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Full length Research Paper

Effects of working depth on mechanical aeration of a grassy soil and its impact on the plant root behavior

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The effects of the working depth of mechanical aeration of a grassy sward were performed at a golf green in Tunisia. The study focused on measurements of roots length, soil resistance to penetration and its bulk density before and after passage of a hollow tines aerator working at a depth of 6 cm and 12 cm treatments. The perforation density of 250 holes/m^2 was applied for the two treatments. Results showed that mechanical aeration was a means of loosening adequate for grassy soils which preserved the existing culture. Indeed, six days after aeration, there was a reduction in soil resistance to penetration compared to the initial state for both treatments. This was also observed at 21 and 40 days after aeration. However, 53 days after aeration, the soil returned to its original state before aeration. Bulk density also showed the same pattern. In parallel, the roots were marked by an increasing development for the first three measurement dates to stabilize at 53 days after aeration. However, it should be noted that aerating at 12 cm of depth, provided the best results of the measured parameters.

Keywords: mechanical aeration, perforation depth, soil resistance, bulk density, roots length.

INTRODUCTION

The grass is a crop for which the soil is undisturbed and not returned. Its ecological and environmental contribution is very important provided that its growth is reasoned and optimized. This is possible if he takes good management (Syngenta, 2011).).

In addition, the installation success of a grassy lawn depends on soil structural and textural states which affect the subsequent performances of the turf and its conservation over time by a good root development. This development depends on the availability of nutrients, oxygen, soil water, temperature, improvement of soil compaction state and the report of the penetration ability of the roots to the soil density (Vitlox, 1998). However, repetitive trampling and passages of maintenance equipments on a grassy lawn promote soil compaction. Therefore turf installed on compacted soil has a low rooting which is favorable to weeds development (Pepin, 2005).

Soil compaction increases its density by compressing essentially larger pores that are responsible for the percolation of water and air. This change leads to yield losses of the plant and causes a reduction of the root system (Giroux et al., 2005).

According to Laborier (1996), unfavorable soil physical characteristics often lead to irregular growth and bad grass development . Compaction which is a consequence of poor structure and soil texture is often considered as the most frequently encountered problem on grassy sward. Indeed, important compaction at 10 to 15 cm of depth prevents water and air circulation and impedes the roots development in depth. This is a result of the reduction in spaces between soil particles that contain water and air on which the roots depend (Martineau et al., 2008;Delage, 2009).

In addition, compacted soil causes an increase of the pressure on the cell walls, which reduces the root elongation and increases their diameter. The plant can respond by reducing the osmotic potential in roots. However, maintaining an optimal root elongation is possible providing that compaction is not too high (Demissy and Farque, 1997).

Aerating the soil by cores extraction is an efficient

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Figure 1. Perforated turf in an experimental plot

solution for grassy tillage (Curran et al., 2011). It promotes microbial life, facilitates the passage of fertilizer, increases the infiltration rate of rainwater and restores soil flexibility. Aerators are materials that burrow spindles, spoons or tines in soil; depending on the type of the material and the forward speed, the number of holes per m² may vary from 40 to 600. The average work depth varies from 10 to 15 cm. The hollow tines aeration allows air to move down. This state can be preserved by penetrating a porous and well draining material (Goxes et al., 2008). Aeration is therefore a mechanical tillage method which allows soil looseness without damage by extraction small soil cores. It regenerates and restores volume to the compacted soil by mechanical work more than 5 cm of depth (Laurent, 2007). It also helps to release soil toxic gases, caused by the death and the decomposition of microorganisms. These gases must be regularly released from soil to avoid their accumulation at dangerous levels for microbial health and grass (Smith, 2004). Aeration by extraction cores promotes deep root development and increases the drainage of clay soils.

Soil resistance to penetration 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 objective of this work is to evaluate the short and long-term effects of aeration with two perforation depths (6 and 12 cm), on some indicators of soil compaction state namely the resistance to penetration and bulk density, and its impact on the plant root behavior.

MATERIALS AND METHODS

The tests were conducted on a green golf course, Citrus, Tunisia, on a sandy soil (90% sand; 10% grapes compost) amended with Scotts (15-8-15), a slow release fertilizerThe coring operation was carried out by a Toro aerator (Toro, Verti-drain 7212, Redexim, North America) (Figure 1). (Technical data of the aerator: 1, 2 m working width; 250 mm Maximum working depth; 65 mm Spades distance; towed Propulsion mode; PTO : Power Take-Off (Drive mode; 470 Kg Weight) equipped with fifteen straight spades grouped in 3, with 6 and 10 mm inside and outside diameters respectively. These spades were spread over five rows and worked alternately.

