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Comparison of corn yield, water use efficiency (WUE), and growth under different tillage systems and fertilizer inputs

Amin Fathi[1], Davood Barari Tari[2], Hormoz Fallah Amoli[3] & Yousef Niknejad[4]

[1]ORCID https://orcid.org/0000-0002-7539-0053, Islamic Azad University, Ayatollah Amoli Branch, Department of Agronomy, Amol, Iran, [2]ORCID https://orcid.org/0000-0003-3712-0746, Islamic Azad University, Ayatollah Amoli Branch, Department of Agronomy, Amol, Iran, [3]ORCID https://orcid.org/0000-0002-7434-3140, Islamic Azad University, Ayatollah Amoli Branch, Department of Agronomy, Amol, Iran, [4]ORCID https://orcid.org/0000-0003-3328-7362, Islamic Azad University, Ayatollah Amoli Branch, Department of Agronomy, Amol, Iran.

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Email: davoodbarari@yahoo.com

Abstract

Context: Corn is one of the four most important cereals in the world after wheat and rice. Nitrogen and various tillage systems are important factors in improving the traits and performance of corn. Sustainable agriculture requires improvements in soil tillage management and more efficient application of fertilizers as agricultural resources.

Objective: Considering the importance of examining the status of nutrients, particularly nitrogen consumption in various tillage systems, and the impact of these factors on the performance, growth, and water use efficiency of corn in Iran, this research was conducted.

Methods: The experiment was performed as a split plot in a randomized completely block design (RCBD) with four replications in Darreh shahr city, Ilam province, Iran. The treatments consisted of three levels of soil tillage including NT (direct sowing), MT (using compound tillage and furrow) and CT (Moldboard plow+ double discs + leveler and furrow) as the main plot.

Results: The results showed that the highest total dry matter (TDM) was obtained in MT treatment at 4542.7 g/m^2 and the lowest in CT treatment at 4029.2 g/m^2. The amount of non-use of fertilizer $(NPK)_0$ was 0.61 kg/m^3. It can be stated that MT can improve the grain yield of corn with the highest WUE as well as increasing the properties during the growing season.

Conclusions: Based on the results of this study, it can be stated that MT can improve maize grain yield with the highest WUE and increase the characteristics during the growing season.

Key words: *net assimilation rate, crop growth rate, leaf area index, tillage, total dry matter.*

