (LA) concerning intergroups. These findings suggested that date palm can

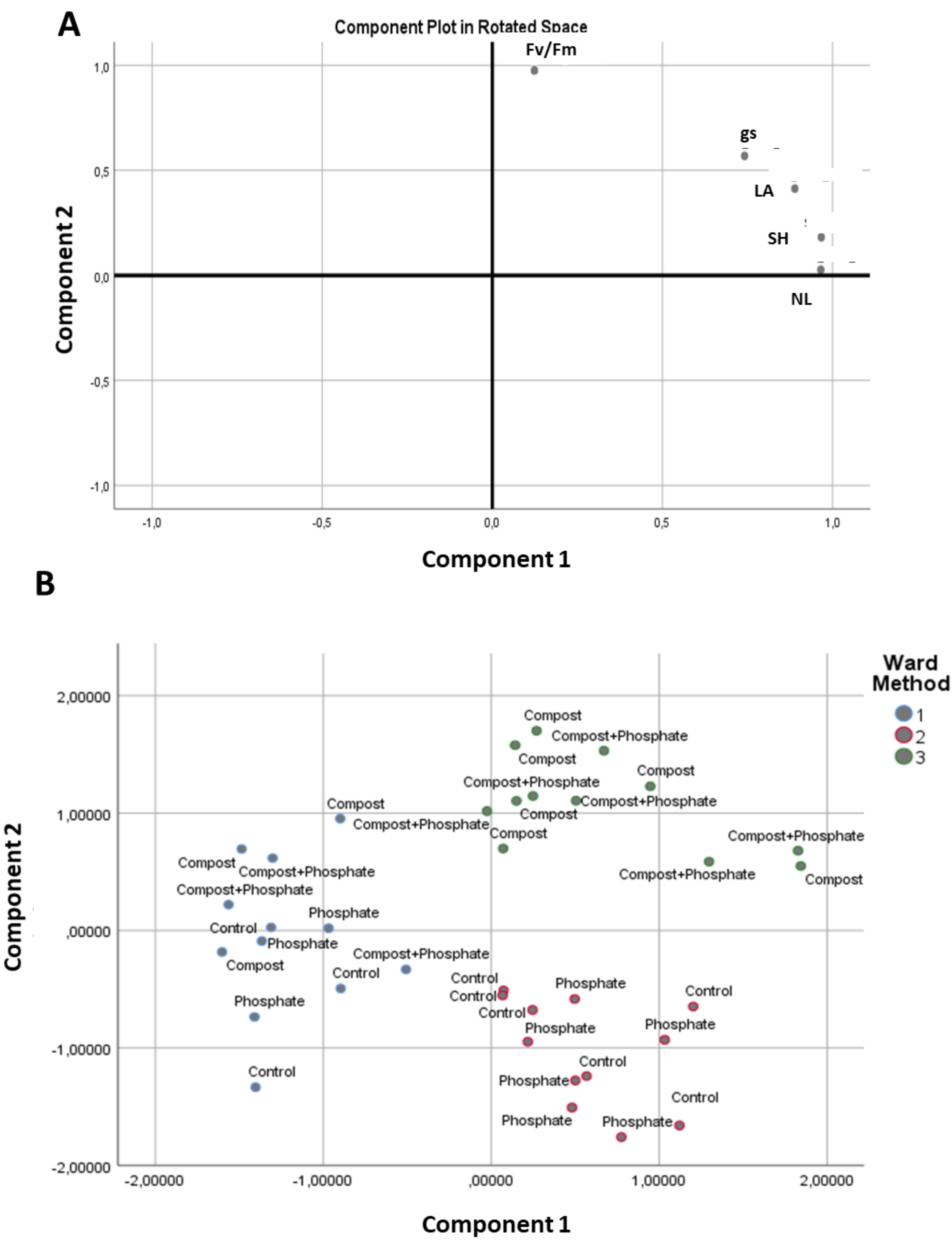

Figure 4. Principal component analysis of the studied parameters for different treatments.

promote the expansion of leaf cells by increasing photosynthetic activities, consequently leading to enhanced growth. A better opening of the stomata and an enhanced photosynthetic activity would also improve the growth of the date palm, particularly the leaf area, in the short term of its development (Anli et al., 2020; Toubali et al., 2020). As for the correlation between the time period and the evaluated parameters (**Table 4**), it was clear that all the measured parameters showed a significant difference except F_v/F_m; this suggested that the date palm over time can maintain its photosynthetic functions to enhance its growth and development.

