



Impact of Tillage and Vegetative Mulch on Growth and Yield of Maize under Ferralitic Soil Conditions in Southern Benin

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Authors' contributions

This work was carried out in collaboration among all authors. Authors MSA and AFK designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript.

Authors TMA and JA 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

Aims: Crop production is exposed to climate change phenomenon resulting in change in rainfall amount and long drought spells. Good conservation practices are important in yield improvement. This study aims to assess the effect of tillage and vegetative mulch on maize growth rate, yield and harvest index in ferralitic soil of southern Benin.

Study Design: The complete randomized block design (CRBD) 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: During this study, two factors were tested (Tillage and mulch) and 6 treatments have been obtained of combination of two factors level (No-tillage, tillage and 0%, 50%, 75% mulch). The growth parameters, yield parameters and harvest index were determined.

Results: The results indicated that tillage and mulching significantly influenced the growth rate, leaf surface and leaf number of maize plants. Tillage increased to 54% the grain yield compared to no tillage whereas 50% and 75% mulch promoted the highest grain yield. Considering the combination of tillage and mulching, LM50 (Tillage + 50% mulch) and LM75 (Tillage + 75% mulch) treatments resulted in about 85% increase of grain yield compared to direct seeding without mulch.

Conclusion: These results reflect the importance of soil cover in improving of maize productivity.

Keywords: No-tillage; mulching; agronomic performance; productivity; maize yield.

1. INTRODUCTION

“Zero hunger” achievement as want by the Sustainable Development Goal (SDG) constitutes a great challenge for agriculture since world population is growing and expected to reach 10 billion by 2050 [1]. The food needs have to increase by 50 to 70 % in 2050, and agricultural production must more than double before covering this needs [2]. Soil appears increasingly unable to meet this global food need due to the continuous decline in soil fertility [3]. Indeed, soil degradation due to lack sustainable agricultural practices (burning, low restitution of crop residues, deforestation) leads to low soil productivity [4]. In Benin, several research works have pointed out the alarming level soil degradation [5-7]. Specially in southern Benin, demographic pressure and low cultivable superficies available lead up to land overexploitation [8]. Likewise, in this part of the Benin, ferralitic soils are the dominant type of soil and most exploited soil [7]. They are essentially made up of red ferralitic soil, developed on sedimentary materials of the Continental Terminal. These soils are the result of extreme alteration that led to the formation of kaolinite, a poor clay with low cation exchange capacity, thus making these soils poor as soon as they are devoid of organic matter [9]. Faced with this situation, farms need to be intensified, sustainable and restored at the same time in order to achieve sustainable development goals.

In fact climate change and accelerated soil degradation threaten food security, agro-ecological transition is an important approach to improving yields. However, conservation agriculture has been promoted as a means to protect soils from erosion, conserve/retain moisture and reduce production costs [10-12]. Because of its importance on the physical, chemical and biological properties of the soil, mulching appears to be an agroecological

practice for conserving and restoring soil fertility and therefore increasing crop yields. Another important factor for increasing maize yield that should be addressed is the tillage method [13].

Evaluation studies of sustainable land management practices have been carried out in many watersheds of Benin to quantify runoff, land loss, nutrient loss and also maize yield [9,12,14]. But none has been conducted on ferralitic soils of the southern plateau, the most important type of soil in southern Benin. Also, for sustainable agricultural intensification, the impact of the combination of mulching and tillage on yield, a type of ploughing inventoried in the south [9] on the Allada and Aplahoue plateaus in central Benin is still poorly known. Therefore, this study aims to assess the impact of tillage and vegetative mulch on the production of maize in ferralitic soil in southern Benin.

2. MATERIALS AND METHODS

2.1 Study Area

The experimental site is located at Allada, in southern Benin, and lies between parallels 06°36'00" and 06°39'30" north latitude and 02°11'40" and 02°15'00" east longitude. The rainfall pattern is bimodal in the two sites: Long Rain season (LR) from April to July and Short Rain season from September to November. The trial was carried out on ferralitic soil, locally known as "terre de barre". The pH_{water} measured was 5.9, therefore soil was few acid. Soil organic carbon, total soil nitrogen and soil available phosphorus are 0.44%, 0.021% and 27.72 ppm, respectively.

