Effects of the density of the mechanical aeration on the resistance to penetration of a turf soil and its impact on the plant root behavior

The purpose of this study is to compare the effects of two densities of aeration on the state of compaction of a grassy lawn and its impact on the behavior of the plant root. The tests were conducted on the main lawn of the Olympic Stadium in Rades, Tunisia. The core aeration was carried out through a Toro aerator equipped with fifteen straight spades, grouped in 3 with 6 and 10 mm inner and outer diameters, respectively, and working at a depth of 80 mm. Two densities of perforation were considered, 144 and 216 holes/m^2. The measurements were performed at baseline before ventilation, and at four subsequent dates, separated by an average of 10 days. They focused on soil resistance to penetration, fresh and dry matter yield and root length. The results found that initially the aeration work unpacks the soil, thus promoting good root development. This is confirmed by an improved amount of fresh and dry roots, and a net root elongation. This situation lasted only twenty days, and then the soil began to compact again, which negatively affected the fresh and dry matter yield and the root length. It should be noted as well that there is a close link between the state of soil compaction and root yield. This connection is confirmed by the presence of a correlation between the measured parameters of the plant (fresh and dry weight of roots, root length) and the state of soil compaction, high coefficient R2. Note also, that it is the aeration work at a high perforation density (216 holes/m^2) which gave the best results for the soil parameter and those of the plant.

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INTRODUCTION

The successful installation of a lawn grass is closely related to the soil textural and structural. These influence the subsequent performance of turf and its preservation over time by developing a good root system. This development depends strongly on the availability of nutrients, oxygen, soil water, temperature, improving the state of soil compaction and the ratio of the root penetration capacity to the soil bulk density (Vitlox, 1998). However, soil compaction by trampling or repeated passage of maintenance equipment on the lawn, led to the crushing of aggregates. This reduces the spaces between soil particles that contain water and air on which depends the root development (Doucet, 1992). Soil compaction increases its density by compressing mainly the larger pores that are responsible for the percolation of water and air. This change led to substantial yield losses and causes a reduction of the root system (Giroux et al., 2005).

Compacted soil causes an increase in pressure on the cell walls, reducing the rate of root elongation and increases their diameter. The plant may respond by reducing the root osmotic potential. In this way, the elongation is maintained provided that the compaction is not too strong (Demissy and Farque, 1997). In addition, a repetitious trampling and passages of maintenance equipment on a grassy lawn promote soil compaction. This reduces the spaces between soil particles that contain water and air on which depend the roots (Martineau et al., 2008, Anonymous, 2009; Delage, 2009). In addition, a turf set on a compacted soil has a low rooting which is favorable to weed growth (Pepin, 2005).

Moreover, the agglomeration of silt and pore clogging prevent air and, therefore, oxygen to flow freely. The medium becomes suffocating for the living organisms (roots, bacteria, etc.). This highly compacted level reduces the useful soil depth; in addition, the danger of surface erosion increases considerably (Toboussou, 2005).

Aeration is a mechanical tillage method that allows a tilling of the turf without damaging it by extracting small cores of soil. It consists in regenerating and restoring soil by mechanical work to more than 5 cm depth (Laurent, 2007). It also frees toxic gases from the earth, occasioned by the death and decay of microorganisms. These gases must be released from the soil regularly to prevent them from accumulating to dangerous levels for microbial health and that of grass (Smith, 2004).

In order to restore a structure meeting the needs of the turf while respecting the architecture of the lawn, aerating the soil by mechanical extraction of feces followed by addition of sand is the proper solution of the mechanical work of turf surfaces. The objective of this work is to assess the short and long terms of this technique, performed according to different perforation densities, on the soil penetration resistance, an indicator of its state of compaction, and its effect on plant root behavior.

