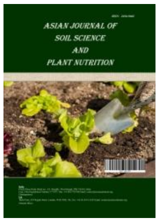

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Effect of Cropping System under Tillage and Mulching on Soil Physical Properties and Water Use Efficiency by Maize (*Zea mays* L.) in Southern Benin

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Authors' contributions

This work was carried out in collaboration among all authors. Authors AFK and MSA designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors JA and TMA managed the analyses of the study. Authors PH and HAA managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

In agriculture, water has become a limiting factor because of the effects of climate change felt by farmers. This situation seriously compromises agricultural production through pockets of drought, delayed and early cessation of rains and then an increase in the length of the dry season.

Aims: This study aims to evaluate the effect of tillage and vegetative mulch on soil physical properties and maize water use efficiency in ferralitic soil of southern Benin.

Study Design: The Factorial Complete Randomized Block Design with 4 repetitions was implemented.

Place and Duration of Study: The experimental site is located at Allada, in southern Benin, and conducted between May 2017 and July 2017.

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Methodology: Tillage (No-tillage, flat tillage) and straw mulch rate (0%, 50%, 75% soil cover) and their interaction was been tested during this study. The physical properties of soil and maize water use efficiency were determined.

Results: Tillage significantly reduced soil temperature by 2.65% and improved soil permeability by 60%. Tillage also significantly improved water use efficiency for maize grain from 3.88 to 7.88 $kg.mm^{-1}.ha^{-1}$ and for maize biomass from 12.67to 23.31 $kg.mm^{-1}.ha^{-1}$. Mulching significantly improved soil moisture from 11.54% to 13.13%, water use efficiency for maize grain from 4.26 to 7.58$kg.mm^{-1}.ha^{-1}$ and for maize biomass from 14.50 to 22.05 $kg.mm^{-1}.ha^{-1}$. Mulching also significantly reduced soil temperature by 11%. The combination of tillage and mulching significantly improved water use efficiency for maize grain and biomass production. The highest water use efficiency (8.87 $kg.mm^{-1}.ha^{-1}$ for maize grain and 25.17 $kg.mm^{-1}.ha^{-1}$ for maize biomass) was achieved with tillage combined with mulching at 75% soil cover. The interaction between these two factors significantly reduced soil temperature by 11.30% (tillage combined with mulch at 75% soil cover) compared to control (no-tillage and no-mulch).

Conclusion: This study showed that tillage and mulching at 50% or 75% soil cover improves soil physical properties and water use efficiency for maize production in the context of climate change.

Keywords: Tillage; mulch; soil cover; soil infiltration rate; plant water used; water use efficiency.

1. INTRODUCTION

In sub-Saharan Africa, degradation and misuse of natural resources limit the potential for agricultural development [1]. As result, soil is severely degraded. Poor agricultural and forestry practices (poor management of irrigation, fertilization, mechanization or phytosanitary treatments, overgrazing, deforestation and other excessive removal of forest products, bush and forest fires, ...) and population boom are major causes of land degradation [2,3]. Approximately, 75-80% of cultivated area would be degraded in Africa, with a loss of 30-60 kg of nutrients per hectare per year [4]. In the last decades, the effects of climate change have exacerbated these difficult conditions. According to the climate projections, the Sahel region will face a rise in temperature associated with a high variability of rainfall and a tendency towards extreme events [5]. Current cropping systems need therefore to be oriented for meeting the challenges of the sustainable use of soil and climate chance mitigation [6]. Soil and water conservation constitutes a key factor in crop productivity stabilization in rain-fed cropping systems in Sub-Saharan Africa.

Water, an essential component of soil, not only for the maintenance of biological activity, but also as an essential dissolving agent for the decomposition of organic matter into the base molecule CO_2, NH_4^+ (Humification, mineralization) and vector for the transfer of these dissolved substances. It is strongly lost by evapotranspiration due to high temperature and sunshine [7]. In agriculture, this water becomes a limiting factor because of the effects of climate change experienced by farmers [8]. This situation dangerously compromises agricultural production through pockets of drought, delay and early cessation of rains and then increases the duration of the dry season [9].

In Benin, agriculture is mainly dependent on rainfall conditions and is characterized by a diversity of crops, with maize being the dominant cereal [10], which requires a good distribution of rainfall [11]. According to projections by 2050, the yield of this staple food of the Beninese population will decrease significantly from 5 to 25% [8] if nothing is done. It is then important to work for water and soil conservation practices for better productivity.

Indeed, essential agricultural intensification practices must be associated with water and soil conservation practices [12]. However, research on soil conservation practices over the past two decades has shown that reduced tillage (zero tillage or minimum tillage) and soil cover contribute to stabilizing aggregates and raising the rate of tillage organic and soil biological activity [13-17]. Due to its importance on the physicochemical and biological properties of the soil, mulching also appears as a cultural practice for restoring soil fertility and consequently yield. According to Azontondé [18], the physical and hydraulic properties of bar ground are conducive to agricultural development, but the low useful reserve is one of the main factors limiting production on these types of soil. In this context, it is important to find an alternative for maintaining water in the soil in order to allow its good use by the plants and to improve the yield of maize crops. It is therefore necessary to develop methods to manage evaporation losses in order to respond to the effects of climate change.

