Original Research Article

Effects of the speed of mechanical tillage progression on iron soil structure

Running tittle:speed of mechanized tillage

ABSTRACT

The present work is to evaluate the effects of the plowing speed of three-body plows/discs attached to a 60 HP tractor, on ferrous soil structure and to determine the optimum rate in the Benin Plateau, from 2019-2021. All tillage was done on the same day on 21 plots, divided into 3 blocks of 7 initial actions. The processors are; V0, V1, V2, V3, V4, V5 and V6, i.e. 2, 4, 6, 8, 10 and 12 km/h. V0 watched. The tests are carried out according to the standards: NF EN ISO 17892-4.2018, for particle size analysis, NF EN ISO 17892.2018, for Atterberg limits, NF P 94-050.1995, for water content by weight, NF XP P 94 -047.1998 for organic matter modifier NF EN 1097-3.1998 for density phenomenon. Soil conductivity is determined by the Muntz method (double loops). The results show that plowing at an average speed (6 km/h) generates better content of water and organic matter which are respectively 5.04 ± 0.76% and 0.304 ± 0.004% for the plow then (6.47 ± 0.35%; 0.324 ± 0.012%) for the disc plow. The high content of water and organic matter generated by an average speed of 6 km/h should limit the risk of embrittlement while ensuring a conservative tendency to fertility. This work will allow operators of agricultural tractors to better perform iron tillage operations while observing the optimum speed of plowing without severe damage to the soil structure, which is a guarantee of sustainable development in agriculture.

***Keywords*:** Tillage, Struct-studies, Agriculture, Technical, Mechanical.

1. INTRODUCTION

Agriculture is significant in Benin due to its interdependencies with food, income production, education, health, and nutrition **(RNDG, 2015)**. Indeed, agriculture in Benin accounts for more than fifty percent of Gross Domestic Product (GDP), contributes eighty percent to the value of commerce, and gives more than fifty percent of raw materials to industry **(FAO, 2016)**. Therefore, agricultural production methods must be strengthened to feed the expanding global population. Therefore, the intensification of these systems entails a number of activities, including the introduction and use of agricultural machinery or equipment in order to satisfy the requirements of the world's population, therefore agricultural mechanization. This agricultural mechanization encompasses the use of tools and machinery for land reclamation, production, and post-harvest practices, powered by human, animal, or chemical internal combustion engines. It is a crucial agricultural product in sub-Saharan Africa with the potential to alter the lives and economic situations of millions of rural households **(FAO, 2019)** and enables farmers to earn a higher income **(Pussemier*et al*., 2017)**. In accordance with this reasoning, the Ministry of Agriculture has developed a strategic plan to revitalize the agricultural sector in order to transform Benin into an agricultural superpower and tackle food insecurity **(MAEP, 2019)**. This approach aims to increase production by mechanizing production variables, in particular the soil, which serves as the foundation for plant development. Because a well-structured soil permits plentiful root development and provides ample aeration, it is optimal for plant growth **(Feddal, 2011)**. Indeed, tilling results in erosion, compaction, loss of organic matter, and restriction of water circulation**(Köller, 2003; Lal *et al*., 2007)**. It influences the biotic and abiotic elements of the soil, either directly by influencing the structural qualities of the soil, such as the arrangement of voids, aggregates, and the connectedness of the pores, or indirectly by modifying the soil's aeration, temperature, and permeability. Soil up to the roots **(Huwe, 2003)**. However, the farmer seeks ideal soil preparation that fulfils the needs of his crop often. According to **(Chehaibi*et al*., 2002)**, tillage may be maximized by selecting the appropriate width of the plow and forward speed. This last component is frequently overlooked while conducting cultural operations. According to **(Chehaibi*et al*., 2008)**, the pace of plowing has a significant effect on the soil's physical properties. Slow-speed tillage (2 km/h) produces a more structured volume of soil with a deeper depth of labour, resulting in a higher crop yield **(Chehaibi*et al*., 2008)**. It has also been demonstrated **(Damien, 2017)** that plowing at too high a pace (more than 10 km/h) can result in the placement of debris on top of the plow strips, so preventing the seeds from being buried deeply. Weeds. According to **(Seine *et al*., 2013)**, plowing at a speed of 4-5 km/h on loamy soil is advised in order to better preserve the structure of the plowing's heart. This demonstrates that the pace of plowing effects the soil structure. However, little research has been conducted on the optimal plowing speed for enhancing soil structure, germination, and crop production. The purpose of this study is to determine the influence of plowing speed on soil structure. It entails analysing the impacts of plowing speed on the physical characteristics of the soil, including grain size, water content, organic matter content, bulk density, porosity, and permeability. To achieve these varied goals, an experimental method was taken: the installation and description of the soil profile, the selection of the plowing depth, the selection of the various speeds, the selection of the experimental instrument, and the measurement of the soil's physical properties.

