Original Research Article

Effects of mulching and watering frequency on some agronomic performances of cocoa plants (*Theobroma cacao* L.) produced in nurseries

ABSTRACT

This study was carried out at Nkoemvone Agricultural Research Station in southern Cameroon, to help cocoa farmers monitor their cocoa nurseries during periods of drought or in areas where water resources are scarce and difficult to access. The objective of this work was to find the production methods for cocoa plants that could use the lowest watering frequencies through straw to ensure optimal growth and development of these plants in the nursery. It was carried out between September 2020 and June 2021 in a randomized complete block design. It comprised eighteen elementary plots, i.e. six treatments repeated three times. The number of cocoa plants tested was 360. That is, 20 plants per treatment. The treatments applied were NMWF1/2 days (control treatment); NMWF1/4 days; NMWF1/6 days; MWF1/2 days; MWF1/4 days and MWF1/6 days. At the end of work, three out of six treatments resulted in better agronomic performance. Firstly, MWF 1/2 days, which had a pH-water of 5.1, 7.97% organic matter, 25.34 cm mean cocoa plant height, 5.63 mm mean stem diameter, 10.97 mean leaf number, 9.26±0. 55 as the average length of the main roots, 52.13±5.70 as the average number of secondary roots, 45.97±2.04 % organic matter content of stems + leaves and 37.86±6.62 % organic matter content of roots at the end of the experiment. Then, there is MWF 1/4 days with 5.8, 6.44 %, 23.42 cm, 5.07 mm, 9.35 cm, 10.45±0.82 cm, 47.32±3.21 cm, 58.41±6.54 %, 47.62± 4.12 % respectively. Finally, NMWF 1/2 days showed 5.6, 5.21 %, 23.30 cm, 4.9 mm, 9.55, 10.15±0.58 cm, 51.75±5.11, 44.63±4.74 % and 28.41±7.67 % respectively in the same period. Although these three treatments resulted in more satisfactory growth and development than the others, we only recommend MWF 1/4 days treatment to the farmers for the purpose of this work.

Keywords: Cocoa plants; nursery; mulching; watering frequency; growth; development.

1. INTRODUCTION

Cocoa cultivation provides beans mainly for the chocolate industry [36]. In Cameroon, this crop has been developed since 1960 and is currently one of the main sources of household income in the forest agro-ecological zones of the country [12]. It occupies one of the most important places in the Cameroonian economy, accounting for over 28% of the non-oil economy and 40% of primary sector exports [23]. At present, the area under cocoa cultivation covers about six hundred thousand hectares and involves nearly six hundred thousand producers. In addition, almost eight million people live directly or indirectly from the cocoa economy. According to a classification based on the human development index (IDH), Cameroon ranks fourth in the world, after Ivory Coast, Ghana and Nigeria, with an annual production of two hundred and ninety thousand tons [1]. However, in 2014, this country set itself the goal of producing six hundred thousand tons per year by 2020. However, this objective is far from being achieved, given the gap between the quantity of cocoa produced now and that which was expected. This low production can be explained in part by constraints related to damage caused by diseases such as brown pod rot [29], and damage caused by insects such as mirids [4]. In addition, the ageing of cocoa orchards, which is not compensated by a rehabilitation dynamic, is one of the factors regularly cited in the drop in yield [16]. In this regard, the government, through the 2014 cocoa and coffee sector recovery and development plan, had undertaken actions relating to, among other things: the rejuvenation of orchards, more than half of which are already over thirty years old; the extension of cultivated areas by another four hundred thousand hectares and the use of high-yielding plant material. In order to achieve these objectives, which are still struggling to be realized, knowledge of good production practices for plant material or quality seeds is one of the conditions to be fulfilled by the producers who constitute the essential link in the cocoa chain. Thus, it is strongly advised to produce these seeds in a nursery since the successful creation of a cocoa plantation most often requires the creation of a nursery, which has the advantage of avoiding high mortality due to direct sowing in the field and is a privileged place on which the success or failure of the future plantation will depend [41]. This nursery should be located near a watering point that does not dry up in the dry season, in order to facilitate watering, which is a very important factor for its success [6-7]. Especially, since the recommended period for the creation of a cocoa nursery is from September to March of the following year, and this always forces the nurseryman to go through a period of drought, during which he must necessarily water the young plants to ensure optimal growth. However, in a context marked by climate change, it has happened in recent years that the dry seasons have been relatively prolonged, causing at times the drying up of water points that were previously observed as inexhaustible during the dry season. In addition, the pressure of land tenure nowadays leads many cocoa farmers to establish their fields and nurseries on sites far from permanent water points, and the latter, who are mostly poor, often do not have enough means to build a water point next to their nursery. All these constraints make it difficult to access water resources in the dry season, while nursery monitoring activities during this period depend heavily on it. So, mulching is an agricultural practice that conserves moisture, limits evapotranspiration, provides organic matter and limits soil erosion [14-33]. This practice is most often observed in the field, but hardly practiced in the nursery. Nevertheless, it seems to be an alternative that would more or less reduce the frequency of watering for the maintenance of a nursery. It could lighten the burden of cocoa farmers when monitoring their cocoa nurseries during periods when water is scarce. Thus, the objective of this study is to find method of monitoring cocoa plants that can use straw to provide low watering frequencies that will allow for optimal growth and development of cocoa nursery.

2. MATERIALS AND METHODS

2.1 Materials

2.1.1 Study site

This trial was carried out at the research station of the Institute of Agricultural Research for Development (IARD) in Nkoemvone, located in the Ebolowa 2nd District, Mvila Department, South Cameroon Region. This station is located at an altitude of 580 m, at 2°49'54.1"N latitude and 11°08'12.4"E longitude. This trial was conducted under a large shed with sufficient light and ventilation to avoid uncontrolled watering and the erosion of the cocoa plants.

2.1.2 Climatic data

The climate in the southern region is equatorial with four seasons, two rainy and two dry seasons. Average annual temperatures are around 25°C and rainfall varies between 1500 and 2000 mm [37]. Between September 2020 and June 2021, the period during which this experiment was conducted, rainfall and temperature data were collected and the corresponding umbrothermal diagram was produced (Fig. 1).

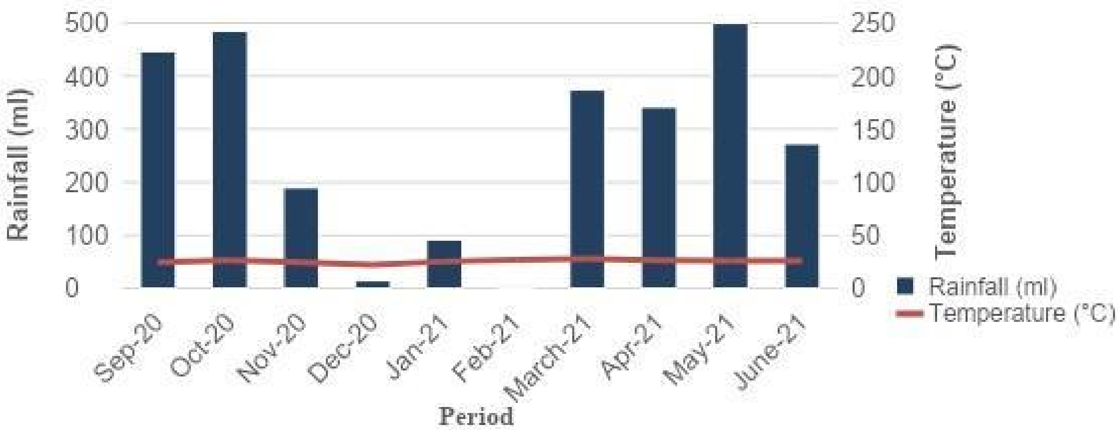

Fig. 1. Ombrothermal diagram of the Nkoemvone agricultural research station *(September 2020 to June 2021)*

2.1.3 Soil data

The cocoa tree requires deep soils of at least 1 to 1.5 m [31] that favour a good anchorage of the pivot that ensures the stability of the tree and on which the lateral roots develop. The presence of coarse elements in the soil can hinder root development, but these only constitute major obstacle when their proportion by volume is greater than 50% [42]. The tree can grow on soils with a wide range of pH values, from high acidity (pH 5) to high alkalinity (pH 8). However, the majority of good cocoa soils are close to neutral (pH 7), the optimum pH being weakly acidic (pH 6.5) [21]. The southern region is covered by ferralitic soils of the lateritic domain, which was formed by erosion due to high temperatures and heavy rainfall. On the other hand, they are rich soils with high nutrient retention capacity [27].

