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Impacts of Conventional Plowing on The Bearing Capacity of Ferralitic Soil in Benin Republic

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ABSTRACT

The present work involved a study of the impact of tillage on soil resistance using a three-body disc plow hitched to a 60 hp tractor, on soil structure. All plowing was carried out on the same day with this plow on 21 plots, divided into 3 blocks of 7 elementary plots serving as treatments. Treatments are designated P0. P1, P2, P4, P8, P12, and P15 corresponding to plowing frequencies: 0, 2, 4, 8, 12, and 15. The P0 treatment is used as a control. The tests were carried out in accordance with the standards: NF P 94-050.1995, for water content by weight, NF EN 1097-3.1998, for apparent density, and NF EN 1097-6.2001 for porosity. Soil conductivity was determined using the Muntz method. The results show that plowing at a minimum frequency of one or two per cycle provides better soil resistance. Two plowings per cycle gave better soil resistance (20.8 (0.27) bc; 19.6 (0.27) d), water content (0.016 (0.002) b ; 0.015 (0.002) b). Soil hardness and density decrease with increasing water content, while porosity increases with plowing frequency (0.437 (0.017) a to 0.478 (0.017) a). For this type of soil, one or two plowings are more than enough to maintain better soil resistance and water conservation. This work has enabled rural actors, and farm machinery operators in particular, to better carry out tillage operations.

Keywords: Agricultural soil, soil tillage, mechanical properties, penetration resistance, Benin Republic.

INTRODUCTION

In certain African areas, spatio-temporal climatic fluctuation is observed today with episodes of alternative and common droughts which lead to a recession of the physical elements of the soil. This painful condition is made worse by the exaggerated use of traditional agricultural cultivation techniques [1]. As a result, inadequate practices in agriculture such as repeated plowing cause a weakening of the levels of organic matter (OM) and water, the density and the bearing capacity of soils which become unproductive and quite precarious to erosion [2]. In view of these difficulties, conservation agriculture is seen as a safe solution against the attacks of shortage and soil destruction [3] and [4]. It is in this context that we must reflect on the effect of motorized plowing on the bearing capacity of the soil compared to no plowing. In many countries like Benin, land degradation phenomena are becoming increasingly widespread. According to estimates from the United Nations Convention to Combat Desertification (UNCCD), from 1981 to 2003, almost a quarter (24%) of the earth's surface was degraded. Nearly 20% of degraded land is arable and 20 to 25% is natural rangeland. Every year, nearly 12 million hectares are lost along with its entire potential to produce 20 million grains [5]. Note also that 78% of degraded soils are found to be in non-arid zones. The UNCCD estimates that land deterioration affects up to two-thirds of productive land in Africa (5). In Benin, 12.57% of the territory's surface area is degraded [[6]].

The main factors responsible for land degradation are erosion, climate change and physical degradation due to pressures such as compaction [[2]]. Indeed, the effects of the use of increasingly heavy machines are caused by the repeated passages of these machines [[8]] and [[9]]. The main causes of these settlements are linked directly or indirectly to the development of mechanization. What justifies the extent of the erosion phenomenon in Africa is undoubtedly the abusive use of equipment, moderate knowledge of agricultural mechanization needs and the machine-soil relationship, the development of the plant being the result of this relationship.

Studies carried out in Moroccan semi-arid zones show that, compared to conventional plowing, direct sowing gives high wheat production [[10]]. Other studies have stated that this cultural action improves soil quality [[11]]. Intensive mechanized work deteriorates the good cohesion of the aggregates and attenuates the structure, while direct sowing ensures a restoration of soil aggregation and increases its structural balance [[12]]. Soil resistance is thus seen as being a consistent informant of soil strength thanks to its function of physical protection of the soil surface, water retention, and structural balance [[13]]

Experiences around the world indicate that this inherent property of soil is influenced by agricultural production practices. Among the approaches to improve the soil, we find tillage reduction systems [[14]]

The present study concerns a ferralitic soil in Beninese agro-ecological zone 5. It is included in a research in order to evaluate the influence mechanized plowing on certain types of soil aimed at soil preservation and conservation. The objective is to determine the effect of tillage on penetration resistance.

