# THE EFFECTS OF VARIOUS TILLAGE SYSTEMS ON SOIL STRUCTURE AND ROOT SYSTEM DEVELOPMENT IN WHEAT (TRITICUM DURUM DESF.)

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(Received October 2020 – Accepted June 2021)

***ABSTRACT***

**Echcherki, S., Feddal, M. A., & Labad, R. (2021). The effects of various tillage systems on soil structure and root system development in wheat (Triticum durum Desf.). *Lebanese Science Journal*, 22(2), 165 - 184.**

*The objective of our study is to compare the effect of agricultural soil preparation on the physicomechanical properties of the soil and the consequences on the root system of wheat. To achieve these goals, three technical tillage chains (chain 1: deep tillage, chain 2: agronomic tillage, chain 3: no-tillage), were compared in the same pedoclimatic and historical situations. The experiment was carried out on silty clay soil in the experimental station of the National Higher School of Agronomy (Algiers). The results show that the techniques affect soil's proprieties and the root system differently. The agronomic tillage has the best favorable effect on soil humidity, Bulk density, and soil Penetration resistance **(11,1%; 50%; 0.6 MPa)** (p-value :**0,0001**). Concerning the roots, the density, the diameter, and length were better when the soil is deeply tilled, non-tilled, or agronomical tilled, respectively **(CH1:3.37 g/dm³; CH3:1.38 mm; CH2:12.23 cm).** Examining all the results of this study has shown how tillage is reflected in and contributes to the farmer's orientation towards the right choice to optimize and conserve soil and water at the same time. Thus, under this study's experimental conditions, the technical itinerary of tillage with agronomic ploughing seems to be an alternative to conventional ploughing. This method of tillage is easily feasible from a technical point of view. Besides, it can generate economic gains compared to ploughing. However, its impacts on the soil and crop yields need to be studied in the longer term.*

**Keywords:** soil water content, Bulk density, Penetration resistance, tillage, roots.

http://dx.doi.org/10.22453/LSJ-022.2.165-184

## INTRODUCTION

The scarcity and reduction of water resources, due to drought and irregular rainfall, is the major problem threatening Algerian agriculture. This problem is exacerbated by the failure of farming practices used by farmers, including tillage and the management of crop residue and weed. Besides, it would be interesting to remind that the establishment of field crops is very demanding in terms of energy needs. (Mebarki et al., 2020).

Tillage is an ancestral practice, one of the primary aims to create a favorable environment for seed germination and root development (Köller, 2003). The first tool for burying and covering seeds appeared around 10,000 years ago in the Sumerian civilization. Then was gradually perfected over the centuries until the first "Roman plough" described by Virgil around the first year of humanity. The "modern plough" was designed in the United States by Thomas Jefferson in 1784 and patented by Charles Newfold in 1796. Its use was widespread and quickly became one of the symbols of modern agriculture (Lal et al., 2007). Nowadays, plowing with a moldboard plow is the most frequent tillage technique in the world. This practice has made it possible to increase crop productivity thanks in particular to its action in controlling weed development and the fragmentation of soil structure.

However, during the 20th-century new soil fertility problems emerged, particularly in the United States, where serious erosion problems ("Dust Bowl") led to the development of alternative techniques to plowing. This movement was initiated by Edward Faulkner, who published the book "Plowman's Folly" in 1942 (Lal et al., 2007). Since then, the results of numerous researches under different climatic zones in the world have revealed problems common to plowed soils: compaction, organic matter’s decrease, erosion, limitation of water circulation (Köller, 2003; Lal et al., 2007; Baumhardt, et al, 2002) and the energy and financial cost of this practice (Monnier, 1994). As a result, in the last few decades, the world shifted to various forms of soil tillage without turning the soil layers, up to direct seeding. In comparison, the conventional plowing (plowing with moldboard, turning the topsoil layer to a depth of 20-30 cm) is going less and less used. These techniques were grouped under simplified cultivation techniques, or conservation agriculture, when they leave more than 30% of the residues of the previous crop on the soil surface (Köller, 2003; Labreuche et al., 2007; Bhattacharyya, et al, 2006). The presence of mulch on the surface and the limitation of vertical soil disturbances protect the soil from wind and water erosion, limit MOS losses. Besides, mulch promotes soil biological activity and makes it possible to increase the working width of implements and thus reduce farmers' workload without reducing crop yields (Kern and Johnson, 1993; Köller, 2003; Arshad et al, 1999; Blanco-Canqui et al, 2007; Dahai Guan, 2015; Hammel, 1989).

In Algeria, the results of research carried out over ten years, under the same conditions as ours notably by Amara et al., 2008, Bekkouche, 2012; Hamani, 2013; Amara et al., 2015; and Ferrah, 2014; have shown that the direct seeding system presents many problems. The development of direct seeding has increased the use of herbicides necessary to control the growth of weeds which is no longer ensured partially by ploughing. These systems are therefore efficient but at high chemical input costs, thus increasing their potential to pollute surface water. Field surveys show that the few farmers using direct seeding are questioning the effect of these techniques on the development of weeds and the adaptation of their equipment stock.

Another observation to be credited to Algerian farmers is the ignorance of the techniques adapted to local conditions and lack of knowledge related to the use of agricultural equipment, where we noticed significant differences in the yield of crops grown under identical environmental conditions. Moreover, the variation in yield is due, among other things, to the different physicochemical characteristics of the soil, which leads to questioning the choice of tillage equipment. Consequently, it shows the lack of information of the decision-maker (the farmer) about the impact of the different tools on land’s state, in various types of soil and variable climatic conditions. Hence, the interest in characterizing the effect of implements on the soil and being able to predict the quality of work that will be obtained under given soil conditions by a chosen sequence of tools and according to a known operation method.

