Research article

Soil texture and watering impact on pot recovery of soil-stripped oil palm \((Elaeis guineensis\) Jacq.) seedlings

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\textbf{Article info}

\textbf{Keywords:}
Oil palm
Plant seedlings
Pot plant recovery
Soil-stripped seedlings
Soil texture impact
Watering impact
Agricultural soil science
Crop biomass
Soil science
Soil hydrology
Plant growth

\textbf{Abstract}

The transportation load of oil palm \((Elaeis guineensis\) Jacq.) seedlings from the nursery to planting sites is a crucial problem facing the extension of smallholder plantations in Cameroon. This load can be considerably reduced by removing soil from the roots, which in turn exposes the plants to water and nutrients stresses. A greenhouse pot experiment was carried out to evaluate the recovery performance of such soil-stripped seedlings as a function of watering frequency and soil texture. Plant recovery potential was monitored on 360 nursery seedlings aged 4 months, under two soil types (sandy clay soil with 46\% fine particles and sandy loam soil with 19\% fine particles) and two watering frequencies (daily and two-days). Three monthly measurements were taken on morphological plant growth parameters including Plant height, Foliar surface, Collar diameter, Root length and Plant weight. Within and between groups analyses of variance and means separation showed the greatest variability for collar diameter, foliar surface and plant weight. All the parameters showed a greater variability and an almost-constant growth from one month to another, except for plant weight that did show a highly significant \((p=0.000)\) increase between the first measurement and the second. Soil type, watering and their interaction explained 97–99.5\% of the variations of all parameters. Except for root length, all other parameters were more sensitive to the effect of soil texture, explaining 83–95\% of the total variation. Only plant weight and root length showed slightly greater values under daily watering, other parameters did not show any sensibility to the two watering frequencies proposed in this experiment. Our results showed a low response of plant growth recovery on the low clay sandy loam soil, revealing that a careful selection of soil type is crucial for the survival of seedlings and further establishment of the plants following drought stress. It is therefore strongly recommended to many tropical countries where oil palm is an economically important crop, to take this into account during the selection of soil type for oil palm seedlings nursery.

\section{Introduction}

The extension of smallholder oil palm \((Elaeis guineensis\) Jacq.) plantations in Cameroon is confronted with numerous economic constraints linked to the transport of seedlings from the nursery to the planting site. Each transported seedling with the nursery polythene bag is about 12 kg and 90\% of this unit weight is attributed to the clod of soil in the polythene nursery bag \((\text{Bitjoka 2008})\). Efforts to establish nurseries nearby the planting sites have failed because farmers were not able to control several pre-nursery and nursery factors such as handling the delicate nature of the oil palm seed, poor technical ability of farmers themselves and the difficulties to control rodent animals that can destroy a whole nursery in one night. Meanwhile, it is very important to make a success of the nursery, so as to get fine young plants since a seedling that has not grown well in the nursery will make a poor oil palm \((\text{Mutert et al., 1999})\). Moreover, the double stage nursery recommended in most cases \((\text{Tetra-Tech-ARD, 2016})\) for large size nurseries involves also transplanting...
porting oil palm seedlings without deteriorating their recovery ability in each nursery stage.

The production of high-quality seedlings is thus dependent on a careful selection of soil on farm on soils ranging from loamy sand to heavy clays and deep peats (Webb et al., 2003; Hewitt 2004; Schroeder et al., 2007a,b). Soil texture is important for its survival and is predetermined by biological adaptation characteristics of plant species (Louille and Ortiz-Monasterio 2006). Defining the potential of seedlings' recovery from drought events will be important for ensuring yield stability in the future, but such studies are scarce for oil palm. An adequate evaluation of water input on the morphological traits of oil palm can deliver a valuable baseline understanding of oil palm seedlings performance under drought stress.

During the recovering phase, the amount of water available to the plant is the difference between the amount of water stored in the soil at field capacity and the water that will remain in the soil at permanent wilting point (Louille and Ortiz-Monasterio 2006). The available water content depends greatly on the soil texture and soil structure (Sanchez et al., 2003; Hewitt 2004; Schroeder et al., 2007a,b). Soil texture is defined by the relative proportions of sand, silt and clay particles in a mass of soil with less than 2 mm particle size (Buckman and Brady 1960). Soils with smaller particles (silt and clay) have a larger surface area than those with larger sand particles, and a large surface area allows a soil to hold more water which is more important for plants. However, it is also reported (Smith et al., 1995) that some species germinate and grow better under sandy than clayey soils. In general, soil texture determines how much and how often to water a plant (Chakraborty and Mistrli, 2015; Scherer et al., 2017). Applying too much water can lead to more disease pressure on the plant or to anaerobic respiration in the roots that produces toxic compounds in the plant. Applying too little water will not trigger the stress recovery.

