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Tillage and Mulching Effect on Maize Crop (ZEA-MAYS) Growth in Iraq's Arid Environments

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Abstract. This study investigates the impact of various tillage and mulching systems on the growth and physiological traits of maize (Zea mays L.) in arid and semi-arid environments. The Split Plot design was conducted using a Randomized Complete Block Design (RCBD), which facilitated the arrangement and distribution of the treatments, the experiment included five tillage and three mulching treatments. Results demonstrated that conventional tillage, particularly deep tillage combined with rotary harrow, significantly enhanced plant height, stem diameter, chlorophyll content, root depth, and dry weight compared to conservation tillage systems. This superiority is mainly attributed to improved soil aeration, reduced bulk density, and enhanced root penetration, which facilitate better water infiltration and nutrient uptake, as well as more uniform heat transfer within the soil profile. Organic mulching proved most effective for improving soil moisture retention and regulating temperature, positively affecting plant growth. Deep tillage with organic mulching consistently delivered superior results in the majority of growth parameters. Additionally, these soil management strategies contribute to sustainable agriculture by improving soil structure, reducing erosion, and conserving water. This study highlights how integrating these practices can optimize crop productivity while mitigating environmental stressors, fostering greater sustainability in arid agriculture systems.

Keywords: Soil Tillage, Mulching Systems, Soil Properties, Crop Growth, Arid Regions.

INTRODUCTION

The practice of tillage and mulching in agriculture has direct effects on physical and chemical characteristics of the soil which in turn on effect crop growth and yield. Although conventional tillage provides a suitable environment for germination during the initial stages of plant development [1], excessive use tends to cause loss of soil moisture, amplified rate of soil erosion and high environmental expenses. This highlights the need to adopt more sustainable conservation tillage methods that help in the optimal utilization of natural resources [2][3][4]. Similarly, both organic and inorganic mulching systems have been found to be effective in improving thermal and moisture properties of soil, increasing biological activity, and preserving soil structure, which are significant considerations in achieving sustainable agriculture [5]. The combination of sustainable tillage systems and mulching methods helps to enhance water use efficiency and a more stable environment, enabling crop growth, which positively influences vegetative growth, including plant height, leaf number, and biomass [6][7][8][9]. These practices are important because they are growing maize (Zea mays L.), which is a strategic product that has broad applications worldwide [10]. Although a lot of literature exists on the topic of tillage and mulching systems, there is limited understanding of how these systems can be integrated in arid and semi-arid regions, as those found in Iraq. Thus, the proposed research intends to determine the best system which can offer a stable thermal and humidity condition which diminishes climatic stressors and promotes vegetative growth in maize. It would help to specify the gap in research related to maize growth specifically.

This study is instrumental in the development of sustainable farming methods especially in the arid and semi-arid areas, whereby water scarcity and soil erosion are burning issues. The main purpose of the study is the determination of the best tillage and mulching systems. The research is expected to deliver viable solutions to the problem of raising the water-use efficiency and minimizing environmental stressors by examining various options of tillage, integration of organic and inorganic mulching, and in this respect, the research is guided by the principles of sustainable development. Although the effects of these systems are very documented in the world, there is still a huge gap about research done on the application of such systems in arid areas such as Iraq. Filling this gap does not only add to the local agricultural landscape but also offers some insights to be used in the similar environment that tackles the issue of climate change. Therefore, this research does not only serve to enhance scientific knowledge on soil management but also aids in the overall objective of attaining sustainable agricultural systems to help in food security and environmental sustainability.

EXPERIMENTAL PART

Experimental Site

The field experiment was conducted in the fields of the Agricultural Research Station affiliated with the Wasit Governorate Agriculture Directorate, specifically in the Al-Kardhiya area (longitude 45°54'7.31" east, latitude 32°32'21.15" north, and at an elevation of 25 meters above sea level). The soil at the field was classified as a silty clay mixture, possessing physical and chemical properties that affect crop behavior and the treatments being studied. The experimental period spanned from July 31, 2024, to December 2, 2024.

Average weather conditions were monitored, throughout the farming period. The average air temperature was 41.51°C, and the average humidity was 27.74%. The locality recorded a significant amount of solar energy, with an average solar radiation of 744.54 W/m² and an average wind velocity of 2.07 m/s. These weather conditions resulted in an average daily evapotranspiration (ET) rate of 6.01 mm.