Many technical and scientific references on the impact of tillage methods on soil quality are available; but these researches highlight the comparison between conventional tillage, minimum tillage, and direct seeding. Otherwise, our work introduces the toolchain comprising conventional tillage, agronomic tillage and comprising no-tillage with an offset disk.

The question we asked ourselves before starting this study is what will be the best way to improve the structural state of the soil, with the tools that the majority of Algerian farmers have at their disposal. As well, we know that almost all farmers have an offset disk, disc, or share plow on their farms and sometimes a harrow, a smooth, or croskill roller.

Therefore, the objective of this study is to compare the impact of chain farming tools on the physicomechanical properties of the soil and the possible consequences on wheat rooting.

To achieve these objectives, we compared three technical tillage chains in the same pedoclimatic and historical situations. The treatments were chosen to represent a gradient of tillage intensification. Each system maintains a minimum level of mechanization to control weed development and prepare the seedbed. These tillage practices are being studied in the context of cereal production.

## MATERIALS AND METHODS

### Presentation of the conditions of the experiment

The experiment was carried out during two agricultural seasons on a field located at the experimental station of the National Higher School of Agronomy (ENSA), which is situated at Belfort in el Harrach Algiers state. The soil of the field has clay loam texture, according to the USDA classification, with the content is presented in the below table 1.

**Table 1: Characteristics of the soil of tests.**

| Clay | Fine silt | Coarse silt | Fine sand | Coarse sand |
|---|---|---|---|---|
| **39.5%** | 20.2% | 3.96% | 20% | 13.6% |

Triticum Durum requires a healthy soil, draining well but not too prone to water stress especially during the period of accumulation of reserves in the grain. The establishment of wheat in poorly draining land makes it more susceptible to fungal diseases such than foot rot and fusarium.

We chose to crop the Vitron wheat variety. This variety spies the first third of April in the coastal areas and at the end of April in the high plains. Moreover, the Vitron variety has an average tillering and slightly higher fertility than Waha (it has an average of 50 to 60 grains/spike). Also, it has a high PMG (thousand-grain weight), according to **ITGC, 2011.**

The seeding rate was 120 kg/ha and 2.5 cm deep, corresponding to an average grain of 300 per square meter, which is the rate recommended by the ITGC (Technical Institute for Field Crops) for the study area.

The average temperature registered during the experimentation period was 14.5°C, with a rainfall average of about 266 mm, which is exceptional compared to the regional average of 749 mm. (Taibi et al, 2017).

**Equipment used**

Taking into account the geometry and topography of the plots and considering the objectives of our experiment, we used the block device. The experimental field measure 0.54 ha in size, while the trial blocks are 500 m (50 m long and 10 m wide) separated by 1 m wide grassed strips. Giving nine blocks, three for each toolchain level (CH). The three combined toolchains of soil tillage referred to as levels of work are described in table 2.

- ✓ For all the experiment, AGRIC PSM 30 seed drill coupled to a JOHN DEERE 5605 tractor was used for sowing operation

**Table 2: The agricultural toolchains studied.**

| Level | Name | Chain |
|---|---|---|
| **Level 1 (CH1)** | Conventional Tillage | Plough with shares (30 cm deep) - offset disk - vibrocultivator – roller. |
| **Level 2 (CH1)** | Agronomique Tillage | Plough with shares (15 cm deep) - offset disk - vibrocultivator – roller. |
| **Level 3 (CH3)** | Minimum Tillage | Offset disk - vibrocultivator – roller |

The choice of agricultural toolchains studied was conditioned by the tools that the majority of Algerian farmers have. Thus, we know that almost all farmers have on their farms a cover crop, a plow and sometimes a harrow and / or foot smooth roller or Crumbler roller.

**Methodology**

The tests focused respectively on the parameters relating to the soil, soil water content, Bulk density, penetration resistance and that relating to the crop, the root density.

- **Soil bulk density measurement**

We used the Coring method to collect soil, which is the most commonly used method. Briefly, a cylinder of known volume (400 cm³) with a sharpened end is mechanically driven in the ground and then cleared by digging around it. To determine the bulk density samples were taken from three broad horizons (0, 10, 30 cm), then drying it in the oven (at 105°C for 24 hours). In the end, the samples were weighed, and the bulk density was calculated according to the equation (1) using the dry weight and the volume of the soil sample.

$$\rho_{as} = \frac{P}{V}$$ Equation (1)

With: $\rho_{as}$ : Bulk density; P: weight of the dry sample; and V: volume of the soil sample.

- **Soil water content (H%) measurement**

To determination of soil humidity, we used the weight moisture method. The samples were taken from five points and three horizons (0-10, 10-20, and 20-30 cm), giving a total of 15 samples in each plot.

The soil water content was calculated directly by weighing the soil before and after drying ((105°C/24h). The immediate weight corresponds to the total mass (Mt), and the mass after drying represents to the solid mass (Ms). The water content (W) was calculated according to the equation (2):

$$W = (\frac{Mw}{Ms}) \times 100 = \left[\frac{(Mt - Ms)}{Ms}\right] \times 100$$ Equation (2)

With: W: humidity level (%); Mw: mass of water (g); Ms: mass of the solid (g); Mt: total soil mass (g).

- **Measurement of total soil Bulk density (P) expressed in %:**

Soil Bulk density was determined as the ratio of bulk density and the actual density. It was calculated using the following equation (3):

$$n\% = 100 \text{ x } (1 - \rho_{as} / \rho_s)$$ Equation (3)

Where: n%: soil Bulk density (%); $\rho_{as}$: Bulk density; $\rho_s$ : is the density of soil, estimated at 2.43 g/cm³ (Feddal, 2015);

- **Penetration resistance Measurement**

The Penetration resistance was measured using a cone penetrometer. The standard cone penetrometer consists of a three channel-instrumented steel probe. The front end of the probe consists of a conical tip with a 60 degree apex. The tip typically has a 5-millimeter cylindrical extension, or lip, located at the upper portion to protect the outer edges of the cone base from excessive wear.