2.1.4 Plant material

The plant material consisted of the IMC 60 cocoa variety whose pods were collected from one of the seed fields at the IARD station in Nkoemvone. This variety is one of those recommended in the cocoa-growing areas of Cameroon [5]. It has good agronomic characteristics, including those listed in Table 1.

Table 1. Agronomic characteristics of the IMC 60 variety [5]

Variety	Potential production (Kg/ha/year)	Tolerance to Phythophthora (%)	Average weight of a bean (g)	Weight of cocoa per pod (g)	Number of beans per pod	Number of pods per tree
IMC 60	1450	30	1,2	19	16	79

2.2 Methods

2.2.1 Experimental design

The experimental design was a complete randomised block design [22]. The trial consisted of eighteen elementary plots, i.e. six treatments repeated three times. In each elementary plot, there were twenty cocoa plants planted in twenty separate bags. Thus, there were a total of three hundred and sixty plants in this trial. The spacing between treatments was 0.5 m, and 1 m between replications. These treatments were: Not mulched with a Watering Frequency of once every two days (NMWF1/2 days) (this was the control treatment); Not mulched with a Watering Frequency of once every four days (NMWF1/4 days); Not mulched with a Watering Frequency of once every six days (NMWF1/6 days); Mulched with a Watering Frequency of once every two days (MWF1/2 days); Mulched with a Watering Frequency of once every four days (MWF1/4 days) and Mulched with a Watering Frequency of once every six days (MWF1/6 days).

2.2.2 Cocoa sowing and treatments application

This experiment was carried out in the period from October 2020 to March 2021 and lasted twenty-four weeks. The cocoa beans were previously cleaned with sawdust and then treated with the fungicide Ridomil Gold 66 WP to avoid damping off due to possible attacks of *Phythophthora* sp. which could reduce the emergence rate of the seedlings. Then, they were sown in polyethylene pots of dimensions 15 x 20 cm previously filled with humus soil. In order to ensure that all the seedlings emerged evenly, two beans were sown in each pot. These pots were watered at a rate of one sprinkle per day for the first two weeks. After emergence, one of the two plants in each pot was pulled out so as to have only one per pot. Then, they were watered once every two days for the next two weeks. Then the treatments were started two weeks after sowing.

For the mulched treatments, 20 g of straw was applied to the surface of the pots so as to completely cover the collar region of the seedling inside. This straw was made of dry grass (*Pennisetum* sp.). The choice of grass as straw in this work comes from the fact that the dry leaves of this Poacea allow a better coverage of the surface of the pots. It is available everywhere and can be easily handled. Another advantage is that the leaves of other species of the Poacea family can be used, in case grass is not available. Unlike tree leaves which are less suitable as they are difficult to handle and are usually not available in sufficient quantities [34].

The plants were then watered regularly according to the watering frequency corresponding to each treatment and the amount of water applied per pot during a watering was the same. The work of [18] and [28] shows that when monitoring cocoa plants in the nursery, it is advisable to use 15 litres of water to water bed of 3 m^2 in area. For this purpose, the volume of water received by each plant during one watering was 57 ml. This volume was determined using the formula for the surface area (S) of the circle, since the surface area (s) of the pots used had a circular shape: $s = \pi r^2$, where s = surface area of the pot and r = radius of the pot surface.

During the follow-up of this trial, the plants were treated by drenching using water containing Ridomil Gold Plus 66 WP at the rate of one 50 g sachet per 15 litres of water [20], and at an frequency of one treatment per month. The application of this fungicide took into account the watering frequency and the volume of water to be given to each plant. The aim was to avoid the appearance of fungal diseases following the use of straw, which has the property of retaining a lot of moisture in the pots. No insecticides were applied since insect damage was hardly observed.

2.2.3 Agronomic parameters

Agronomic parameters of growth (stem length and collar diameter) and development (number of leaves) were collected at a frequency of once a week for twenty-four weeks. These data were taken on twenty cocoa plants previously labelled in different treatments. At the end of the work, the plants that had resisted at the different treatments applied were carefully removed. The length of their main root was measured (growth parameter) and their secondary roots were counted (development parameter). With the help of secateurs, the roots were separated from the stems, by cutting at the level of the collar. These roots were placed in envelopes previously labelled according to the treatments. The stems were also collected by treatment and the different batches were labelled. In the laboratory, data were collected on the fresh weight of stems + leaves and roots using a sensitive balance. The dry matter weight was determined after drying the fresh organs in an oven for 48 hours at a temperature of 60°C [21]. The dry matter content (DMC) was obtained using the following formula: DMC (%) = (DW / FW) X 100; with DW = dry weight; FW = fresh weight; DMC = dry matter content [17].

2.2.4 Soil analysis

The soil (initial substrate) used in the experiment was taken from forest areas between 0 and 20 cm from the surface. This soil was analysed in the laboratory, as were the soils taken from the different treatments at the end of the experiment. The physico-chemical parameters of these different soils were determined according to the international methods in force at the Laboratory of the Research Unit of Soil Analysis and Environmental Chemistry (URASCE) of the University of Dschang as recommended by [30], and respecting the ISO, AFNOR NF and EN standards (Table 2).

2.3 Data analysis

Statistical analyses were carried out using R software version 3.5.1. The comparison of means was performed using the Duncan Multiple Range Test (DMRT) at the 5% probability level. The correlation between the measured parameters was done using the Pearson correlation coefficient.

3. RESULTS AND DISCUSSION

3.1 Results

3.1.1 Effects of treatments on the physico-chemical properties of the experimental soils

The physico-chemical properties of the initial substrate evolved with time and according to the treatments applied (Table 2). The initial soil belonged to the Clay-Sand textural class. On the other hand, the soils where the different treatments were applied evolved and belonged to the textural class Clayey-Sandy Loam at the end of the experiment. Their physical characteristics show a dominance of the sandy fraction. In both textural classes, the sand content was overall higher than the other two elements. The initial substrate had the lowest sand content (45.8%), while higher contents (ranging from 47.8% to 55.8%) were observed in the soils of the different treatments. However, the not mulched treatments (ranging from 47.8 to 55.8 %) had higher contents than the mulched treatments (ranging from 49.8 to 53.8 %), and these contents increased with the frequency of watering. Clay content was average overall, but the initial soil had an higher content (37.4%). In the other hand, the clay content decreased in the soils of the different treatments at the end of the experiment, and their values varied between 28.4 and 33.4%. The silt fraction is less represented. In the initial substrate, its content was 16.8%, whereas at the end of the trial, the silt content increased significantly in the soils of most of the treatments, except for the NMWF1/2days (12.8%) and NMWF1/6days (14.8%) treatments, which had low silt content compared to the initial substrate.