MATERIAL AND METHODS

Presentation Of The Study Site

The experiment was carried out in the Sudano-Guinean zone at the Kétou permanent production center. This center is located about 3km from the south of Kétou-center and in the village of Akpangbahou in the district of Kpankou. It is characterized by ferralitic soils; soils on loose clay-sand sediment of the Continental Terminal. It is in fact a seed farm, where basic corn and cotton seeds are produced. The farm under the supervision of the Directorate of AGRIculture (DAGRI) covers approximately 500 ha. The climate is tropical with a bimodal rainfall regime with two nuances: a long rainy season: March to July, a short dry season: August, a short rainy season: September to October and a long dry season: November to February. The annual rainfall average is around 1073 mm in 65 days [[15]]. The two maxima of this regime are centered on June and September. The (fig.1) shows the situation of the Commune of Kétou which houses the study site.

Experimental Protocol

The tests are carried out on a field of 2160 m² in area, delimited and divided into 3 blocks. Each block represents 7 treatments (0 motorized plowing for the control plot designated by P0, 1 plowing for P1, 2 plowings for P2, 4 plowings for P4, 8 plowings for P8, 12 plowings for P12 and 15 plowings for P15). Each block, constituting a repetition, is randomized through these treatments arranged in elementary plots of 40 m² in area each, spaced 3 m apart from each other to allow the passage of the tractor. A successive plowing frequency is carried out in the same day per plot by a 3-disc plow with a working width of 1.20 m coupled to a 60 HP tractor, with a forward speed of 4 km/ h. The plowing depth is 25 cm for each treatment. In total, 21 elementary plots of 40 m² distributed in 3 blocks each containing 7 treatments as illustrated in (fig. 2) below.