2.1. MATERIALS AND METHOD

2.1.1. Presentation of the study site

The study site **(Fig. 1)** is located in the Sudano-Guinean zone, towards the northern end of the Benin Plateau between latitudes 7°10 and 7°41' 17" North on the one hand and longitudes 2°24' 24" and 2°47'40" East on the other hand **(IGN, 2020)**.

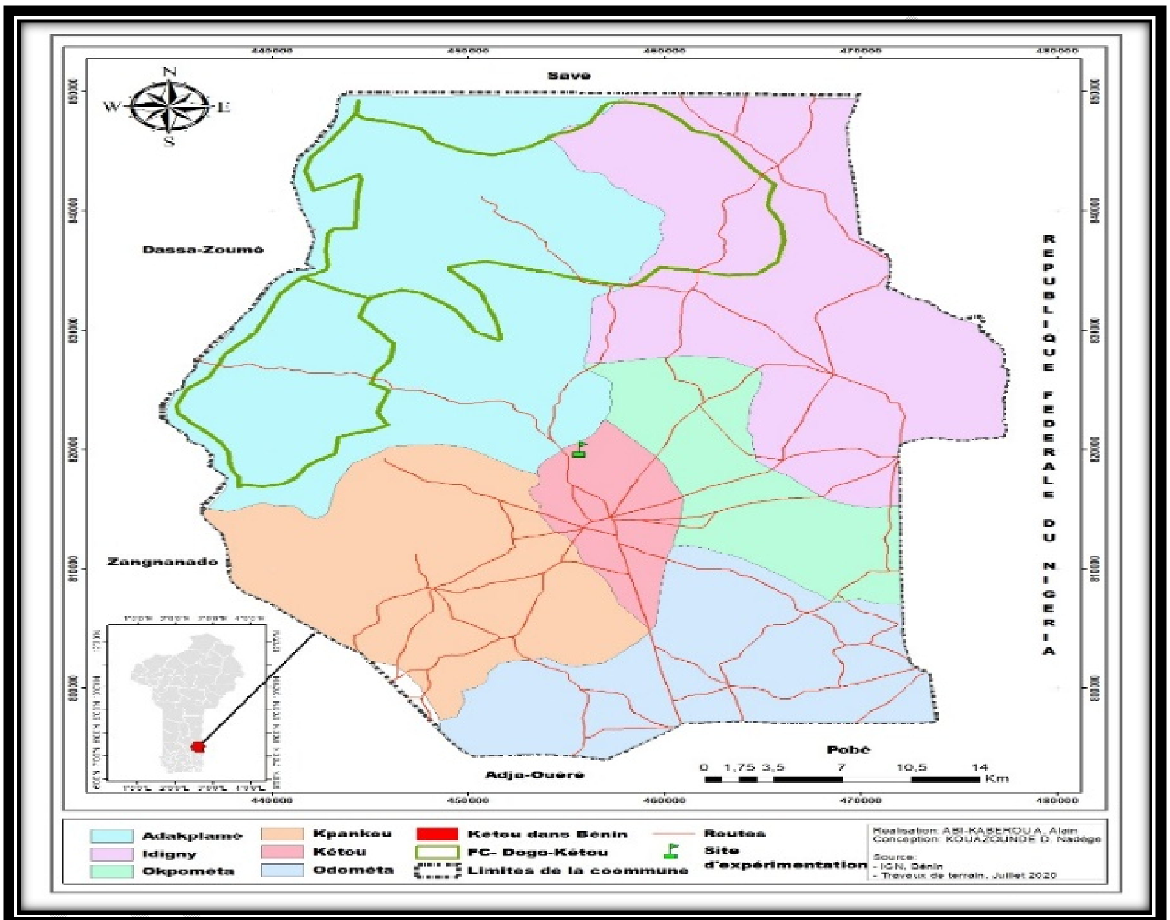

Fig. 1: Geographic location of the study site

Source: IGN2020 (**National Institute of Geographic and Forest Information), Benin Plateau**

2.1.2. Description of the experimental protocol

The adopted experimental protocol is a complete random block with total randomization with 2 factors, random factor which is the block and fixed factor which is the speed of plowing. In this study, the main plot is (2124 m²) in area, inside this plot we have three blocks separated by (3 m) alleys to allow the passage of the tractor. Each block each contains seven elementary plots of (40 m²) in area separated by (3 m) alleys to allow the passage of the tractor. The **Fig. 2** below illustrates the experimental device adopted. Plowing is carried out with a 3-body ploughshare plow with a working width of (1.20m), hitched to a 60 HP agricultural tractor.