The initial soil had a PH-water of 5.5. The substrates of the treatments had PH-water values ranging from 4.9 to 5.8. The soils of the MWF1/4 days (5.8) and NMWF1/2 days (5.6) treatments showed higher pH values than the initial substrate. However, these values decreased significantly in the soils of the other treatments until they reached a value of 4.9 in the soil of the MWF1/6days treatment.

The organic matter content was 3.98% for the initial substrate. This content increases from 4.29 to 7.97 % in most of the treatments, with the exception of MWF1/6 days (2.57 %) which showed a lower content than the initial soil. On the other hand, the soil of the NMWF1/6 days treatment (4.44 %)

showed a higher organic matter content than the initial substrate. The initial soil showed a carbon content of 2.31%. These contents varied from 2.49 to 4.62 % in the majority of the treatments. Only MWF1/6 days (1.49%) had a lower content than the initial substrate. Overall, the total nitrogen content was relatively low. The total nitrogen content was estimated to be 0.19 % in the initial soil. The total nitrogen content increased from 0.22 to 0.31% in the treatments. As for the C/N ratio, it is 12 in the initial substrate and this ratio increases in three treatments. While it decreases in the soils of the treatments MWF1/6 days (7); NMWF1/2 days (11); NMWF1/4 days (11). However, NMWF1/6 days (13) also showed a higher ratio than the initial soil.

The sum of exchangeable bases increased during the experiment. The sum of exchangeable bases was 4.59 meq/100 g in the initial soil and then increased from 6.45 to 8.07 meq/100 g in the majority of the treatments. While it decreased slightly in MWF1/6 days (4.59 meq/100 g), compared to that of the initial soil. These substrates are globally richer in Calcium ions and its content is 4.00 meq/100 g in the initial soil, while the majority of the experimental soils showed higher levels (4.80 to 5.60 meq/100 g) at the end of the trial, except for the MWF1/6days (3.60 meq/100 g) and NMWF1/6days (4.00 meq/100 g) treatments which presented significantly decreasing and stable values respectively. Concerning the Mg^{2+} ion, it was evaluated at 0.64 meq/100 g in the initial soil, while this value increased (0.80 to 3.20 meq/100 g) in all other substrates during the experiment. K^+ (0.05 to 0.22 meq/100 g) and Na^+ (0.14 to 0.37 meq/100 g) ions were very weakly represented and their contents varied little during the experiment in the different substrates.

The cation exchange capacity (CEC), measured at pH7, varied slightly in all the substrates. Its value was 9 meq/100 g in the initial soil. This value increased slightly (10 meq/100 g) in three treatments. While the CEC value remained stable in MWF1/4 days (9 meq/100 g) and NMWF1/4 days (9 meq/100 g). In MWF1/6 days (8 meq/100 g) a slight decrease compared to the initial amount was observed instead.

The assimilable phosphorus content was 7.96 mg/Kg in the initial soil. This content increased in the different substrates during the trial, with values varying from 10.27 to 28.62 mg/Kg. The MWF1/4 days treatment (28.62 mg/Kg) showed a very high content compared to the others.

3.1.2 Effects of treatments on growth and development of cocoa plants

The height of the cocoa plants was almost uniform four weeks after sowing. In the treatments MWF1/2 days, NMWF1/2 days and MWF1/4 days the height of the stems increased significantly (P .05) over time, except for the other three treatments where the height decreased over time (Fig. 2). At the 16th week after sowing, the height value of the plants in the NMWF1/6 days treatment was cancelled out.

Collar diameter was also significantly influenced by the treatments over time (Fig. 3). There was no significant difference at week four in all treatments. However, a significant increase (P .05) in collar diameter was observed from week 12 to week 24 for the MWF1/2 days, NMWF1/2 days and MWF1/4 days treatments, compared to the other three treatments where a drop in diameter values was observed from week 8. This value was also cancelled out by week 16 for the NMWF1/6 days treatment.

The number of leaves was also significantly influenced by the treatments (Fig. 4). For the treatments MWF1/2 days, NMWF1/2 days and MWF1/4 days, the number of leaves increased significantly (P.05) from week eight to week twenty-four (5.78 to 9.55; 6.3 to 10.97 and 6.05 to 9.35 respectively). In the other three treatments, however, the value of the number of leaves decreased over the same period of time. This value was again cancelled out at week 16 after sowing for the NMWF1/6 days treatment.

An interpretation of the treatments in which the cocoa plants performed better at the twenty-fourth week after sowing, allows us to say that the best agronomic performances (stem height, neck diameter and number of leaves) were observed in the MWF1/2 days treatment (25.3 cm; 5.6 mm and 9.4). Although there were no significant differences (P.05) at this time between this treatment and the NMWF1/2 days and MWF1/4 days treatments with respect to height and crown diameter. However, there was a significant difference (P.05) between MWF1/2 days and the other two treatments with respect to the number of leaves. Also, there is no significant difference between NMWF1/2 days and MWF1/4 days for all these agronomic parameters, although observation of the mean values of these parameters shows that the MWF1/4 days treatment (23.4 cm; 5.1 mm and 11) is slightly better than NMWF1/2 days (23.3 cm; 4.9 mm and 9.6).

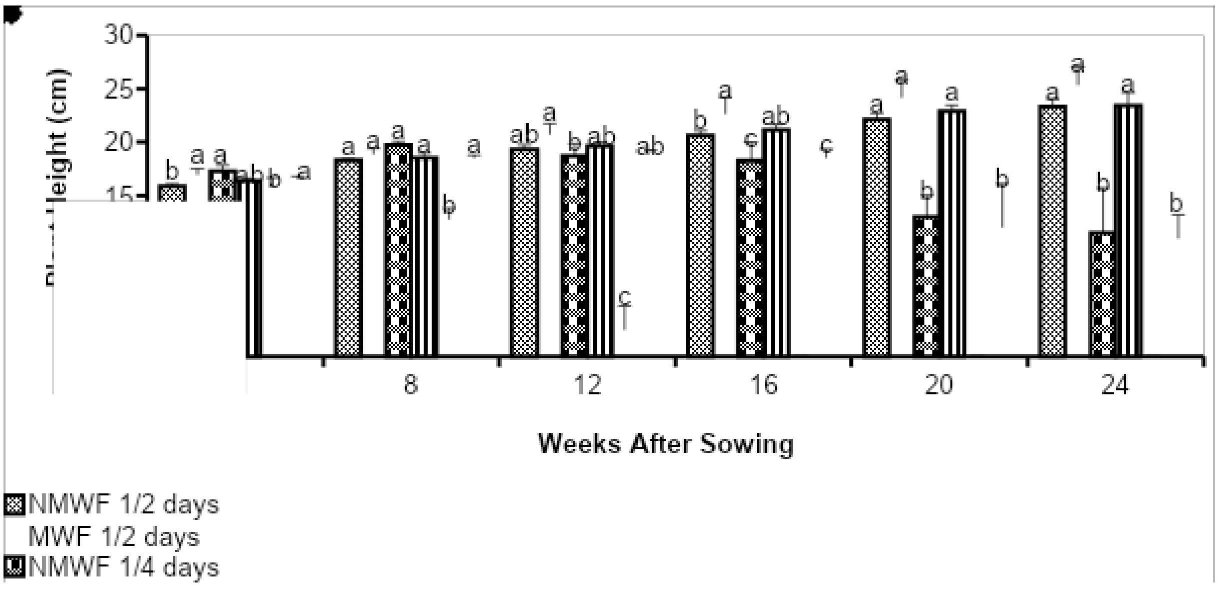

Fig. 2. Effect of treatments on the height of cocoa plants

NMWF1/2 days: Not mulched with Watering Frequency of once every two days (control); MWF1/2 days: Mulched with Watering Frequency of once every two days; NMWF1/4 days: Not mulched with Watering Frequency of once every four days; MWF1/4 days: Mulched with Watering Frequency of once every four days; NMWF1/6 days: Not mulched with Watering Frequency of once every six days; MWF1/6 days: Mulched with Watering Frequency of once every six days - Treatments with the same letters or group of letters do not differ significantly. Those with different letters differ significantly