Soil aeration was carried out by hollow tines with an average perforation density of 250 holes/m^2. Two working depths were used, which resulted in two soil treatments: mechanical aeration with hollow tines at 6 cm of depth and at 12 cm of depth respectively.

Mechanical soil tillage was achieved on a 450 m^2 grassy sward of *Agrostis Stoliniffère* species and *Penncross* variety. The sward was split into three plots of 150 m^2. Each plot was divided into two sub-plots corresponding to the two treatments. Three repetitions of each treatment were performed.

The evaluation of the compaction of the green was based on the determination of soil resistance to penetration and its bulk density.

The measurements of soil resistance to penetration were done with an electronic penetrometer, also called penetrologger (Eijkelkamp company, Germany).
The plots were sampled at each 5 cm to a depth of 20 cm. Soil water content was measured jointly (Elaoud and Chehaibi, 2011). The weighing method was adopted for determining soil water content: samples were taken with an auger at the same hole. We weigh the humid sample then we put it in stove at a temperature of 105°C for 24 h. Water content will be determined by the expression: W = Ph-Ps/Ps × 100
Ph is the wet weight of soil sample (g), Ps the dry weight of soil sample (g) and W is the water content (%).
Bulk density of the soil was measured bysoil density (g/cm3) using a cylinder densimeter (INADCO, Germany). The samples, soil cores (5 cm diameter and 5 cm height) were taken every 5 cm at a depth of 15 cm. The dry mass of the sample was obtained after drying at 105° C for 24 h (Yoro and Godo, 1990). Measurements were performed at 10, 20 and 30 cm of depth, respectively.

Turf root length measurements were performed at the

Table 1. ANOVA results for soil resistance to penetration data. Aeration correspond without aeration treatment and mechanical aeration with hollow tines at 6 cm of depth and at 12 cm of depth respectively; Date correspond at 6, 21, 40 and 53 days after aeration, respectively.

Source of variation	D.F.	M.S.
Aeration	2	18.732**
Depth	4	82.641**
Date	3	2.783**
Aeration * Date	6	0.921**
Error	120	0.008

**: significant at the 1% level.

initial state, before aeration and 6, 21, 40 and 53 days after. The roots were washed and then measured by flat ruler.

Statistical analysis of the different measurements was based on the analysis of variance (ANOVA) through the software SPSS 13 (IBM, New York). The comparison between means was performed according to the Duncan test at 5%.

RESULTS AND DISCUSSION

Statistical analyses of the soil resistance to penetration data show highly significant effects of the aeration treatment, the depth and the date of measurements (Table 1). The higher resistance corresponds to the control whereas the lowest occurs after mechanical aeration with hollow tines at 12 cm of depth.

Examination of penetrometric profiles (Fig. 2) shows an increase in the soil resistance to penetration from the surface to the depth as all curves have the same pattern. Pathern However, six days after aeration, the initial state E0 is indicated by the highest resistance to penetration compared to treatments 1 and 2 except treatment 1 at 5 cm of depth (Fig. 2.a). Indeed, at 5 and 10 cm of depth, soil resistance is respectively 1.83 and 3.13 daN/cm^2 at initial state, against 2.36 and 2.8 daN/cm^2 for treatment 1 and 1.06 and 1.53 daN/cm^2 for treatment 2. It appears that soil mechanical aeration leads to a decrease in its resistance to penetration for the two treatments. However, working at a depth of 12 cm (T2) led to more soil loosening.

In addition, measurements performed 21 days after aeration did not show an improvement in soil resistance compared to the previous state. Indeed, except at 5 cm of depth where soil resistance decreased for treatment 1, the other depths showed no remarkable improvement. This may be due to the sward use on the hand and the aeration slow effect on the other hand. Studies of Chehaibi et al., (2012) And Abrougui et al., (2012) showed that the effects of mechanical aeration of grassy soils are late.