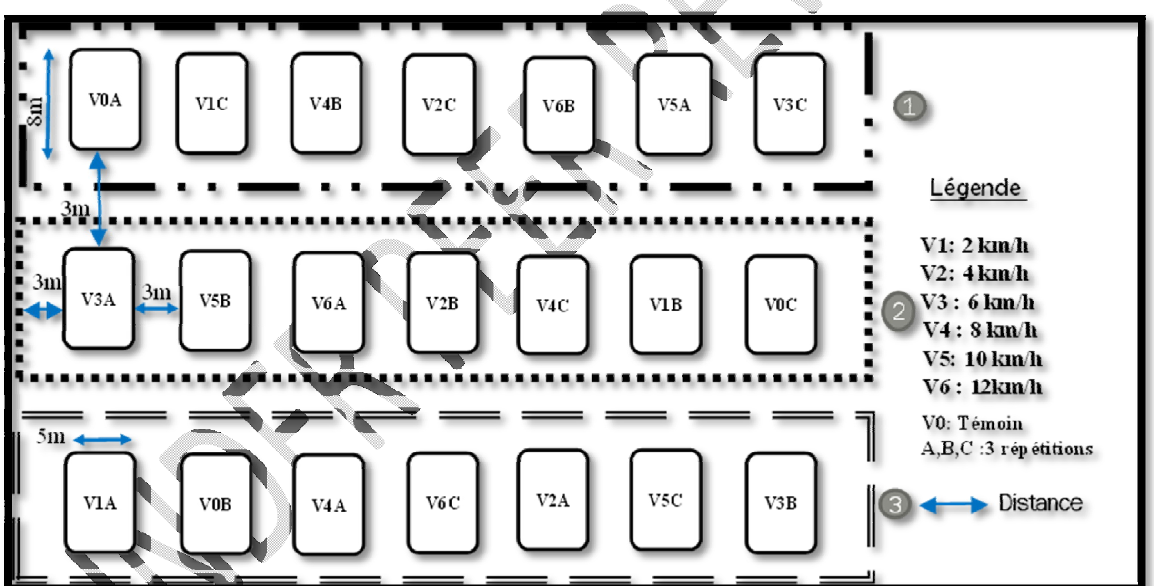

Figure 2: Diagram of the experimental device of the test: Complete random block (BAC)

Legend : V1 - Speed 2Km/h, V2 - Speed 4km/h, V3 - Speed 6km/h, V4 - Speed 8km/h, V5 - Speed 10km/h, V6 - Speed 12km/h, V0 - No speed, A, B, C - Repetition of treatments.

2.1.3. Sample Collection Methods

The cultural profile was analysed from the wall of a hole using the procedures of **(Delaunois, 2008)**. The cultural profile of (1.5 m wide, 2.0 long and 1.0 m deep) was installed to measure the depth of the topsoil. The observed topsoil depth is (25 cm), hence the retained plowing depth is (20 cm). Regarding the soil analysis tests (particle size analysis, Atterberg limits, and organic matter), reworked soil samples are collected using a manual auger at three sites along the diagonal of each plot, beginning at the ends and ending in the middle. These per-plot samples are combined in order to create representative samples per plot and subsequently per treatment. For the water content and bulk density measurements, samples are manually coring using a metal cylinder with a 100 mm diameter, 10 cm height, and a 20 cm depth. In addition, the two orifices of the cylinders are hermetically sealed to preserve the soil's humidity and density until the time of laboratory analysis.

Measurements made at ground level

- ***Particle size analyzes***

It was carried out up to (80 µm) by sieving the material by dry process (for large grains) or by wet process (for materials containing particles less than 0.063 mm) according to standard NF EN ISO 17892-4.2018.

- ***Atterberg limits***

The Atterberg limits conventionally translate the differences in behaviour of a soil according to its water content. They apply to the soil, the elements of which pass through a (400 µm) mesh sieve according to standard NF EN ISO 17892.2018. The Atterberg limits are determined using the plasticity index Ip which measures the range of water content in which the soil is found in the plastic state. It is determined by the following expression:

$$Ip = wl - wp \quad \textbf{(1)}$$

- *wl* represents the liquidity limit; - *wp*represents the plastic limit

- **Water content by weight (w)**

It represents the ratio of the mass of water evaporated during steaming (Mw) to the mass of solid grains (Md), obtained according to standard NF P 94-050.1995. The mass of solid grains is obtained after 4 hours of drying in the oven at (105°C). The water content by weight is expressed as a percentage and is determined by the following formula:

$W=Mw/Md*100$ **(2)** *W*: the water content by weight; Mw: mass of water; *Md*: the mass of solid grains.