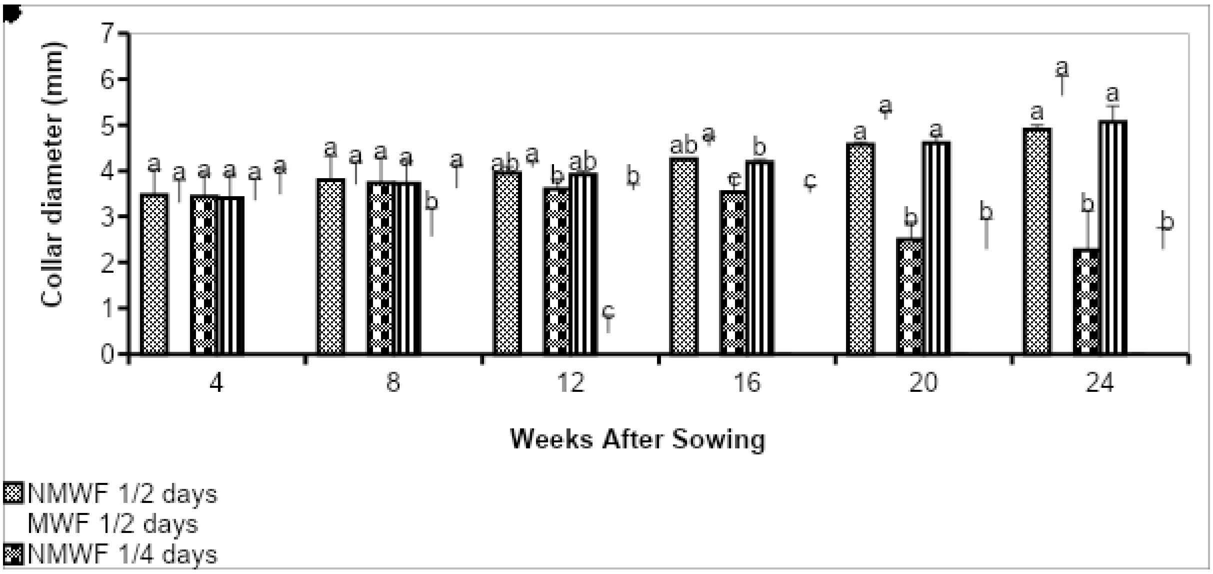

Fig. 3. Effect of treatments on the stem collar diameter of cocoa plants

NMWF1/2 days: Not mulched with Watering Frequency of once every two days (control); MWF1/2 days: Mulched with Watering Frequency of once every two days; NMWF1/4 days: Not mulched with Watering Frequency of once every four days; MWF1/4 days: Mulched with Watering Frequency of once every four days; NMWF1/6 days: Not mulched with Watering Frequency of once every six days; MWF1/6 days: Mulched with Watering Frequency of once every six days - Treatments with the same letters or group of letters do not differ significantly. Those with different letters differ significantly

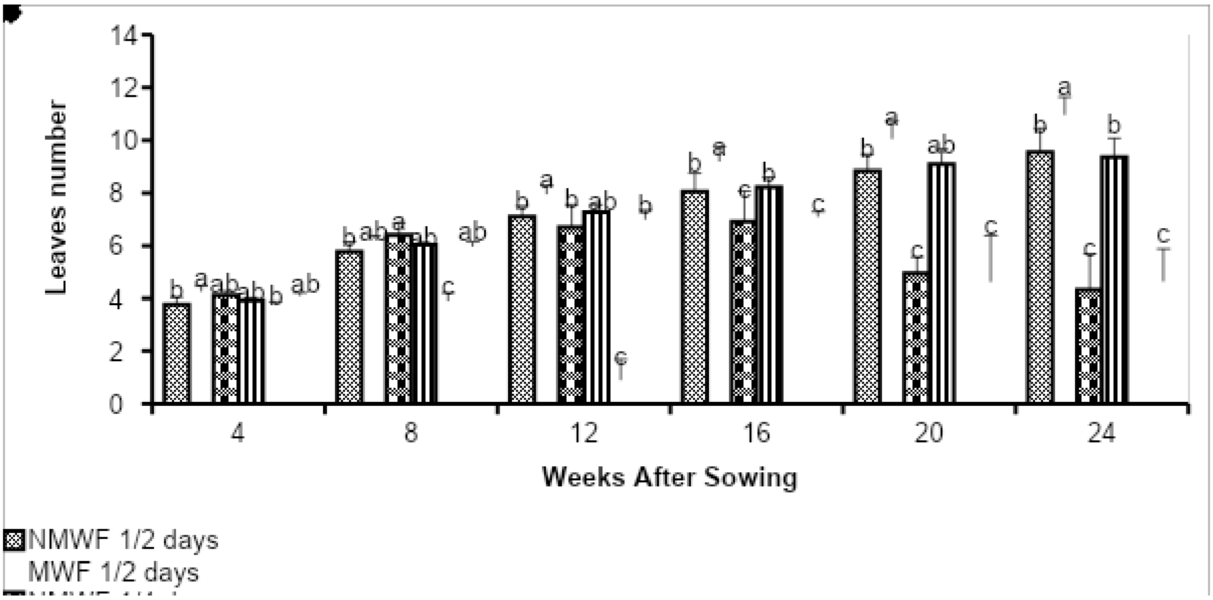

Fig. 4. Effect of treatments on the number of leaves of cocoa plants

NMWF1/2 days: Not mulched with Watering Frequency of once every two days (control); MWF1/2 days: Mulched with Watering Frequency of once every two days; NMWF1/4 days: Not mulched with Watering Frequency of once every four days; MWF1/4 days: Mulched with Watering Frequency of once every four days; NMWF1/6 days: Not mulched with Watering Frequency of once every six days; MWF1/6 days: Mulched with Watering Frequency of once every six days - Treatments with the same letters or group of letters do not differ significantly. Those with different letters differ significantly

3.1.3 Effect of treatments on the length of the main root and on the number of secondary roots

Twenty-four weeks after sowing, the average length of the main roots and the average number of secondary roots showed significant differences (P.05) between the different treatments (Table 3). Overall, this length and number increased with decreasing watering frequency. The highest root lengths and numbers were observed in the MWF 1/4 days (10.45 ± 0.82 and 47.32 ± 3.21 respectively) and MWF 1/2 days (10.15 ± 0.58 and 51.75 ± 5.11) treatments, respectively; in contrast to the NMWF 1/6 days (0.00 ± 0.00 and 0.00 ± 0.00) and MWF 1/6 days (4.91 ± 1.16 and 26.65 ± 4.28 respectively) treatments, which recorded the lowest values.