Results obtained 40 days after aeration reveal a significant decrease of soil resistance, especially for horizons 10 to 20 cm. Indeed, at 10 cm of depth for example, soil resistance recorded a decrease compared to the initial state by 53 and 58% respectively for T1 and T2. As for reduction of soil resistance recorded at 20 cm of depth, it corresponds to 42% for treatment 1 and 47% for treatment 2.

Regarding measurements 53 days after aeration, they show a recovery of soil compaction and a return to the initial state for all horizons. This indicates that the effect of mechanical aeration work on a grassy sward is temporary. These results confirm those of Chehaibi et al., (2012) and Abrougui et al., (2012). Other work has shown that the benefits of mechanical aeration can be dependent on soil type. Some soils quickly revert back to their compacted state (Burgess et al.. 2000; Hamilton-Manns et al., 2002), particularly dispersive soils such as those found in the NORD (Adcock et al., 2007; Hewitt and Shepherd 1997).

Figure 2. Average penetrometric profiles (± *SE*) without aeration (light grey) and mechanical aeration with hollow tines at 6 cm of depth and at 12 cm of depth in middle and dark grey respectively , Figures a to d correspond at 6, 21, 40 and 53 days after aeration, respectively.

Statistical analyses of bulk density data show highly significant effects of the treatment, the depth and the date of measurements on soil bulk density (Table 2). The higher density corresponds to the initial state whereas the lowest occurs after mechanical aeration with hollow tines at 12 cm of depth.

Results obtained 6 days after aeration (Fig. 3.a), show that bulk density decreases after the aerator passage for the two treatments. In fact, before aeration, bulk density was 1.7 g/cm^3 at 10 cm of depth. After aeration, it is 1.62 and 1.55 g/cm^3 respectively for treatments 1 and 2. At 20