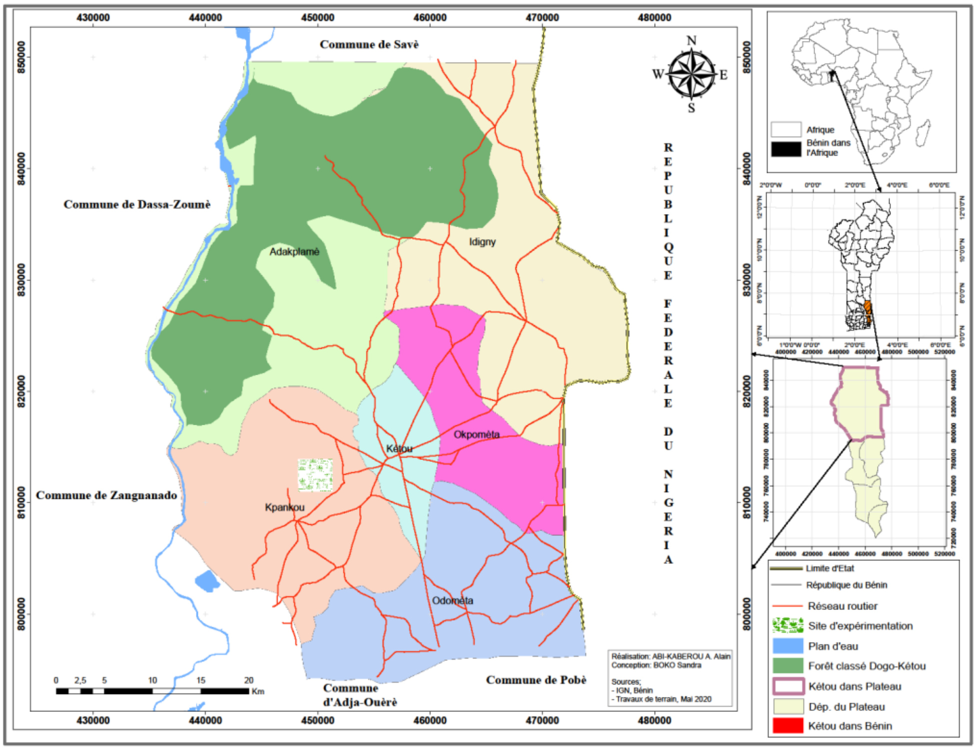

Fig.1: Location map of the Municipality of Kétou

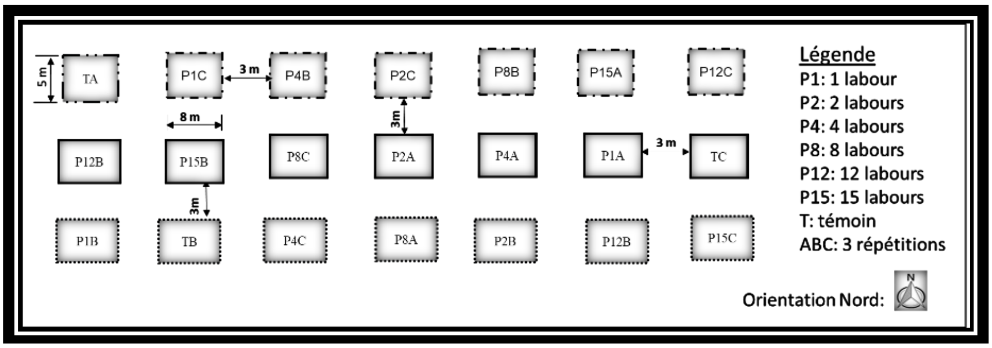

Fig. 2: Complete random block experimental setup

Legend: P0: No plowing/Control plot, P1: 1 plowing; P2: 2 plowings; P4: 4 plowings; P8: 8 plowings; P12: 12 plowings; P15: 15 plowings. A, B, C: Repetitions

Measurements And Analyzes Carried Out

A cultural profile of 1.5m x1m produced following the different stages of [16] is examined to determine the depth of the topsoil. It came back after measurement that the topsoil is 30 cm. Thus the plowing depth retained is 25 cm. The resistance of the ground is determined by the static penetration test with a mechanical point cone. According to the NF EN ISO 22476, 2010 standards. To determine the penetrometric resistance, a static cone soil penetrometer or compactometer: 6120 is used. The surface area of the cone in contact with the ground is 1.7766 cm². Thus three penetrometric resistances were taken on the diagonal of each plot at the plowing depth (25 cm) of the topsoil. The average of its resistance is retained per plot. Concerning the measurement of humidity, real density, apparent density, porosity, a sampling kit of 21 cylinders of 100 cm3 volume and 53 mm diameter was used. Four other parameters, namely: humidity, absolute density, apparent density and porosity were evaluated in the laboratory. A sample was taken from the middle of each plot using the 100 cm^3 cylinder at the time of cotton capsulation and was used for analyzes at the Hydraulics and Water Control Laboratory of the University of Abomey- Calavi.

The absolute density was determined according to standard NF EN 1097-6.

The porosity following the formula of:

$n = 1 - (\gamma s\ /\ ((1 + w)\gamma s),$ (1)

w : water content; γ : *masse volumique en place* ; γs : *masse volumique absolue* ;

Weight water content of materials

Obtained according to standard NF P 94-050.1995, it designates the ratio of water evaporated by steaming to the mass of solid grains:

$w\ (\%) = (Mw * 100/Md,)$ (2)

Where, w denotes the weight water content, Mw- the mass of water and Md- the mass of solid grains.

The apparent dry density was determined according to the standard: NF EN ISO 11272. 2014

Where Ms, designates the apparent dry density, Md- the mass of dry solid grains and V, the apparent volume.