3.1.4 Effect of treatments on root architecture of young cocoa plants

Twenty-four weeks after sowing, the cocoa plants showed different types of root architecture depending on the watering frequency (Fig. 5). For treatments with high watering frequencies (once every two days), the main roots seemed to be mostly shorter, with more secondary roots distributed along the length of the main root. These secondary roots were somewhat denser and longer in the collar area of the plant and shortened as one approaches the tip of the main root. In contrast, with the exception of MWF 1/4 days, treatments with low watering frequencies (once every four and six days), had mostly longer main roots, with fewer secondary roots present mainly at the collar and root tip, where they were longer and denser.

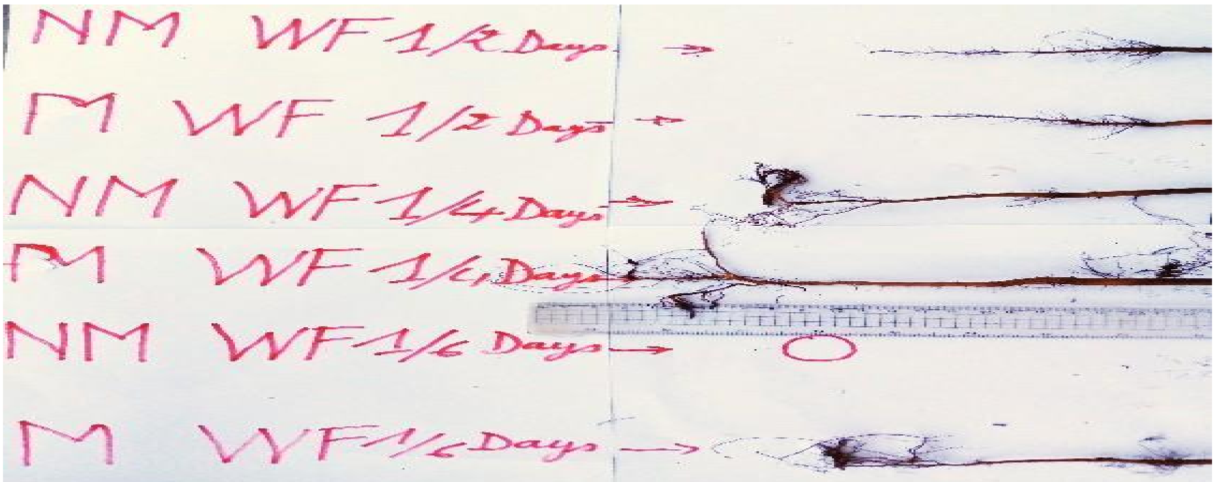

Fig. 5. Architectures of the roots of young cocoa plants according to the treatments at 24 weeks after sowing

3.1.5 Effect of treatments on the dry matter content of cocoa plant organs

The dry matter contents obtained differed significantly (P.05) according to the type of treatment (table 4). In all organs, the average dry matter content of stems + leaves (41.23 ± 3.00%) was higher than that of roots (34.40 ± 5.23%). The MWF 1/4 Days and MWF 1/6 Days treatments significantly (P.05) increased the dry matter content of both stems + leaves (58.41 ± 6.54 and 53.99 ± 3.35 %

respectively) and roots (47.62 ± 4.12 and 55.56 ± 9.62 % respectively). On the contrary, the NMWF 1/6 days treatment (0.00 ± 0.00 %) showed a zero content for all organs.

3.1.6 Correlation

The analysis of the correspondence table between the measured parameters showed that most of them are significantly (P.01) positively correlated (Table 5). While DRW and MCD (r = 0.881*), DRW and MPH (r = 0.891*), DRW and MLN (r = 0.894*), DRW and LMR (r = 0.849*), DRW and SR (r = 0.900*), FRW and MCD (r = 0. 874*), FRW and MPH (r = 0.864*), FRW and MLN (r = 0.838*), FRW and LMR (r = 0.877*), FSLW and MLN (r = 0.905*) respectively showed significant (P.05) and positive correlations with each other. Overall, mean plant height (MPH) was more strongly and significantly (P.01) correlated (r = 0.996**) with mean crown diameter (MCD). While the weakest correlation (r = 0.838*) was observed between fresh root weight (FRW) and mean leaf number (MLN), although it was also significant (P.05).

Table 2. Physico-chemical properties of the initial substrate and the substrates of the different treatments, 24 weeks after sowing

Sample code	ECH 1/ Initial substrate	ECH 2 / MWF1/2 days	ECH 3 / MWF1/4 days	ECH 4 / MWF1/6 days	ECH 5 / NMWF1/2 days	ECH 6 / NMWF1/4 days	ECH 7/ NMWF1/6 days
Depth (Cm)	0-20	//	//	//	//	//	//
Laboratory code	1	2	3	4	5	6	7
Texture (%)							
Clay	37.4	28.4	27.4	31.4	31.4	33.4	29.4
Silt	16.8	17.8	18.8	18.8	12.8	18.8	14.8
Sand	45.8	53.8	53.8	49.8	55.8	47.8	55.8
Textural class	SC	SCL	SCL	SCL	SCL	SCL	SCL
Soil reaction							
pH-water	5.5	5.1	5.8	4.9	5.6	5.2	5.1
pH-KCl	4.5	4.4	4.4	4.5	4.7	4.6	4.5
∆ pH	-1	-0.7	-0.4	-0.4	-0.9	-0.6	-0.6
Organic matters							
CO (%)	2.31	4.62	3.73	1.49	3.02	2.49	3.73
MO (%)	3.98	7.97	6.44	2.57	5.21	4.29	4.44
N tot, (%)	0.19	0.31	0.27	0.22	0.27	0.23	0.28
C/N	12	15	14	7	11	11	13
Exchangeable cations (meq/100 g)							
Calcium	4.00	5.20	5.60	3.60	4.80	4.80	4.00
Magnesium	0.64	2.40	1.44	0.80	1.20	2.80	3.20
Potassium	0.07	0.10	0.22	0.05	0.17	0.07	0.07
Sodium	0.28	0.37	0.37	0.14	0.28	0.28	0.28
Sum of bases	4.99	8.07	7.62	4.59	6.45	7.95	7.55
Cation Exchange Capacity (meq/100 g)							
CEC pH7	9	10	9	8	10	10	9
Saturation (%)	55	81	85	57	65	80	84
Assimilable phosphorus							

Bray II (mg/Kg)	7.96	13.04	28.62	11.31	15.11	11.59	10.27

SC = Sandy Clay; SCL = Sandy Clay Loam
Source: Soil Analysis and Environmental Chemistry Research Unit, FASA, Uds, 2021.