2.2 Experimental Design and Treatments

The experiment was laid out in Fisher block with four replications (Fig. 1). Two tillage practices

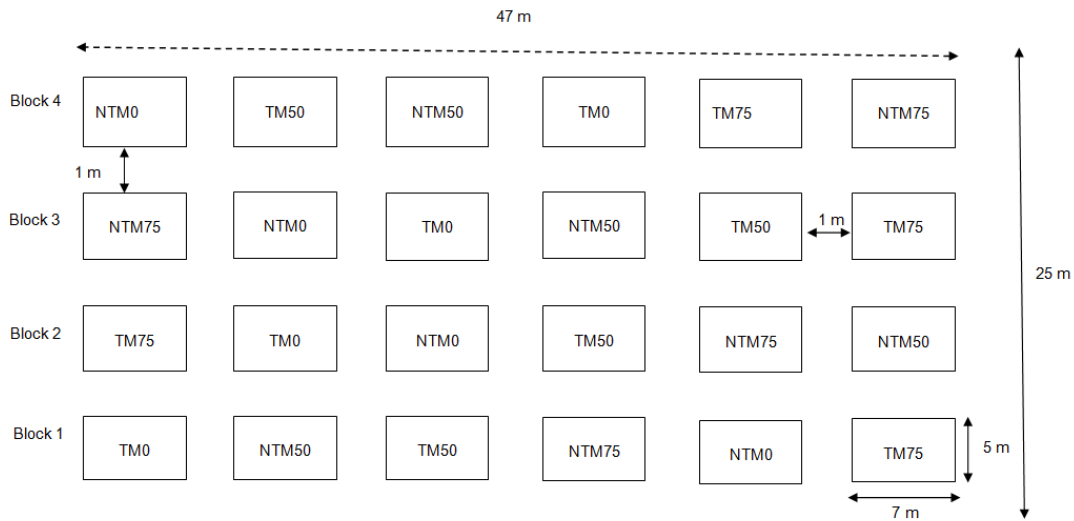


Fig. 1. Experimental layout

Table 1. Details and codification of the treatments

Treatments	Codification
No-tillage + 0% soil cover with mulch	NTM0
No-tillage + 50% soil cover with mulch	NTM50
No-tillage + 75% soil cover with mulch	NTM75
Tillage + 0% soil cover with mulch	TM0
Tillage + 50% soil cover with mulch	TM50
Tillage + 75% soil cover with mulch	TM75

(no-tillage and tillage) were combined with three mulching levels (0%, 50% and 75% mulch). The details of the tested treatments are shown in the Table 1.

The tillage was carried out manually with hoe on the top 20 centimeters. Mulching was made with maize straw. The investigated levels of soil cover were obtained as follow: 0 t.ha⁻¹ for 0% soil cover; 10 t.ha⁻¹ for 50% soil cover and 19.25 t.ha⁻¹ of dry matter for 75% soil cover [15]. Maize variety AK 94 DMR ESR-Y was sown at 50 × 40 cm². The fertilizer dose of the 30 kg K₂O.ha⁻¹ and 50 kg P₂O₅.ha⁻¹ were applied. Weeds management was done manually.

2.3 Data Collected and Analysis

2.3.1 Growth parameters

The height of the plants was taken 5 times from the 15th to the 75th days after sowing (DAS) at 15 days interval. Height was measured from the crown to the ligule of the leaf recently well extended by the maize plant. The growth speed

(a) was determined by the evolution of the average height (y) of the plants as a function of time (x) giving a trend curve of the equation:

$$y = ax + b \text{ where "a" is the growth rate;}$$

The number of leaves was obtained by counting the plants sampled at the 30th and 60th DAS. The number of leaves is counted from the first leaf at the base to the last fully developed leaf at the top;

The length and width of the floral leaf were measured at the end of male flowering (about 75th DAS) on the selected plants per experimental unit. Leaf length is measured along the midrib on the underside of the leaf while starting from the base of the leaf at the ligule, while width is measured at the middle of the leaf where it appears to be wider. These measurements will allow the conventional calculation of leaf area (LA) according to the method developed by [16]. They estimate that the ligulate leaf has a fixed surface area that is maximum in the shape of a trapezium. Surface

area of the leaf is calculated by the formula below:

$$LA = 0.75 \times L \times W,$$

With: LA = the leaf area (cm²); L = length of the leaf and W = maximum width of the leaf.