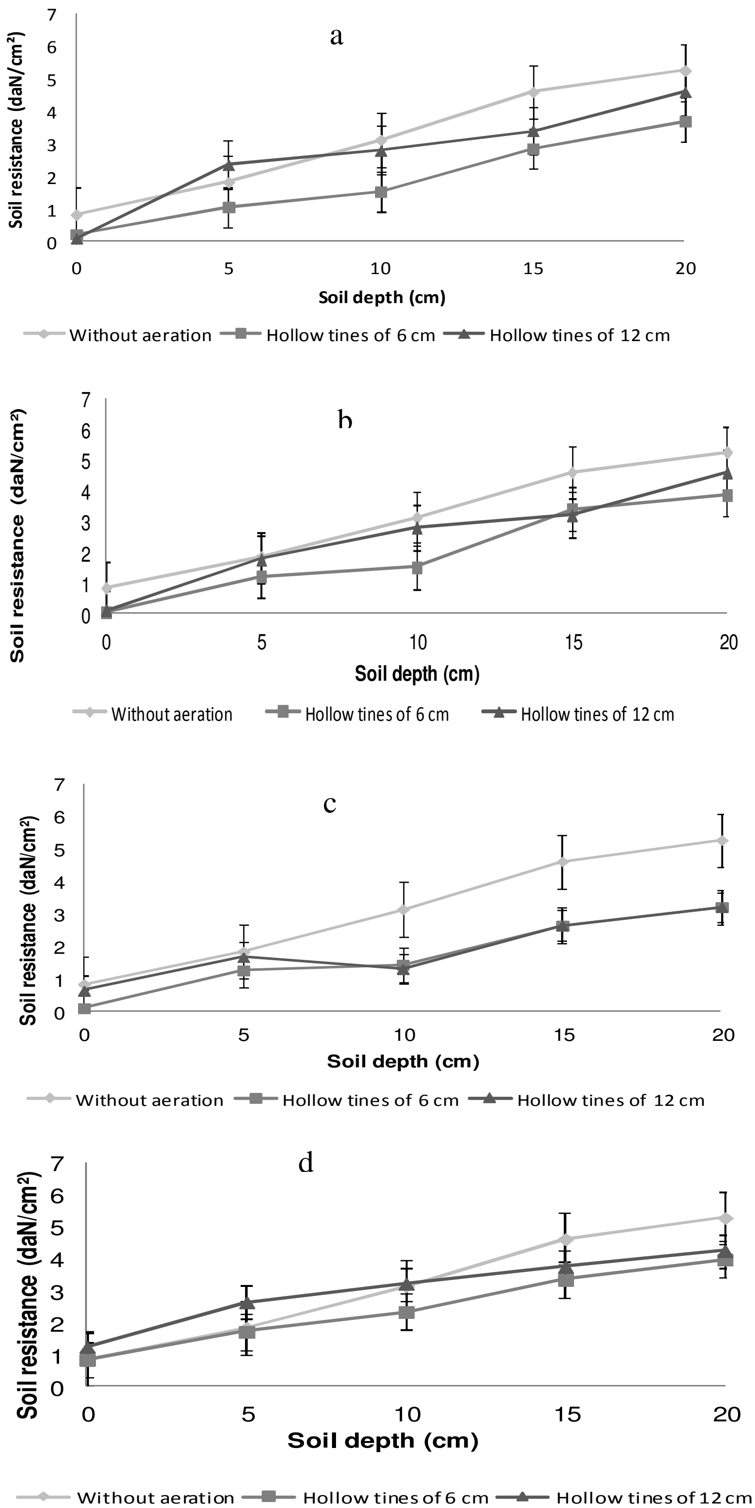

Figure 2: Average penetrometric profiles (± *SE*) without aeration (light grey) and mechanical aeration with hollow tines at 6 cm of depth and at 12 cm of depth in middle and dark grey respectively , Figures a to d correspond at 6, 21, 40 and 53 days after aeration, respectively.

Table 2. ANOVA results for soil bulk density data. Aeration correspond without aeration treatment and mechanical aeration with hollow tines at 6 cm of depth and at 12 cm of depth respectively; Date correspond at 6, 21, 40 and 53 days after aeration, respectively.

Source of variation	D.F.	M.S.
Aeration	2	0.17**
Depth	4	0.32**
Date	3	0.011**
Aeration * Date	6	0.003**
Error	72	0.001

**: significant at the 1% level.

cm of depth and equally 30 cm, the bulk density recorded a decrease compared to the initial state of 5 and 8% for T1 and 9 and 8% for T2.

The higher natural bulk density, above the 1.46 g/cm³ threshold value considered to be restrictive to root development in a fine textured soil, would be expected to reduce fine root development (MacDonald et al., 2004) .

It appears that mechanical aeration of grassy soil causes a decrease of the bulk density in the worked horizons. Mechanical aeration has been used to assist in reversing the adverse effects of soil compaction by loosening soils to greater depth within the profile, usually around 25 cm (Drewry and Paton 2000b). Soil thus undergoes decompaction. However, it should be noted that plots worked at a depth of 12 cm (treatment 2) are better unpacked.

According to figure 3.b, the soil bulk density recorded a decrease, especially at the horizon 10 cm. This is due to the progressive effect of mechanical aeration that occurs over time. Indeed, the bulk density is 1.6 and 1.5 g/cm^3 respectively for the treatments 1 and 2. However, at the depths of 20 and 30 cm, it increases compared to the previous state which could be due to the deep extension of the pressure practiced by tines on the soil.

Examination of the density obtained 40 days after aeration (Fig. 3.c) shows that aeration effect is always present, especially for plots worked at 12 cm of depth (treatment 2) for all considered horizons. Indeed, there was a remarkable decrease in soil bulk density compared to the previous state. This may be due to the aeration effect that occurs over time, even at 40 days after aeration.

However, 53 days after aeration (Figure 3.d), the density for the two treatments recorded an increase in its value. This can be explained by a soil densification caused by the deep extension of the pressure. This is a consequence of the pressure practiced by the passage of maintenance machinery and trampling of players at soil surface.

Figure 3. Soil bulk density (± *se*) of the without aeration treatment (E0) and mechanical aeration with hollow tines at 6 cm of depth and at 12 cm of depth respectively treatments 1 and 2 , according to the depth. Figures a to d correspond at 6, 21, 40 and 53 days after aeration, respectively. Statistical analyses of the longest roots length show highly significant effects of the treatment and the date of measurements (Table 3). The lowest length corresponds to the initial state whereas the higher one corresponds to aeration at 12 cm of depth.

The roots length measured 6 days after aeration, showed an elongation of 0.5 and 1 cm respectively for treatments 1 and 2 compared to the initial state, an increase of respectively 9 and 18%. In addition, measurements performed 21 days after aeration, show a continuous root development which can be explained by the soil loosening provided by the aeration work. Indeed, we record an increase, compared to the initial state, of 27 and 54% respectively for T1 and T2.