Experimental Design and Experimental Treatments

The experiment was conducted using a Split Plot Design under a Randomized Complete Block Design (RCBD). Tillage systems served as the primary factor, while mulching systems were considered the secondary factor. The experiment included five different tillage patterns: zero tillage (no tillage) as the control, reduced tillage using disc harrows, mulch tillage with 13.5 kg of straw added to each experimental unit followed by plowing with disc harrows, conventional tillage using a moldboard plow, and deep tillage with a rotary harrow. For the mulching systems, three patterns were tested: organic mulch using wood sawdust, adding 281.25 g of mulch per plant; inorganic (mineral) mulch using gravel, adding 281.25 g of gravel per plant; and no mulch, serving as the control treatment. The total number of experimental units was 45 (5x3x3), covering an area of 600 m² (50x12 m), with each experimental unit measuring 9 m² (3x3 m).

Agricultural Operations

Maize (Zea mays L.), a hybrid variety of Nahrain, was planted on July 31, 2024, in rows, with four rows per plot. Each row contained 12 plants (48 plants per experimental unit). The distance between holes was 25 cm, and between rows was 75 cm. Three seeds were planted in each hole, then thinned after germination to one plant to ensure uniform growth.

Fertilization

Chemical fertilizers were applied following the recommendations of the Ministry of Agriculture: Triple superphosphate fertilizer (P_2O_5 20%) was applied at a rate of 240 kg/ha^{-1} before planting, potassium sulfate fertilizer (K_2SO_4 41.5%) was applied at a rate of 100 kg/ha^{-1} before planting, and urea fertilizer (N 46%) was applied at a rate of 200 kg/ha^{-1} in two batches, one month and two months after planting.

Soil Physical and Chemical Properties

Soil samples were collected from three depths (0-0.10 m, 0.10-0.20 m, and 0.20-0.30 m) and analyzed in the laboratory to determine basic properties such as pH, EC, organic matter, apparent soil density, total porosity, and others, as shown in Table 1.

TABLE 1. Some chemical and physical properties of field soil before planting

Property	Unit	Soil Depth (m)		
		0-0.10	0.10-0.20	0.20-0.30
Electrical Conductivity (EC)	dS/m	4.08	2.80	3.20

Property	Unit	Soil Depth (m)		
		0-0.10	0.10-0.20	0.20-0.30
pH	-	7.48	7.42	7.39
Organic Matter	%	1.50	1.25	1.05
Bulk Density	g/cm³	1.36	1.39	1.41
Particle Density (True Density)	g/cm³	2.43	2.45	2.47
Total Porosity	%	44.03	43.27	42.92
Soil Aggregation Stability	%	15.29	2.6	1.7
Saturated Hydraulic Conductivity	cm/hr	4.6	4.3	3.9
Field Capacity (Volumetric Moisture Content)	%	37	36.3	36.7
Permanent Wilting Point (Volumetric Moisture Content)	%	17.8	15.8	15.7
Sand	g/kg soil	193	212	255
Silt	g/kg soil	471	474	452
Clay	g/kg soil	336	314	293
Soil Texture	-	Silty Clay Loam	Clay Loam	Clay Loam

Measurements Studied

Various physiological and vegetative characteristics were measured which included plant height (cm), stem diameter (mm), leaf relative chlorophyll content (mg kg-1), root depth (cm), and dry weight of the vegetative system (g). The height of the plants in an experimental unit was measured randomly, by using a graduated ruler, between the emergence of the stem above the soil surface to the male inflorescence node at a physiological maturity [11]. Diameter of stems was determined using a Vernier meter to the nearest mm, at the second node above ground considering that the leaf sheaths were removed and the mean was obtained using the same plants that were used in height measurements [12]. The chlorophyll content of leaves was ascertained against a spectrophotometer of five plants each of the experimental unit [13]. In the case of root depth, the soil was laboriously excavated around the plant with a depth of 15 to 20 cm and the measurements of root extension were done with the help of a measuring scale [14]. Lastly, the dry weight of vegetative system was calculated by picking a certain number of plants, washing them with plain and distilled water to remove the suspended matter, cutting and oven-drying at 65 o C until the weight was constant and the average was taken [15].

Statistical Analysis

An analysis of variance (ANOVA) was conducted using the GenStat statistical program. The significance of differences between means was then tested using the least significant difference (LSD) test at a probability level of 0.05. This test was chosen for its suitability for balanced designs and its accuracy in identifying statistical differences between agricultural treatments.