$Mv = Ms/V,$ (**3**)

STATISTICAL ANALYSIS:

The statistical analysis of all measurements taken on the impact of plowing frequency for the different variables was conducted using R software. The analysis was based on the analysis of variance method, followed by the t-test for structuring means. A mixed-effects model was run, including a random block and fixed number of plowings. The influence of plowing frequency for each evaluated parameter was compared using analysis of variance. We conducted Shapiro's normality test to determine whether to use parametric or non-parametric Kruskal-Wallis ANOVA when measurements are not normally distributed. Then, we used the agricultural package by Mendiburu (2019) to organize the means of these properties for different tillage frequencies. Student-Newman-Keuls tests were not necessary. If the data are non-normal, we perform Kruskal-Wallis structuring (Schumacker et al., 2013). Hypothesis validation relies on the confidence interval (CI) for the IC, using a fixed α level of 0.05 as the first type error risk.

3. RESULTS

The results are presented for each characterization parameter, after highlighting the validation of their statistical data. The results of the linear mixed effects model measuring the importance of the impact of plowing on soil strength, soil density, volumetric water content and soil porosity were summarized in the following Table 1. The statistical results of analyzes of variance of the parameters studied as a function of plowing frequency are illustrated in Table 1. According to Table 1, it results from the significance test of soil resistance by treatment that this parameter varies significantly depending on the frequency of plowing at the 5% threshold. The intra-class correlation (Icc) linked to the random effect of the block gave 37.625%; justifying the low effect of the blocks on the resistance of the soil for each of the treatments. The tests carried out on the different treatments are validated, therefore the soil resistance values are acceptable. The coefficient of determination R^2 of the model produced gave 84% with significant results at 95%. It is noted that the results of soil resistance from P0 (no-till) and P1 on the one hand, and those from P2 to P15 on the other hand, differ statistically. We thus deduce that the frequency of plowing has a clear influence on the resistance of the soil. This is demonstrated by the mean values and standard errors of soil resistance followed by the letters a, b, c, d, e designating the classes of values according to plowing frequencies. In addition, it results from the analysis of variance test of the density by treatments that the latter does not vary significantly according to the frequency of plowing at the threshold of 5% (df=6, $P=1^{ns}$). In addition, the threshold of the intra-class correlation due to the random effect of the block is 41.38%; which means that the block has a weak effect on the variation in soil density by treatment. We conclude that the large difference between treatments is not linked to

the block (df=2 and P=1^{ns}). In addition, the coefficient of determination R^2 of the model produced gave 86% with significant results at 95%. According to the analysis of variance, the significance test is not validated; therefore, the densities of the different treatments are due to the technical itineraries adopted before the capsular massage phase. It is noted from the mean values and standard errors of the density as a function of the plowing frequency that those of P0, P1 and P2, P4 up to P15 do not differ statistically. Following the results of the significance test of porosity by treatment, we note that it does not
vary significantly depending on the number of plowings 0, 1, 2, 4, 8, 12 and 15 at the 5% threshold. In addition, the proportion of the intra-class correlation due to the random effect of the block is 41% according to the R software; which reflects that the block has a weak effect on the variation in plowing frequency by treatment. We conclude that the large difference between treatments is not related to the block. Thus, this table 1 reveals that the statistical tests of variance analyzes of soil porosity as a function of plowing frequency carried out on the different treatments are validated. In addition, the determination coefficient R^2 of the model produced gave 87% and also statistically, the results are significant at 95%; thus 87% of the data between plowing treatments are explained by porosity with a precision of 95%. From all of the above, it appears that the porosity parameters are acceptable and that the porosity results of P0 and P1 are statistically different. Concerning the significance test of the water content by treatment, we note that it varies significantly depending on the frequency of plowing at the 5% threshold. The intra-class correlation (Icc) linked to the random effect of the block gave 0%; justifying the effect of the blocks on the water content for each of the treatments. The tests carried out on the different treatments are validated, therefore the water content values are acceptable. The determination coefficient R^2 of the model produced gave 54% with significant results at 95%. It is noted that the results of the water content of P0 (no-tillage) and P1 on the one hand, and those of P2 up to P15 on the other hand, differ statistically. We thus deduce that the frequency of plowing has a clear influence on the water content.