Several other investigations (Drury and Beauchamp 1991; Sorensen et al., 1994; Sorensen and Jensen 1995; Tramontini et al., 2013) have indicated that nutrient availability is primarily determined by soil texture. Soil texture influences the turnover of organic matter in the soil by adsorption of organic matter on inorganic clay surfaces (Gill et al., 2000; Ahmadi et al., 2014) to increase nutrient availability in soils. Clayey soils have thus, the ability to attract and hold soil nutrients so that only fewer nutrients are lost when water drains through the root; while sandy soil does not hold nutrients very tightly and when water drains through, this leads to leaching that carries nutrients out of the root zone and makes them unavailable to plants. Gill et al. (2000) also showed that soil texture affects the development of Rhizoctonia root of wheat seedlings. In the same light, Fang et al. (2018) and (2019) have demonstrated that sandy soils with macropores provide a favorable environment (better soil aeration and low resistance to penetration) for root growth in length and ramification. Although oil palm can be grown on farm on soils ranging from loamy sand to heavy clays and deep peats (Ng Siew, 1968, 1972), it is not recommended to use sandy or clayey soils in nursing its seedlings (Rosenani et al., 2016). The production of high-quality seedlings is thus dependent on a careful selection of soil texture of the growing medium in each nursery stage.

Following the challenge of soil stripping to reduce the cost of transporting oil palm seedlings without deteriorating their recovery ability back in the farm, a greenhouse pot experiment was carried out in order to evaluate the recovery performance of soil-stripped seedlings in second stage nursery as a function of watering frequency and soil texture. The experiment was designed to provide a solution to the question of ‘how do the plant growth parameters respond to these treatments?’ Plant recovery potential was thus measured here with morphological parameters of plant growth such as root length, leaf area, collar diameter, plant height and plant weight. Such study has not yet been carried out on bare roots oil palm seedlings and their recovery in the second stage nursery and the results of this experiment are expected to have large echo in many oil palm grower countries.

2. Materials and methods

2.1. Study site

This study was carried out at the specialized Oil Palm Research Center (CEREPAH) of the Institute of Agricultural Research for Development (IRAD) in Dibamba, located in the Littoral Region of Cameroon with geographical coordinates between 3°50’ - 3°58’ N and 9°46’ - 9°54’ E (Figure 1). The elevation is less than 50 m asl. The locality of Dibamba is situated at about 50 km SE from Douala Town. The average annual rainfall is about 3000 mm with a monomodal distribution pattern and high mean temperatures (around 27°C). The minimum average temperature for 30 years in Douala is 22.6°C in July and the maximum average temperature is 32.3°C in February. The relative humidity of the air remains high throughout the year and is close to 100% (Din et al., 2008).

2.2. Soil material

Two soil types collected respectively from Dibamba (Littoral Region of Cameroon) in a sandy loam textured Ferralsol and from Obala (4°11’ N - 11°31’ E in the Centre Region of Cameroon) in a sandy clay textured Ferralsol (Figure 1), were used for the pot trial. The experimental soil was taken from a layer of 0–20 cm. A composite sample from each soil was analyzed in the IITA soil laboratory in Nkolbisson (Yaoundé). Determinations included particle size distribution (pipette method), organic carbon (Walkley and Black method), total nitrogen (mineralization with a Tector), available phosphorus (Bray II), exchangeable cations (1N ammonium acetate at pH7) and cation exchange capacity (by KCl at pH 6.1). All these methods are well-described in Pauwels et al. (1992) and Van Reeuwijk (1993). The physico-chemical characteristics of the two soils are shown in Table 1. The two soils are differentiated by the clay and silt content and the related CEC and nutrients content. Obala soil has 46% of fine particles (clay + silt) and a CEC of about 14 cmol kg⁻¹, while Dibamba soil has 19% of fine particles and a CEC of 5 cmol kg⁻¹. Therefore, in further analyses, the difference in data on plant growth was attributed to soil texture and water input.

2.3. Plant material

Plant material used was oil palm of the "tenera" variety. The experimental sample consisted of 360 nursery seedlings aged four months. The experiment was carried out between the 4th and the 9th month within the nursery stage the oil palm. The "tenera" material is a hybrid of the second cycle selection from Deli x La Me (origin LM 2699 x DA 115D; category C2301 II) currently distributed to farmers by the CEREPAH. This material is characterized by its high yield (4.5 tons of oil ha⁻¹ year⁻¹ under the Dibamba conditions), a reduced growth rate of the stipe (about 45 cm year⁻¹) and early bearing aptitude (2.5–3 years after planting).

The nursery seedlings were less than 5 m high and had at least four functional leaves. Apart from the control treatment seedlings (C), all the seedlings were soil-stripped and then dressed as described in Anaba et al. (2018). To reduce evapotranspiration that could increase water stresses on soil-stripped plants, the treated seedlings were packaged in batches of

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Figure 1. The elevation is less than 50 m asl. The locality of Dibamba is situated at about 50 km SE from Douala Town. The average annual rainfall is about 3000 mm with a monomodal distribution pattern and high mean temperatures (around 27°C). The minimum average temperature for 30 years in Douala is 22.6°C in July and the maximum average temperature is 32.3°C in February. The relative humidity of the air remains high throughout the year and is close to 100% (Din et al., 2008).