2.3.2 Yield parameters

Yield in grains, straws, spathes and stalks: The data needed to estimate these different yield parameters were collected at harvest after maturity and almost complete drying of all plants. Maize was harvested from a net area of 4 m x 2 m (or 8 m²) in each plot. Once the plants have been cut at the collar, samples of the cobs, straws and spathes were separated and fresh weights were determined.

Samples of cobs, straws and spath are placed in an oven at 65°C for 72 hours as such as constant weight and weighted. The cobs were shelled per experimental unit and the weight of the grains and the stalks were weighted using the precision balance. Grains, straw, spathe and stalk yields was estimated as follow [17]:

$$GY = \frac{10000 \times W \times DM \times r}{HA}$$

Where GY: Grain yield (kg DM. ha⁻¹); W: Total weight of ears weighed in the field (kg); DM: Dry matter content of cob; HA: Harvested net area (m²) and r: Ratio weight dry grains of the sample after ginning to total weight dry cobs sample.

$$SY = \frac{10000 \times TW \times DM}{HA}$$

Where SY: Straw Yield, spathe or stalk (kg DM. ha⁻¹); TW: Total weight of straw, spathe or stalk weighed in the field (kg); DM: Dry matter content

of straw, spathe or stalk and HA: Harvested net area (m²).

The Harvest Index, HI [18]:

$$HI = \frac{\text{Grain Yield}}{\text{Grain Yield} + \text{Straw Yield}}$$

3. RESULTS

3.1 Effect of Tillage and Mulching on Growth Parameters

3.1.1 Effects of treatments on growth speed

Findings of the analysis of variance on growth speed showed that tillage, mulching and their interaction significantly ($P = 0.0001$; 0.0001 and 0.02 respectively) influenced the growth speed of maize crop (Table 2). Tillage increased plant growth speed compared to no-tillage, i.e. an increase of 19%. For mulching, maize growth speed on plots without mulch was significantly lower than the one on plots with mulching (50% and 75% mulch), i.e. in the order of 2.29, 2.74, 2.82 cm per day for 0%, 50% and 75% mulch respectively (Table 3). Both 50% and 75% mulch increased the growth speed of maize crop by more than 15%. Tillage and mulching also significantly interacted to influence the growth of maize crop. The treatments, tillage combined both 75% mulch and 50% mulch (TM75 and TM50) had the highest growth speed followed by TM0, NTM75 and NTM50 treatments which were not significantly different and finally NTM0 generating the lowest growth speed (Fig. 2). Mulching increased growth speed on ploughed plots compared to no-ploughed plots. In addition, plant growth speed was higher on No-tillage plots with mulch than on No-tillage plots without mulch. This result is in agreement with those of [14,19,20] who indicated that tillage and mulching enhances maize plant growth.

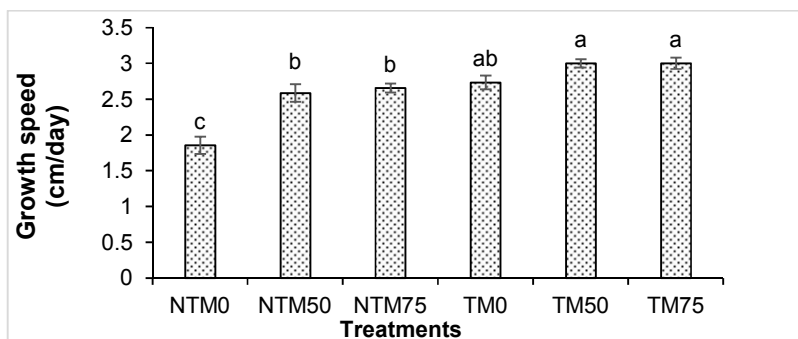


Fig. 2. Effect of treatments on maize growth rate

NTM0: No-tillage + 0% soil cover, NTM50: No-tillage + 50% soil cover, NTM75: No-tillage + 75% soil cover, TM0: Flat tillage + 0% soil cover, TM50: Flat tillage + 50% soil cover, TM75: Flat tillage + 75% soil cover. For the same factor and the same variable, the values with the same letter are not significantly different. Mean \pm S.E.M = Mean values \pm Standard error