Introduction

Corn is considered to be an important food source in many different parts of the world (USDA 2021). Corn is one of the four most important cereals in the world after wheat and rice. More than one hundred million hectares of the world's agricultural land area are annually dedicated to corn cultivation. Corn is the third important cereal crop after wheat and rice in the world. On average, a corn field absorbs and removes 200 to 300 kg of nitrogen, 80 to 120 kg of phosphorus, and 200 to 300 kg of potassium per hectare of land (Fathi et al., 2016). Nitrogen management in corn could affect multiple process, directly or indirectly affecting the following soybean crop, modifying N nutrition, and eventually seed yield Besides the contribution to plant N demand from soil N supply, soybean establishes a symbiosis with Bradyrhizobium spp. that contributes, on average, 50–60% of N requirements (Salvagiotti et al., 2008) via the symbiotic N fixation (SNF) process. Therefore, avoiding negative pressures on ecological and improving developmental plans that meet the nutritional needs of crops is a prerequisite for conserving soil health. Conventional agriculture systems did not show an acceptable success in resources management and these systems by relying on artificial inputs. Among other variables, greater amounts of corn residue could negatively affect no-till soybean systems by affecting soil N and soybean nodulation (Vanhie et al., 2015). Tillage causes a wide range of changes in the soil environment, such as decomposition of plant residues (Mutegi et al., 2010). The NT system had a different temperature regime compared to tillage system (Muñoz-Romero et al., 2015) and often has more surface compression leading to weak drainage and ventilation and slower release of the gases from the soil (Ball et al., 1999; Kardoni et al., 2019). On the other hand, compared to the CT, higher amount of crop residues remains on the soil surface in the NT system. Since these residues are not mixed with soil are less exposed to microorganisms and have a slower decomposition rate. Applying desirable technologies, such as conservation tillage systems as one of the most effective methods in sustainable agriculture, can slow down land degradation and increase sustainability in agriculture (Fathi & Zeidali, 2021). On the other hand, the restriction of water resources of the country and the intensification of this limitation due to the drought and the continued increase in demand, has led to the maximum use of available water resources, increase productivity and increase production per unit area. More product production in soils of these areas depends on soil moisture storage and irrigation management (Unger, 1994). Conservation tillage increases the amount of soil moisture (Habtegebrial et al., 2007; Kardoni et al., 2019), while water penetration in soil is increased by using a Moldboard plow (Quincke et al., 2007). The researchers reported that using the Moldboard plow to increase soil moisture losses and eventually reduces grain yield and leads to reduced evapotranspiration and runoff compared to NT systems. Therefore, it can be stated that irrigation management and tillage method have an essential role in the physical properties, how the water flows and the volume of water used in the soil (Halvorson et al., 2006). Quantitative growth analysis is a method for justifying and interpreting plant responses to different environmental conditions during the growing season, through which photosynthetic material can be transferred and accumulated in various organs by measuring the amount of DM produced Achieved. The use of growth indicators, especially LAI, is an excellent tool to show the process of plant production and light usability. The researchers confirmed the correlation between leaf area and yield in maize and stated that the relationship was so high that maize yield could be estimated based on leaf area level (Karimi & Siddique, 1991). In maize, leaf area index increase is sigmoidal from seedling stage to pre-cropping stage and shows slight decrease during grain filling period, but a rapid decrease in leaf area index is observed at the end of life cycle. The shape of the RGR curve changes with photosynthetic status and plant respiration. Therefore, with RGR over time, plant growth declines with increasing respiration rate at the end of the growth period. RGR indicate the amount of DM accumulated in the plant per unit time, which was higher in the early stages of growth when the plants were small and often exposed to direct sunlight. But at the same time, plant growth and Increasing shading rather than producing photosynthetic materials has more to do with the role of the parasite Decreases (Karimi & Siddique, 1991). The researchers stated that maximum DM production per unit area depends on the early and early leaf area development at the beginning of the season to utilize the net early absorption rate (Thomas et al., 2003). In recent years, the use of different soil tillage methods and the use of chemical fertilizers (NPK) has significantly been considered or taken into consideration. Therefore, the study of yield, WUE, and growth analysis is of great importance.

Materials and methods

Location of the experiment site

Experiments were conducted for two years (2016 and 2017) on a farm located 5 km from Darreh shahr city, Ilam province, Iran. The experiment site is located at latitude of 33^{0}11'N longitude, 47^{0}21'E latitude, and 636 m above sea level. To determine the soil characteristics before experimenting, the sampling test from 0 to 30 cm of the soil was carried out, and its properties were analyzed. The results of the soil samples analysis are shown in table 1, and weather characteristics in the experiment location (reported by the Weather Administration of Ilam province) are mentioned in table 2.

Table 1. Physical and chemical properties of the experimental field

Deph (cm)	Soil texture	pH	EC (ds/m^{-1})	Organic carbon (%)	Total N (%)	Available P ppm	Available K ppm
0-30	Loam-clay	7.3	1.01	0.88	0.07	10	90

Table 2. Monthly values of the climatic variable of the study region during the growing season 2015-2016 to 2016-2017

Month	Precipitation (mm)		Minimum temperature (°C)		Maximum temperature (°C)		Relative humidity (%)		Evaporation (mm)	
	2016	2017	2016	2017	2016	2017	2016	2017	2016	2017
Jun	0	0	16.8	14.7	42.6	45.1	20	14	336.2	423.5
July	0	0	23.2	21.6	47.4	48.9	13	11	397.3	445.6
August	0	0	22.4	23.9	47.5	36.6	12	10	487.3	454.2
September	0	0	17.4	18.7	45.9	33.5	15	12	377.7	380.5
October	0	0	13.3	10.7	39.2	41.3	18	21	237	239
November	0.6	0.4	6	9	32.6	38	31	14	143.4	138