### Root Density Measurement

Soil samples were taken from the plots using coring techniques with a metal cube of known volume (18000 cm³), 30 cm long, 30 cm wide, and 20 cm high. The cube was mechanically driven into the soil (0-20 cm) by its sharp end, then freed by digging around it. The roots were extracted from the soil samples using the water floating technique. After that, the roots were separated from the organic debris, and their weight was measured. The root density was calculated by dividing the weight (gr) by the volume of the cube. (18000 cm³).

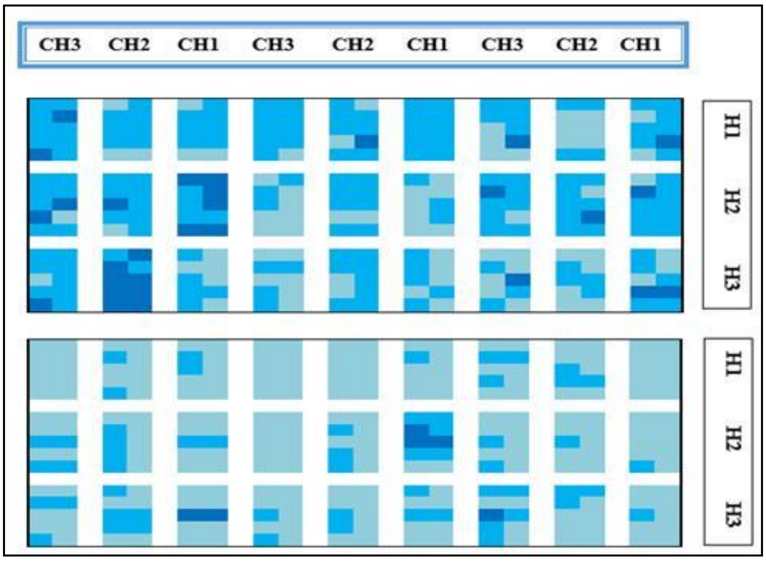
- **Statistical analysis methods**

For the processing of the results, we used two XLSTAT software, and the test used is the Kruskal-Wallis test, It allows to test whether k samples (k > 2) come from the same population, or from populations with identical characteristics.

## RESULTS AND DISCUSSION

### Impact of the succession of farming tools on soil water content (H%)

The first moisture observations were mapped using grid sampling on the plots before and after tillage (Figure 1). The mapping clearly shows that the passage of tillage tools has a decreasing effect on soil water content in the three horizons (H1), (H2), (H3) (0-10-20-30 cm).




| Moisture | Nuances |
|---|---|
| H<11 | |
| 11>H>20 | |
| H>20 | |

**Figure 1: Mapping of soil moisture variation in relation to depth (H1, H2, and H3) for the three techniques.**

This finding is valid for all three chains of tools. To dive our findings, statistical analysis (table 3), and histograms (Figure 2) were carried out using a chain-by-chain analysis on the three horizons (Figure 2 A, B, C):