Table 2. Probability of effect of study factors on growth parameters

Sources of variation	DDL	Plant Growth		Leaf_30DAS		Leaf_60DAS		Leaf_area	
		F value	P value	F value	P value	F value	P value	F value	Pr value
Tillage	1	51.01	<0.0001***	11.37	0.003**	29.08	<0.0001***	5.92	0.03*
Mulching	2	20.35	<0.0001***	0.19	0.83ns	10.40	0.001**	4.47	0.03*
Tillage*Mulching	2	4.79	0.025*	0.88	0.43ns	3.36	0.06ns	0.71	0.5ns

ns: No significant ($P > 0.05$); *: significant ($P < 0.05$); **: highly significant ($P < 0.01$); ***: very highly significant ($P < 0.001$)

Table 3. Effect of tillage and mulching on growth parameters

Study factors	Modalities	Growth speed (cm/day)	Number of leaves_30DAS	Number of leaves_60DAS	Leaf_area (cm ²)
Tillage	No-tillage	2.37 ± 0.12 b	6.54 ± 0.24 b	10.93 ± 0.35 b	581.15 ± 27.58 b
	Tillage	2.91 ± 0.06 a	7.59 ± 0.18 a	12.45 ± 0.20 a	663.91 ± 27.07 a
Mulching	M0	2.29 ± 0.18 b	7.06 ± 0.45 a	10.79 ± 0.53 b	552.11 ± 31.16 b
	M50	2.79 ± 0.10 a	7.19 ± 0.19 a	12.05 ± 0.33 a	670.58 ± 38.30 a
	M75	2.83 ± 0.08 a	6.95 ± 0.30 a	12.23 ± 0.25 a	644.90 ± 26.57 a

For the same factor and the same variable, the values with the same letter are not significantly different. Mean ± S.E.M = Mean values ± Standard error

Table 4. Probability of effect of study factors on yield parameters

Sources of variation	DDL	Grain yield		Straw yield		Spathe yield		Stalk yield		Harvest index	
		F value	P-value	F value	P-value	F value	P-value	F value	P-value	F value	P-value
Tillage	1	33.2	< 0.0001***	11.37	0.005**	6.22	0.027*	21.08	0.0005***	1.4	0.258ns
Mulching	2	9.42	0.003**	1.5	0.26ns	5.18	0.02*	7.68	0.006**	3.76	0.052ns
Tillage*Mulching	2	64.29	< 0.0001***	28.76	< 0.0001***	39.86	< .0001***	58.66	< 0.0001***	0.73	0.7272ns

ns: No significant ($P > 0.05$); *: significant ($P < 0.05$); **: highly significant ($P < 0.01$); ***: very highly significant ($P < 0.001$)

Table 5. Effect of tillage and mulching on yield parameters

Factors	Modalities	Grain yield (kg DM. ha ⁻¹)	Straw yield (kg DM. ha ⁻¹)	Spathe yield (kg DM. ha ⁻¹)	Stalk yield (kg DM. ha ⁻¹)	Harvest index
Tillage	No-tillage	1335.73 ± 284.50b	2266.08 ± 449.46b	446.84 ± 90.92b	313.5 ± 72b	0.36 ± 0.03a
	Tillage	2899.99 ± 220.3a	4401.05 ± 389.52a	681.91 ± 56.53a	598.61 ± 39.12a	0.399 ± 0.01a
Mulching	M0	1565.59 ± 407.36b	2955.33 ± 672.53a	434.15 ± 99.02b	364.1 ± 90.58b	0.32 ± 0.02a
	M50	2786.35 ± 376.11a	3995.3 ± 278.07a	701.36 ± 107.41a	615.57 ± 43.65a	0.41 ± 0.03a
	M75	2527.84 ± 382.74a	3696.63 ± 771.47a	647.13 ± 64.35a	495.17 ± 79.43ab	0.419 ± 0.03a

For the same factor and the same variable, the values with the same letter are not significantly different. Mean ± S.E.M = Mean values ± Standard error

3.1.2 Effects of treatments on the leaf surface

Tillage and mulching significantly ($P = 0.03$) influenced the leaf area of maize crop (Table 2). Tillage increased the leaf area of maize crop by 663.91 cm² compared to 581.15 cm² for no tillage (Table 3). As for mulching, 75% and 50% mulching increased the leaf area by 17% compared to the bare plots with the lowest leaf areas. Contrariwise, the combination of tillage and mulching had no significant effect on this parameter (Table 2). Nevertheless, the treatments can be classified as follows, in descending order based on their arithmetic means: TM50; TM75; NTM50; NTM75; TM0 and NTM0 (Fig. 3). These results are similar to that of [21] who also reported higher leaf area plant in conventional tillage compared to no-tillage in maize and thus was attributed to higher leaf area plant in conventional tillage abundant root growth compared to that of zero tillage.