Table 3. Average root length and number, 24 weeks after sowing

Treatments	Average length of main roots (cm)	Average number of secondary roots
NMWF 1/2 days	10.15 ± 0.58 b	51.75 ± 5.11 a
MWF 1/2 days	9.26 ± 0.55 b	52.13 ± 5.70 a
NMWF 1/4 days	5.80 ± 1.06 c	24.32 ± 3.64 b
MWF 1/4 days	10.45 ± 0.82 a	47.32 ± 3.21 a
NMWF 1/6 days	0.00 ± 0.00 d	0.00 ± 0.00 c
MWF 1/6 days	4.91 ± 1.16 c	26.65 ± 4.28 b

Table 4. Influence of treaments on dry matter content (%) of cocoa plants

Cacao plants organs	Treatments	Dry Matter content (%)
Stems + Leaves	MWF 1/2 Days	45.97 ± 2.04 b
	NMWF 1/2 Days	44.63 ± 4.74 b
	MWF 1/4 Days	58.41 ± 6.54 a
	NMWF 1/4 Days	44.37 ± 1.32 b
	MWF 1/6 Days	53.99 ± 3.35 a
	NMWF 1/6 Days	0.00 ± 0.00 c
Means Stems + Leaves		**41.23 ± 3.00**
Roots	MWF 1/2 Days	37.86 ± 6.62 bc
	NMWF 1/2 Days	28.41 ± 7.67 c
	MWF 1/4 Days	47.62 ± 4.12 ab
	NMWF 1/4 Days	36.94 ± 3.37 bc
	MWF 1/6 Days	55.56 ± 9.62 a
	NMWF 1/6 Days	0.00 ± 0.00 d
Means Roots		**34.40 ± 5.23**

Table 5. Correlation matrix of the measured variables of cocoa plants

	MCD	MPH	MLN	LMR	SR	DRW	FRW	DSLW	FSLW
MCD	1								
MPH	0.996**	1							
MLN	0.976**	0.992**	1						
LMR	0.984**	0.966**	0.927**	1					
SR	0.975**	0.960**	0.925**	0.976**	1				
DRW	0.881*	0.891*	0.894*	0.849*	0.900*	1			
FRW	0.874*	0.864*	0.838*	0.877*	0.944**	0.958**	1		
DSLW	0.966**	0.965**	0.950**	0.949**	0.979**	0.968**	0.963**	1	

FSLW	0.948**	0.935**	0.905*	0.953**	0.981**	0.954**	0.979**	0.991**	1

*** Correlation is significant at the 0.01 level (two-tailed).*
** Correlation is significant at the 0.05 level (two-tailed).*
MCD: Means collar diameter; MPH: Means plant height; MLN: Means leaves number; LMR: Main roots; SR: Secondary roots; DRW: Dry roots weight; FRW: Fresh roots weight; DSLW: Dry stems+leaves weight; FSLW: Fresh stems+leaves weight.

3.2 Discussion

The determination of the physico-chemical characteristics of the experimental soils showed that the soil used for this experiment belongs to the Clay-Sandy textural class. This is the best soil texture recommended for cocoa cultivation [25]. However, at the end of the trial, the soils of the different treatments showed sandy clay loam texture and an increase in the sandy fraction was observed in these soils. This was especially true for the unmulched treatments (no organic matter) and those with a high watering frequency. These results may be explained by the fact that the initially available organic matter would have been leached out and would have favoured the increase of the sandy fraction. Because maintaining sufficiently high concentrations of organic matter makes it possible to limit the intensity of leaching very significantly [35]. Similarly, the work of the [14] shows that high watering frequencies can contribute to the depletion of the finer elements of the substrate through the phenomenon of leaching, whereas straw helps to limit this phenomenon. It is for these reasons that the soils of the mulched treatments kept a sand content close to that of the initial soil, whereas this content increased in the non-mulched treatments and especially in those with a high watering frequency. In this sense, [13] also showed that the migration and dispersion of soil particles depend on the water regime of a given horizon. Also, this thesis of leaching can be justified by the fact that the clay content in the initial soil was higher, but this content had more or less decreased with time, in the substrates of the different treatments. This shows that some of the clay fraction was probably washed away during the different watering events and this would have contributed to the increase of the sand fraction in these soils. On the other hand, the silt content increased slightly from its initial content. This significant increase in silt content could also be explained by the leaching phenomenon which would have depleted the clay substrates more than the silt.

The results also show that the pH of the different substrates varied from 4.9 to 5.8 overall and the work of [19] states that the ideal pH of suitable soil for cocoa cultivation is around 5 [9]. Thus, these results prove that all these soils were suitable for cocoa plant production. However, [28] specifies in his book entitled "Le cacaoyer" that the optimal soil pH value for cocoa farming is 6.5. Similarly, the work of [21] also states that the optimum soil pH for cocoa cultivation is weakly acidic (pH 6.5). This means that the MWF 1/4 days treatment (5.8), which recorded a pH tending most towards 6.5, has a soil whose pH is most conducive to cocoa cultivation. Furthermore, these results also show that mulching with dry grass, at a quantity of 20 g for the 15 cm x 20 cm bags, would contribute to improving the soil pH for a frequency of watering every four days.

For the organic matter, its content was 3.98% in the initial substrate. [2] shows in his work that the optimum organic matter content of cocoa-growing soil is above 3.5%. This shows that the initial substrate had a good organic matter content and that this soil is suitable for the production of cocoa plants. Similarly, the soils of the different treatments had mostly higher organic matter content than the initial soil, especially in the mulched treatments with high watering frequency such as MWF 1/2 days (7.97%) and MWF 1/4 days (6.44%). This could be explained by the higher watering frequencies which contributed to a more or less rapid degradation of part of the straw, enriching these soils in organic matter and thus improving their structure [11]. These results are also similar to those obtained by [33] who showed the importance of mulching in the supply of organic matter. However, only the MWF 1/6 days treatment (2.57%) was below the optimal value. This result can be explained by low supply of organic matter due to the low frequency of watering which would not have favoured a certain degradation of the straw. Thus, a large part of the quantity of organic matter available at the beginning in the initial substrate and the small fraction of organic matter provided by the very low degradation of the straw would have been consumed by the cocoa plants in the substrate and these plants would have thus contributed to reducing this value below the optimum. For the NMWF 1/6 days treatment (4.44%), it rather presented a higher organic matter content than the initial substrate (3.98%) despite the absence of straw and its watering frequency equal to that of MWF 1/6 days. This would be due not only to the progressive and early death (sixteen weeks after sowing, for the last plants) of the cocoa plants which would have consumed very little organic matter from this substrate, but also to the rotting of the roots and some organs of these dead plants which probably contributed to increase this organic matter content towards the end of the trial.

For the C/N ratio, it reflects the rate of mineralization, which makes it possible to assess the availability of mineral elements for the plant. According to the work of [15] and [40], the optimal C/N ratio should be between 9 and 15 for good cocoa tree development. For the initial substrate, this ratio was 12, while in all mulched treatments MWF1/2 days (15) and MWF1/4 days (14) this ratio was above 12, with the exception of MWF1/6 days (7) which showed a value below 9. This means that the initial soil in the trial showed a good C/N ratio for cocoa plant production. In addition, the higher the watering frequency, the more easily the straw degrades and the faster the mineralization. This corroborates the work of [10] in which he showed the importance of water in the mineralization process. While at low watering frequencies, straw degradation is less and mineralization is low. Thus, the cocoa plants grown in this treatment (MWF1/6 days) would have contributed to decrease the amount of mineral elements initially available in its substrate, reducing the C/N value to 7. In the absence of the straw, there was not enough organic matter supply, which may explain the decrease in C/N ratio in most of the unmulched treatments. Thus, in these treatments, the cocoa plants had probably consumed part of the mineral elements initially available in their substrates to ensure their growth and this would have contributed to the decrease in the C/N ratio of these treatments.

The sum of exchangeable bases, the cation exchange capacity at pH7 and the quantity of assimilable phosphorus increased overall in the different treatments and especially in the soils of the mulched treatments. These results can be explained by the high mineralization [10] due to the higher watering frequencies applied to the straw (organic matter) in these treatments. On the other hand, the MWF 1/6 days treatment showed values of the sum of exchangeable bases (4.59 meq/100 g) and cation exchange capacity (8 meq/100 g) below the values obtained in the initial soil. This result can be explained by the low frequency of watering, which would not have favoured a good mineralization of the organic matter (straw), since water supply is one of the most determining factors for the decomposition and mineralization of organic matter in the soil [38] and [24]. These different physico-chemical characteristics of soils have resulted in more or less satisfactory agronomic performance (growth and development) of cocoa plants depending on the treatments applied.