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The nursery seedlings were less than 5 m high and had at least four functional leaves. Apart from the control treatment seedlings (C), all the seedlings were soil-stripped and then dressed as described in Anaba et al. (2018). To reduce evapotranspiration that could increase water stresses on soil-stripped plants, the treated seedlings were packaged in batches of
20 seedlings in cartons, then hermetically sealed and deposited in an aerated room at 23–24 °C for 7 days before replanting.

2.4. Experimental design

The experiment was designed in completely randomized block with three replicates per treatment. The oil palm seedlings four-month old were soil-stripped, dressed and transplanted seven days after storage. About 5500 cm³ of soil material was filled into 360 black polythene bags (180 bags filled with the sandy loam soil and 180 bags filled with the sandy clay soil). Each treatment was then made of 20 plants with three replicates (total of 60 plants) and each control was made of 10 plants with three replicates (total 30 plants). To improve the nutrient status of the soils, fertilizer was added monthly to each pot as follows: 20 g of urea (N), 10 g of KCl and 10 g of kieserite (Mg). All pots were watered with the same amount of water (500 ml) at two frequencies. For the same soil type, some pots were watered daily and others after every two days. Treatments were thus labelled as follows: 11T (Obala soil watered daily), 12T (Obala soil watered every two days), 21T (Dibamba soil watered daily), 22T (Dibamba soil watered every two days) and the control made of unstripped seedlings transplanted to large bags using both soil types and the same treatments and labelled 11C, 12C, 21C and 22C respectively.

2.5. Data collection

Data collection began two months after the trial was set up and was pursued for two other months. Data were collected on 300 pots out of 360, leaving out the pots on the outer rows of the experiment. The following plant growth parameters were measured in the greenhouse: length of the longest root, leaf area using Raunkier method on the 3rd leaf (Tailliez and Ballo 1992), collar diameter, plant height and plant growth parameters.
2.6. Statistical analyses

Descriptive statistics, analysis of variance (ANOVA) and means separation (Tukey’s HSD) methods were used to describe the data on plant growth. These analyses were performed using SYSTAT Version 13 (Systat Software 2009). A one-way ANOVA was used to investigate the effects of soil type and watering frequency on plant growth parameters. To differentiate the two effects on plant growth, a factorial ANOVA was performed modelling soil type, watering and the interaction between the two factors. The coefficient of determination ($R^2$) that gives the contribution of each factor to the model was calculated as follows: $R^2 = \frac{\text{Explained sum of squares of each factor}}{\text{Total sum of squares}}$.

3. Results

3.1. Summary statistics and relationship amongst the plant growth variables

Table 2 summarizes the statistics of the variables on plant growth recovery for each month for the whole same population and for the two soil types. All showed a skewness around 1 and -1, and frequency distribution near normal with close means and medians. So, no transformation was done on the original dataset since ANOVAs are rather insensitive to slight departure from normality (Webster 2000). A coefficient of variation varies between 0.10 and 0.66, with collar diameter, foliar surface and plant height showing the greatest variability amongst the treatments.

Table 3 shows the coefficients of variation of plant parameters with treatments and controls for the three-monthly measurements (M1, M2 and M3). Plant weight showed less variability on the first measurement and the two following measurements. Foliar surface and collar diameter showed high variability as from the first measurements throughout the experiment, followed by plant height.

As from Figure 2, treatment 21T and 22T tend to show low values for all the plant growth parameters, portraying a low response of plant growth recovery under the Dibamba sandy loam soil as compared to the Obala sandy clay soil. It is noticeable on the graphs of plant weight that the values of the controls (11C, 12C, 21C and 22C) are especially high in the first measurement M1. As mentioned in section 2.3 above, this is because apart from the control treatment seedlings, all the seedlings were soil-stripped and then dressed by cutting 2 of the functional leaves to facilitate the transport. This effect on plant weight is, however, more remarkable only on the first month measurement, for telling a rapid plant weight recovery during the following months of the experiment.

In exploring the more suitable plant growth parameters that best discriminate the effect of the factors, we evaluated the correlation of variables over the whole dataset. The Pearson correlation was computed on the multivariate data matrix. Table 4 shows the matrix of coefficients of correlation (R) from pair wise combinations of the five plant growth parameters on the last measurement (M3). Highly correlated plant parameters are plant height, foliar surface and collar diameter in one group,
and plant weight, root length and plant height in another group. Root length has no correlation with the foliar surface and plant height.

3.2. Plant growth recovery trends

The collection of data for three consecutive months provided the possibility to analyze the increasing trend of plant growth parameters during the pot recovery of the soil-stripped plants. Figure 2 shows the four growth parameters grouped in four chart-graphs presenting the monthly growth of each parameter with treatments. All the parameters showed an almost-constant growth rate from one month to another, apart from plant weight that did show highly significant ($p < 0.001$) increase between the first measurement and the second. Throughout the treatments, the controls tend to show higher values in all the parameters but not always a significant difference at $p < 0.05$ with treatments under the Obala sandy clay soil. However, Dibamba sandy loam soil (treatments 21T, 22T and their controls 21C and 22C) showed highly significant ($p = 0.000$) low values for all the parameters; thus strengthening the presumption of a low response of plant growth recovery under the sandy loam soil, meaning that the soil texture plays a key role in this plant recovery process.