RESULTS AND DISCUSSION

Table 2 showed that the mean height of the plant was least in the No Tillage treatment (140.70 cm). This is explained by the fact that it raises the bulk density of soils and their inability to be aerated, resulting in minor growth of the root and a decrease in the rates of water and nutrient uptake as noted in [11]. On the contrary, Deep Tillage with rotary harrow treatment was the best in terms of plant height (160.17 cm). This is because the hardpan layers were loosened and aeration and permeability improved and this increased the ability of the roots to lengthen and absorb water and nutrients thus increasing vegetative growth. These are the same results as [9][12]. Another observation indicated that there was no significant influence of mulch systems on maize plant height. The mean of the height was (148.92 cm) in the no-mulch treatment, (152.10 cm) in the organic mulch treatment and (149.96 cm) in the Inorganic mulch treatment. Although there are no real differences, the overall pattern suggests that organic mulch is the best in terms of enhancing the plant height as opposed to the other treatments. This can be attributed to the fact that organic mulch helped in enhancing the physical properties of the soil by lowering the evaporation rate and raising the moisture levels which were exhibited in the vegetative growth. as supported by [13][14]. Regarding the interaction effect of tillage systems with the soil mulch on the maize height, the appendix findings indicated that the maximum plant height was attained using Deep Tillage with rotary harrow + organic mulch, which was (162.1 cm). This is as a result of the fact that deep soil gets to be loosened, moisture is maintained and it gets to be supplemented with organic matter which, provides the perfect environment in which roots and shoots thrive. This is in agreement with [15]. The treatment with the lowest values was No Tillage + no-mulch (140.1 cm), which was the consequence of the poorer aeration and the surface soil being dry, and this hinders the growth of vegetation [16].

TABLE 2. Effect of tillage and soil mulching systems on plant height (cm)

Tillage Systems	Soil mulching			Average of Tillage Systems
	No mulching	Organic mulching (Wood)	Inorganic mulching (Gravel)	
No-Tillage	140.1	141.7	140.3	140.7
Reduced Tillage	143.1	144.3	143.8	143.73
Mulch Tillage	144.8	153.7	148.5	149
High Tillage	157.7	158.7	157.7	158.03
Conversional Tillage	158.9	162.1	159.5	160.17
l.s.d	13.56			l.s.d 5.61
Average of Soil Mulching	148.92	152.1	149.96	
l.s.d	N.S			

Table 3 indicates that the lowest value was obtained in the No Tillage treatment with a stem diameter of (19.79 mm). This can be attributed to high soil bulk density, poor aeration, and difficulty in root penetration, Consequently, this leads to decreased photosynthesis and stunted vegetative growth. In contrast, Deep Tillage and rotary harrow on the other hand were the best due to attaining (23.68 mm). The loosening of deep soil also enhanced aeration, moisture availability and permeability, thereby promoting growth of roots and its efficiency in water and nutrient uptake, thereby, efficiency of vegetative growth, and stem thickness. The findings are in line with the works of [14][16]. Table 3 also shows that three systems of mulch had a massive impact on the diameter of the stems, with the number being different depending on the kind of mulch used. The lowest figure was observed in the no-mulch treatment (21.29 mm) and this can be explained by the fact that the moisture of the surface was lost as well as the temperature in the surroundings changed significantly. This resulted in low nutrient absorption capability and adversely affected the strength of stems, which goes in line with the results reported in ([18]. Organic mulch on the other hand had the highest average stem diameter (22.27 mm). The reason is that the organic compounds enhanced the ability of the soil to retain moisture and enhance the level of nutrients by decomposing them through biology thereby supporting growth in stem and making it thicker according to [13][14]. In the case of interaction effect of tillage systems and soil mulch on the stem diameter, it was found that the Deep Tillage with rotary harrow + Organic mulch treatment had the highest value (257.2 mm). The harmonious movement of enhancing the physical make-up of the soil, making it more fertile and retaining its moisture gave an optimal habitat of robust and dense stem growth. This is in line with the research by [15]. On the other hand, the No Tillage + no-mulch treatment had the lowest reading (195.9 mm) that represents the cumulative adverse effects of the high soil bulk density and moisture loss that undermine photosynthesis and vegetative growth. This is in conformity with the results of [17].

TABLE 3. Effect of tillage and soil mulching systems on stem diameter (mm)

Tillage Systems	Soil mulching			Average of Tillage Systems
	No mulching	Organic mulching (Wood)	Inorganic mulching (Gravel)	
No-Tillage	19.59	20.18	19.6	19.79
Reduced Tillage	20.75	21.21	21.04	21
Mulch Tillage	21.68	22.01	22	21.9
High Tillage	22.08	22.25	22.17	22.17
Conversional Tillage	22.34	25.72	25.72	23.68

Tillage Systems	Soil mulching			Average of Tillage Systems
	No mulching	Organic mulching (Wood)	Inorganic mulching (Gravel)	
l.s.d	2.137			l.s.d 1.496
Average of Soil Mulching	21.29	22.27	21.56	
l.s.d	0.929			