3.1.3 Effects of treatments on the number of leaves

Tillage has significantly influenced (Table 2) this number of leaves at 30 and 60 days after seeding (DAS). Tillage resulted in higher leaf counts on the plants than no tillage. Compared to mulching, tillage had no effect on this parameter at 30 days after seeding but significantly influenced leaf count at 60 days after seeding. At this date, the mean number of leaves with 75% and 50% mulch did not show a significant difference but increased by 2 leaves compared to the soil without mulch. Compared to their

interaction (tillage and mulching), there was no significant effect at 30 DAS while the effect was significant at 60 DAS (Fig. 4).

3.2 Effect of Tillage and Mulching on Maize Yield Parameters

The results of the analysis of variance showed that tillage, mulching and their interaction significantly (respectively $p = 0.0001$; 0.003 ; 0.0001) influenced grain yield (Table 4). Tillage increased grain yield (2900 kg.ha⁻¹) by 54% compared to the no-tillage (1336 kg.ha⁻¹) modality (Table 5). For mulching, the 50 and 75% mulch modalities showed the best grain yields and are not significantly different from the no-till modality, but they do show a difference in grain yield compared to the no-cover modality (Zero mulch).

Compared to the combination of tillage and mulching (Fig. 5), the TM50 and TM75 treatments (3268.08 kg DM/ha) gave the highest grain yield, an increase of about 85% compared to direct seeding; followed by the TM0; NTM50 and NTM75 treatments which are intermediate. The combinations showed that the TM75; TM50; TM0; NTM50; NTM75 treatments were not significantly different.

Similar results are obtained likewise with the other performance parameters (Fig. 6). Thus, tillage, mulching and their interaction significantly influenced straw, spathe and stalk yields, but mulching had no significant effect on straw yield (Table 4).

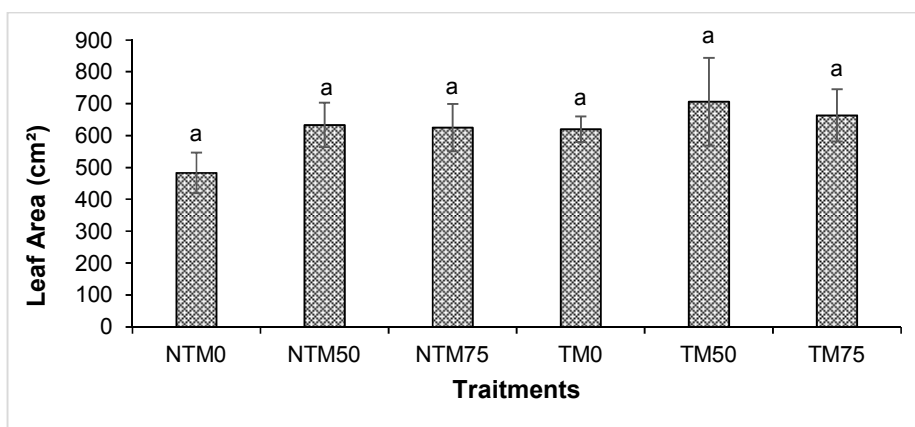


Fig. 3. Effect of treatments on leaf area

NTM0: No-tillage + 0% soil cover, NTM50: No-tillage + 50% soil cover, NTM75: No-tillage + 75% soil cover, TM0: Flat tillage + 0% soil cover, TM50: Flat tillage + 50% soil cover, TM75: Flat tillage + 75% soil cover. For the same factor and the same variable, the values with the same letter are not significantly different. Mean \pm S.E.M = Mean values \pm Standard error