The different treatments applied significantly (P.05) influenced the growth and development of cocoa plants during their follow-up in the nursery. Overall, the agronomic parameters of the mulched treatments performed better than the unmulched ones, since straw provides organic matter, conserves soil moisture and reduces evapotranspiration [14]. Whereas in the unmulched treatments, watering water evaporates more quickly and therefore requires a higher watering frequency. The NMWF1/2 days treatment is the one whose watering frequency is often recommended to growers. But at 24 weeks after sowing, when the plants are ready to be planted in the field, the results show that the mulched treatments MWF1/2 days and MWF1/4 days showed better growth and development of the different agronomic parameters measured (stem height, crown diameter and number of leaves) than this treatment (NMWF1/2 days). This result can be explained by the fact that these treatments benefited from a straw supply that not only favoured the permanent maintenance of humidity, but also the supply of a large quantity of organic matter, which were responsible for the agronomic performance obtained. It confirms the results obtained by [39] and [3] who showed that the cocoa tree requires soils rich in organic matter, i.e. a minimum rate of 3%. On the contrary, the different values of these agronomic parameters started to decrease from the eighth week for the rest of the treatments and these values were cancelled out by the sixteenth week for the NMFW 1/6 days treatment (0.00 ± 0.00). This can be explained by the fact that this time interval falls within the dry season (December-February) when there was hardly any rain and temperatures were highest according to the umbrothermal diagram (Fig.1). Thus, these climatic elements had probably contributed to a decrease in air humidity and an increase in evapotranspiration, and these factors would have progressively caused the early drying of the various substrates and the death of the cocoa plants, depending on the treatments applied.

On the other hand, the average length of the main root and the average number of secondary roots increased with increasing watering frequency (Table 2), whereas observations showed that the length of the main root seemed to increase with decreasing watering frequency (Fig. 5). This result can be explained by the amount of water-stressed dead plants recorded in some treatments, which strongly contributed to reduce the number of plants and consequently the average length and number of secondary roots, in those treatments with low watering frequencies like NMWF 1/4 days, MWF 1/6 days and especially NMWF 1/6 days. This increase in the length of the main roots observed in the low watering frequency treatments could be explained by a form of adaptation of the roots of young cocoa plants to avoid water stress. Since the amount of water available to a plant after watering decreases progressively with time and certain climatic elements (temperature, hygrometry), moving from the surface of the substrate to its depth. This would have contributed to an adaptive lengthening of the main root and the formation of secondary root clumps at the root tip, according to the architecture described in paragraph 3.1.5 and illustrated in figure 5. This architecture probably allowed the roots of the cocoa plants to easily obtain water, which was more available at the bottom of the substrate on which they developed, in contrast to the roots of the plants from the treatments with high watering frequencies, in which the plants (with shorter main roots) had undergone less water stress. The cocoa plants generally showed more developed secondary root clumps at the base of the hypocotyl. This presence of secondary roots at this level allows the cocoa plants to better supply themselves with organic matter [26].

In the different organs of the cocoa plants, the dry matter content increased when the watering frequency decreased. Thus, plants in the high watering frequency treatments had relatively low dry matter content, while plants in the low watering frequency treatments had higher contents. In contrast, the NMWF 1/6 days treatment showed zero content in the different organs. This result is explained by the fact that all the plants in this treatment (NMWF 1/6 days) died around the sixteenth week, so that at the end of the experiment there were no cocoa plants left. Therefore, all agronomic parameters of this treatment were zero at the twenty-fourth week after sowing.

A correlation study revealed that all the different agronomic parameters were significantly and positively correlated to the parameters they were compared to. The different correlation coefficients obtained were all close to 1 and this means that there is a strong linear relationship between these different variables [32].

4. CONCLUSION

This study aimed to assist cocoa farmers in monitoring their cocoa nurseries during periods or in areas where water is scarce. Thus, its objective was to find methods of monitoring cocoa plants that could use the lowest watering frequencies through the straw that would allow for optimal growth and development of a nursery. The trial showed that out of the six treatments applied, three treatments, namely MWF 1/2 days, MWF 1/4 days and NMWF 1/2 days (controls) respectively contributed to improving the physico-chemical properties (sand, clay and silt contents; pH-water; organic matter; C/N ratio; sum of exchangeable bases; cation exchange capacity; saturation rate and assimilable phosphorus) of their substrate. In addition, they promoted satisfactory agronomic performance (plant height, collar diameter, number of leaves, number of secondary roots and length of main roots) to the cocoa plants produced in the nursery for 24 weeks. However, the interest is to seek the lowest watering frequency that could reduce watering difficulties, so we advise cocoa growers to adopt the MWF 1/4 days treatment, which reduces the currently recommended watering frequency (one watering every two days) by half. Cocoa farmers wishing to establish new plantations are often advised to do so at a rate of half a hectare per year. This area requires only about six hundred cocoa plants to be produced per year. Also, the easy availability of straw throughout the different cocoa producing areas of Cameroon makes it easy for cocoa farmers to apply this treatment.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Antonie C. and Huetz-Adams F. Cocoa Barometer. 2020; 120 p. Available: http://www.cocoabarometer.org. French.

2. Assiri AA. Identification of peasant practices in the management of cocoa orchards in Côte d'Ivoire. Dissertation for Diploma of Advanced Studies, UFR STRM option Agro-pedology, University of Cocody, Abidjan, Ivory Coast. 2007; 68 p. French.

3. Aweto AO and Obé AO. Comparative effects of a tree crop (cocoa) and shifting cultivation on a forest soil in Nigeria. The Environmentalist. 1993; 13 (3): 183-187.

4. Babin R, Dibog L, Bisseleua DBH. Description and evaluation of a new breeding method, and elements of the biology of *Sahlbergella singularis* Hagl. (Hemiptera: Miridae), the main cocoa pest in Cameroon. 2006; 15th International Cocoa Research. French.

5. Begoude D. How to grow cocoa in Cameroon. Technical sheet. 2017; 4 p. French.

6. Bourgoing R and Todem H. Association of cocoa trees with fruit trees: innovative system in cocoa farming. Creation of a new plot on fallow land or savannah. Center for International Cooperation in Agronomic Research for Development (CIRAD). 2010a; 83p. French.

7. Bourgoing R and Todem H. Association of the cocoa tree with the palm tree or the coconut tree: innovative system in cocoa farming. Creation of a new plot on fallow land or savannah. Center for International Cooperation in Agronomic Research for Development (CIRAD). 2010b; 111p. French.

8. Boyer J. Cycles of organic matter and mineral elements in a Cameroonian cocoa plantation. Coffee Cocoa Tea. 1973; 17 (1): 3-24. French.

9. Cocoa-Coffee Council. Technical manual for sustainable cocoa farming – For the attention of the technician. The Council for Regulation, Stabilization and Development of the Coffee-Cocoa Sector. 2015; 166p. French.

10. Delmas D. Mineralization of organic matter and ion exchanges at the water-sediment interface of the Etang de Berre, Mediterranean. Oceanology Acta. 1980; Flight. 3(3):347-356. French.