Several studies have so far shown the impact of conservation practices on erosion and the modification of soil physical and chemical characteristics [17,19-21], but very few are interested in the effect of these practices on water conservation and the efficiency of water use by corn on bar land. The present work aims at accessing the effect that cultural practices i.e. tillage and mulching might have on soil water conservation and its use by maize crop.

2. MATERIALS AND METHODS

2.1 Experimental Site

The experimental site is located in Sékou in Allada district between 06°36'00'' and 06°39'30''N and 02°11'40" and 02°15'00''E (Fig. 1). The study area has a subequatorial climate. The annual rainfall is 1200 mm in average with bimodal pattern: long rain season from April to July and short rain season from September to November. The maxima and minima temperature oscillate around 32°C and 25°C respectively. Nearly 90% of Allada district consists mainly of rhodic ferralsol, locally called "Terre de barre". The soil has a sandy clay texture and the pH of the soil is acidic (5.9). The soil organic carbon content, the total soil nitrogen and the available soil phosphorus are respectively 4.4g.kg^{-1}; 0.21g.kg^{-1} and 27.72 ppm [22]. The soil chemical characteristics show that the soil is severely degraded.

2.2 Methodology

2.2.1 Experimental design

The experiment was set up with a factorial treatment structure consisting of two tillage methods (no tillage and flat tillage) and three rates of residue/mulch cover (0%, 50% and 75% of soil cover). The treatments were arranged in a factorial randomized complete blocks design with three replications. Tillage was made manually with the hoe at 20 cm depth, but the zero tillage plots received no tillage after cleaning. As for the mulching, coverage levels 0; 50 and 75% were obtained by covering the soil with 0 respectively; 3.5 and 7 t DM.ha^{-1} of mulch [23]. Experimental units had 35 m² (7m x 5m) as area. The details of the treatments tested are as follows: NTM0: No tillage + 0% soil cover; NTM50: No tillage + 50% soil cover; NTM75: No tillage + 75% soil cover; TM0: Tillage + 0% soil cover (Zero mulch); TM50: Tillage + 50% soil cover and TM75: Tillage + 75% soil cover as mulch.

2.2.2 Test installation

The tillage was done manually on the plots to plow. The AK 94 DMR ESR-Y maize (*Zea mays* L.) variety was used for this study at a density of 100,000 plants.ha^{-1}. It is a medium early yellow seeded composite variety with a 90 days growing cycle with an average farming yield of 2.5 to 3 t.ha^{-1} against 3.5 to 4 t.ha^{-1} at the station [24]. Simple fertilizers KCl (60% K_2O) and TSP (46% P_2O_5) were used as bottom fertilizer. The respective application rates are: 30 Kg K_2O.ha^{-1} and 50 Kg P_2O_5.ha^{-1}. After emergence 8 days after sowing), the mulching was applied according to the treatments. The mulch consisting of wasteland, maize biomass (previous crop) was set up in the proportions 0%, 50% and 75% of soil cover respectively 0 kg DM.ha^{-1}, 10.5 kg DM.ha^{-1} and 19.25 kg DM.ha^{-1}. Weeds management was done twice using a hand hoe on no-mulched plots while under mulched plots, it was by hand pulling.

2.2.3 Data collection method

2.2.3.1 Soil physical properties

- ✓ ***Soil temperature***: A mercury thermometer (-10 to 150°C as measurement capacity) was used to measure soil temperature 3 or 4 days after each rain event during the experiment.
- ✓ ***Soil moisture content***: it was determined by gravimetry which consists of a difference in weight with respect to the dry weight. Samples are weighed directly in the field. In the laboratory, they were oven-dried at 105°C until constant weight. The soil moisture content (HP) is determined by the following formula proposed by Saidou, et al. [25] :

$$\mathrm{HP} = \frac{\mathrm{MF} - \mathrm{MS}}{\mathrm{MS}} \times 100$$

With MF = Mass of fresh soil and MS = Mass of dry soil

Soil moisture content (m^3 of water per m^3 of soil) is then deduced by:

$\mathrm{H} = \mathrm{Da} \times \mathrm{HP}$ [26]

With Da: the bulk density of the soil ($g.cm^{-3}$)

- ✓ **Bulk density** : The bulk density is determined according to the formula below: $Da = \frac{m_{sol_{sec}}}{V_{apparent}}$
- ✓ **Permeability (Infiltration coefficient K)**: Porchet's method are used. It involves digging a cylindrical hole 6 cm in diameter and 20 cm deep using a calibrated probe. After having filled it with water, one observes the variation of the level of water as a function of time. Then we note the heights h1 and h2 at time t1 and t2. Let r be the radius of the well. The infiltration rate k is given by the formula:

K=r/2(t2-t1)*Log (h1+r/2)/ (h2+r/2)

2.2.3.2 Water use efficiency

- ✓ ***Plant Water Used***: The amount of water used (PWU) by crop or evapotranspiration was evaluated by the equilibrium equation of the water cycle developed by Chen, et al. [27] and Fellahi, et al. [28] on soil with negligible drainage and runoff (very low slope) and unsaturated hydraulic conductivity.

$$PWU = \Delta H + P$$

With ΔH the difference between the moisture density H (mm) at sowing and at harvest, P (mm) the rainfall recorded during the crop cycle.

- ✓ ***Water Use Efficiency*** (WUE): The Efficiency of Water Use by the crop is determined by the formula defined by [29-31]; which equates it with the productivity of water by making the ratio of the dry matter produced to the quantity of water used by the crop. Then, the water use efficiency for maize grain and total biomass production are estimated according to the respective formulas.

$$\mathrm{WUE\ grain} = \frac{\mathrm{Grain\ yield}}{\mathrm{PWU}}\ ;\ \mathrm{WUE\ biomass} = \frac{\mathrm{Biomass\ yield}}{\mathrm{PWU}}$$

With WUE grain ($kg.mm^{-1}.ha^{-1}$): Water use efficiency for maize grain production WUE biomass ($kg.mm^{-1}.ha^{-1}$): Water use efficiency for maize total biomass production PWU (mm): Plant Water Use (amount of water used by the crop during its cycle).

2.2.4 Statistical analysis

Analysis of Variance (ANOVA) was conducted using SAS GLM procedure version 9.2 to determine the effect of tillage practice and mulching on the physical properties of the soil (i.e temperature, moisture content and Permeability) and Water Use Efficiency b maize crop. Student-Newman-Keuls test was used for the separation of the 5% threshold means. The data on the water parameters are repeated in time and are independent. So, for the statistical processing of these data, the SAS GLM procedure is used with the introduction of the time factor.

3. RESULTS

3.1 Soil Physical Properties

3.1.1 Soil moisture content

Analysis of the variance (ANOVA) showed that the mulching factor significantly ($p < 0.0001$) influenced moisture content of the soil. The different modalities of mulching made it possible to obtain 13.13%; 12.53% and 11.54% as moisture content respectively for 75%, 50% and 0% mulch (Table 1). This parameter increases with the soil cover rate. Contrary to mulching, the effect of tillage was not significant ($p = 0.0805$) on soil moisture content. The combined effect of tillage and mulching was not significant (0.73) on the soil moisture content at the 5% threshold. However, the treatments can be classified as follows, in descending order on the basis of their arithmetic difference: TM75; NTM75; TM50; NTM50; TM0 and NTM0 (Table 1). Soil cover has improved soil moisture in general, which remains higher on tillage than on no-tillage plots.

The interaction between the observation dates and the main factors (tillage and mulching) did not influence the soil moisture content. However, the time taken individually has significant ($p<0.05$) effect on the soil moisture content. Fig. 2 shows the soil moisture changes over time. From the 20th to the 40th day after sowing and from the 55th to the 90th day after sowing, no-till without mulching (NTM0) had the lowest soil moisture content. Overall, treatments with mulch had high soil moisture content compared with the treatments without mulch. Between the 40th and 55th day after planting, a dry pocket period during which no rainfall events were recorded, only plowed and mulched plots had the highest soil moisture.