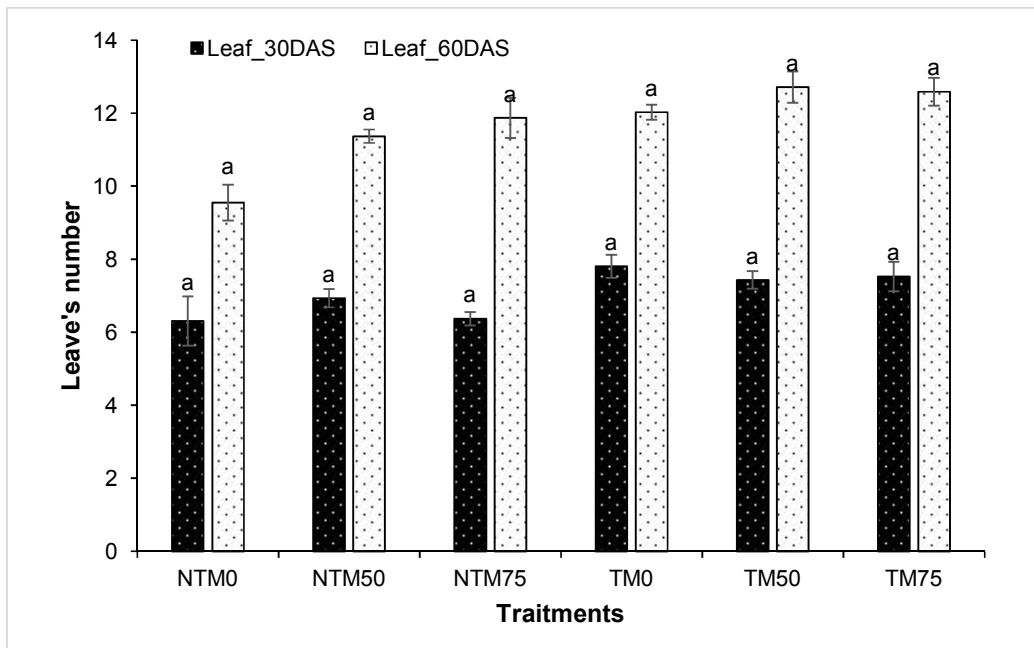


Fig. 4. Effect of treatments on the number of leaves at 30 and 60 JAS

NTM0: No-tillage + 0% soil cover, NTM50: No-tillage + 50% soil cover, NTM75: No-tillage + 75% soil cover, TM0: Flat tillage + 0% soil cover, TM50: Flat tillage + 50% soil cover, TM75: Flat tillage + 75% soil cover. For the same factor and the same variable, the values with the same letter are not significantly different. Mean \pm S.E.M = Mean values \pm Standard error