- ***Organic matter content (OM)***

The test is carried out on particles with a diameter of less than (0.400 mm) according to standard NF XP P 94-047.1998. It is carried out using equipment consisting of a graduated cylinder, a tare, a Biomax solution, a stirrer, an oven and an electronic balance. The MO content is expressed as a percentage and is determined by the following formula:

$$MO = (Mi-MF)/Mi*100 \quad \textbf{(3)}$$

MO: Organic Matter; Mi: Initial mass before parboiling; *Mf*: Final mass after parboiling.

- ***Soil Bulk Density***

It is determined according to standard NF EN 1097-3.1998.

The formula for determining the bulk density of soil is given by the expression below:

$$Da = (P2\text{-}P1)/V \quad \textbf{(4)}$$

- *P2*: is the total weight of the sample; - *P1*: is the weight of the empty box; - *V*: is the volume of the box.

- ***Soil porosity***

It is conducted according to standard NF EN 1097-6.2001 and is determined by the following formula:

$$Porosity = 1-[[da]/((1+w)*ys)] \quad \textbf{(5)}$$

With

da: apparent density; *w*: water content; *Ys*: actual density.

- ***Soil hydraulic conductivity***

The test consists of evaluating the evolution of vertical infiltration of a sheet of water under constant load into the ground over time. It is based on the müntz method principle **(Colombani*et al.*, 1972)**, commonly known as double müntz rings. It is derived using the formula:

$$Ks = Hi/tc \quad \textbf{(6)}$$

where*Hi* is the depth of infiltrated water and *Tc*, the cumulative duration.

2.1.4. Statistical analysis and data processing

All the statistical analyzes were carried out with the R software **(R Core Team, 2019)** and the level of significance of the statistical tests was set at 5%. First, we performed the correlation test between the physical properties of the soil in order to see the relationship between them. The analysis of variance made it possible to compare the influence of the plowing speed for each parameter evaluated. As for the other physical properties of the soil, the Kruskal-Wlalis comparison test was used. We performed Shapiro's normality test to decide whether to use parametric or nonparametric

KruskalWalis analysis of variance when measurements are not normally distributed. The Student-Newman-Keuls tests were then carried out with the agricultural package from **(Mendiburu, 2019)** in order to structure the averages of these properties for the different plowing speeds. In case of non-normality, the structuring of KruskalWalis is carried out.

3. RESULTS

The results of the normality tests showed that only the data for water content (coulters and discs), porosity and organic matter discs are normally distributed. According to **Table 1**, the plowing speed significantly influences these aforementioned parameters ($P < 0.05$).

Table 1: Results of the analysis of variance.SD - standarderror, DF - degree of freedom, Prob - probability, the averagesfollowed by the same letters are not different by only 5%.

Speed (km/h)	Property	Mean (SD)	F-value (DF=6)	prob
0	Water content Socs (%)	5.23 (0.93)a	5.811	0.003
2		2.57 (0.46)b		
4		3.45 (0.12)ab		
6		5.04 (0.76)a		
8		4.89 (0.63)a		
10		4.54 (1.07)a		
12		4.16 (0.38)a		
0	Water content Discs (%)	5.05 (3.92)a	1.25	0.005
2		5.85 (4.72)a		
4		5.26 (4.14)a		
6		6.47 (5.35)a		
8		4.89 (3.77)a		
10		5.04 (3.92)a		
12		4.97 (3.84)a		
0	Soil porosity Discs (%)	0.458 (0.45)a	2.51	0.003
2		0.438 (0.43)a		
4		0.439 (0.43)a		
6		0.442 (0.43)a		
8		0.449 (0.44)a		
10		0.436 (0.42)a		
12		0.433 (0.42)a		

0	Organic Matter Discs (%)	0.437 (0.012)a	1.57	0.009
2		0.274 (0.012)a		
4		0.312 (0.012)a		
6		0.324 (0.012)a		
8		0.312 (0.012)a		
10		0.299 (0.012)a		
12		0.274 (0.012)a		

As shown in **Table 2**, the results of the Kruskall Wallis tests indicate that, for the soil plowed with these tools, negative correlation indicates that plowing at high speeds results in low levels of organic matter and reduced soil densities, whereas positive correlation indicates that plowing at high speeds results in the lowest plasticity indices and low levels of organic matter. Thus, via positive association, slow plowing yields the lowest indices of plasticity and organic matter for soils plowed with discs that have a high density; the soil plowed with ploughshares is rich in organic matter, has a low density, and a high plasticity index. However, 6 km/h provides the greatest results for water content, organic matter, indices, densities, and average porosity. In contrast to other speeds, six kilometres per hour defines the optimal physical ground conditions that result in superior performance.

Table 2: Kruskall Wallis test results. SD - standard error, χ^2- Chi-square statistic, DF - degree of freedom, Prob - probability, the averagesfollowed by the same letters are not different by only 5%.