11. Dembele CO. Dynamics of nitrogen and carbon during the decomposition of three legumes used as cover crops. Université Laval, Master's thesis in plant biology. Quebec, Canada. 2019; 63p.

12. Efombagn MIB, Sounigo O, Nyassé S, Manzanares-Dauleux M, Cilas C, Eskes MAB and Kolesnikova-Allen. Genetic diversity in cocoa germplasm of southern Cameroon revealed by simple sequence repeat (SSRS) markers. African Journal of Biotechnology. 2006; 5 (16):1441-1449.

13. Faivre P and Chamarro C. Biotic factors and mechanisms of particulate leaching in soils. The example of the characteristic toposequences of the Andes of Colombia. Soil Study and Management. 1995; (1): 25-42. French.

14. FAO. Mulching in organic farming, Philippines. IFOAM–International Federation of Organic Agriculture Movements. 2015; 4p. French.

15. Huber G and Schaub C. Soil fertility: The importance of organic matter. Environment – Innovation Department. 2011; 46p. French.

16. Jagoret P, Bouambi E, Menimo T, Domkam I and Batomen F. Analysis of the diversity of practice systems in cocoa farming. Case of the Cameroon Center. Biotechnol. Agron. Soc. About. 2008; 12(4): 367-377. French.

17. Kamtchoum SM, Nchoutnji I, Nono TC, Tonfack BL, Lucas FL, Tchuenga STG, Mbieji KC, Kamdem NF, Suh C and Youmbi E. Comparative Effect of Biological Fixation of Nitrogen and Chemical Fertilizer on Yield Optimization of Two Sorghum Varieties in the Western Highlands. AJAHR. 2019; 4(3): 1-10.

18. Kebe BI, N'guessan KF, Tahi GM, Assiri AA, Koko LK, N'goran KJ, Zahouli IB, Koffi NG. Properly growing the cocoa tree in Ivory Coast. Data sheet, Edition CNRA-CTA, Abidjan. 2009; 4 p. French.

19. Koko LK, Yoro GR, Ngoran K and Assa A. Evaluation of soil fertility under cocoa trees in the south-west of Côte d'Ivoire. African Agronomy. 2008; 20 (1): 81-95. French.

20. Kokou EA and Ngo-Samnick LE. Cocoa production and processing. PRO-AGRO collection. 2014; 44 p. www.isf-cameroun.org. French.

21. Kouassi KG. Evaluation of different fertilizers on the growth and development of cocoa tree nurseries (*Theobroma cacao* L.) raised on different substrates. National Polytechnic Institute. Master's Degree in Advanced Agronomy. Ivory Coast. 2012; 74 p. French.

22. Lecompte M. Experimentation and fertilizers. Agricultural engineer (I.N.A). 1965; 91 p. French.

23. Lescuyer G, Bassanaga S, Boutinot L, Goglio P. Analysis of the value chain of cocoa in Cameroon. Report for the European Union, DG-DEVCO. Value Chain Analysis for Development Project (VCA4D CTR 2016/375-804). 2019; 121 p + appendices. French.

24. Lynch MJ, Mulvaney MJ, Hodges SC, Thompson TL, and Thomason WE. Decomposition, nitrogen and carbon mineralization from food and cover crop residues in the central plateau of Haiti. Springer Plus. 2016; 5(1):973. Doi: 10.1186/140064-016-2651-1.

25. Martin D. The soils of the cocoa plantations of Woleu-N'Tem. Overseas Scientific and Technical Research Office. Center of Libreville. 1969; 29p. French.

26. Martin JP. The cocoa tree. Course ENSA 6 Abidjan. 1970; 81p. French.

27. MINADER. Cameroon: Preparatory study for the agricultural infrastructure development project in Cameroon. Final report. Japan International Cooperation Agency. NTC International CO., LTD. Earth and human corporation CO., LTD. 2017; French.

28. Mossu G. The cocoa tree. The tropical agriculture technician, Maisonneuve and Larose. 1990; 90-110. French.

29. Nyassé S. Study of the diversity of *Phytophthora megakarya* and characterization of the resistance of the cocoa tree (*Theobroma cacao* L.) to this pathogen. Doctoral Thesis Inst. Nat. Polytech., Toulouse (France). 1997; 133 p. French.

30. Pauwels JE, Ranst V, Verloo M, and Mvondo ZEA. laboratory manual pedology, soil and plant analysis methods; equipment and management of glassware and chemical products, Publications Agricoles n° 28, A, G, C, D, Brussels, Belgium. 1992; 180 p. French.

31. Petithuguenin P. Cocoa farming and environmental change, a contribution to the reflection on the reproducibility of these cropping systems. In: Proceedings of the seminar on Fertility of the Environment and Farming Strategies in the Humid Tropics (Montpellier, 13–17 November 1995). J Pichot, N Sibelet and JJ Lacoeuilhe (eds). 1995. French.

32. Rakotomolala R. Correlation analysis. Study of dependencies – Quantitative variables. Lion 2 Light University. 2017; Version 1.1. 105p. French.

33. Roose E. Restoring the productivity of tropical and Mediterranean soils – Contribution to agroecology. IRD Editions. Montpelier. 2015; pp-191-199. French.

34. Sallet P, Biowallonie, Wiaux F. Mulching of vegetables in market gardening. Market gardener and independent researcher/trainer in soil biology. Technical advice – Seasonal advice for market gardening. 2018; 3p.

35. Sauzet O, Cammas C, Gilliot MJ, Montagne D. Limiting the leaching of clays in the soils of the Paris basin – Role of soil fauna and the supply of organic matter. Agronomy, ecology and innovation. TCS No. 95. 2017; 6p. French.

36. Shahin SA, Shao J, Lary JD, Kronmiller AB, Shen D, Strem DM, Amoako-Attah I, Akrofi YA, Begoude DAB, Hoopen MG, Coulibaly K, Kebe IB, Melnick LR, Guiltinan JM, Tyler MB, Meinhardt WL, and Bailey AB. *Phytophthora megakarya* and *Phytophthora palmivora*, closely

related causal agents of cocoa black pod rot, underwent increases in genome sizes and gene numbers by different mechanisms. Genome Biol. Evol. 2017; 9(3): 536–557.

37. Sighomnou D. Analysis and redefinition of the climatic and hydrological regimes of Cameroon: Prospects for the evolution of water resources. University of Yaoundé 1. Doctoral thesis 3rd cycle. 2004; 292p. French.

38. Singh Y, Singh B and Timsiana J. Crop residue management for nutrient cycling and improving soil productivity in rice-based cropping systems in the tropics. Advances in Agronomy. 2005; 85: 269-407.

39. Smith AJ. Soil classification and the cocoa grower. Cocoa Grwers' Bull. 1980; 30 (5): 5-10.

40. Snoeck D, Koko L, Joffre J, Bastide P and Jagoret P. Cocoa nutrition and Fertilization: Sustainable Agriculture Reviews, Vol. 19, Chapter 4. E. Lichtfouse (Ed.). Cham, Springer International Publishing. 2016; 155-202.

41. World Agroforestry Centre/FTNS. Support for the promotion of sustainable agriculture in a redd+ perspective in the periphery of the Lobeké and Dzanga Ndoki parks: Training of nurserymen in cocoa tree and fruit tree nursery techniques. Compendium of technical sheets / Learner's manual. 2017; French.

42. Yoro GR and Kassin KE. Morphological characterization of soils in degraded cocoa plantations in the east, south-east and south of Côte d'Ivoire. STCP Project Technical Report, CNRA internal document, Abidjan, Côte d'Ivoire. 2004; 46p. French.