MATERIAL AND METHODS

Objectives of the mechanical aeration of turf

Aeration, also called perforation, staking, or core drilling is a mechanical operation which involves extracting soil cores to be picked up later, leaving on the turf soil vertical holes (Figure 1a). It aims to improve the soil structure and texture by the addition of sand amendment. It stimulates the development of the root system of turf, increases soil microbial life and allows rapid decomposition of organic matter. The apparatus used (Figure 1b) is called aerator.

a b

Figure 1: Soil mechanical aeration, a: perforated turf, b: turf aerator

It includes hollowed spades (stems) with beveled lower edges arranged vertically and animated with an alternating up and down movement from a rod-crank system controlled from the tractor power take. By penetrating the soil, the spades extirpate cores and return back. Their return to soil allows ejecting the first cores. Aeration is always followed by an infusion of sand along the perforated surface, most often called sand blasting.

Experimental conditions

The tests were conducted on the main lawn of the Olympic Stadium in Rades, Tunisia. The coring operation was carried out by means of a Toro aerator equipped with fifteen straight spades grouped in 3 with 6 and 10 mm inside and outside diameters respectively and 125 mm in length and set to a working depth of 80 mm. These spades are spread over five rows and work alternately.

Two perforation densities were considered:

Treatment 1 (T1): soil mechanical aeration at a density of 144 holes/m^2;

Treatment 2 (T2): soil mechanical aeration at a density of 216 holes /m^2.

Characterization and measurement modalities

At the soil level

Resistance to penetration

The evaluation of the compaction of the turf of the football field is based on the determination of soil resistance to penetration (Vitlox and Loyer, 2002). It is a nondestructive method considering the importance of the experimental site. Furthermore, this method is more sensitive than the bulk density to characterize the differences in soil compaction (Allen and Musick, 1997).

The penetrometer used is of the electronic type, also called penetrologger (Figure 2). Coupled to a recorder, this device allows the storage and immediate processing of data. It consists of a force sensor, a recorder, a drill pipe, a cone, and an ultrasonic depth gauge. The apparatus is run by two very ergonomic handles for easy access to various commands. The application of equal pressure on both handles pushes the cone vertically into the soil. A mechanism of integrated measuring allows recording the penetration resistance encountered during the phase of insertion of the cone. It is also possible to immediately display the results of measurements on the screen as a graph or table of numerical data.

The measurements of soil resistance to penetration are done each 5 cm to a depth of 30 cm. Soil water content is measured jointly.

Figure 2: Electronic penetrometer or penetrologger

Brand	*Type*	*Work width (m)*	*Max work depth (mm)*	*Spades distance (mm)*	*Propulsion mode*	*Drive mode*	*Weight* (Kg)
Toro	*Verti-drain 7212*	*1,2*	*250*	*65*	*towed*	*Power take*	*470*

Table 1: Technical data of the verti-drain

At the plant level

Fresh and dry weights of the underground part

The root system in an important criterion in assessing the need for improvement the soil physical properties by an aeration operation, and also a criterion for the evaluation of field compaction. Samples were taken from the field by a cylinder with a known section, called coring technique, with two samples per elementary plot (Maertens, 1964). Then we conducted a sieving of the soil under water jet, with a 1 mm sieve mesh. Once the roots are extracted and separated from organic debris, we measured their fresh weight. The dry weight was determined after drying in an oven at 80° for 24 hours. Then we determined the fresh and dry weights in g/cm^2 of surface. This is done in the initial state E0 before aeration work, and after four different dates (7 days after aeration, 17 days after aeration, 27 days after, and 37 days after aeration).

Root length

Roots play a fundamental role in the plant functioning and production. It is due to them, that the plant is supplied with water and mineral elements (Chopart, 2003).

Root length is an important criterion in assessing the effects of mechanical aeration of turf soil following different densities of perforation. Indeed, the more the soil is well structured, more its compaction is reduced allowing the roots to find their way better in the soil to develop properly.

Statistical analysis

The statistical treatment of all measurements for different variables was based on the method of variance analysis.

RESULTS AND DISCUSSIONS

Soil resistance to penetration

Examination of the average penetrometric profiles (Figure 3) shows an increase in soil resistance to penetration from the surface to the depth. The curves show the same shape. However, 7 days after aeration, the initial state E0 is characterized by the highest values of the resistance to penetration compared to treatments T1 and T2 (Figure 3a).