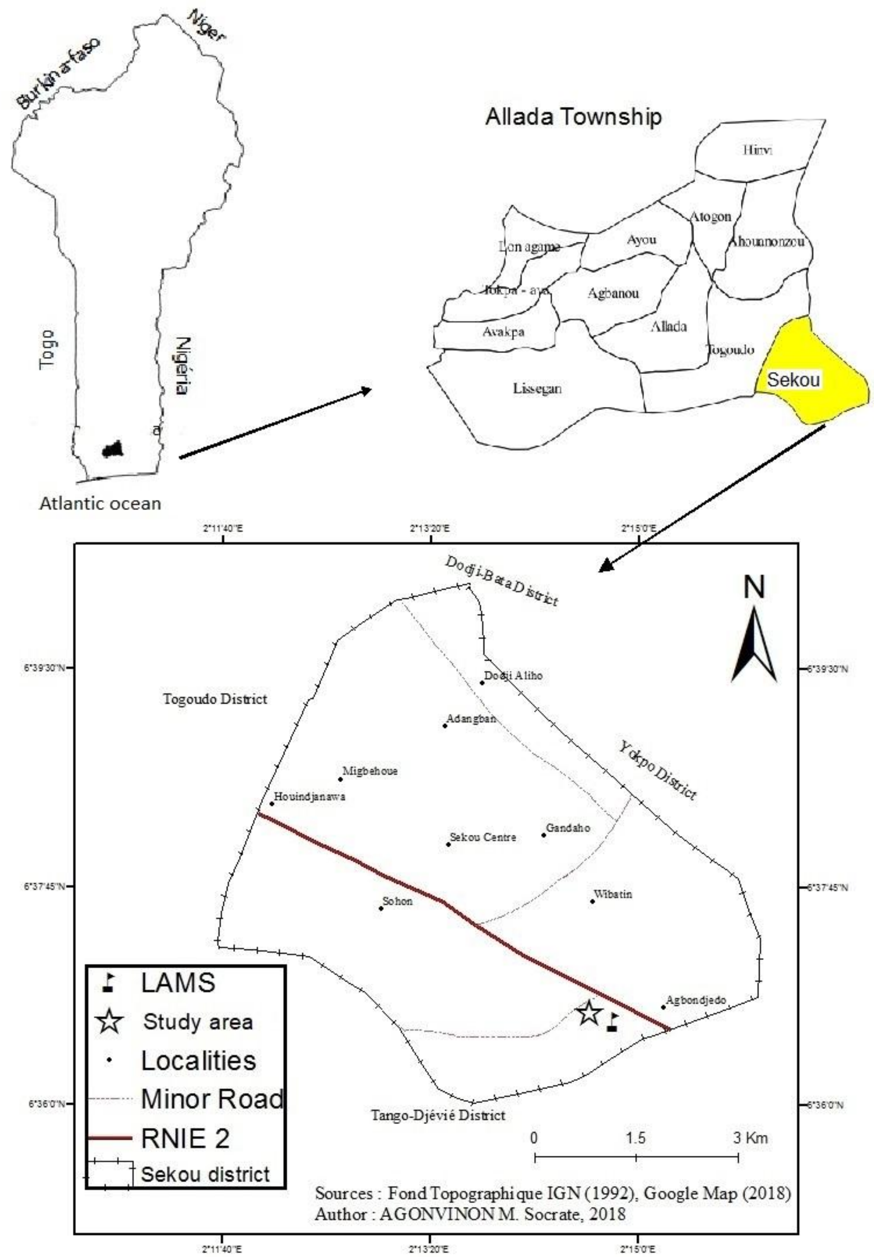

Fig. 1. Experimental site map

3.1.2 Soil bulk density

The effect of tillage and mulching as well as their interaction was not significant ($p < 0.05$) on the soil bulk density. However, conservation practices have reduced it. No-tillage generated of 1.34 $g.cm^{-3}$ as soil density compared to 1.35 $g.cm^{-3}$ flat tillage. Likewise, the soil density was reduced by the practice of mulching. Based on the average soil density (Fig. 3), the treatments can be classified in ascending order as follows: NTM75, TM50, NTM0, NTM50, TM75, TM0.

3.1.3 Soil temperature

Tillage significantly ($p < 0.0001$) reduced the soil temperature from 30.91°C to 30.09°C. Mulching has also decreased the soil temperature ($p < 0.0001$). As the amount of mulching increases, the more the temperature significantly decreased. The interaction between tillage and mulching generated similar results (p = 0.0123) on soil temperature (Table 2). No tillage without mulching (NTM0) led the highest temperature (32.92°C) and tillage with 75% soil cover (TM75) gave the lowest temperature (29.20°C). Fig. 4 shows the evolution of soil temperature over time under the different treatments. As it can be seen, no tillage with 75% soil cover (TM75) and tillage with 50% soil cover (TM50) kept the soil temperature significantly lower than the other treatments. These results could be explained by the fact that tillage loosens the soil and facilitates gas exchanges between the soil and the atmosphere. Mulching would protect the soil from the sun's rays and reduce potential soil evapotranspiration.

Table 1. Effect of tillage, mulching and their interaction on soil moisture content

Sources	Modalities	Soil Moisture content (%)[1]
Tillage	NT	12.24 ± 0.22a
	T	12.59 ± 0.17a
Mulching	M0	11.54 ± 0.21a
	M50	12.53 ± 0.19b
	M75	13.13 ± 0.26c
Tillage x Mulching	NTM0	11.28 ± 1.61a
	NTM50	12.47 ± 1.43a
	NTM75	12.87 ± 1.96a
	TM0	11.78 ± 1.21a
	TM50	12.59 ± 1.12a
	TM75	13.38 ± 1.57a
Mean		12.42
CV		10.45