Speed (km/h)	**Property**	**Mean (SD)**	**χ^2(DF=6)**	**prob**	**Speed (km/h)**	**Property**	**Mean (SD)**	**χ^2(DF=6)**	**prob**
0	Organic matters Shares (%)	0.304 (0.004)a	17.09	0.008	**0**	Soil porosity (%)	0.458 (0.012)a	8.79	0.190
2		0.207 (0.003)ab			**2**		0.438 (0.006)a		
4		0.305 (0.002)a			**4**		0.439 (0.006)a		
6		0.304 (0.004)a			**6**		0.442 (0.009)a		
8		0.103 (0.003)b			**8**		0.449 (0.016)a		

10		0.105 (0.003)b			**10**		0.436 (0.006)a		
12		0.106 (0.003)b			**12**		0.433 (0.004)a		
0		1.346 (0.002)d			**0**		9.505 (0.003)ab		
2		1.385 (0.005)bc			**2**		10.007 (0.003)a		
4		1.383 (0.003)c			**4**		9.007 (0.002)c		
6	Soil density(%)	1.357 (0.002) cds	18.74	0.004	**6**	Plasticity index(%)	10.003 (0.002)a	18.22	0.005
8		1.395 (0.005)a			**8**		9.004 (0.004)c		
10		1.394 (0.002)ab			**10**		9.006 (0.003)c		
12		1.354 (0.004)d			**12**		9.001 (0.000)c		
0		1.405 (0.002)ab			**0**		10.1 (0.000)a		
2		1.407 (0.001)a			**2**		9.1 (0.000)d		
4		1.398 (0.003)c			**4**		9.0 (0.000)e		
6	Disc soil density (%)	1.395 (0.001) cds	178.15	0.001	**6**	Disc plasticity index (%)	9.2 (0.000)c	3.21	0.001
8		1.385 (0.001)e			**8**		9.3 (0.000)b		
10		1.394 (0.003)d			**10**		9.3 (0.000)b		
12		1.403 (0.0001)b			**12**		9.0 (0.000)e		

3.1. Particle size analysis

The **(Fig. 3)** below illustrates the plotted particle size analysis curves. It presents the percentage of passers-by as a function of the different sieve meshes at different plowing speeds with a ploughshare plow.

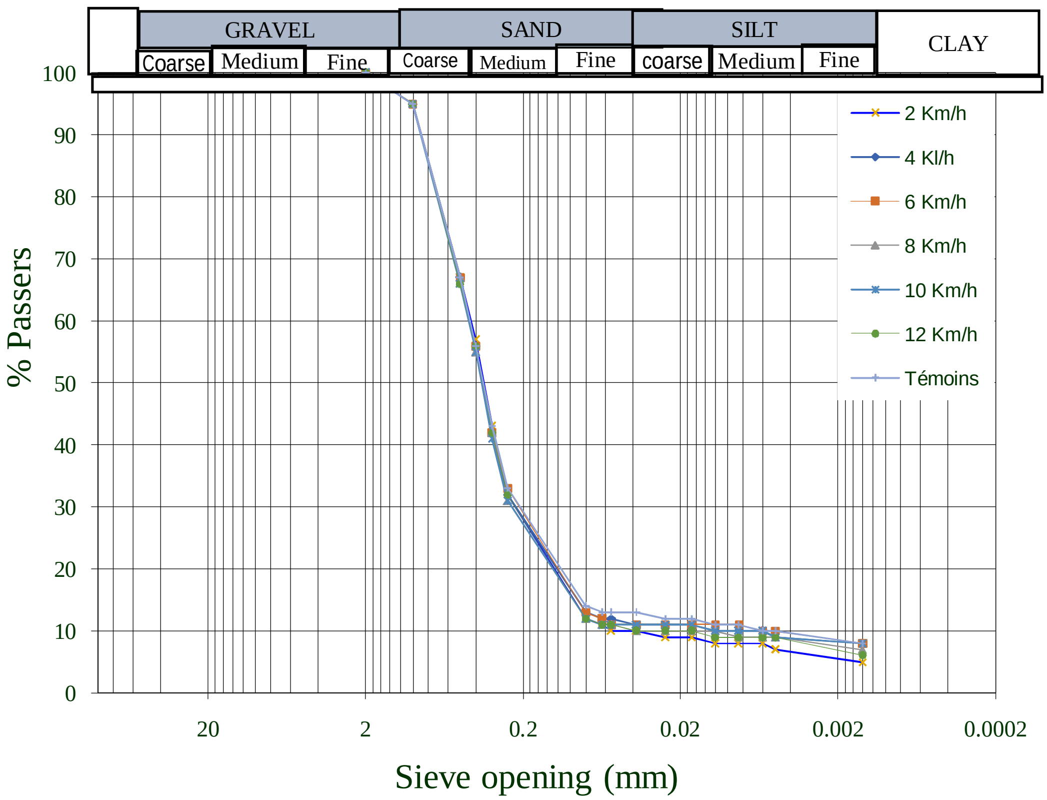

Figure 3: Particle size analysis curve of the differentplowing speeds

Legend : V1 - Speed 2Km/h, V2 - Speed 4km/h, V3 - Speed 6km/h, V4 - Speed 8km/h, V5 - Speed 10km/h, V6 - Speed 12km/h, V0 - No speed, no plowing.