Indeed, at 10 and 20 cm deep, respectively, the soil resistance measures 6.13 and 9.65 daN/cm^2 at baseline (E0), against 6.24 and 7.6 daN/cm^2 for treatment 1 and 4 daN/cm^2 and 7.44 daN/cm^2 for treatment 2. It appears that aeration reduces soil mechanical resistance to penetration and this is for the two densities. However, soil aeration at high density (216 $holes/m^2$) has provided a less compacted soil indicated by the lowest values of resistance on the horizon from 0 to 20 cm.

It appears that the effect of mechanical aeration on the soil is not fast, but it manifests itself over time. This can be explained by the fact that, with aeration, the number of impacts of spades on the soil is relatively low (144 or 216 $holes/m^2$). These are 1.1 and 1.7% of area actually worked per m^2, the rest being still compacted soil that needs time to relax in the presence of sandy holes, especially, that the lawn is used on average once every 15 days.

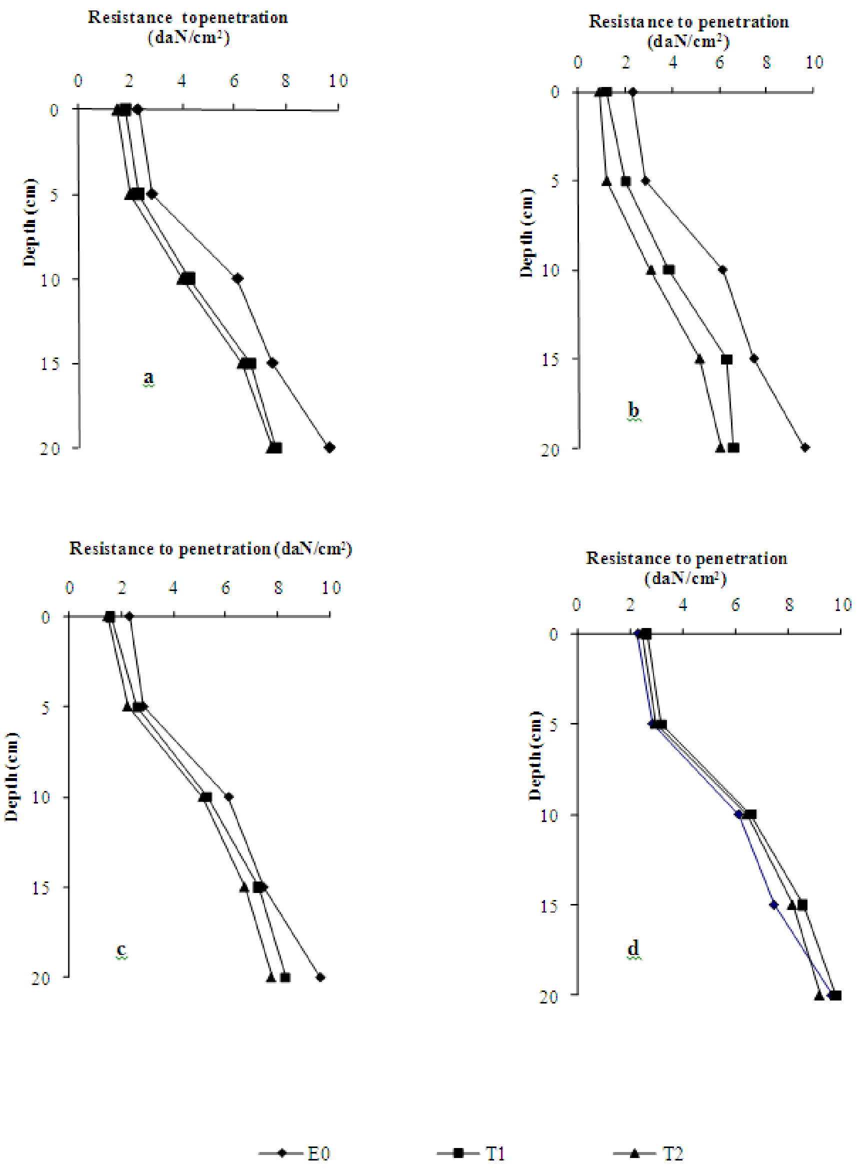


Figure 3: Average penetrometric profiles at the baseline (E0) and treatments T1 and T2.a: 7 days after aeration; 1.b: 17 days after aeration; 1.c: 27 days after aeration; 1.d: 37 days after aeration.