With data of measurement M3 after four months of the experiment, a one-way ANOVA model comparing all the treatments of each variable showed highly significant differences ($p = 0.000$) amongst the treatments. The coefficient of determination (multiple $R^2$) of the ANOVA varied from $13.3\%$ ($R^2 = 0.133$) to $84.2\%$ ($R^2 = 0.842$); foliar surface showing the poorest explained model, followed by plant height with $29.5\%$, collar diameter with $47.2\%$, root length with $51.3\%$ and plant height.

| Treatments | N   | Root length M3 | Plant weight M1 | Plant weight M2 | Plant weight M3 | Plant height M1 | Plant height M2 | Plant height M3 | Collar Diameter M1 | Collar Diameter M2 | Collar Diameter M3 | Foliar surface M1 | Foliar surface M2 | Foliar surface M3 |
|------------|-----|----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-------------------|-------------------|-------------------|-----------------|-----------------|------------------|
| 11C        | 30  | 0.09           | 0.07            | 0.05            | 0.04            | 0.12            | 0.12            | 0.11            | 0.13              | 0.16              | 0.12              | 0.21            | 0.21            | 0.16              |
| 11T        | 60  | 0.04           | 0.12            | 0.05            | 0.06            | 0.14            | 0.14            | 0.12            | 0.17              | 0.21              | 0.15              | 0.36            | 0.30            | 0.24              |
| 12C        | 30  | 0.02           | 0.04            | 0.04            | 0.04            | 0.15            | 0.15            | 0.10            | 0.11              | 0.16              | 0.13              | 0.32            | 0.26            | 0.24              |
| 12T        | 60  | 0.03           | 0.10            | 0.07            | 0.08            | 0.16            | 0.14            | 0.12            | 0.21              | 0.28              | 0.24              | 0.34            | 0.33            | 0.30              |
| 21C        | 30  | 0.04           | 0.06            | 0.08            | 0.07            | 0.14            | 0.13            | 0.12            | 0.09              | 0.14              | 0.10              | 0.28            | 0.26            | 0.23              |
| 21T        | 60  | 0.11           | 0.10            | 0.09            | 0.08            | 0.12            | 0.13            | 0.11            | 0.20              | 0.19              | 0.15              | 0.29            | 0.20            | 0.17              |
| 22C        | 30  | 0.02           | 0.06            | 0.09            | 0.07            | 0.11            | 0.12            | 0.12            | 0.13              | 0.11              | 0.07              | 0.22            | 0.22            | 0.19              |
| 22T        | 60  | 0.07           | 0.11            | 0.07            | 0.09            | 0.11            | 0.11            | 0.10            | 0.18              | 0.21              | 0.12              | 0.24            | 0.21            | 0.18              |

Key of Treatments: 11T = Obala sandy clay soil watered daily; 12T = Obala sandy clay soil watered every two days; 21T = Dibamba sandy loam soil watered daily; 22T = Dibamba sandy loam soil watered every two days. 11C, 12C, 21C and 22C are controls for the corresponding treatments.

Table 4. Pearson Correlation Matrix of coefficients of correlation (R) correlating plant growth variables at M3 in pairwise combinations.

| Plant weight | Foliar surface | Plant height | Collar Diameter | Root Length |
|--------------|----------------|--------------|-----------------|-------------|
| Plant weight | 1              |              |                 |             |
| Foliar surface | 0.172         | 1            |                 |             |
| Plant height  | 0.443***       | 0.649***     | 1               |             |
| Collar Diameter | 0.510***     | 0.326*       | 0.533***        | 1           |
| Root Length   | 0.507***       | 0.012        | 0.096           | 0.188       | 1            |

Significant determinations of ANOVA models are: * = $p < 0.05$; ** = $p < 0.01$; *** = $p < 0.001$. 

Figure 2. Monthly trend of plant growth parameters with treatments. Key: Plant Weight; Foliar Surface; Plant Height and Collar Diameter (each parameter with three monthly-measurements M1, M2, M3). Treatments: 11T = Obala sandy clay soil watered daily; 12T = Obala sandy clay soil watered every two days; 21T = Dibamba sandy loam soil watered daily; 22T = Dibamba sandy loam soil watered every two days. 11C, 12C, 21C and 22C are control for the corresponding treatment.
weight with the highest contribution model. Figure 3 summarizes the results of this ANOVA on bar-charts and the results of means separation based on Turkey’s HSD test. Here, bar-charts with different letters show significant differences (at $p < 0.05$) between the treatments. Most parameters showed a significant difference between treatments with Obala soil (11T, 12T) and treatments with Dibamba soil (21T, 22T); even the controls showed a similar trend. As shown by most plant parameters, plant recovery performed better on the Sandy clay soil of Obala than on the Sandy loam soil of Dibamba. The poorest growth parameters were from the Dibamba sandy soil watered every two days.