Table 1: Results of variance analyzes of the parameters studied according to treatments and blocks

Frequencies plowing	Properties	Mean (SD)	F-value (DF=6)	Prob
P0	Soil resistance (%)	20.9 (0.27) a		0.001
P1		20.8 (0.27) bc		
P2		19.6 (0.27) d		
P4		19.5 (0.27) cd		
P8		18.9 (0.27) b		
P12		18.2 (0.27) b		
P15		17.1 (0.27) e		
P0	Soil density (%)	1.50 (0.046) a		1
P1		1.45 (0.046) a		
P2		1.44 (0.046) a		
P4		1.44 (0.046) a		
P8		1.44 (0.046) a		
P12		1.40 (0.046) a		
P15		1.40 (0.046) a		
P0	Soil porosity (%)	0.437 (0.017) a		1
P1		0.459 (0.017) a		
P2		0.459 (0.017) a		
P4		0.461 (0.017) a		
P8		0.462 (0.017) a		
P12		0.477 (0.017) a		
P15		0.478 (0.017) a		
P0	Volumetric water content (%)	0.012 (0.002) a		0.005
P1		0.016 (0.002) b		
P2		0.015 (0.002) b		
P4		0.013 (0.002) a		
P8		0.013 (0.002) a		
P12		0.011 (0.002) a		
P15		0.010 (0.002) a		

3.1. Influence Of Motorized Plowing Frequency On Soil Resistance

Conducted according to the NF EN ISO 22476 standard, the soil resistance as a function of plowing frequency is presented in (fig. 3) opposite. We note that the resistance of the soil is inversely proportional to plowing. In fact, the bearing capacity of the soil is greater with manual plowing; it thus shows that the floor is very resistant. On the other hand, from P1 to P15, this decreases due to the repeated mixing of the tool with the soil creating its loosening and fragmentation of the soil. Hence the observation of more fine particles and a falling lift.

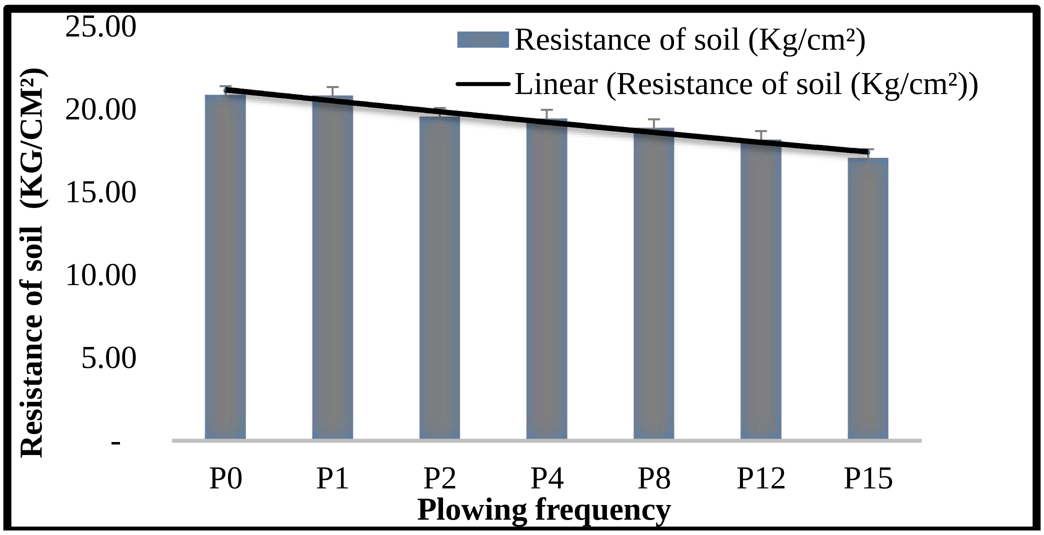

Fig. 3: Influence of plowing frequency on soil resistance

3.2. Impact Of Motorized Plowing Frequency On Soil Density

It can be seen that the apparent density is inversely proportional to the plowing frequency.