Experimental Design and treatments

The experiment was performed as a split plot in a randomized completely block design (RCBD) with four replications in Darreh shahr city, Ilam province, Iran. The treatments consisted of three levels of soil tillage including NT (direct sowing), MT (using compound tillage and furrow) and CT (Moldboard plow+ double discs + leveler and furrow) as the main plot. Also, the chemical fertilizer resources of nitrogen, phosphor, and potassium (NPK) in three levels including without NPK $(NPK)_0$, with 50% recommended amount of NPK $(NPK)_{50}$ and 100% recommended amount of NPK $(NPK)_{100}$ as subplot have been used in the present study. In this experiment, 100% of the recommended nitrogen was applied as 184 kg pure nitrogen, 100% of the recommended phosphor was used as 38 kg pure phosphor, and 100% amount of recommended potassium was used as 67 kg pure potassium.

Crop Management

The interval between the plots was 3 m and between the blocks was 6 m. The plots were 5×15 for the main plots and 5×5 for the subplots. Each subplot consisted of six rows, and the intervals between rows and plants were 75 cm and 20 cm respectively. The amount of seed consumption was 25 kg/ha. Sowing was done in late June immediately after first irrigation. Nitrogen fertilizer was applied in three stages (Planting, stemming and flowering times) and phosphor and potassium fertilizers were used to the soil before planting.

Measurements

In order to determine grain yield, we eliminated the lateral rows and 50 cm of the beginning and end of each plot. The following equation was used to determine the WUE

(1) WUE based on economic yield=Yec/ WU

In the equation above, WUE is the economic efficiency of water use (kg/m^3), Yec is the grain yield with Moisture content of 15% (kg), and WU is the volume of water consumed (cubic meter).

In 8-leaf stage, every 21 day's intervals to measure leaf area index (LAI), total dry matter (TDM), crop growth rate (CGR), relative growth rate (RGR), net absorption rate (NAR) and Sampling was done. The following relationships were used to measure the indices.

(2) CGR= (w2-w1)/ (t2-t1)

(3) NAR= CGR/LAI

(4) RGR= lnw2- lnw1/t2-t1

(5) LAI= LA / GA

In the above equations, w is the dry weight of the plant, t time and LA leaf area. GA Land area in square meters occupied by the plant.

Statistical analysis

The results were analyzed using SAS (SAS Institute, 2001) statistical software version 9.3 using the PROC GLM method or program. To compare the average of traits, the LSD test was used at 5% probability level.

Results and discussion

Grain Yield

Results showed that soil tillage and fertilizers resources and their interaction significantly impacted grain yield. However, the year and three-way interaction effect of year*tillage*fertilizer had no significant impact on yield (Table 3). Mean comparison of interaction effects showed that the highest grain yield was obtained in MT tillage and

$(NPK)_{100}$ treatment with 8401 kg/ha that this amount was higher than NT and $(NPK)_0$ treatment with 5239kg/ha yield (Fig. 1). According to the results, it can be stated that in MT tillage in the first year, nutrients are easily accessible for the plants. Hence, the fertility and conversion rate of florets to seeds is higher. But, in the NT system for the studied region, relative humidity of the air was low. The decay process for plant residues was slow and since those nutrients are released slowly, they cannot be in the access of plants appropriately in the first year. Therefore, plants in the pollination stage are faced with a nutritional shortage, and finally, fertility is reduced. The results of this study showed that the adsorption and transfer of elements to a different part of plants were increased by applying higher amounts of fertilizers (NPK). Also, the grain yield was raised at the reproductive growth stage such as the seed filling stage, because of nutrient remobilization. Macro elements (NPK) increased the crop yield due to their contribution to vegetative growth. On the other hand, the high ability of maize in the adsorption of these elements is due to its effective photosynthetic system. Hence, increasing fertilizers application can indirectly lead to a higher yield by increasing 1000-seed weight and the number of seeds. Applying the appropriate tillage and bedding system affects the crop yield (Fathi & Zeidali, 2021). The reasons for grain yield reduction in the first year of the NT system are the low seed-soil contact due to remaining plant residues on the soil surface and higher soil resistance against growth. Also, the yield losses in the NT system compared to a conventional system results from increased soil compaction and lack of appropriate conditions for root growth. This soil compaction leads to root growth reduction, thereby reducing water and nutrient absorption by the crop.