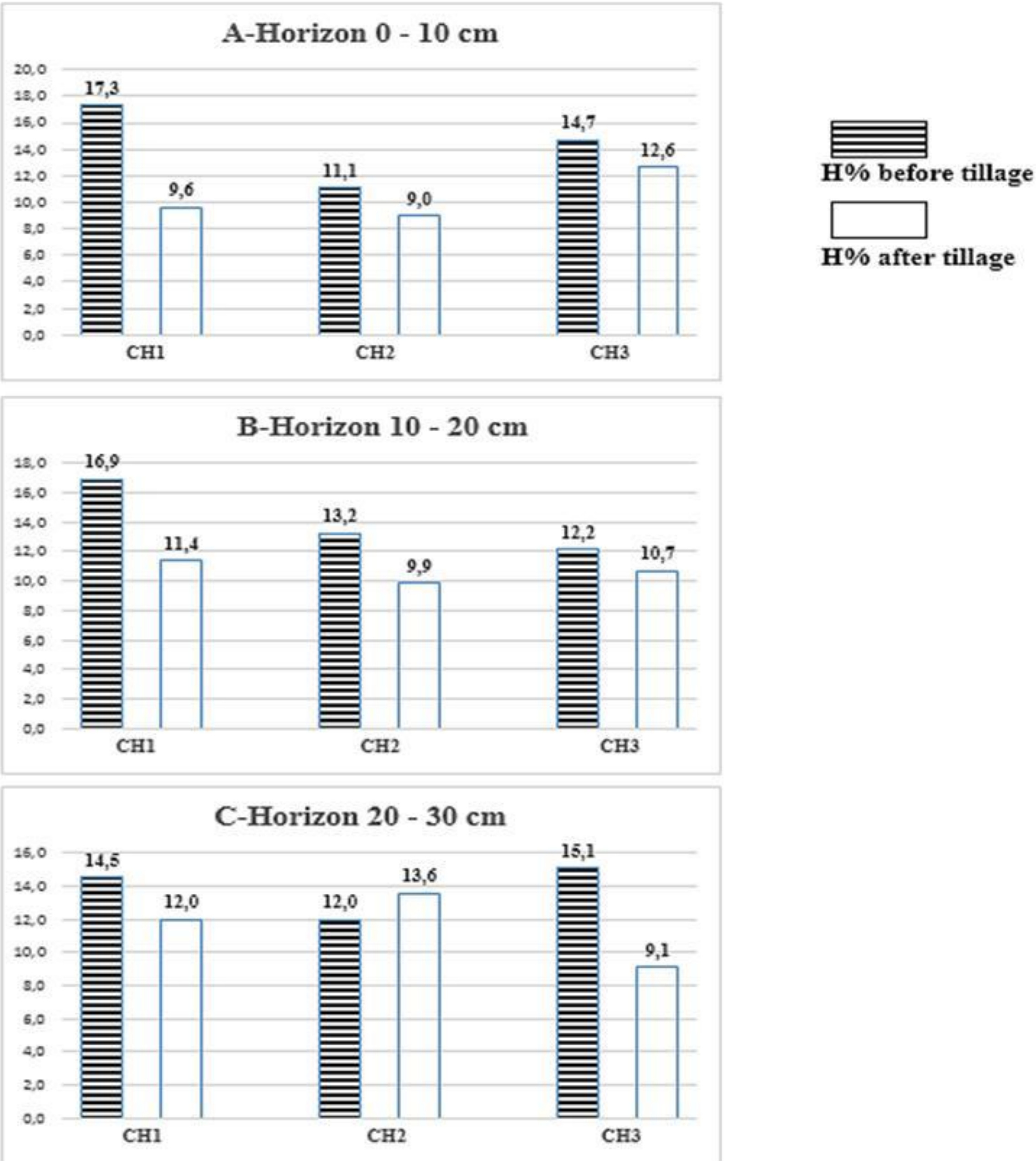



**Figure 2: The variation of H% before and after tillage for the three toolchains for the three horizons A, B, C.**

**Table 3: Statistical Analysis of the Effect of Cultivation Techniques on soil water content.**

| | CH1 | CH2 | CH3 |
|---|---|---|---|
| **Horizon 1** | p-value : **0,004**<br>alpha 0,05<br>**THS** | p-value :0,242<br>alpha 0,05<br>**NS** | p-value :0,892<br>alpha 0,05<br>**NS** |
| **Horizon 2** | p-value :**0,006**<br>alpha 0,05<br>**THS** | p-value :**0,003**<br>alpha 0,05<br>**THS** | p-value :**0,027**<br>alpha 0,05<br>**HS** |
| **Horizon 3** | p-value :0,38<br>alpha 0,05<br>**NS** | p-value :0,24<br>alpha 0,05<br>**NS** | p-value :**0,0001**<br>alpha 0,05<br>**THS** |

In a general way, we can conclude that the farming tools, whatever their application and passage, decrease soil water content on the first two horizons. Soil dryness can be explained by high evaporation resulting from the disturbance of the soil by the working parts of the tillage tools on the first 15 centimeters. On the other hand, on the third horizon, no moisture loss was registered for chains 2 and 3, where tillage affected only the first 15 cm. In contrast, the decrease in moisture was recorded at the level of plots plowed to 30 cm.

**Impact of the succession of tillage tools on the total Bulk density of the soil (n %)**

The first analyses of the soil's total Bulk density, as for moisture, were based on grid mapping sampling on the plots before and after tillage (Figure 3).

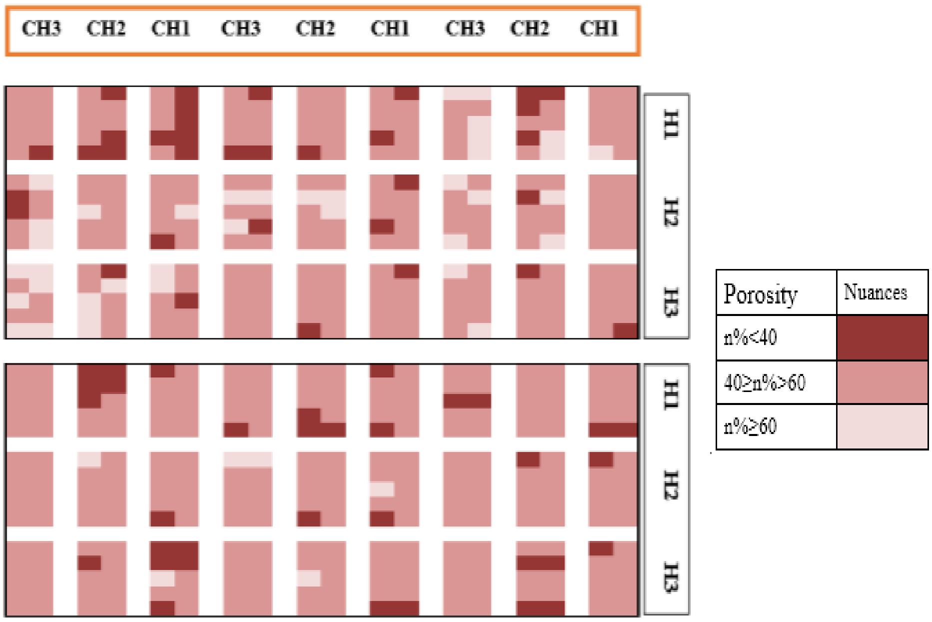



**Figure 3: Mapping of soil Bulk density variation in relation to depth (H1, H2, and H3) for the three techniques.**

The mapping illustrates that agricultural tools' passage had a diminishing effect on soil Bulk density on the three horizons. A more precise analysis of the Bulk density results is presented for the three toolschains on the three horizons (Figure 4 A, B, C):