Plowshare plowing therefore did not lead to a change in grain size. Thus, the plowing speed factor does not influence the grain size. Moreover, the particle size analysis does not make it possible to characterize the particles having sizes less than 80 µm (fine particles). Characterization tests on fine soils (the Atterberg limits) will certainly allow us to classify these particles.

3.2. Characterization of soils according to the Atterberg limits

The **(Fig. 4)** presents the different values obtained for the limits of liquidity and plasticity and which are represented in the plasticity diagram of Casagrande.

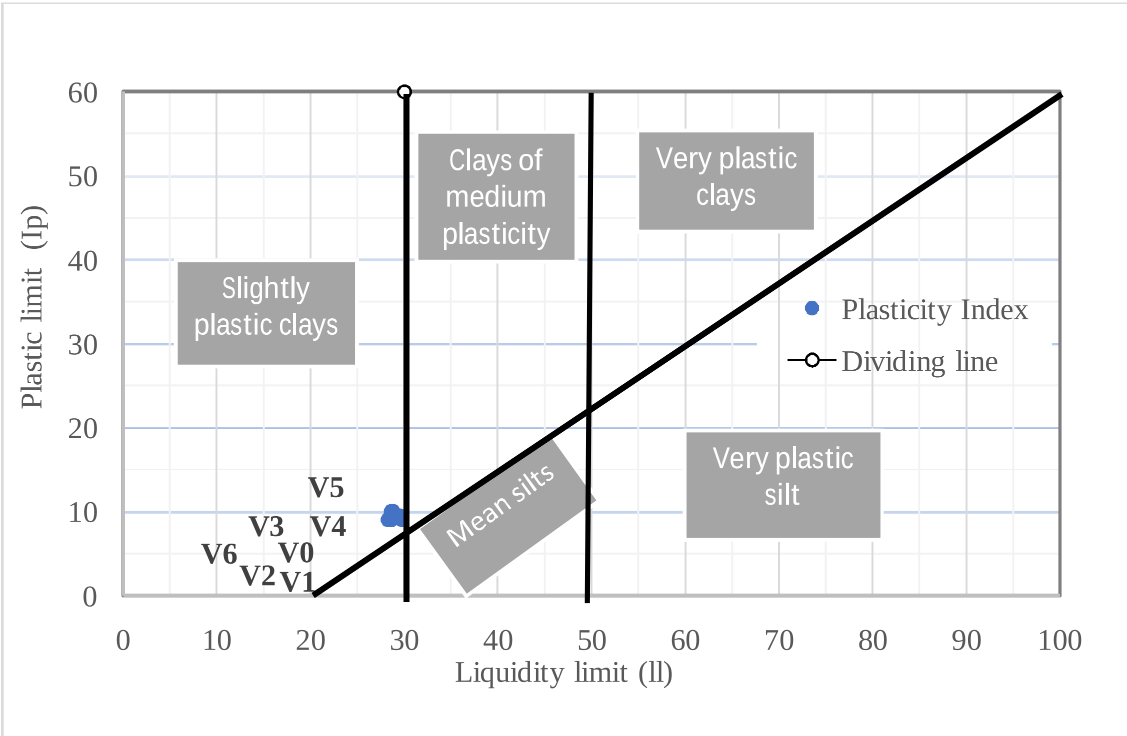

Fig. 4: Liquidity and plasticity limits in the Casagrande plasticity diagram

Legend : V1 - Speed 2Km/h, V2 - Speed 4km/h, V3 - Speed 6km/h, V4 - Speed 8km/h, V5 - Speed 10km/h, V6 - Speed 12km/h, V0 - No speed, no plowing.

The plasticity diagram of Casagrande, allowed us to identify through these values, the various fine particles of passers-by resulting from the granulometric analysis of each parcel. Note that the fine particles of passers-by from V0 to V6 all belong to the class of less plastic clays.

Indeed, the plowing speed does not significantly influence the plasticity index at the (5%) threshold **(Table2)**. Moreover, it is seen that the action of the tool (ploughshares and discs) on the ground, did not change the class of the fine particles of the ground, which confers on it the same character. Furthermore, the presence of clay soil with low plasticity at the level of plots V0 to V6, will make them impermeable and poorly ventilated and then form an obstacle to root penetration but with a good capacity to transport water by capillary action from the deep layers. Clay soil is an ideal seedbed for cotton, because its surface is friable and has fine water-stable clods, which allowsquick and uniform emergence of seedlings **(Daniel, 1998)**.