The results obtained 17 days after aeration (Figure 3b), show a remarkable decrease of soil strength compared to baseline, for both treatments. However, work at high perforation density is also the one with the greatest impact on the decompaction of the soil. Indeed, there has been 3.9 and 3.1 daN/cm^2 respectively for treatments T1 and T2 to 10 cm depth against 6.1 daN/cm^2 at the initial state. This is a decrease of the resistance for the two treatments of 36 and 49%, respectively. At 20 cm depth, the decrease in resistance of the soil compared to the initial state is 31% and 37% for the treatments T1 and T2, respectively. At this stage, the soil undergoes a marked improvement manifested by a remarkable decrease of its resistance to penetration on all the horizons. These results highlight the delayed impact of mechanical aeration of turf soil and its impact on his compaction state.

Measurements made 27 days after aeration (Figure 3c), show that soil resistance is growing again and its values tend towards those of the initial state before aeration for all horizons. Indeed, at 10 cm depth was, it was recorded 13.5 and 16% reduction for treatments T1 and T2, respectively. This reduction is 14% for treatment T1 and 19% for treatment T2 at 20 cm depth. So, it is the upper horizons that are undergoing the most compaction following the passage of maintenance machinery and trampling.

However, 37 days after soil aeration (Figure 3d), the resistance profiles of the two treatments become comparable to that of the initial state, especially at horizon 0-10 cm. There is a recovery of the soil situation before aeration. This may be due to the pressure at the surface by the passage of maintenance machinery and trampling of players. It appears that the effect of aeration on a grassy lawn subject to trampling and passages of maintenance machinery disappear over time and the soil is compacted again.

Statistical analysis shows a highly significant effect of treatment and measurement date on soil resistance (Table 2). Treatments are different from each other.

These results agree with those of Chehaibi et al. (2010) and Chehaibi et al. (2012) who showed that mechanical aeration of a turf soil affects its penetration resistance and that this effect is limited in time when the soil is still used. They also confirm those of Martineau et al. (2008) and Delage (2009) who reported that a repetitive trampling and passages of maintenance equipment on a grassy lawn promote soil compaction and reduce the spaces between the particles.

Source of variation	*D.F*	*M.S*
Bloc	2	6,46 NS
Date	4	230,61**
Treatment	2	910,97**
Error		12

(*) Significant according to Duncan test at $p < 0.05$
(**) Significant according to Duncan test at $p < 0.01$

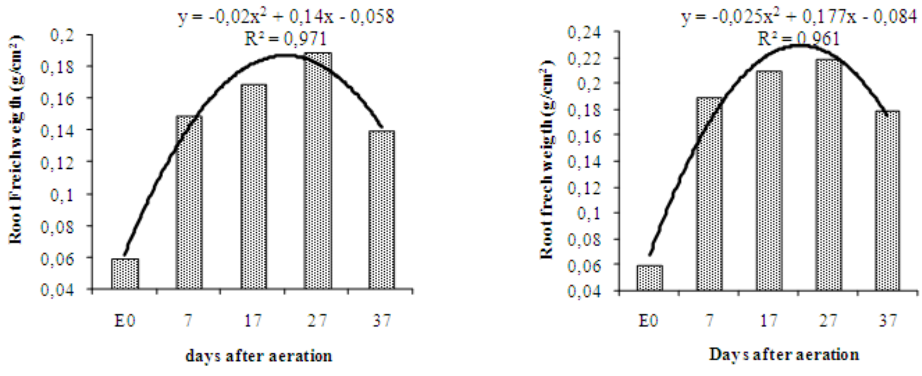
Table 2: Analysis of Variance for soil resistance to penetration

Fresh and dry weights of roots

Performance review on fresh grass roots (Figure 4), taken at baseline and at four dates after aeration showed that the fresh weight of roots is closely related to the state of soil compaction. Furthermore, the worked plots at a high perforation density (treatment T2) are indicated by the higher yields. Indeed, the initial state where the soil is not worked, the yield recorded was 0.06 g/cm^2. In contrast, at 7 and 17 days after aeration, soil strength decreased. Consequently, the yield of fresh roots underwent a marked improvement. The values are 0.15 and 0.17 g/cm^2 for treatment 1 and 0.19 and 0.21 g/cm^2 for treatment 2.