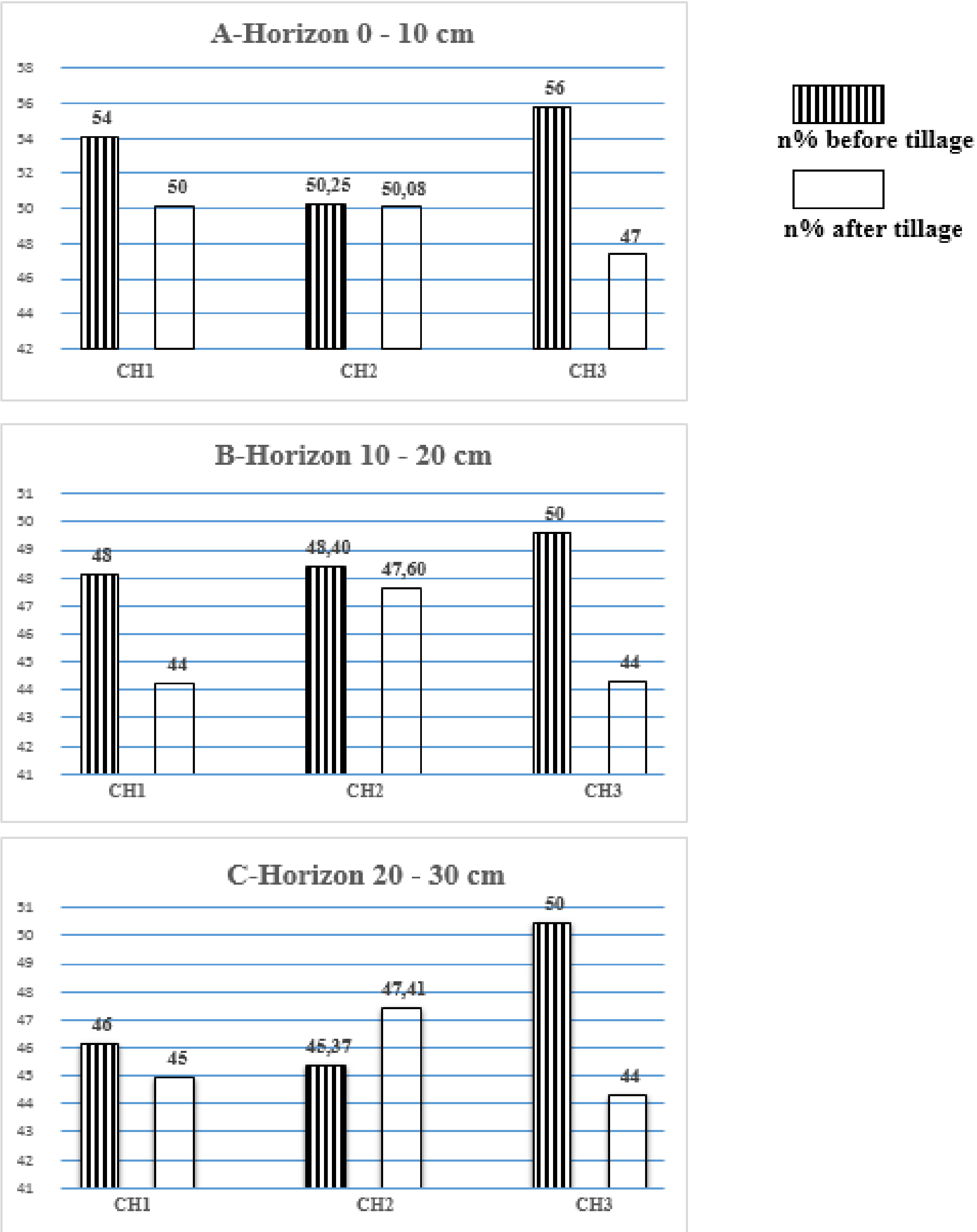



**Figure 4: Variation of n% before and after tillage for the three toolchains for the three horizons A, B, C.**

**Table 4: Statistical Analysis of the Effect of Cultivation Techniques on soil Bulk density.**

| | CH1 | CH2 | CH3 |
|---|---|---|---|
| **Horizon 1** | p-value : 0,493<br>alpha 0,05<br>**NS** | p-value :0,876<br>alpha 0,05<br>**NS** | p-value :**0,0001**<br>alpha 0,05<br>**THS** |
| **Horizon 2** | p-value :0,416<br>alpha 0,05<br>**NS** | p-value :0,725<br>alpha 0,05<br>**NS** | p-value :**0,05**<br>alpha 0,05<br>**S** |
| **Horizon 3** | p-value :0,869<br>alpha 0,05<br>**NS** | p-value :0,389<br>alpha 0,05<br>**NS** | p-value :**0,008**<br>alpha 0,05<br>**HS** |

The results in the first horizon show that the successive passage of the offset disk and the vibrant shank cultivator reduced the Bulk density by 9%. In contrast, in deep conventional work, we registered only a reduction of 4%. On the other hand, CH2 with agronomic plowing seems to have the best Bulk density since it remained stable on this horizon with 50%.

In line with the first horizon, the second horizon seems to be more stable with the CH2 compared to CH1 and CH3, where we registered a decrease in Bulk density by 4 and 6%, respectively.

At the third horizon, the Bulk density was stabile with CH1 (1% decrease), compared to CH3 with a 6% of decreasing. On the other hand, CH2 increases Bulk density by 2%.

According to table 4, the statistical analysis showed a significant effect on total soil Bulk density only with CH3 on the first and second horizons.

**Impact of the succession of farming tools on the mechanical resistance of the soil**

The Penetration resistance (**Rp**) is one of the indicators frequently used to provide insight into the state of soil compaction and the stress the soil places on root progression. We analyzed the evolution of the soil Penetration resistance concerning the depth of the three toolchains studied.

**a. Horizon A (0 – 10 cm) :**

The figure 5 shows the effect of the passage of the different tillage tools of the three chains on the soil's Penetration resistance in the first horizon. We notice that CH2 allows the lowest Rp with a decrease of 0.6 MPa, followed by CH1 with 0.5 MPa and finally CH3 with 0.4 MPa.

**b. Horizon B (10 – 20 cm) :**

At the level of the second horizon, the observation is quite the same as the first. The tools have a reducing effect on Rp; we have to mention that the deeper we go, the more Rp increases.