3.3. Quantification of the effect of the experimental factors (soil texture and watering) on plant growth parameters

3.3.1. Variance components of various factors to the variation of each plant growth parameter at the end of the experiment

Since the data in Table 1 showed a soil textural difference between the two soil types (Obala soil and Dibamba soil), a factorial ANOVA (by soil type and watering frequency) was used to partition the variance between the watering effect and the soil texture effect on the plant growth variables. The soil texture effect is the part of the variance that is due to the difference between the two soil types while the watering effect is the part of the variance that is due to the difference between the two watering frequencies (daily and every two days). Figure 4 shows the contribution of each level to the variation of plant growth parameters. Soil texture, watering and their interaction explained 97–99.5% of the variations of all plant growth parameters. Root length appeared to be the most sensitive to the two factors and their interaction with explained 23% for soil texture, 22% for watering and 52% for their interaction. All other plant growth parameters (plant weight, plant height, collar diameter and foliar surface) were more sensitive to the effect of soil texture explaining 83–95% of the total variation for these variables.

3.3.2. Effect of soil texture on plant growth parameters

As from Figures 2, 3, and 4, there is a sound difference in plant growth parameters between the Obala sandy clay soil and the Dibamba sandy loam soil. The two soil types are differentiated mainly with their soil textural content (Table 1). With a difference of 26% less sand and 27% more fine particles, the Obala sandy clay soil has shown a highly significant ($p = 0.000$) positive response on plant growth parameters.
making a positive difference of 21–43 g (20–39%) on plant weight, 26–44 cm² (12–20%) on the foliar surface, 6–7 cm (13–15%) on plant height and 6–7 cm (23–30%) on collar diameter. Root length showed a negative difference of about 3 cm (-9%).

The impact of soil texture was further confirmed by the results of factorial ANOVA modelling soil type and watering from which the coefficient of determination of each soil variable was computed as the ratio between explained variance and the total variance to evaluate the contribution of soil texture effect on plant growth. For most plant growth parameters, the difference between the two soil types is highly significant (p = 0.000) as presented on graphs of Figure 5 showing the comparison through means separation using Least Squares Means for the measurement M3. The variations of plant weight (66%), collar diameter (41%), plant height (24%) and root length (23%) were thus the most explained by the factorial ANOVA models.

3.3.3. Effect of watering frequency on plant growth parameters

As presented on Figures 3 and 6, only plant weight and root length have shown a significant (p = 0.05) difference due to watering frequency. From the third measurement (M3), the two parameters showed higher values when the plants were watered every day. The three other parameters (foliar surface, plant height, collar diameter) did not show any sensibility on the two watering frequencies proposed in this experiment.

As shown in Figure 3, only the Dibamba sandy loam soil showed a significant difference between the two watering frequencies (daily and every two-days), with the lowest values when the plants were watered every two days. The low watering frequency on the sandy soils has thus negatively affected the more sensible parameters (plant weight and root length). Given that the two soil types received the same watering frequency, this result also confirms that water movement is controlled by the soil texture content as seen above.
3.3.4. Interaction between soil type and watering frequency

The factorial ANOVA by soil type and watering frequency showed for most variables highly significant ($p = 0.000$) variation with the two modelled factors, and with their interaction (Figures 3, 4, and 7). Much higher contributions to the factorial ANOVA model were observed for soil type as compared to watering. Whereas, the interaction showed that

**Figure 6.** Graphs showing the comparison of plant growth parameters between the two watering frequencies (1 = Daily watering, 2 = Every two-days watering) through means separation using Least Squares Means for the measurement M3.

**Figure 7.** Graphs showing the interaction between soil type and watering frequency of plant growth parameters using Least Squares Means for the measurement M3.
the magnitude of change with watering frequency differs between the two soil types. Those plant parameters that show highly significant (p = 0.001) interaction between soil type and watering frequency are plant height, root length and collar diameter, all related to parameters of allometric studies of plant growth. They all tend to show a negative interaction indicating that where the effect of soil type is high, the effect of watering is low, and vice versa. The most significant (p = 0.000) negative interaction is with root length, showing higher root length on sandy loam soil (Dibamba soil) with daily watering. The same trend is also shown by plant weight. The strong relationship shown in Table 3 between plant weight and root length (R² = 0.55) can explain this similar trend. The longer the root, the greater the plant weight.

4. Discussion

Results of plant growth parameters showed variations of plant parameters with treatments and monthly measurements. Plant weight did show highly significant (p = 0.000) increase between the first measurement and the second. This implies that the stressed soil-stripped seedlings took about two months (that corresponds to the first measurement) to endeavor and resist the stress effect. As from the second measurement, the resilience is effective, and the plant grows with constant increments. Modelling the C stock accumulation in fallow vegetation and cocoa plantation in southern Cameroon, an empirical model in the form of a continuous function of time adapted by Silatsa et al. (2016) reported similar trend of biomass accretion in both systems.