Table 4 results indicated that the lowest values were obtained in No Tillage treatment (731.15 mg kg -1). This is explained by the elevation of the bulk density of soils and inability to develop roots well, which inhibits the uptake of nitrogen required in the formation of chlorophyll as it has been substantiated by [17]. Deep Tillage with rotary harrow on the other hand performed the best (937.27 mg kg -1). This is because it is involved in loosening hardpan layers and enhancing the permeability of soils and aeration and also increasing the absorption capacity of nitrogen, iron, magnesium and water, which are major constituents of chlorophyll. This was a perfect background to growth of roots and the vegetative stage as was evidenced by the increased photosynthetic efficiency and chlorophyll content as reported in [14][15]. Another finding in Table (4) also showed that the mulch systems did not have the same extent of influence on the chlorophyll content of maize leaves. The mean content in the treatment of (812.56 mg kg -1) was due to the loss of moisture through evaporation and the rise in the fluctuations of temperature, which undermined the ability of the nutrient absorption, particularly that of nitrogen, thereby lowering the chlorophyll content. This is in agreement with what was reported by [18][19]. In the meantime, the highest value was registered by Organic mulch (855.11 mg kg -1). The differences were not significant however the overall trend shows the superiority of Organic mulch over the other treatments. The excellence of Organic mulch can be discussed due to the fact that it improves the environment of the soil by making it more moist and minimizes the number of thermal fluctuations every day. Moreover, it also helps in the improvement of soil fertility by decomposing organic materials and biological activity, which favored the uptake of nitrogen and other nutrients needed to form chlorophyll in the leaves, which is consistent with what [14] has found. In the case of the interaction effect between tillage and soil mulch, the highest value (961.73 mg kg -1) was obtained in Deep Tillage with rotary harrow + Organic mulch treatment. This was attributed to incorporation of a better physical properties of the soil along with incorporation of organic matter that enhanced the ability of soil to absorb nitrogen hence leading to an increase of the level of chlorophyll, a conclusion that is in line with the research by [15]. Conversely, the least (702.4 mg kg -1) was registered in the No Tillage + no-mulch treatment because the soil had deteriorated greatly in terms of aeration and loss of moisture, resulting in the stress of the plant as well as loss of chlorophyll content. This is in accordance with the study carried out by [17].

TABLE 4. Effect of tillage and soil mulching systems on leaf chlorophyll content (mg kg^{-1})

Tillage Systems	Soil mulching			Average of Tillage Systems
	No mulching	Organic mulching (Wood)	Inorganic mulching (Gravel)	
No-Tillage	**702.4**	**754.93**	**736.13**	**731.15**
Reduced Tillage	**764.73**	**802.07**	**773.13**	**779.98**
Mulch Tillage	**818.93**	**848.67**	**840.2**	**835.93**
High Tillage	**863.47**	**908.13**	**882.67**	**884.76**
Conversional Tillage	**913.27**	**961.73**	**936.8**	**937.27**
l.s.d	**5.216**			**l.s.d 2.728**
Average of Soil Mulching	**812.56**	**855.11**	**833.79**	
l.s.d	**2.573**			

Table 5 results revealed that the average of dry weight was lowest in the treatment with No Tillage, which was (108.57 g plant -1). This is attributed to the fact that the soil bulk density increased, aeration was poor, and the root penetration was high thus resulting in poor absorption of water and nutrients. This, in its turn influenced plant development and, by extension, plant dry mass, which can be expected given ([18]. On the other hand, Deep Tillage with rotary harrow treatment was the best treatment as it had the highest average dry weight of (345.07 g plant -1).

This is explained by the fact that it can break a hardpan layer and enhance the physical structure of the soil and enhance the porosity and permeability. This has offered a perfect root environment that supported the high efficiency of water and nutrient uptake which was expressed in an increased physiological efficiency of the plant and massive accumulation of dry mass. These results are compatible with the ones indicated [14][20]. Table (5) had shown that the mulch systems influenced the dry weight of the maize plants significantly and the values had a perceptible difference across treatments. The treatment with Organic mulch registered the highest (242.08 g plant -1) average. This is because it enhances the physical characteristics of the soil lowering water loss and alleviating fluctuations in daily temperatures, besides the fact that it contributes to the enhancement of organic matter and acts in promoting biological activity. This improved nutrient uptake of vital nutrients and the plant dry mass. This finding is in line with the results of [13]. To the contrary, the no-mulch treatment had the lowest mean dry weight of (171.9 g plant -1). This is due to the loss of moisture by direct evaporation and greater thermal variations that resulted in ineffective absorption of nutrients and ineffective physiological activities of the plant thus reducing the accumulation of dry mass. These findings are similar to those by [18].In the case of interaction effect of tillage systems and soil mulch on maize plant dry weight, the findings indicated that Deep Tillage with rotary harrow + Organic mulch had the best value (379 g plant -1). This is explained by the fact that deep loosening of the soil to improve the physical characteristics and enhancing the natural fertility of the soil by decomposing organic substances to increase the absorption of nutrients and the build of dry matter. This is in line with the results of [15]. In the meantime, the minimum value was registered in the treatment of No Tillage + no-mulch (60.2 g plant -1). This can be attributed to a drastic reduction in physical structure of the soil and the loss of moisture on the surface and this caused poor absorption of water and nutrients and also reduced the accumulation of dry matter. This is in line with the conclusions of [17].