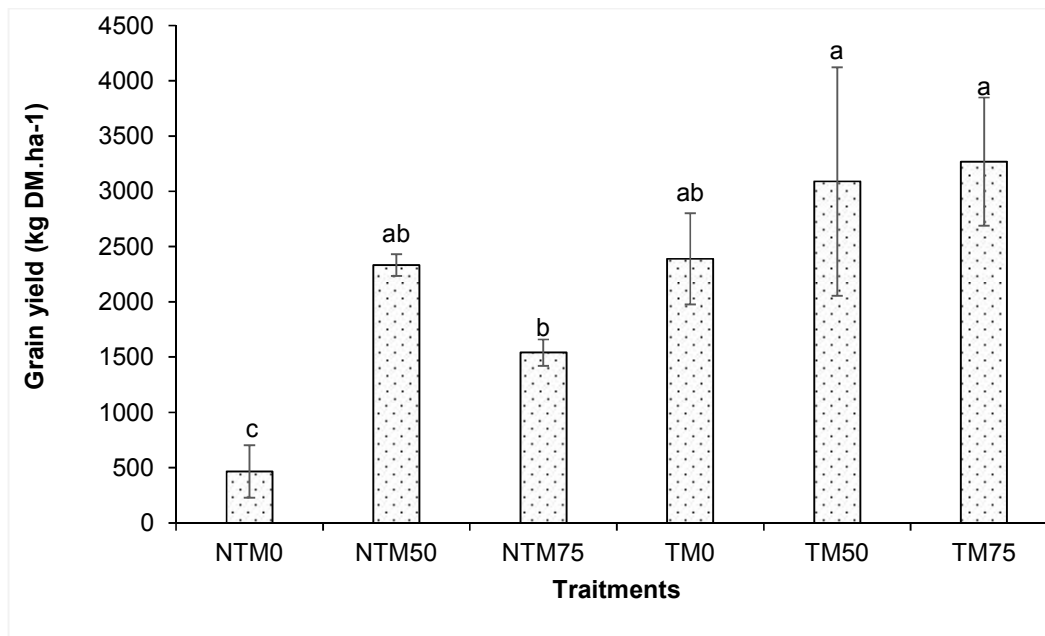


Fig. 5. Effect of combined tillage and mulching on grain yield

NTM0: No-tillage + 0% soil cover, NTM50: No-tillage + 50% soil cover, NTM75: No-tillage + 75% soil cover, TM0: Flat tillage + 0% soil cover, TM50: Flat tillage + 50% soil cover, TM75: Flat tillage + 75% soil cover. For the same factor and the same variable, the values with the same letter are not significantly different. Mean \pm S.E.M = Mean values \pm Standard error

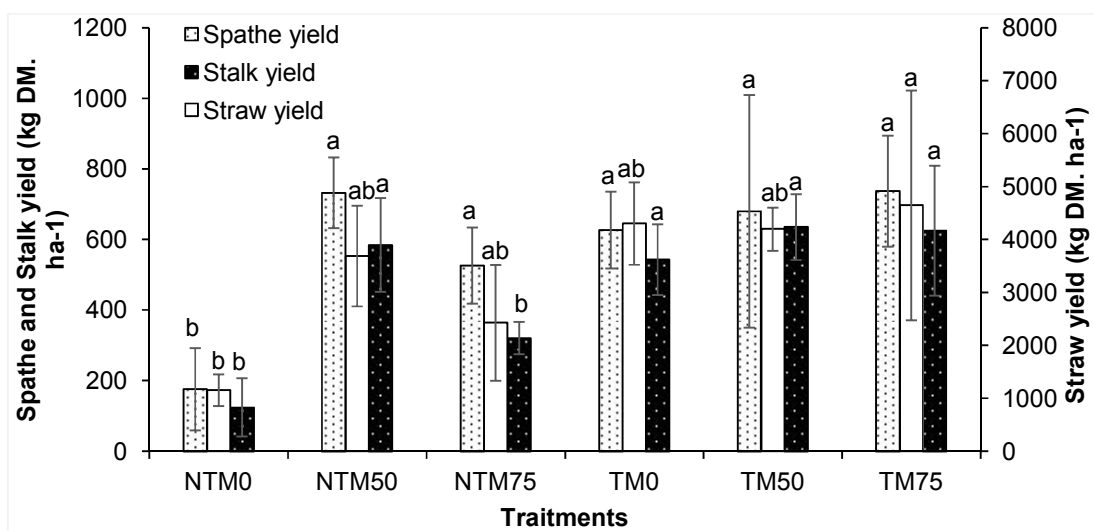


Fig. 6. Interaction Effect of tillage and mulching on biological yield

NTM0: No-tillage + 0% soil cover, NTM50: No-tillage + 50% soil cover, NTM75: No-tillage + 75% soil cover, TM0: Flat tillage + 0% soil cover, TM50: Flat tillage + 50% soil cover, TM75: Flat tillage + 75% soil cover. For the same factor and the same variable, the values with the same letter are not significantly different. Mean \pm S.E.M = Mean values \pm Standard error