We thus deduce that the number of plowings has a slight influence on the density of the soil compensated with the powders. The apparent density values obtained made it possible to trace the curve illustrated in (fig. 4).

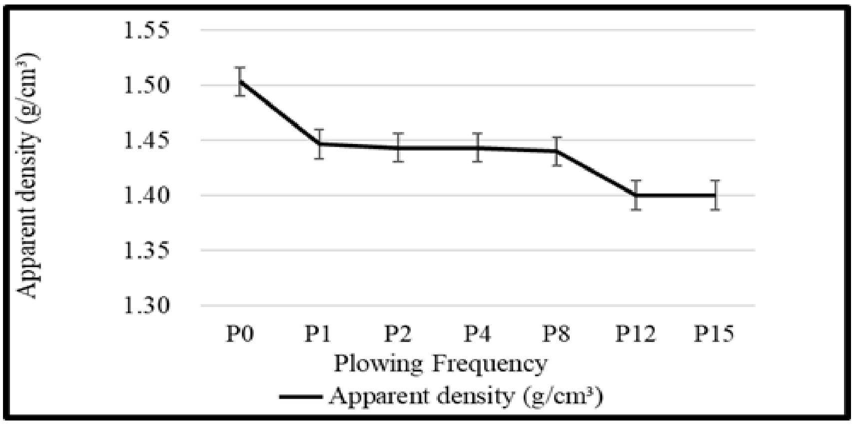

Fig. 4: Apparent density as a function of plowing frequency

3.3. Effects Of Motorized Plowing Frequency On Soil Porosity

Fig.5 below shows the variation in porosity depending on plowing. Porosity increases with plowing frequency.

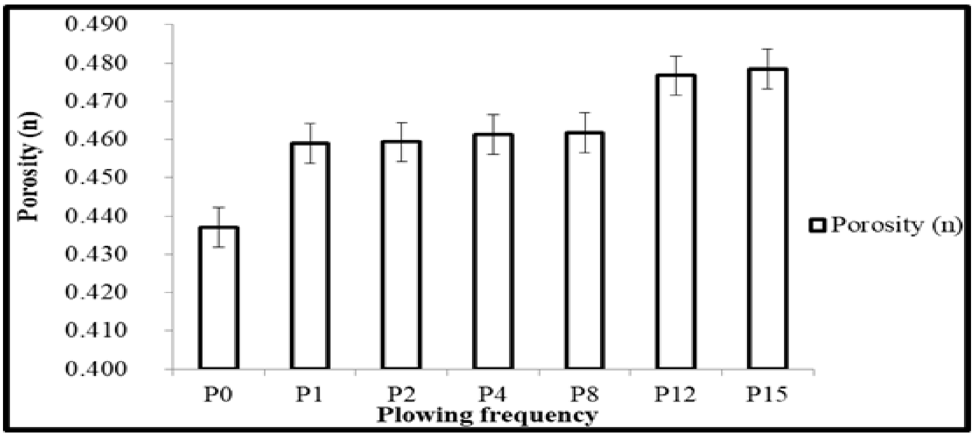

Fig.5: Porosity as a function of plowing frequency

3.4. Impact Of Motorized Plowing Frequency On Water Content

The water content values obtained made it possible to draw the curve illustrated in (fig.6) below. We see through this (fig. 6) that the water content is generally inversely proportional to the number of plowings.