Moreover, at 27 days after aeration, the soil is indicated by the values of the lowest resistance. This led to an appreciable development of roots, and their yield was 0.19 and 0.22 g/cm^2 for treatments T1 and T2, respectively. However, 37 days after aeration, root fresh matter decreased by 0.14 and 0.18 g/cm^2 for treatments T1 and T2, respectively. Thus, it appears that the plant root development is directly affected by soil resistance to penetration. This is confirmed by the determination regression coefficients R2 of 0.97 and 0.96 relative to treatments T1 and T2, respectively.

Highly significant effects of treatment and measurment date are recorded by the statiscal analysis of the root fresh weight (Table 3).



a b

Figure 4: Evolution of root fresh weight. a. Treatment 1; b. Treatment 2

Source of variation	*D.F*	*M.S*
Bloc	2	6,46 NS
Date	4	230,61**
Treatment	2	910,97**
Error		12

(*) Significant according to Duncan test at $p < 0.05$
(**) Significant according to Duncan test at $p < 0.01$

Table 3: Analysis of Variance of root fresh weight

Regarding root dry matter (Figure 5), it has evolved in the same direction as the fresh matte. Tillage with a high perforation density gave, also, the best dry matter yields at all measurement times. Indeed, the performance follows a section of a parabola and measurements at 17 and 27 days after aeration resulted in 0.06 and 0.065 g/cm^2 for treatment 1, and 0.07 and 0.08 g/cm^2 in case of treatment 2, respectively. Measurements at 37 days after aeration are marked by a drop in root dry matter yield resulting from a substantial recovery of soil compaction that affected their development. There has been a determination between dry matter yield and date of measurement, characterized by a regression coefficient R2 of 0.81 and 0.87 for treatments T1 and T2, respectively. From this, it appears that the performance in root fresh and dry matter depends on, among other things, soil resistance to penetration, an indicator of its state of compaction.

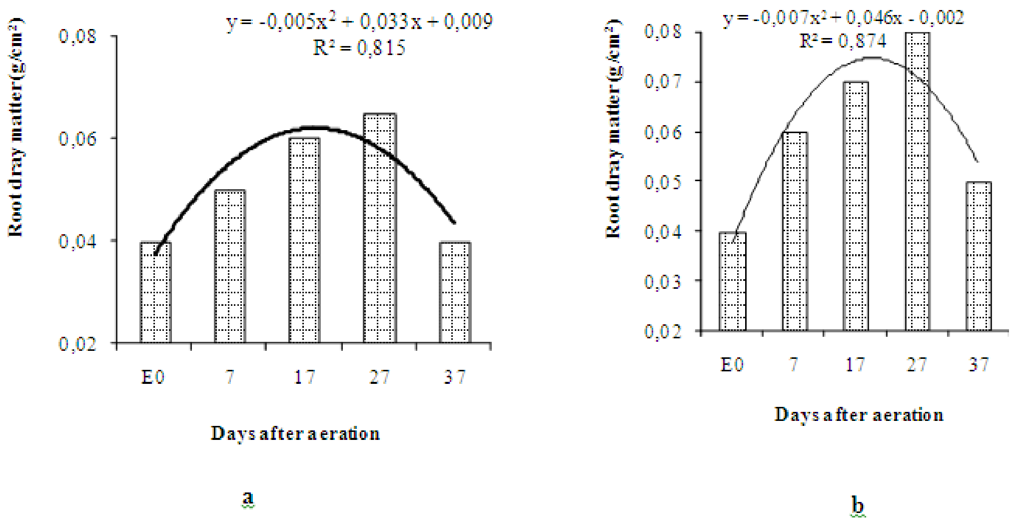


Figure 5: Evolution of root dry weight. a. Treatment 1; b. Treatment 2

Source of variation	*D.F*	*M.S*
Bloc	2	0,984 NS
Date	4	22,77**
Treatment	2	51,07**
Error		3,48