In exploring the more suitable plant growth parameters that best discriminate the effect of the factors, plant height, foliar surface and collar diameter were more correlated in one group and plant weight, root length and plant height in another group. The three parameters in the correlated group (R² = 0.55) with plant weight (root length and collar diameter) are all related to parameters of allometric studies of biomass accumulation in plant growth (Chave et al., 2005). The relationship expressed between plant weight and root length, even on the interaction, reflects here, the well-known link between plant biomass and root biomass that was defined in a general term by Mokany et al. (2005), taking root biomass as ¼ of plant biomass. A study in a Lowland Amazonian forest ecosystem by Whendee et al. (2000) showed, however, that the soil carbon stock in a 1-m soil depth had 62% contribution from plant roots in sandy soils as compared to only 48% in clay soils.

Throughout the experiment, the control tended to show higher values in all the parameters but not always a significant difference at p < 0.05 with treatments under the Obala sandy clay soil. Only Dibamba sandy loam soil treatments showed highly significant (p = 0.000) low values for all the parameters. This result has strengthened the presumption of a low response of plant growth recovery under the Dibamba sandy loam soil, leading to the conclusion that the soil texture plays a key role in this plant recovery process. Several authors (Lobell and Ortiz-Monasterio 2006; Chakraborty and Mistri 2015) have also reported a significant effect of soil texture on plant growth due to its significant influence on ecological and hydrological processes, such as water retention, ion exchange and nutrient cycling. Although, such a study on the effects of soil texture under field conditions is quite challenging as reported by Turner (2004) because of confounding effects of factors such as precipitation that interact in such conditions, our experiment in the greenhouse condition has completely minimized such confounding effects and clearly showed the effect of finer soil textured soils in favoring oil palm seedlings regrowth after soil-stripping stress. According to Parton et al. (1987), Chaudhari (2008) and many other authors, this influence of soil texture on top performance is well known and is due to its significant influence on water-related processes. The lowest response to the soil texture effect was from root length. This may, to some extent, corroborate the results from Komolafe and Joy (1981), Fang et al. (2018) and (2019) who reported that clayey soils as compared to sandy soils were poorly drained and very difficult for plant root penetration.

Our results, however, showed no significant difference at p < 0.05 between the control and clayed soils; revealing that a careful selection of soil texture is crucial for sufficient seedlings’ growth and further establishment of Elaeis guineensis Jacq, to ensure plant survival following drought stress. Such a conclusion was also reported by Paramananth (2000) and Travlos and Karamanos (2006) on the effects of soil texture on vegetative growth of the tropical legume Marama bean (Tylosoma esculentum) under extensive drought conditions. Soils with finer particles (clay + silt) have a larger surface area than those with coarser particles, and a large surface area allows soil to hold a more important part of water useful for plant’s growth. This determines the soil water capacity to facilitate plant growth (Chakraborty and Mistri 2015; Scherer et al., 2017). During the stress recovery phase, the amount of water available to the plant depends on the watering frequency and on the water retention capacity of soils, which is also strongly linked to soil texture (Sanchez et al., 2003; Hewitt 2004; Schroeder et al., 2007a, b).

Only the Dibamba sandy loam soil showed a significant difference between the two watering frequencies (daily and every two-days) on plant weight and root length. Given that the two soil types received the same watering frequency, this result confirms that water movement is controlled by the soil texture content as shown above. The poorest growth parameters observed from the Dibamba sandy soil watered every two days can be explained as reported elsewhere by Fang et al. (2018) and (2019), by the fact that the sandy soil with coarser particles and a higher macro porosity favors high gravitational water and poor water retention in the soil. Meanwhile, the Obala soil, with finer particles, provides higher water retention capacity, which is very important for plant recovery. This is in line with all the theories explaining the relationship between soil texture and water movement in soils (Sanchez et al., 2003; Hewitt 2004; Lobell and Ortiz-Monasterio 2006; Jalota et al., 2010; Chakraborty and Mistri 2015; Scherer et al., 2017). This strongly suggest recommending the use of sandy clay to loamy textured soils to establish palm nurseries.

The interaction showed that the magnitude of change with watering frequency differs between the two soil types. All those plant parameters with highly significant (p = 0.001) interaction between soil type and watering frequency tend to show a negative interaction meaning that where the effect of soil type is high, the effect of watering is low, and vice versa. The most significant (p = 0.000) negative interaction is with root length, showing higher root length on sandy loam soil (Dibamba soil) with daily watering. The same trend is also shown by plant weight. The longer the root, the greater the plant weight. This result implies that with more watering, plant root grows longer in coarse textured soil than in the fine textured one. The question is to know whether this root length extension in coarse grain soil is controlled by available pore spaces in sandy soil or by the search of nutrient elements for the plant growth. Indeed, soils with smaller particles have a larger surface area than those with larger sand particles, and a large surface area allows a soil to hold more water and nutrients (Chakraborty and Mistri, 2015). Fang et al. (2018) and (2019) have reported that sandy soils with macropores provide a better soil aeration and low resistance to penetration for roots to grow in length and ramification. Furthermore, a recent study (Helliwell et al., 2017) revealed that tomato root architecture was markedly different for plants as a function of soil texture: the plants developed a thicker tap root in sandy loam soil but grew thinner roots with more laterals in clay soil. This means that in sandy textured soil, root systems generally develop to greater depth and are thicker than roots growing in fine textured soil. Sandy soil dries quicker in the upper layer; therefore, the root systems must grow deeper in order to access water (Hacket et al., 2006; Jackson et al., 2005; Li et al., 2005).