TABLE 5. Effect of tillage and soil mulching systems on root depth (cm)

Tillage Systems	**Soil mulching**			**Average of Tillage Systems**
	No mulching	**Organic mulching (Wood)**	**Inorganic mulching (Gravel)**	
No-Tillage	**13.78**	**13.97**	**13.89**	**13.88**
Reduced Tillage	**14.02**	**14.54**	**14.33**	**14.3**
Mulch Tillage	**15.3**	**15.61**	**15.41**	**15.44**
High Tillage	**16.51**	**16.72**	**16.6**	**16.61**
Conversional Tillage	**16.81**	**17.69**	**17.55**	**17.35**
l.s.d	**1.638**			**l.s.d 0.795**
Average of Soil Mulching	**15.28**	**15.71**	**15.56**	
l.s.d	**NS**			

As indicated in Table 6, No Tillage treatment had the lowest average root depth of (13.88 cm). This can be attributed to the fact that the soil had high bulk density and low porosity, thus reducing the vertical and horizontal diffusion of roots a research that corroborates the findings of the study conducted by [18]. On the other hand, the Deep Tillage with rotary harrow treatment had the highest score as it obtained the highest average value of root depth of (17.35 cm). This is because it is effective to reduce the hardpan layers, enhance physical structure of the soil, and enhance its permeability. This enabled the roots to go deeper and effectively tap water and nutrient resources found in the lower layers. These findings are in line with those of [9]. Table (6) results revealed that there were no significant differences in the root depth in the mulch systems. The average root depth in the no-mulch treatment was (15.28 cm) and (15.71 cm) in the Organic mulch treatment respectively. There were no statistically significant differences, however, the result is that there is some slight advantage of Organic mulch over the other treatments. This growth can be attributed to the fact that Organic mulch offered a more conducive environment to growth of roots by which it minimized the thermal variation and retained moisture in addition to increasing the fertility because of the decay of the organic matter and the activity of the biological activity that enhanced vertical root growth. These results agree with [14]. The outcome of the interaction effect between the tillage systems and the soil mulch also revealed that Deep Tillage with rotary harrow + Organic mulch registered the best (17.69 cm) outcome. The interaction between the deep soil loosening, and the presence of better environmental factors, such as improved biological environment and conserved moisture enabled the sporulating roots to develop more freely, which confirms the study by [15]. Meanwhile, the treatment with No Tillage + no-mulch had the lowest value (13.78 cm), which can be explained by the high resistance to root penetration and a large proportion of surface moisture loss, which is similar to the results of [17].

TABLE 6. Effect of tillage and soil mulching systems on the dry weight of the vegetative group (g plant-1)

Tillage Systems	Soil Mulching			Average of Tillage Systems
	No Mulching	Organic Mulching (Wood)	Inorganic mulching (Gravel)	
No-Tillage	60.2	160.5	105	108.57
Reduced Tillage	131	171.2	148.2	150.13
Mulch Tillage	121.5	241.5	207.8	190.27
High Tillage	233.3	258.2	238.3	243.27
Conversional Tillage	313.5	379	342.7	345.07
l.s.d	54.07			l.s.d 30.47
Average of Soil Mulching	171.9	242.08	208.4	
l.s.d	26.1			

CONCLUSIONS

Conventional and deep tillage with rotary harrow systems demonstrated clear superiority over conservation tillage systems (zero, reduced, and mulched) in all vegetative and physiological traits of maize. These practices resulted in the highest values for plant height, stem diameter, chlorophyll content, root depth, and dry weight. Organic mulching contributed to improving and increasing soil fertility compared to inorganic mulching and no mulching, which positively impacted plant growth. The combination of deep tillage with thinning and organic mulching had the greatest impact on improving most traits, while the no-till and no mulching treatment recorded the lowest values, reflecting the negative impact of soil compaction and surface moisture loss in arid and semi-arid environments.

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