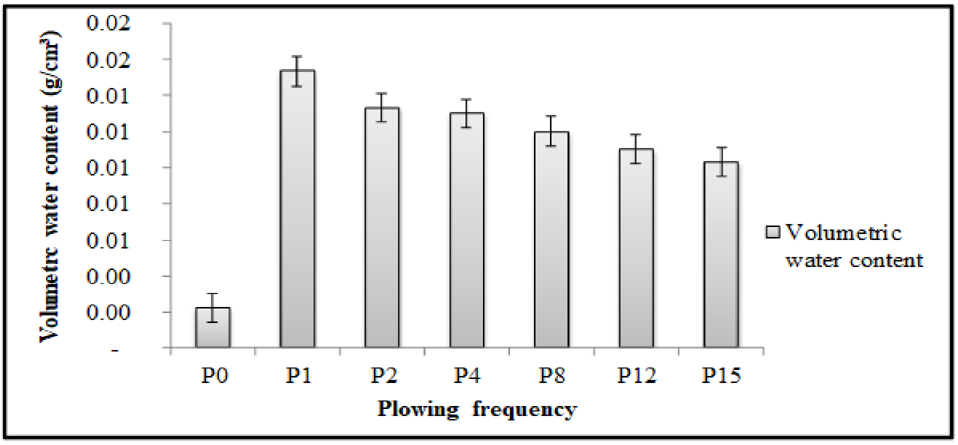

Fig.6: Volumetric water content as a function of plowing frequencies

3.5. Relationship Between Soil Resistance And Water Content Depending On Plowing Frequency

We note that the resistance of the soil is proportional to the volumetric water content with the frequency of plowing (fig.7). Both parameters decrease with plowing frequency; while the water content is low when the soil bearing capacity is high on the no-till control plots.

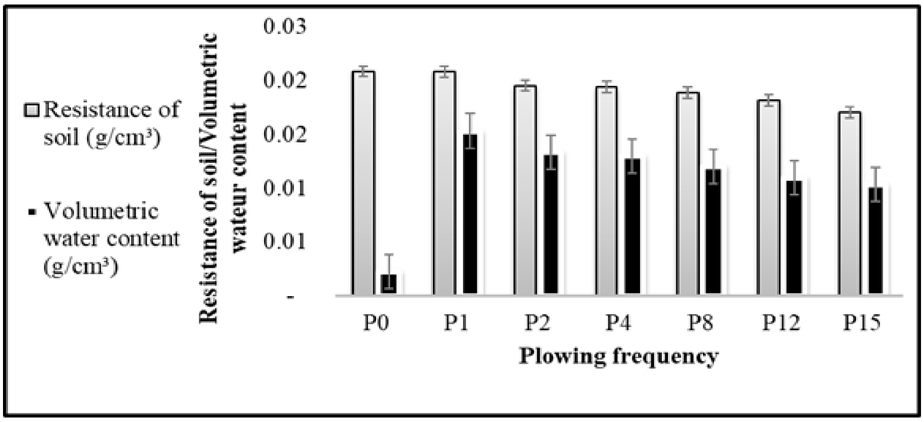

Fig.7: Comparative evolution of penetrometric resistance with water content as a function of plowing frequency

4. DISCUSSION

4.1. Effects Of Plowing Frequency On Soil Bearing Capacity And Density

The bearing capacity of the soil at penetration is a parameter which provides information on the load-bearing capacity of the soil and the ease with which the roots will make their way into the soil. Soils that offer better resistance are in good physical conditions offering plant roots and the extent of soil fauna a pleasant living environment and enough air for their respiration [17]. Repeated plowing disrupts the structural stability of the soil with plant roots by reducing their resistance or compactness forces (fig. 3). According to this author, through the perception of the farmers surveyed, revealed that the current community is far from the fertile life of intact soil; and only correct control of the soil could ensure a humanity with sufficient food in the long term. Repeated plowing is the source of disruption of the equalization and balance of the soil and the source of deep settlement. Repeated tillage results in severe fragmentation of the grains resulting in a multitude of fine particles making the soil less resistant (fig.3 and 4). [18] having studied the impact of the working parts of the tools on the behavior of the penetrometric resistance revealed that it is very influenced by the water content parameter of the soil. Resistance to soil penetration is one of the common indicators of soil physical properties in agronomic evaluation [19]. Several studies have shown the capabilities that penetrometers have to spatially distinguish variations in mechanical properties in soils [20]. Soil resistance strongly depends on its volume, density, texture, structure and organic matter components [21]. It should be noted that for soil, settlement can change significantly in space depending on land use (fig. 3 and 4). In the case of the present study, its reduction in the face of repeated plowing is a fundamental cause of the drop in volumetric water content (fig. 6) and increase in porosity (fig.5).