5. Conclusion

Defining the potentials of oil palm seedlings recovery from drought events due to soil-stripping stress is important as a valuable baseline for ensuring future yield stability in the plantation. This greenhouse...
The study confirms that water movement is controlled by the soil texture content and determines the soil water capacity to facilitate plant growth at the nursery stage. It is therefore strongly recommended to many tropical countries where oil palm is an economically important crop, to take this into account during the selection of soil type for oil palm nursery: foundation for high production. Better Crops Int. 13 (1), 39–44.

Ahmadi, S.H., Sepaskhah, A.R., Andersen, M.N., Flinborg, F., Jensen, C.R., Hansen, S., 2014. Modelling root length density of field-grown potatoes under different irrigation strategies and soil textures using artificial neural networks. Field Crop. Res. 162, 99–107.

Anaba, B.D., Ngando, E.G.F., Abossolo, M., Ntsomboh-Ntsefong, G., Likeng-Li-Ngue, B.C., Biljoa, P.L., Okia, D., 2018. Facilitating transportation and recovery of oil palm (Elaeis guineensis Jacq.) seedlings in the field by leaf dressing and soil stripping. IOSR J. Agric. Vet. Sci. (IOSR-JAVS) 11 (6), 39–51.

Biljoa, P.L. 2008. Effet du dechaussement sur la reprise et la croissance des plants de palme à huile (Elaeis guineensis Jacq. var. inerme) en champ. Mémoire de DESS, Université de Yaoundé I, p. 43.

Buckman, H.O., Brady, N.C., 1960. The Nature and Properties of Soils, fifteenth ed. Macmillan, New York, p. 212.

CERRAD, 2011. Document de cas de recherche sur le palmier à huile au concours pour le prix de l’excellence scientifique du président de la république. Journées d’excellence de la recherche scientifique et de l’innovation au Cameroon 153.

Chakraborty, K., Mistri, R., 2015. Importance of soil texture in sustenance of agriculture: a study in Burdwan-I C. D. Block, Burdwan, West Bengal Eastern Geographer, XXI (1), 475–482. Jan. 2015.

Choudhuri, S., Singh, R., Kundu, D., 2006. Rapid textural analysis for saline and alkaline Soils with different physical and chemical properties. Soil Sci. Soc. Am. J. 70, 431–441.

Chavez, J., Andalo, C., Brown, S., Cairns, M.A.; Chambers, J.A., Eamus, D., Folster, H., Forman, F., Higuchi, N., Kira, T., Lescure, J.P., Nelson, B.W., Ogawa, H., Puig, H., Riera, B., Yamakura, T., 2005. Tree allometry and improved estimation of carbon stock and balance in tropical forest. Oecologia 145 (1), 87–99.

Davies, W.J., Bacon, M.A., 2003. Adaptation of roots to drought. In: de Kroon, H., Visscher, E.J.W. (Eds.), Root Ecology. Ecological Studies 168. Springer Verlag, Berlin, and Heidelberg, pp. 173–192.

Din, N., Prior, J.R., Dibong, S.D., Amougou, A., 2008. Logging activities in mangrove forests: a case study of Douala Cameroon. Afr. J. Environ. Sci. Technol. 2 (2), 22–30.

Durry, C.F., Beauchamp, E.G., 1991. Ammonium fixation, release, nitrification and immobilization in high- and low-fixing soils. Soil Sci. Soc. Am. J. 55, 125–129.

Fang, H., Rong, H., Hallett, P.D., Mooney, S.J., Zhang, W., Zhou, H., Peng, X., 2019. Impact of soil puddling intensity on the root system architecture of rice (Oryza sativa L.) seedlings. Soil Tillage Res. 193, 1–7.

Fang, H., Zhou, H., Norton, G.J., Price, A.H., Raffan, A.C., Mooney, S.J., Peng, X.H., Hallett, P.D., 2018. Interaction between contrasting rice genotypes and soil physical conditions induced by hydraulic stresses typical of alternate wetting and drying irrigation of soil. Plant Soil 430, 233–243.

Gill, J.S., Sivasithamparam, K., Smettem, K.R.J., 2000. Soil types with different texture affects development of Rhizoctonia root rot of wheat seedlings. Plant Soil 221, 113–120.

Hackle, U.G., Sperry, J.S., Ewers, B.E., Ellsworth, D.S., Schaffer, K.V.R., Oren, R., 2000. Influence of soil porosity on water use in Pinus taeda. Oecologia 124, 495–505.