However, 40 days after aeration, the average length of roots recorded a reduction compared to previous measurements. It is 0.5 cm for treatment 1 and 0.3 cm for treatment 2. This seems to be related to the recovery of the top soil compaction due to the pressure practiced on the surface. Measurements performed 53 days after aeration, reveal a growth arrest for treatment 1 and a decrease for treatment 2. This can be explained by the soil trend to its original state before aeration (Chehaibi and Abrougui, 2012).

According to Figure 3, we note a considerable correlation between Bulk density and the Root length with a determination coefficient ($R^2 \approx 0.7$) and more the bulk density decreases, the length of the roots increases. However, the same figure showed a poor correlation soil resistance-root length.

Figure 4. A correlation bulk density-root length and soil resistance-root length

It appears that soil compaction has a significant effect on root growth of the plant. Indeed, at initial state the

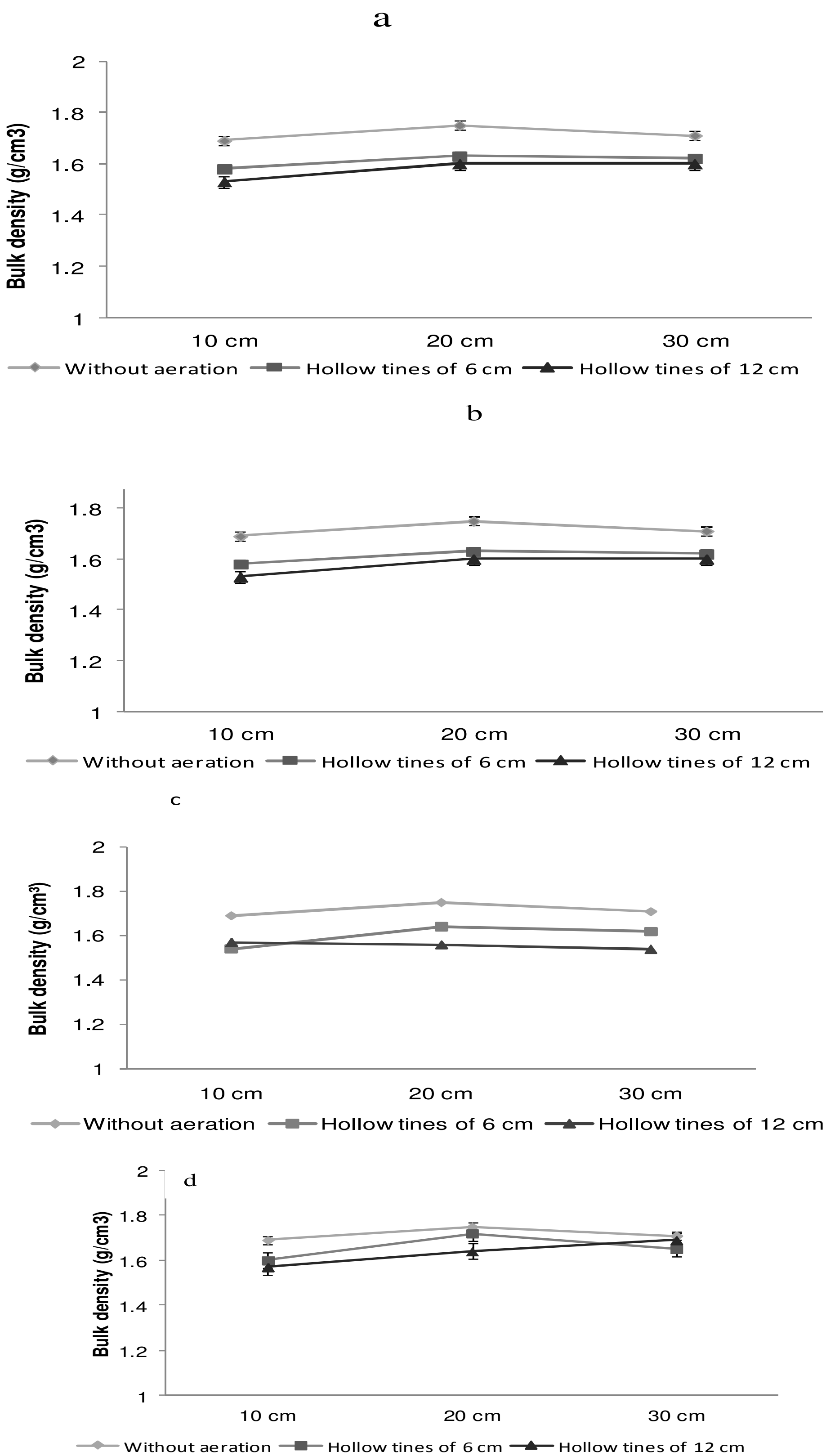

Figure 3. Soil bulk density (± *se*) of the without aeration treatment (E0) and mechanical aeration with hollow tines at 6 cm of depth and at 12 cm of depth respectively treatments 1 and 2 , according to the depth. Figures a to d correspond at 6, 21, 40 and 53 days after aeration, respectively.

Table 3. ANOVA results for the roots length data. Aeration correspond without aeration treatment and mechanical aeration with hollow tines at 6 cm of depth and at 12 cm of depth respectively; Date correspond at 6, 21, 40 and 53 days after aeration, respectively.

Source of variation	D.F.	M.S.
Aeration	2	20.19**
Date	3	3.08**
Aeration * Date	6	0.91**
Error	24	0.145

**: significant at the 1% level.

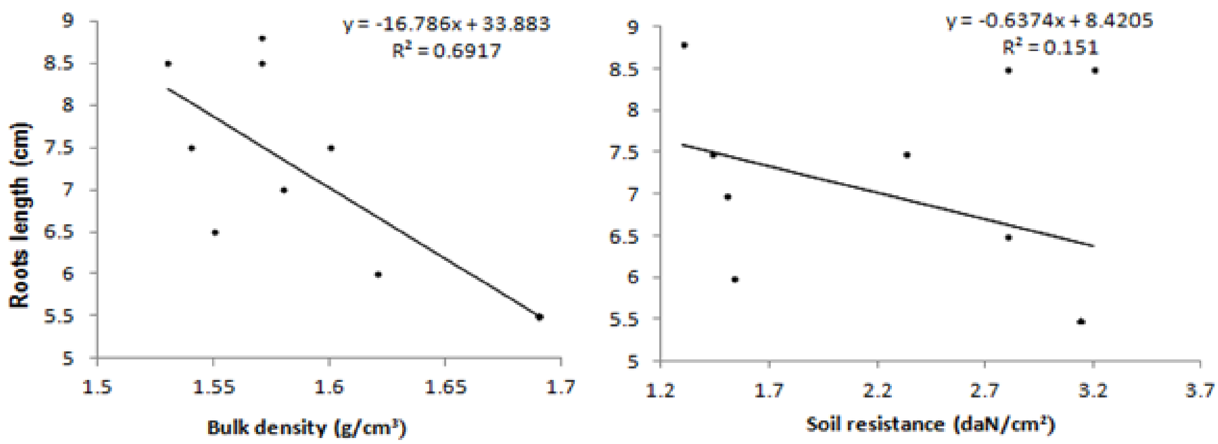