According to [10], The apparent density of the soil tells us about the porosity of the soil which constitutes a major characteristic controlling the hydrodynamic properties of the soil and the root development of plants. It also constitutes an indicator of soil quality which varies with the cultivation techniques adopted (fig. 4). It increases when soils are compacted, which affects their quality and reduces porosity. The accumulation of organic matter on the surface layers, particularly depending on the type of crop rotation, contributes to the improvement of the physical properties of the soil, in particular the apparent density to give better porosity. Several studies carried out in particular in the semi-arid conditions of Morocco have shown that no-till improves the physical and chemical properties of the soil compared to conventional [22].

4.2. Effects Of Plowing Frequency On Soil Density, Porosity And Water Content

Conventional plowing influences the physical parameters of the soil (Figs 4, 5, 6,7). Soil density and water content decrease with plowing frequency while porosity increases. These results are underlined by other authors who have proven that water is better conserved with reduced tillage (manual or minimum). Constantly repeated plowing provides soil aeration through grain fragmentation which exposes the soil causing rapid evaporation of water [23]. A strong modification of the soil therefore favors the acceleration of evaporation of the drying time of the surface and maintains a significant porosity of the soil associated with a reduction of water. This dropped water content (fig. 6) leads to high porosity (fig. 5) of which air is important and a reduction in the density of the soil (fig. 4). Indeed, the increase in porosity (decrease in apparent density) under plowing in the worked layers is due to the action of turning and fragmentation of the soil by the plow [24]. However, no significant differences in bulk density, porosity and water content were noted with plowing frequency.

The available soil water content represents the maximum amount of water that a soil can hold and that is directly usable by plants. The higher this value, the more plants will be able to withstand long conditions of water stress [25]. Several factors influence available soil water content, particularly soil texture and structure, etc. [26] Repeated plowing of the soil therefore influences this water retention capacity in the soil since it acts on the level of organic matter in the soil [27-28] and the apparent density of the soil. Generally, when the density of the soil is low, the greater the water retention capacity of the soil [29-30] ; but for the soil worked a certain number of times, being exposed to solar radiation, the water experienced evaporation followed by rapid mineralization of the humus in the soil.

Porosity provides information on the water or atmospheric capacities of a soil, in volume or flow. Indeed, direct seeding techniques are characterized by an absence of soil disturbance, and the presence of soil cover which makes it possible to limit the evaporation of water following the limitation of capillary rise. This allows for better water conservation by limiting the effect of abiotic factors, namely high temperatures and winds [10]. Direct sowing helps maintain soil fertility and fight against erosion.

5. CONCLUSION

The results of this article clearly explain the influence of tillage with a disc plow on the bearing capacity, density, porosity and water content of the soil. They confirm that water acts on the physical behavior of the soil in relation to other parameters under the influence of the plowing tool used. The choice of tool therefore has an effect on the soil and consequently on the roots which provide nutrients to the plants. The lift of the ground makes it possible to estimate the pressure, the force of resistance that the ground opposes and is strongly linked to water. Soil strength and density decrease with water content while porosity increases with plowing frequency. For this type of soil, 1 or 2 plowings are more than enough to maintain better soil resistance and good water conservation. A study on the effect of motorized plowing speed on soil resistance will provide more precision.

Declaration by Authors

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