Hellwell, J.R., Sturrock, C.J., Macleho, S., Craigon, J., Ashton, R.W., Miller, A.J., Whalley, W.R., Mooney, S.J., 2017. The emergent rhizosphere: imaging the development of the rhizosphere architecture at the root-soil interface. Sci. Rep, 7, 14875.

Hewitt, A.E., 2004. Soil properties relevant to plant growth: a guide to recognizing soil properties relevant to plant growth and protection. In: Landcare Research Science Series, No. 26. Whenua Press, 2004;

Jackson, R.B., Sperry, J.S., Dawson, T.E., 2000. Root water uptake and transport: using physiological predictions. Trends Plant Sci. 5, 482–488.

Jalota, S.K., Singh, S., Chahal, G.B.S., Ray, S.S., Panigrahy, S., BhopinSingh, Singh, K.B., 2010. Soil texture, climate and management effects on plant growth, grain yield and water use by rainfed maize-wheat cropping system: field and simulation study. Agric. Water Manag. 97 (1), 83–90.

Kolek, J., Kozinka, v., 1992. Physiology of the Plant Root System 46. Kluwer Academic publishers, Dordrecht, Netherlands, p. 361.

Komolafe, M.F., Joy, D.C., 1981. Agricultural Science for West African Schools and Colleges. University press Ltd. Badan.

Li, Y., Xu, H., Cohen, S., 2005. Long-term hydraulic acclimation to soil texture and radiation load in cotton. Plant Cell Environ. 28, 492–499.

Lobel, D.B., Ortiz-Monasterio, J.L., 2006. Evaluating strategies for improved water use in spring wheat with CERES. Agric. Water Manag. 84, 249–258.

Mokany, K., Raison, J., Prokushkin, A.S., 2005. Critical analysis of root: shoot ratios in terrestrial biomes. Global Change Biol. 12, 84–96.

Mutert, E., Esperéz, A.S., De los Santos, A.O., Cervantes, E.O., 1999. The oil palm nursery: foundation for high production. Better Crops Int. 13 (1), 39–44. May 1999;

Ng Siew, K., 1968. Soil Suitability of Oil Palms in West Malaysia. Oil Palm Development in Malaysia. Incorp. Soc. Planters, Kuala lumpur P11–17.

Ng Siew, K., 1972. The Oil Palm, its Culture, Manuring and Utilisation. The International Potash Institute, P.O. Box, CH-3000 Berne 14/Switzerland.

Paramanathan, S., 2000. Soil requirements of oil palm for high yields. In: By Koh, K.J. (Ed.), Managing Oil palm for High Yields: Agronomic Principles, 18-38, Malaysian Soc. Soil Sci./Param Agric. Surveys, Kuala Lumpur.

Pauwels, J.M., Van Ranst, A., Verloo, M., Mvondo-Ze, A., 1992. Manuel de laboratoire de terre, gestion de stocks et informatique: MAMO, Royal de Belgique.
Rosenani, A.B., Rovica, R., Cheah, P.M., Lim, C.T., 2016. Growth performance and nutrient uptake of oil palm seedling in prenursery stage as influenced by oil palm waste compost in growing media. Int. J. Agron. 2016, 8. Article ID 6930735.
Sanchez, P.A., Palm, C.A., Buol, S.W., 2003. Fertility capability soil classification: a tool to help assess soil quality in the tropics. Geoderma 114, 157–185.
Scherer, F., Thomas, F., Fransen, D., Chacek, L., 2017. Soil, Water and Plant Characteristics Important to Irrigation. North Dakota State University, Fargo, North Dakota. www.ag.ndsu.edu.
Schoorler, B., Wood, A., Panitz, J., 2007b. Accelerating the Adoption of Best Practice Nutrient Management: Burdekin District. BSES Limited, Brisbane.
Schoorler, B.L., Hubert, J.W., Hubert, C., Hubert, P.G., Panitz, J.H., Wood, A.W., Moody, P.W., 2007a. Recognizing differences in soil type to guide nutrient inputs on-farm - a case study from Bundaberg. Proc. Aust. Soc. Sugar Cane Technol. 29, 138–148.
Silatsa, F.B.T., Yemefack, M., Dameni, H., Ewane-Nonga, N., Kemga, A., Hanna, R., 2016. Modeling carbon stocks dynamics under fallow and cocoa agroforest systems in the shifting agricultural landscape of central Cameroon. Agrofor. Syst. 91, 993–1006.
Smith, M., Brandt, T., Stone, J., 1995. Effect of soil texture and microtopography on germination and seedling growth in Boltonia decurrens (asteraceae), a threatened floodplain species. Wetlands 15 (4), 392–396. December 1995.
Sorensen, P., Jensen, E.S., 1995. Mineralization-immobilization and plant uptake of nitrogen as influenced by the spatial distribution of cattle slurry in soils of different texture. Plant Soil 173, 283–291.
Sorensen, P., Jensen, E.S., Nielsen, N.E., 1994. The fate of 15N labelled organic nitrogen in sheep manure applied to soils of different texture under field conditions. Plant Soil 162, 39–47.