3.3. Evaluation of soil permeability

The **Fig. 5** below shows that the best permeability is obtained with the two tools at a speed of 6 km/h on ferritic soil. However, the soil worked by the ploughshare plow has a more permeable layer.

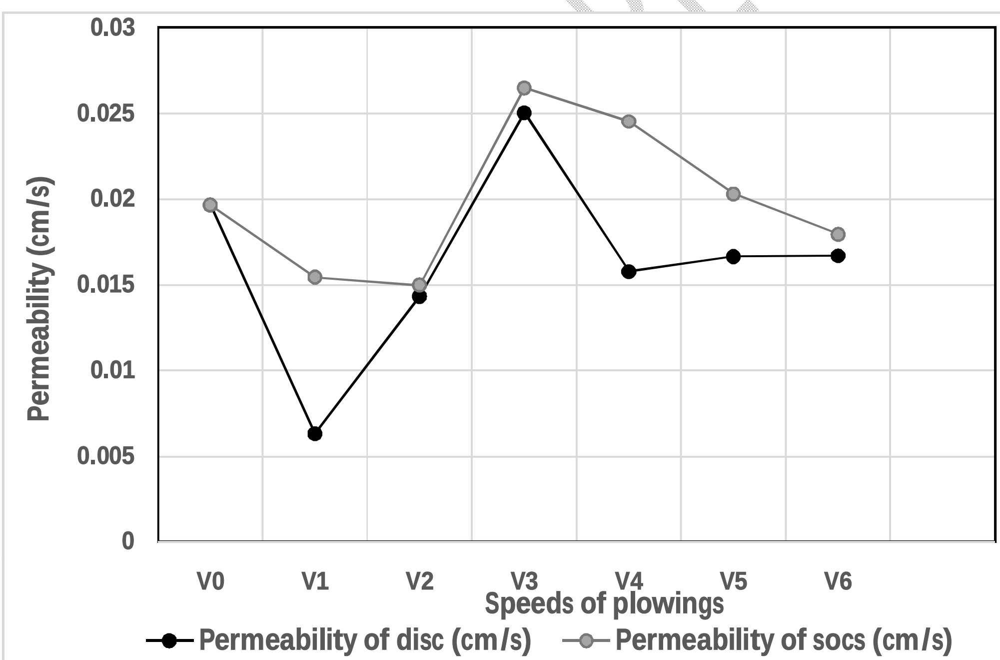

Figure 5: Permeability of plowed soil to coulters and discs as a function of plowing speed

Legend : V1 - Speed 2Km/h, V2 - Speed 4km/h, V3 - Speed 6km/h, V4 - Speed 8km/h, V5 - Speed 10km/h, V6 - Speed 12km/h, V0 - No speed, no plowing.

It can be seen that, from V0 to V2, V3 to V6, the permeability is inversely proportional to the plowing speed. In addition, the maximum perméabilités are obtained at the level of V3 (6 km/h). Thus, the soil must be permeable especially at the level of the root zone and impermeable at the level of the basement in order to avoid too deep drainage. So, plowing at a speed of 6 km/h made it possible to obtain good soil permeability. We observe that at slow speeds, it is less, this is justified by the fact that the plowing by the plows has created fewer pores following a lesser dislocation of the earthen clods of the arable layer, giving enough difficulties to the water to cross them.