This study explained a clear time period effect on evaluated parameters under the different applied treatments, especially on growth and physiological traits (**Figures 1 and 2**). As for growth parameters, they presented a linear change, which was linked directly with applied treatments and time period factor. Significant differences were obtained from time periods P4 to P9 for LA and P8-P9 for NL and SH for control and PS as well as Compost and PS + Compost treatments. These results suggested that date palm growth in terms of LA could be improved by applying compost alone or combined with PS from the second month of their application. As for NL and SH, their slow change in time can only be explained because it is a slow-growing plant. This agrees with a previous study of Anli et al. (2021b), who reported that compost application on date palm seedlings exhibited an improvement in LA, while NL and SH showed no significant difference compared to the control after four months of the experiment. However, Ait-El-Mokhtar et al. (2020) reported that date palm seedlings cultivated in the greenhouse after 14 months of compost application boosted the LA, NL, and SH traits compared to those in the control conditions. This suggests that the application of organic amendment could significantly improve morphological characteristics after a long cultivation period.

On the other hand, the physiological parameters showed fluctuations whatever the treatments applied during all the experiment periods. These fluctuations showed differences regarding control and PS and Compost and PS + Compost treatments from P4-P9 for F_v/F_m and P3-P9 for g_s. This could have been due to different environmental factors, such as the periods of measurements or the development stage of the date palm seedlings. This could be due to the plants' growth over time and improved absorption of mineral elements such as phosphorus (P), potassium (K), calcium (Ca), and magnesium (Mg) that are important for photosynthesis in the Compost and PS + Compost treatments compared to the PS and control treatments (Hosseini et al., 2019; Sitko et al., 2019; Begum et al., 2020; Tabbasum et al., 2021). The fluctuations can result from different climatic conditions during the experiment and the other leaf-stage growth of the plants (Abohatem et al., 2011; Ait-El-Mokhtar et al., 2019; Trottier et al., 2020).

The findings showed that a highly significant difference was recorded for all evaluated traits (**Table 5**). Moreover, plants treated with Compost or PS + Compost recorded a positive impact of boosting all studied parameters. However, in the presence of PS (PS and PS + Compost treatments), we recorded a decrease in the correlation coefficient (-0.236 and 0.440, respectively) for F_v/F_m compared to that of the Compost treatment (0.507). Based on the findings, it can be concluded that PS, either alone or in combination with Compost, has a negative impact on F_v/F_m over time. Compost alone has a positive and better effect in improving the photosynthetic activity of date palm seedlings. This could be explained by the fact that Compost is rich in phosphorus and other mineral elements. The addition of PS in the presence of Compost may cause chelation of P with other ions such as Mg^{2+} or Ca^{2+}, which are crucial elements in photosynthetic activity and development of plants (Usmani et al., 2019).

Furthermore, compared to the control and PS treatments, the compost application in the absence or the presence of PS enhanced F_v/F_m, g_s, and LA (**Table 6**). These results stipulate that organic amendment alone or combined with inorganic substances could boost plant physiology and, consequently, growth performance. For example, in another study with tomato, the effect of PS was positive on tomato plants by improving growth in terms of biomass, SH, and NL, unlike in our study. This could be justified by the plant's variety and stage of development (Ait-El-Mokhtar et al., 2021; Haouas et al., 2021b). Another study showed an increment in potato yield and growth when a phospho-compost was applied as a biostimulant in the soil (Kammoun et al., 2017). Our findings exhibit that combining PS with compost had a beneficial impact, suggesting that this technique could be employed for PS valorization and the production of high-quality plant biostimulants. Several studies revealed the positive impact of phospho-compost in improving agro-physiological traits on different crops such as garlic, tomato, and maize (El Gabardi et al., 2020; Boutasknit et al., 2021a; Haouas et al., 2021a).

In addition, the findings of this study showed a beneficial impact of compost alone or combined with PS (**Figures 3 and 4**). The results showed the importance of compost application as organic fertilizer and its combination with PS to promote date palm seedling development under greenhouse conditions and different time periods. Recent studies report that organic fertilizer application could boost date palm, other plant growth and physiological traits, and mineral nutrition (Ait-El-Mokhtar et al., 2020a; Anli et al., 2021b; Ben-Laouane et al., 2021; Zafar-ul-Hye et al., 2021). Other studies also showed a positive impact of phospho-compost supplementation on different crops such as lettuce, chickpea, and tomato by improving mineral nutrient uptake, photosynthetic activities, stomatal conductance, and growth traits (Ditta et al., 2018; Anli et al., 2021a; Haouas et al., 2021a).

Conclusion

This study showed that the effect of the time period factor is remarkable from period P4 to period P9 for the physiological parameters such as g_s and F_v/F_m separating the impact of control and PS treatments compared to that of the Compost and PS + Compost treatments. Moreover, the same trend was observed for growth parameters such as NL, SH, and LA from period P8 to period P9. Furthermore, the results obtained in this study showed the effectiveness of compost alone or in combination with PS to boost the growth and physiology of date palm seedlings from the second month of the experiment with an apparent difference after four month of application of compost and PS. Therefore, further studies need to be carried out to better understand the effect of PS and optimize its dose to favor date palm under poor and challenging soil conditions. Optimal formulations for enriching composts with a reasonable amount of PS to enhance date palm development should also be considered for future studies.

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