NT = No tillage; T = Tillage; M0 = No mulch; M50 = Mulch at 50% soil cover; M75 = Mulch at 75% soil cover; NTM0 = No tillage and no mulch; NTM50 = No tillage and mulch at 50% soil cover; NTM75 = No tillage and mulch at 75% soil cover; TM0 = Tillage and no mulch; TM50 = Tillage and mulch at 50% soil cover; TM75 = Tillage and mulch at 75% soil cover; CV = Coefficient of variation; For the same factor and the same variable, the values with the same letter are not significantly different. [1]Mean values ± Standard error

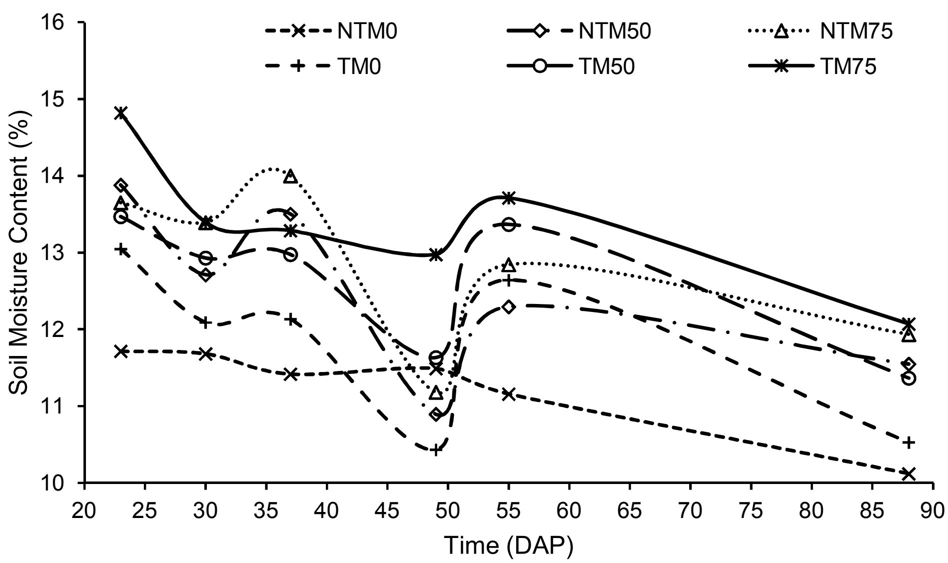

Fig. 2. Soil moisture content evolution over time under the effect of tillage combined with mulching

NTM0 = No tillage and no mulch; NTM50 = No tillage and mulch at 50% soil cover; NTM75 = No tillage and mulch at 75% soil cover; TM0 = Tillage and no mulch; TM50 = Tillage and mulch at 50% soil cover; TM75 = Tillage and mulch at 75% soil cover; DAP = Days After Planting

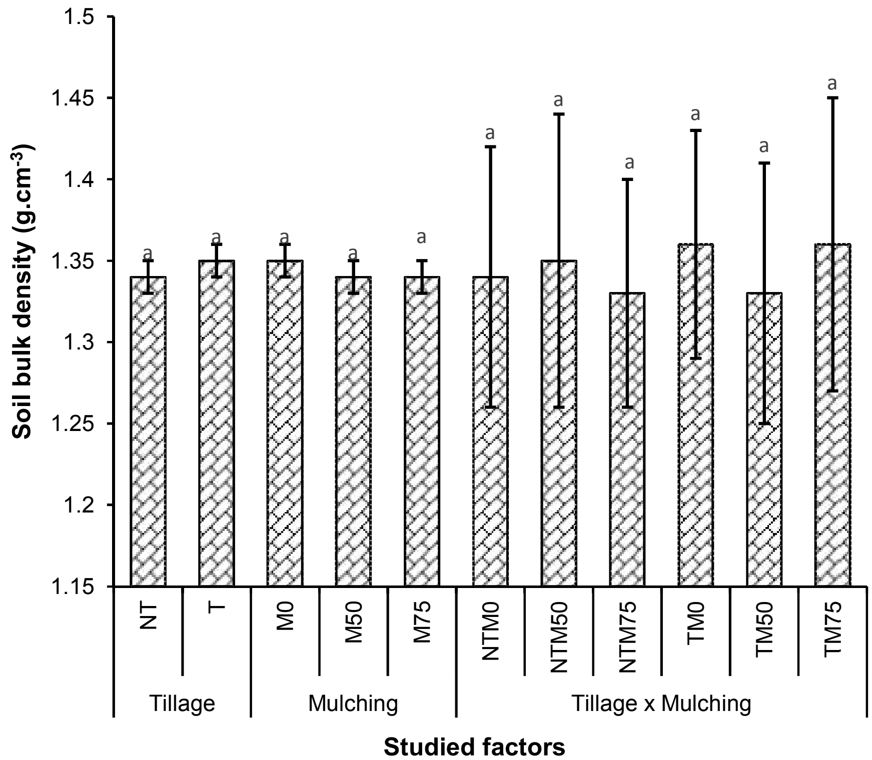

Fig. 3. Effect of tillage, mulching and their interaction on the soil bulk density