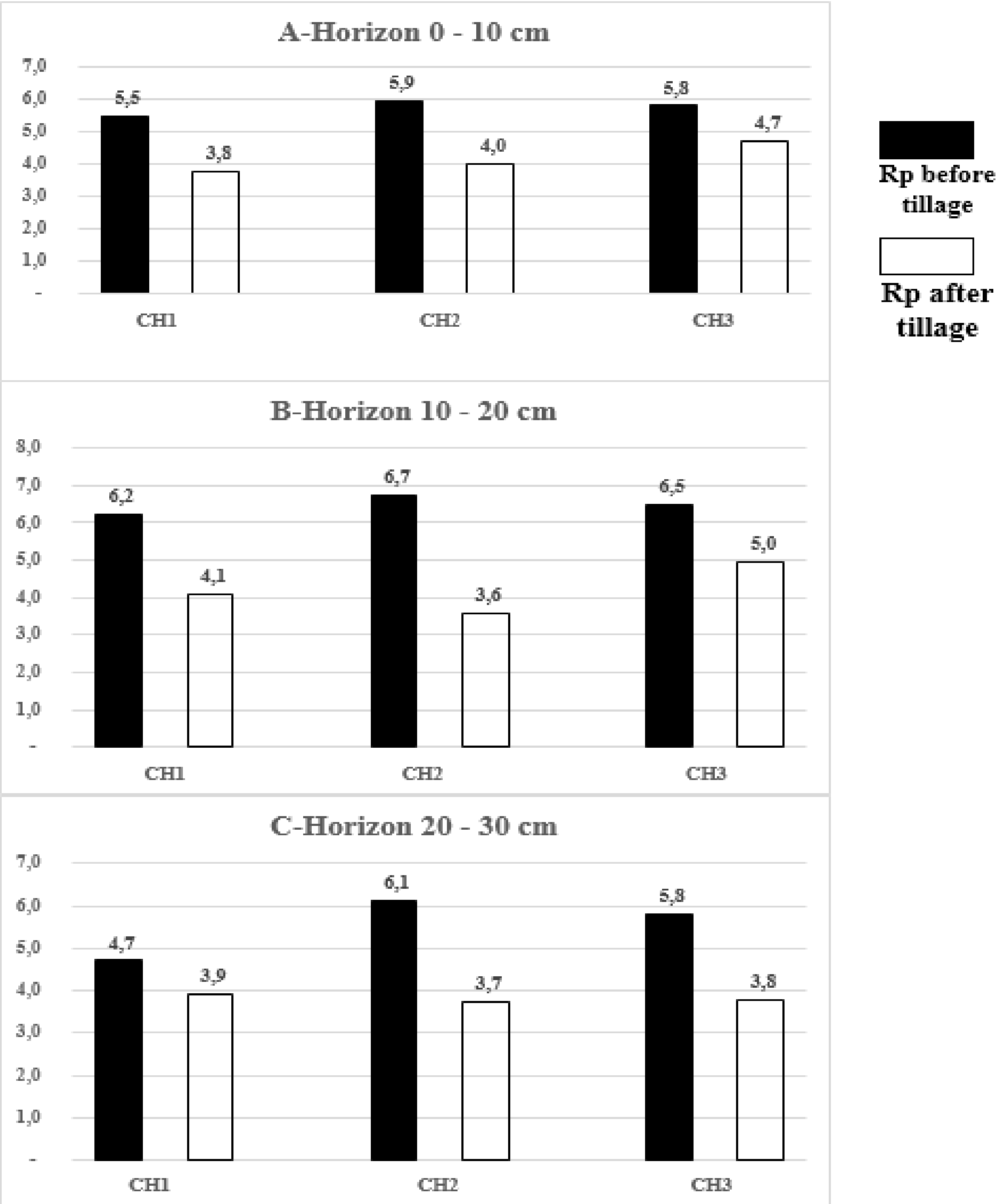



**Figure 5: The variation of Rp (MPa) before and after tillage for the three tool chains for the three horizons A, B, C.**

**c. Horizon C (20 – 30 cm):**

The three tillage chains allow a reduction of Rp on the third horizon. The largest reduction was recorded with CH2 with a difference of 0.8 MPa, followed by CH3 and CH1 with 0.67 Mpa and 0.33 MPa.

The student test in the table 5 confirms that there is a highly significant effect of the three toolchains on Rp over the 20 - 30 cm horizon. However, it should be noted that CH2 has a greater effect on Rp than CH1 and CH3.

**Table 5: Student test (Rp, horizon1, toolchain).**

| | **CH1** | **CH2** | **CH3** |
|---|---|---|---|
| **p-value** | **0,028** | **0,001** | **0,022** |
| **Alpha** | 0,05 | 0,05 | 0,05 |
| **Interprétation** | **S** | **HS** | **S** |

Generally, the three chains of soil tillage implement, despite their differences, have a diminishing effect on soil Rp; chain 2 with agronomic ploughing allows the greatest reduction in Rp over the entire soil horizon.

It must be pointed out that Rp reaches its maximum values for the three chains at a depth of 20 cm, which can be linked to the history of the plot which has been ploughed for several years at the same depth, which induced a ploughing sole, the values of Rp then decrease at the horizon 20 - 30 cm.

Multiple regression analysis between the dependent variable Rp and the independent variables H%, n% yielded the following model equation (4):

**Rp CH1 = -3, 19 - 0, 15 *H% (CH1) + 0, 12 * n% (CH1)** Equation (4)

(with: **$R^2$=0, 71** and **P-value <0.05)**

The equation illustrates the relationship between Rp, n and H, where 71% of the variability in Rp ($R^2 = 0.71$) could be explained by the moisture (H %) and Bulk density (n %). We notice that H% correlated negatively to Rp, contrary to n% where there is a significant positive correlation (especially if the soil is dry). Further, H% has slightly more effect than n% on Rp, with the coefficients 0.15 and 0.12, respectively. We cannot physically link them because Rp is a point measurement and porosity is a volume measurement.