(*) Significant according to Duncan test at $p < 0.05$
(**) Significant according to Duncan test at $p < 0.01$

Table 4: Analysis of Variance of root dry weight

Length of roots

According to Figure 6, the root length has evolved in the same way that the yield of fresh and dry weight. Initially, the roots are indicated by short length (E0), then they begin to elongate after aeration, especially at soil level worked to high perforation density. Indeed, the average length obtained 17 days after aeration, for example, is 12.25 and 13 cm for treatments T1 and T2, respectively; thus, an increase relative to the initial state of 27 and 35%, respectively. In contrast, the average for 37 days after aeration is only 10.2 cm for treatment T1 and 10.4 cm for treatment T2. However, it should be noted also that for this parameter, the soil resistance to penetration has a significant effect revealed by the existence of a determination between the state of soil compaction and root length with values of R2 of 0.87 and 0.96, respectively.

These results confirm those of Demissy and Farque (1997) who showed that a compacted soil causes an increase in pressure on the cell walls, which reduces root elongation. They also agree with those of Giroux et al., (2005), who reported that soil compaction increases its density by compressing mainly larger pores that are responsible for the percolation of water and air. This change causes a reduction of the root system.

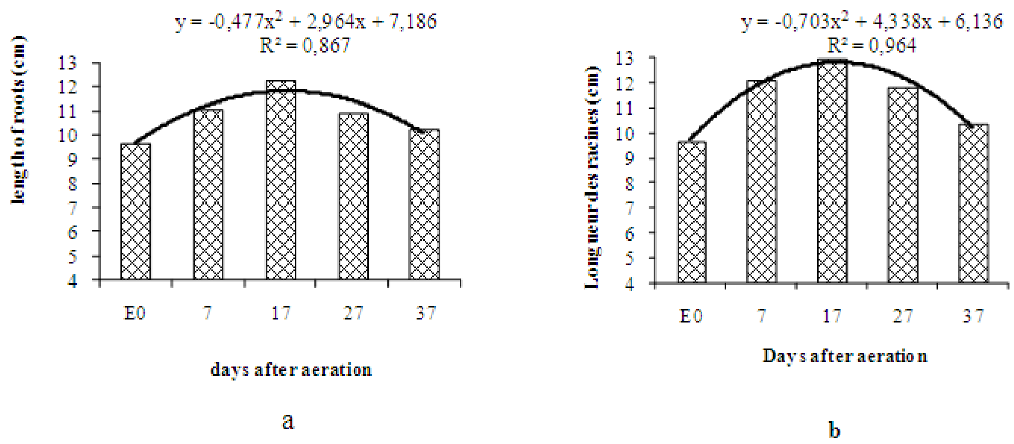


Figure 6: Evolution of root length. a. Treatment 1 ; b. Treatment 2

CONCLUSION

Based on experimental results, it was demonstrated that mechanical aeration by core drilling a turf soil, followed by sand blasting, improves soil structure by reducing its resistance to penetration. However, this action is limited in time, especially when the lawn is used. Indeed, for both perforation densities, measurements at 7 and 17 days after aeration show that the soil had a remarkable decompaction and resistance to penetration is clearly declining. However, from 27 days after aeration, there is a recovery and compaction of the soil resumes its initial state to 37 days after aeration. It should be noted that it is air flow at high perforation density which gave the lowest soil resistance to penetration.

Regarding the underground part of the plant, it should be noted that the root fresh and dry matter has evolved in the same direction as the soil strength, but with, however, the best yields for the aeration at high density. There has been a determination between fresh and dry weight of plant and state of soil compaction with high R2 coefficients (0.97 and 0.96 for T1 and T2 for fresh weight and 0.82 and 0, 86 for T1 and T2 for dry weight).

As for root length, there is a close link with the state of soil compaction. Indeed, before aeration, roots are marked by short length. But, after aeration, their length experienced an elongation initially when the soil is well structured, and they begin to shorten as soon thereafter as the soil is compacted again. This highlights the close interaction between soil structure and root elongation confirmed by a determination regression coefficient R2 of 0.86 and 0.96 for treatments T1 and T2, respectively.

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