4. DISCUSSION

The optimal tillage speed leads to a significant enhancement of soil physical qualities, excellent root system expansion, nutrient efficiency, and enhanced germination and yield **(Majid, 2010)**. Low or high plowing speeds affect the conservation of soil organic matter, moisture and water capillary capacity, and soil bulk density **(Jasim*et al.*, 2015; Mahmoudi, 2015)**. Indeed, there is a link between the characteristics examined for characterization. Slow (2 km/h) or quick (8 to 12 km/h) plowing leads to a drop in the soil's water content, porosity, and rate of organic matter, as well as an increase in the soil's apparent density, resulting in reduced yields with the plowshare. Average plowing speed (6 km/h) increases soil permeability, water content, organic matter content, and porosity while decreasing bulk density, resulting in a higher yield. The results demonstrated that the granulometry of the ground does not vary in response to variations in speed, but that the speeds do appear to affect these properties. However, **(Chehaibi*et al.*, 2008)**, having studied the effect of the forward speed of the tractor on the behavior of loamy-sandy soil in the region of Chott-Mariem (Sousse), reveal that working at slow speed provides a much larger volume of plowed soil with few voids at depth, resulting in high compaction at depth, in contrast to high-speed tillage, which generates less compaction at depth with a smaller volume of soil The plow has fewer pores and a high density, resulting in a moderate penetration rate, whereas the disc plow has a lower infiltration rate. Then, we see that the discs mix the soil considerably more and increase the number of small particles, resulting in larger voids. In addition, **(Jasim*et al*., 2015)**, who evaluated the effect of tillage speed on the physical attributes of clay-loam soil and maize yields, discovered that operation speeds had a substantial impact on soil bulk density and hydraulic conductivity values. As working rate rose, soil bulk density increased and hydraulic conductivity dropped; thus the optimal maize yield is reached at a speed comparable to our study (six kilometres per hour). Therefore, it appears that an increase in working speed causes an increase in apparent soil density and a decrease in soil conductivity. Therefore, moving the soil at a moderate speed might lead to an increase in the soil's hydraulic conductivity and a decrease in its bulk density, resulting in a higher yield. Working at slower speed results in a substantially bigger volume of soil worked, massive aggregates with numerous deep holes, and a reduction in energy consumption **(Holland, 2004; Zokpodo*et al*., 2017)** without necessarily affecting crop production. Therefore, good plowing at a moderate pace indicates better-structured soil **(Zokpodo*et al*., 2017)**. The influence of plowing speed on the physical parameters of clay-loam soil and maize yields was analysed by **Jasim*et al*. (2015)**. They found that soil bulk density and hydraulic conductivity values were considerably impacted by operation speeds. As operating speed rose, soil bulk density increased and hydraulic conductivity dropped; the optimal maize yield is achieved at a pace of six kilometres per hour. Therefore, it appears that an increase in working speed causes an increase in apparent soil density and a decrease in soil conductivity. Therefore, cultivating the soil at an average pace might lead to an increase in the soil's hydraulic conductivity and a decrease in its bulk density, resulting in a higher yield. At a speed of six kilometres per hour, soil bulk density increased and hydraulic conductivity dropped, resulting in the highest maize yield. Therefore, it appears that an increase in working speed causes an increase in apparent soil density and a decrease in soil conductivity. Therefore, cultivating the soil at an average pace might lead to an increase in the soil's hydraulic conductivity and a decrease in its bulk density, resulting in a higher yield. At a speed of six kilometres per hour, soil bulk density increased and hydraulic conductivity dropped, resulting in the highest maize yield. Therefore, it appears that an increase in working speed causes an increase in apparent soil density and a decrease in soil conductivity. Therefore, cultivating the soil at an average pace might lead to an increase in the soil's hydraulic conductivity and a decrease in its bulk density, resulting in a higher yield. **Namdari*et al.* (2010)** studied the influence of plowing depth and speed using a moldboardplow on the quality of tillage in sandy-loam soil. Therefore, the depth and speed of plowing are two determinants of the quality of tillage. Thus, for this author, plowing at a speed of (5.5 km/h) increases the pace of soil inversion and decreases the weight average diameter of the clods at a plowing depth of (15-20 cm), resulting in an improvement in the quality of tillage. Alternatively, **(Kadhim*et al.*, 2010)**indicate that raising the tillage speed to 7 km/h significantly reduces the weight diameter of the clods and the overall porosity. From the above, it is clear that the pace of tillage affects the structure of the soil, with slower tillage resulting in better-structured soil, greater working depth, and a higher yield. Rapidly, it reduces the volume of worked soil, the weight diameter of earth clods, the soil's conductivity and porosity, and increases the soil's apparent density. The FAO envisions that, by 2030, nations will have minimized the expenses associated with healthy and diverse agriculture. To achieve this, it is necessary to encourage: the promotion of equipment systems adapted to the soil and good methods of driving agricultural machinery; the manufacture of simple machines for working the soil at a lower cost; the increase of productivity through innovative techniques to ensure good sustainability while meeting the requirements for healthy, balanced nutrition of the poor population and environmental protection; and the manufacture of simple machines for working the soil at a lower cost**(FAO, 2014)**. Thus, the research has demonstrated that lowering the frequency of plowing to a minimum and performing it at the ideal pace is important for automation that assures optimal productivity and sustainable agriculture.

5. CONCLUSION

The results obtained show that the plow/disc plowing speed has an impact on soil physics. This research has made it possible to prove that plowing at a very slow or fast speed leads to a reduction in the water content of the soil, the porosity, the rate of organic matter and consequently a drop in yields. Plowing with the plow on the ferralitic soil at an average speed of (6 km/h) generates on the other hand an increase in the rate of organic matter, the porosity, the water content and the permeability with a decrease in the apparent density of the soil. Which will definitely lead to a good yield. Finally, we can conclude that in the agro-pedological and climatic conditions specific to our trial, working at a speed of 6 km/h guarantees good physical soil conditions leading to better cotton yield.All this to contribute to the mastery of appropriate farming mechanization techniques in a context of soilsustainability.

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