The work of **Isabelle Breune** in 1997 can explain the increase of Rp in the function of n%. The author reported that for a matrix potential of 33 kPa, which corresponds approximately to the field capacity in sandy soil, the relationship between Bulk density and Rp is almost linear.

Furthermore, since the Bulk density is a volume measurement and the Rp is a precise measurement, the information provided by one or the other is sometimes quite different. Besides, sometimes it is possible to observe an increase in Rp with depth without noticing a remarkable difference in bulk density. This phenomenon is generally explained by the increase in friction along the stem with depth (**Soane, 1973**). Thus, occasionally the Rp values wrongly define the presence of a compact zone. Therefore, it is recommended to measure Rp together with other parameters such as H (%) and n (%).

For CH2 and CH3, the established regressions were not significant.

**Effect of Tillage on Durum Wheat Root Development**

- **Root Density**

Figure (6) shows the variation in root density for the three chains over the last physiological stages (head emerging, Flowering, and Maturity), these stages allow the development of the root system, essential for the development of plants.

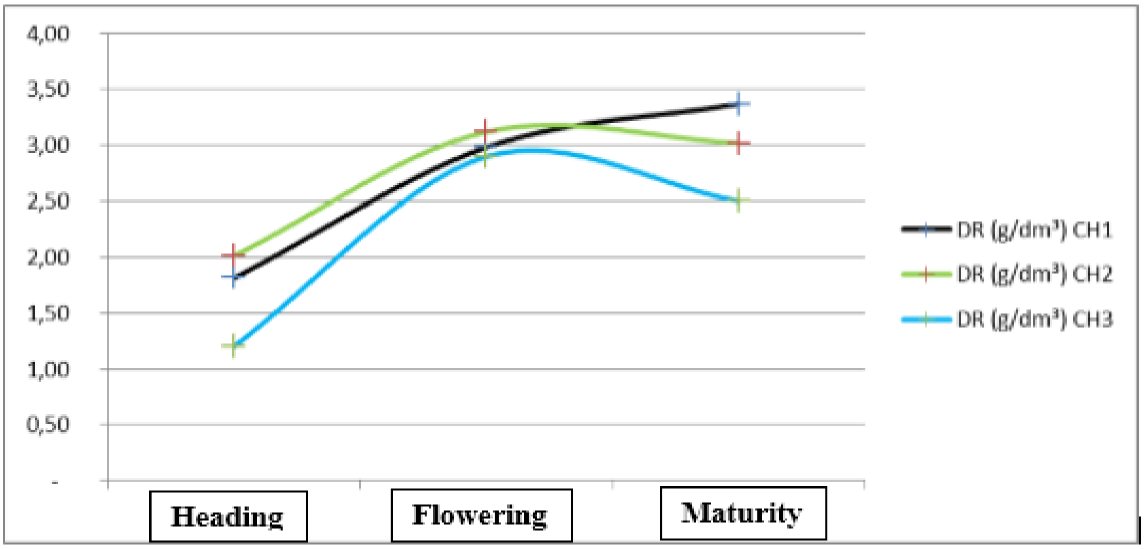



**Figure 6: Variation in root density for the three chains during the last three stages of durum wheat development.**

The results showed that the average root density is variable across both factors (physiological stage and toolchain), and the values vary from 1.2 g/dm³ and 3.37 g/dm³.

The root density increases from head emergence to flowering using all the three toolchains. The CH2 shows the highest root density during both stages. However, while the CH1 keeps increasing the root density until maturation to reach 3.37 g/dm³, the root density decreases slightly after flowering to achieve 3.02 g/dm³ and 2.5 g/dm³ with CH2 and CH3.

- **Root diameter**

Figure (7) shows the variation in root diameter for the three chains over the last three stages of durum wheat development.

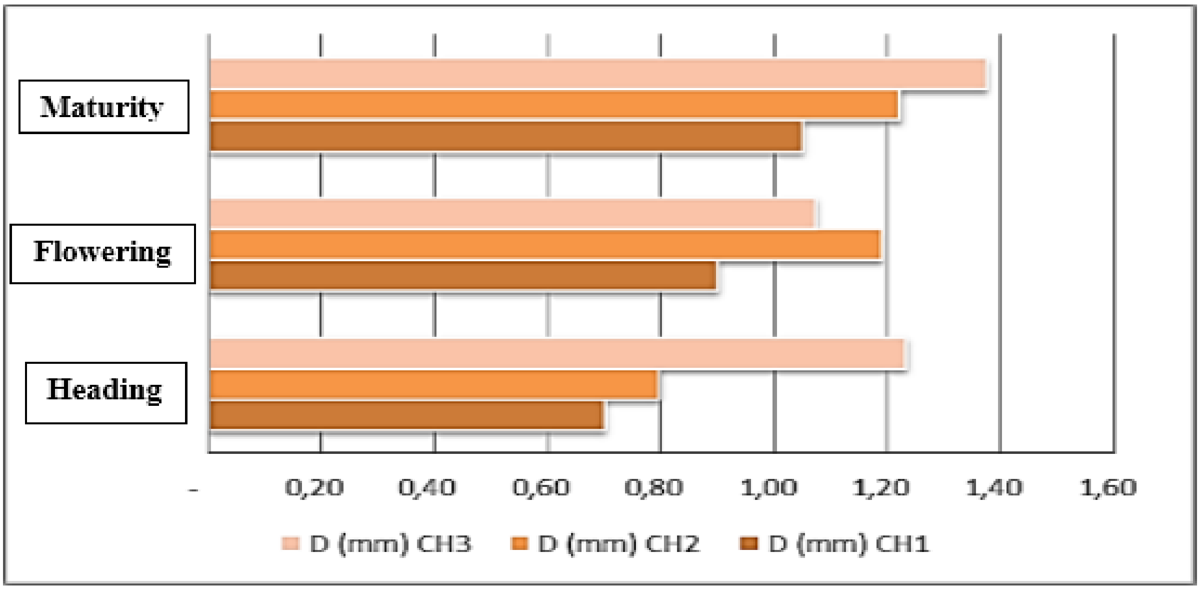



**Figure 7: Variation in root diameter for the three chains during the last three stages of development of durum wheat.**

The root diameter measured during the last three growth stages of wheat is significantly higher in plots worked without the share plow (CH3). The mean root diameter in CH3 was 1.38 mm, compared to 1.22 mm and 1.08mm for CH2 and CH1.