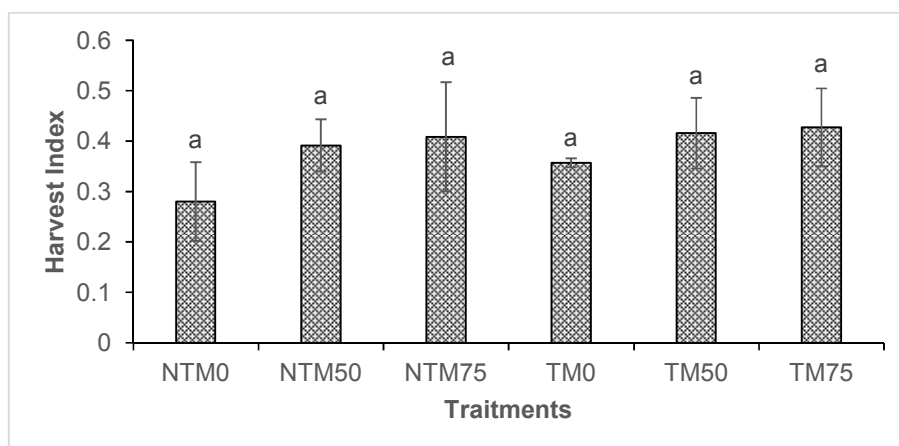


Fig. 7. Effect of combined tillage and mulching on harvest index

NTM0: No-tillage + 0% soil cover, NTM50: No-tillage + 50% soil cover, NTM75: No-tillage + 75% soil cover, TM0: Flat tillage + 0% soil cover, TM50: Flat tillage + 50% soil cover, TM75: Flat tillage + 75% soil cover. For the same factor and the same variable, the values with the same letter are not significantly different. Mean \pm S.E.M = Mean values \pm Standard error

Concerning harvest index, the factors taken individually and their combination have no significant effect on this parameter (Table 4). Nevertheless, interactions with the mulching practice presented the highest yield indices (Fig. 7).

4. DISCUSSION

This study adds to the assessment combined effect of ploughing and mulching on growth and

yield parameters of maize on ferralitic soil, major soil in southern Benin. Results on growth parameters showed that tillage and mulch significantly increased growth rate, leaf area and leaf count of maize plants. Similar results are obtained by other authors [22-25] who showed that maize plants develop slowly in no-till without ground cover [14]. This can be explained, on the one hand, by the fact that tillage allows soil aeration by loosening the superficial humus layer of the soil, thus increasing soil macroporosity by

accelerating more rapidly the mineralization of organic matter [26] due to the relatively high temperature. On the other hand, from [27] and [28] results, no-tillage maize cultivation and plots with mulch had a positive influence on: soil moisture conservation, water infiltration, soil temperature regulation and high soil compaction. This is consistent with studies by [29], who showed that any moisture gain achieved, based on good conservation practice, is important because it can induce significant yield increases. For [30], mulching improves soil physical, chemical and moisture properties compared to no-till without organic input through higher soil infiltration, moisture, porosity and structural stability. These results reflect the importance of soil cover in improving plant growth that determines crop yield.

Studies by other authors among elite producers who were accompanied by extension services showed conclusive results and benefits of soil fertility status in different agro-ecological zones following the practice of conservation agriculture [31]. Indeed, according to the results obtained, tillage significantly increases maize grain, biomass, husk and cob yields, and these are even higher with the practice of mulching. All else being equal, the same observation was made on the no-tillage plots when the soil is covered with mulch and allows a yield that is more or less equal to the plots worked. These results attest to the strong plant growth allowed by the gain in soil moisture, water infiltration and soil temperature regulation with the presence of 50 to 75% mulch cover. In addition, similar evaluation studies of dryland conservation agriculture have shown that yield performance under Conservation Agriculture is influenced by soil type, rainfall amount and distribution, inorganic fertilizer and manure application [3]. Also, they showed that tillage has no effect on yield. It is therefore important to encourage all practices that aim to improve soil water parameters. Mulching technology can effectively modify the crop growth environment and crop production due to differences in climatic conditions, spatial distribution characteristics, and cropping system. Several researchers [14,32,33] unanimously agreed on the importance of soil cover and a consequent rate on maize productivity. Comparing the treatments, [26] found that isohypse tillage combined with crop residue management improved soil nutrient stocks in upslope sites, Eutric Plinthosol, upslope in Burkina and Plinthic Lixisol, upslope in Benin. They report that mulching improves soil structure

through high biological activity under mulch and the decomposition of the mulch increases the cation exchange capacity and water retention capacity of the soil and improves soil nutrient stocks. This confirms the importance of mulching both in maize productivity and sustainable soil conservation [33].

5. CONCLUSION

The findings of this present study showed tillage and mulching effect on maize productivity in South Benin, specifically on ferrallitic soils. Thus, tillage and mulching significantly influenced the evaluated growth parameters. In fact, treatments combining tillage and mulching (50 and 75% mulch) significantly increased growth speed, leaf area and the number of leaves on maize plants. Tillage, mulching and their interaction significantly influenced all yield components of maize. The results showed that tillage increases grain yield by 54% compared to the no-till modality. Concerning mulching, the 50 and 75% mulch modalities had the highest grain yields. The combination of tillage and mulching (50 or 75% mulch) gave the highest grain yield (3268 Kg MS/ha), i.e. an increase of about 85% compared to no tillage without mulch.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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