Figure 4: A correlation bulk density-root length and soil resistance-root length

roots are short. These results confirm those of Demissy and Farque (1997) who showed that soil compaction creates pressure on the cell walls, inducing a reduction in root elongation. They are also consistent with those of Giroux et al., (2005), who reported that soil compaction increases its density by compressing essentially larger pores that are responsible for the percolation of water and air. This change causes a reduction of the root system. However, after aeration, soil loosening caused by cores extraction followed by sandblasting, promoted root development in depth. These results are consistent with those of Chehaibi et al., (2012) and Abrougui et al., (2012) who showed that root development of the plant is among the consequences of mechanical aeration of grassy swards.

CONCLUSION

The mechanical aeration of grassy sward by extracting cores, followed by sandblasting, improves soil structure by reducing its resistance to penetration and bulk density. However, it should be noted that this action is limited in time. Indeed, for the two tested working depths, measurements at 6, 21 and 40 days after aeration showed a significant soil decompaction characterized by a decrease of its resistance to penetration and bulk density. However, 53 days after aeration, there was a compaction recovery and soil physical parameters tend to those of the initial state. It thus appears that soil aeration is a transient operation.

The length of the roots present a close link with soil compaction state.

Furthermore, it is important to note that aeration work at 12 cm of depth provided good soil loosening characterized by lower resistance to penetration and bulk density. Therefore, plant roots showed the best development.

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