Reduced tillage such as CH3 does not favour proper root development at depth due to the superficial intervention of the tools. This finding confirms the results of Rp, where deep compaction was recorded, which may have caused a horizontal root development and not vertical.

- **Root elongation**

Figure (8) shows the variation in root elongation for the three chains over the last three stages of durum wheat development.

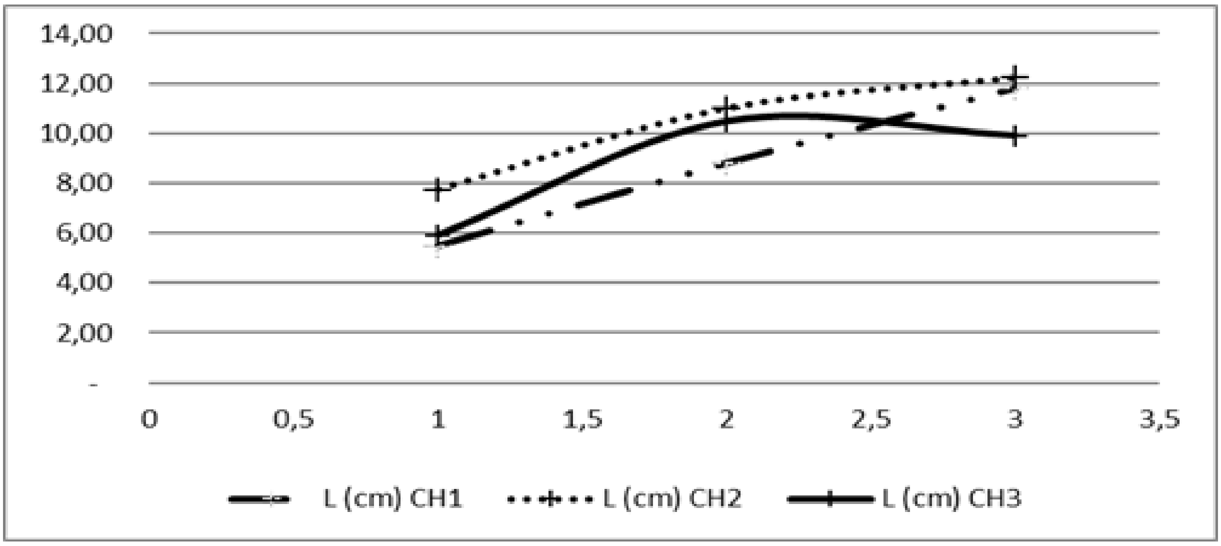



**Figure 8: Variation in root elongation for the three chains over the last three stages of durum wheat development.**

The results show that the root length rate is faster with CH3, increasing from 5.9 cm at heading stage to 10.46 cm at flowering. However, the elongating stagnate in this value until the end of wheat development. The rapid root elongation using CH3 may be explained by the structure created at the surface layers that favors growth initiation. In contrast, at depth, the soil is not tilled, or the soil Rp is high, forcing the elongation to stops.

The deep plowing and agronomic plowing tillage with the share plough, keep the root length increase until maturity stage. The root length reaches the highest value of 12.23 cm with CH2 compared to 11.81 cm using CH1.

## CONCLUSION

The passage of tillage tools had a decreasing effect on soil water content, Bulk density, and Penetration resistance on the three horizons (10-20-30 cm), using both CH1 and CH3. At the same time, CH2 allows conservation of water content in the third horizon (20 -30 cm), due to the undisturbed soil at depth and homogeneity of soil Bulk density over almost the entire profile. This result is encouraging insofar as there is currently high rainfall variability in northern Algeria, agronomic ploughing may offer a solution to soil drying.

The Bulk density results are directly related to the bulk density, which does not show a remarkable change during this experiment. However, the interpretation of results is delicate, it can be mistaken by other mechanisms including wetting, desiccation, and settling that’s why it must be done carefully. The soil Bulk density is generally reduced in conservation tillage systems due to non-ploughing which decreases macroBulk density formed by soil tilling. But, just like direct seeding systems, they favor the formation of biological macropores. These changes occur gradually, and differences between systems can be observed after several years of application.

Soil preparation with tillage promotes root development better than other techniques due to the creation of an excellent structure. Agronomic plowing allows good root elongation, while deep plowing provides a better root density. The minimum tillage provides the best root diameter but a low root elongation, which calls into question the simplified cultivation techniques.

Today, under this study's experimental conditions, the technical itinerary of tillage with agronomic plowing can be an alternative to conventional plowing. This tillage method is easily feasible from a technical point of view and can generate economic gains compared to plowing, but its effects on the soil and crop yields need to be studied in the longer term, because there is another factor to consider which is the mechanical management of weeds. The latter is a challenge to be taken very seriously, as weed control will become increasingly difficult in the future as weed resistance continues to develop to herbicides.

For the future, we recommend focusing on other parameters, such as the weight distribution of the aggregates. The aggregation weight distribution is the best way to assess and characterize the action of tools on the soil structure by giving more details on the size of the clods formed after the passage of the devices, and their proportion concerning the volume of soil stirred.

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