NT = No tillage; T = Tillage; M0 = No mulch; M50 = Mulch at 50% soil cover; M75 = Mulch at 75% soil cover; NTM0 = No tillage and no mulch; NTM50 = No tillage and mulch at 50% soil cover; NTM75 = No tillage and mulch at 75% soil cover; TM0 = Tillage and no mulch; TM50 = Tillage and mulch at 50% soil cover; TM75 = Tillage and mulch at 75% soil cover

Table 2. Effect of tillage, mulching and their interaction on soil temperature

Sources	Modalities	Soil temperature (°C)[1]
Tillage	NT	30.91 ± 0.25a
	T	30.09 ± 0.20b
Mulching	M0	32.22 ± 0.33a
	M50	29.90 ± 0.15b
	M75	29.37 ± 0.13c
Tillage x Mulching	NTM0	32.92 ± 2.34a
	NTM50	30.26 ± 1.02c
	NTM75	29.55 ± 1.01dc
	TM0	31.53 ± 2.02b
	TM50	29.55 ± 0.92dc
	TM75	29.20 ± 0.81d
Mean		30.5
CV		3.56

NT = No tillage; T = Tillage; M0 = No mulch; M50 = Mulch at 50% soil cover; M75 = Mulch at 75% soil cover; NTM0 = No tillage and no mulch; NTM50 = No tillage and mulch at 50% soil cover; NTM75 = No tillage and mulch at 75% soil cover; TM0 = Tillage and no mulch; TM50 = Tillage and mulch at 50% soil cover; TM75 = Tillage and mulch at 75% soil cover; CV = Coefficient of variation.

For the same factor and the same variable, the values with the same letter are not significantly different.

[1]Mean values ± Standard error

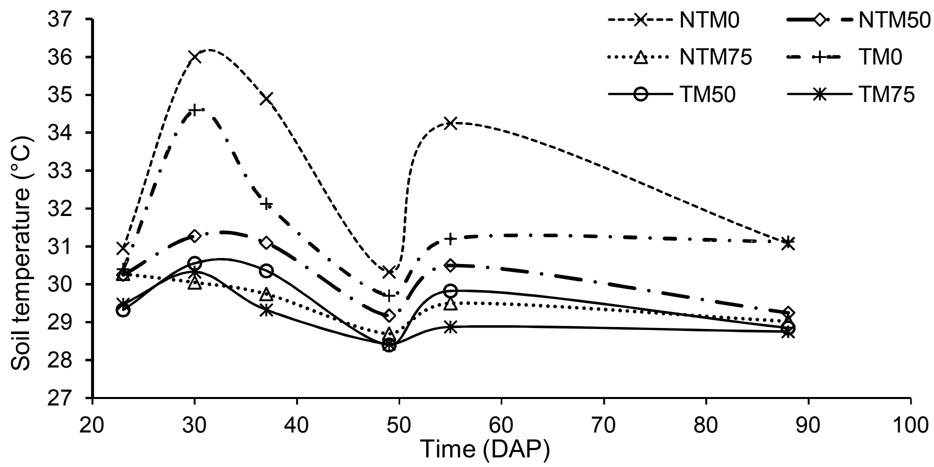

Fig. 4. Soil temperature evolution over time under the effect of tillage combined with mulching

NTM0 = No tillage and no mulch; NTM50 = No tillage and mulch at 50% soil cover; NTM75 = No tillage and mulch at 75% soil cover; TM0 = Tillage and no mulch; TM50 = Tillage and mulch at 50% soil cover; TM75 = Tillage and mulch at 75% soil cover; DAP = Days After Planting

3.1.4 Soil permeability

The Table 3 shows the soil permeability under the effect of tillage and mulching. The results showed that tillage significantly improved soil permeability (p = 0.0154) by about 60%. Mulching had no significant effect on soil permeability (p = 0.2028). Tillage combined with mulching also had no significant effect (p = 0.3506) on soil permeability. However, no-till and tillage with 75% soil cover by mulching improved soil permeability. These results show that tillage loosens the soil and improves soil permeability.

3.2 Maize Water Use Efficiency

3.2.1 Plant water use

Tillage, mulching and their combination had no significant ($p<0.05$) effect on water use by maize crop. However, tillage moderately improve the water supply to the maize plants compared to no tillage. Under mulching, the maize plants also slightly improved their water use (Table 4). Similar results were obtained by combining tillage and mulching modalities. Tillage with 75% soil cover (TM75) generated the highest amount of water used by the plants at 368.70 mm (Fig. 5).

3.2.2 Water use efficiency

The results showed that tillage increased the water use efficiency for maize grain (p = 0.0001) and biomass production (p = 0.0009) by 57% and 62% respectively compared to no tillage. Water use efficiency for grain (p = 0.0024) and biomass (p = 0.0216) were higher on straw plots (50% and 75% mulch) with an increase of 47.45% and 38% respectively. Mulching thus improves water use efficiency for maize (Table 5).

Tillage combined with mulching significantly improved the water use efficiency of maize grain (p = 0.0001) and biomass (p = 0.0001) production. In fact, combined tillage with 50% and 75% mulch, and no-tillage with 75% mulch generated the best grain maize and biomass yields per unit volume of water consumed. No-tillage with no mulch gave the lowest water use efficiency by maize plants.

4. DISCUSSION

4.1 Effect of Tillage and Mulching on Soil Physical Properties

Results of the present study showed that mulching significantly improved soil moisture. The presence of mulch on the soil surface is therefore a factor in maintaining and increasing soil moisture. These results are consistent with those of [32] who showed that organic mulching had significant effect on soil moisture content. Several authors have obtained the similar results. [20,33,34] indicated that mulching reduces soil evapotranspiration, limit the air circulation on soil surface and conserve

Table 3. Effect of tillage, mulching and their interaction on soil permeability

Sources	Modalities	Permeability ($cm.s^{-1}$)[1]
Tillage	NT	0.010 ± 0.001 b
	T	0.016 ± 0.002a
Mulching	M0	0.014 ± 0.003a
	M50	0.010 ± 0.00 a
	M75	0.016 ± 0.003a
Tillage x Mulching	NTM0	0.009 ± 0.003a
	NTM50	0.009 ± 0.002a
	NTM75	0.011 ± 0.007a
	TM0	0.018 ± 0.006a
	TM50	0.011 ± 0.002a
	TM75	0.020 ± 0.010a
Mean		0.013
CV		46.41

NT = No tillage; T = Tillage; M0 = No mulch; M50 = Mulch at 50% soil cover; M75 = Mulch at 75% soil cover; NTM0 = No tillage and no mulch; NTM50 = No tillage and mulch at 50% soil cover; NTM75 = No tillage and mulch at 75% soil cover; TM0 = Tillage and no mulch; TM50 = Tillage and mulch at 50% soil cover; TM75 = Tillage and mulch at 75% soil cover; CV = Coefficient of variation.
For the same factor and the same variable, the values with the same letter are not significantly different. [1]Mean values ± Standard error

Table 4. Effect of tillage and mulching on maize plant water use

Factors	Modalities	PWU (mm) [1]
Tillage	NT	363.87 ± 2.16a
	T	367.89 ± 0.69a
Mulching	M0	364.71 ± 2.49a
	M50	367.13 ± 0.75a
	M75	367.02 ± 1.48a
	Mean	366.1961
	CV	1.229

NT = No tillage; T = Tillage; M0 = No mulch; M50 = Mulch at 50% soil cover; M75 = Mulch at 75% soil cover; CV = Coefficient of variation; For the same factor and the same variable, the values with the same letter are not significantly different. [1]Mean values ± Standard error

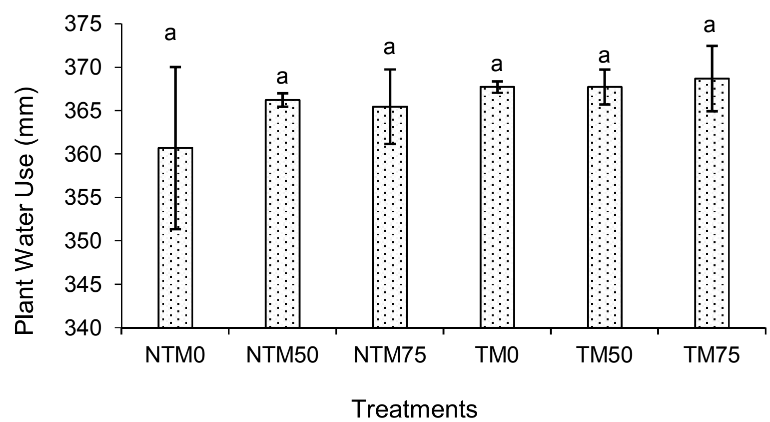

Fig. 5. Effect of tillage combined with mulching on maize plant water use
NTM0 = No tillage and no mulch; NTM50 = No tillage and mulch at 50% soil cover; NTM75 = No tillage and mulch at 75% soil cover; TM0 = Tillage and no mulch; TM50 = Tillage and mulch at 50% soil cover; TM75 = Tillage and mulch at 75% soil cover

Table 5. Effect of tillage, mulching and their interaction on maize water use efficiency

Sources	Modalities	WUE grain ($kg.mm^{-1}.ha^{-1}$)	WUE biomass ($kg.mm^{-1}.ha^{-1}$)[1]
Tillage	NT	3.88 ± 0.82b	12.67 ± 2.48b
	T	7.88 ± 0.59a	23.31 ± 1.59a
Mulching	M0	4.26 ± 1.10b	14.50 ± 3.41b
	M50	7.58 ± 1.01a	22.05 ± 1.71a
	M75	7.13 ± 0.94a	20.86 ± 3.05a
Tillage*Mulching	NTM0	1.27 ± 0.63c	5.30 ± 1.64c
	NTM50	7.36 ± 1.85ab	20.04 ± 2.81ab
	NTM75	4.76 ± 0.90b	15.11 ± 4.79b
	TM0	6.50 ± 1.11ab	21.39 ± 3.58ab
	TM50	8.39 ± 2.78ab	23.39 ± 4.50ab
	TM75	8.87 ± 1.55a	25.17 ± 7.55a
Mean		6.19	18.828
CV		24.116	25.765

NT = No tillage; T = Tillage; M0 = No mulch; M50 = Mulch at 50% soil cover; M75 = Mulch at 75% soil cover; NTM0 = No tillage and no mulch; NTM50 = No tillage and mulch at 50% soil cover; NTM75 = No tillage and mulch at 75% soil cover; TM0 = Tillage and no mulch; TM50 = Tillage and mulch at 50% soil cover; TM75 = Tillage and mulch at 75% soil cover; CV = Coefficient of variation;For the same factor and the same variable, the values with the same letter are not significantly different.

[1]Mean values ± Standard error

soil moisture. Generally, mulch has a great role in soil moisture conservation through modification of microclimatic soil conditions [32]. It helps to control weed growth [35], reduce evaporation, and increase infiltration of rain water during growing season [36]. Mulch increases soil moisture through increasing infiltration, reducing evaporation, and modifying water retention capacity of the soil [37]. The conservation of soil moisture by mulching has been sufficiently proven through several research works [38-41]. This study showed that tillage is no significant effect on soil moisture content. Contrary to this result, [42] showed that tillage practice resulted in significant differences in moisture content.

Tillage and mulching and their interaction did not significantly affect the soil bulk density. This result is in agreement with those of [43]. According to Husnjak, et al. [44], tillage at the beginning of the growing season temporarily decreases soil bulk density but subsequent trips in the field for agronomic practices, rainfall events, and other disturbances activities can recompact the soil. Lower bulk density at the end of the growing season could be attributed to the short term loosening effect of the tillage method used. But, these results disagree with those found by [45] who showed that tillage and mulching significantly affect the soil density. In addition, several research indicated that tillage has a significant effect on soil bulk density [45,46].

Soil temperature is one of the important factors that influence soil properties processes involved in plant growth. It control the soil physical, chemical and biological processes in the soil [47,48]. Factors influencing soil temperature include soil cover [49], the degree and timing of tillage [50]. In the present study, tillage, mulching and their combination affected significantly the soil temperature. These results are consistent with those of [51] who indicated that tillage had significant effects on soil temperature in 10 of 15 weekly periods and higher residue coverage caused lower soil temperature. Islam, et al. [52] showed that tillage and mulching, with or without crop cover, substantially affect time and depth variations of soil temperature.

This study showed that tillage significantly improved soil permeability by about 60%. But no mulching nor his interaction with tillage had no significant effect on soil permeability. These results show that tillage loosens the soil and improves soil permeability. Islam, et al. [52] obtained the same result indicating that the rate of infiltration was affected by tillage treatment which increased with the increase in tillage depth.

4.2 Effect of Tillage and Mulching on Maize Water Use Efficiency

Water use efficiency depends on the amount of water uptake by plants, of which the majority is lost through transpiration [53,54]. For sustainable management of already limited soil water, improving water use efficiency in crop production is one way to increase production [55]. Chennafi and Aïdaoui [56] showed that water scarcity severely limits cereal production. The results of this study showed that tillage, mulching and their interaction increased the water use efficiency for maize grain and biomass production. These findings showed the beneficial effects of tillage, which makes the soil looser, and of mulching in terms of water conservation [57]. These results are in agreement with those obtained by Peng, et al. [54], Choudhary [58] and Liu, et al. [59]. Sarkar and Singh [60] observed that deep and shallow depth plowing with mulch had marked impact and increased grain production and WUE than no mulched. Straw mulch on soil surface is considered important to promoting soil moisture content [61], improving crop yields and water use efficiency (WUE) [62].

5. CONCLUSION

The present study demonstrated that tillage and mulching influenced significantly soil physical properties (soil moisture content, soil temperature, soil infiltration rate) and water use efficiency for production both maize grain and biomass. Tillage increased water use efficiency for maize grain (WUEg) and biomass (WUEb) production by 57% and 62% respectively compared to no tillage. They are higher on mulched plots (M50 and M75) than on bare plots, an increase of 47.45% and 38% respectively. Compared to the combinations, the treatments tillage + 75% soil cover, tillage + 50% soil cover and No tillage + 50% soil cover as straw mulch generated the highest WUEg and WUEb and tillage + 0% soil cover (Zero mulch) had the lowest water use efficiency.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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