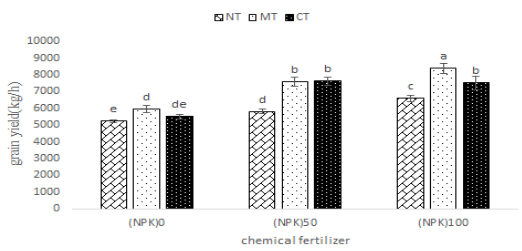

Fig. 1. Interaction between tillage and fertilizer on grain yield

WUE: The results of this study showed that the effect of primary treatment of tillage and fertilizer resources and their interaction on the WUE has a significant impact ($p<0.01$), while the main impact of the year and the triple interaction (year, Tillage and fertilizer resources) did not have a significant effect on this trait (Table 3). Comparison of mean interactions showed that the highest WUE in conservation treatment with consumption of $(NPK)_{100}$ was obtained at 0.98 kg/m^3, which is more than NT. The value of non-use of fertilizer $(NPK)_0$ was 0.61 kg/m^3 (Fig. 2). It seems that in conservation tillage and NT, due to plant residues and water evaporation, as well as increasing soil moisture persistence and soil infiltration in protective soil, the highest WUE was obtained. The researchers reported that using the NT system in all irrigation treatments increased water permeability and water conductivity in the ground and increased irrigation efficiency (Adiku et al., 2001; English & Raja, 1996). MT or NT saves more water than is typical (Farahani et al., 1998). The researchers also reported that NT systems could be a solution to increase water storage in soil and bean yield (López-Bellido et al., 2003).

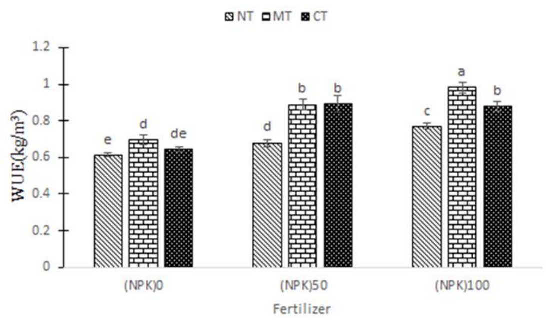

Fig. 2. Interaction between tillage and fertilizer treatment on economic WUE

LAI: Results of this study showed that the effect of primary tillage and fertilizer treatments had a significant impact on LAI, while year and double and triple interaction (year, tillage, and fertilizer) had a significant effect on LAI It had no significant effect. The results showed that the impact of tillage and chemical fertilizer sources on LAI were significant at 70 and 91 days after planting (Table 3), but at 49 days and 112 days after planting, it had no significant effect. In the second and third stages, the maximum LAI is obtained and then the LAI decreases. The results showed that the highest LAI was obtained in the MT treatment with 5.1 and the lowest in CT treatment with 4.6. Also, the highest LAI at 91 days after planting in NPK 100 treatment was 5.29, and the lowest leaf area index in treatment without chemical fertilizer application was 4.4 (Fig 3 and 4). Due to the availability of chemical fertilizers for maize through protective tillage and crushing of wheat plants and soil mixing, the nutrients required are gradually released, resulting in increased nitrogen availability for maize, which increases LAI Is. LAI in MT was higher at all stages of growth than the other two methods, which can be attributed to optimum seedbed conditions and vegetation completion more rapidly and at a lower time. LAI is a critical factor in determining the photosynthetic capacity of plants. According to some studies, LAI can be used as a reliable measure to estimate changes in crop yield.

Kim et al. (2012) found that leaf area is highly correlated with both the potential for photosynthesis and growth. Fey et al. (2012) also reported similar findings. The TDM is a result of the plant community's efficiency in using sunlight during the growing season. For the plant community to achieve optimal light absorption and coverage, it is necessary to have a sufficient amount of leaf area that is uniform and covers the plant thoroughly (Fortin et al, 2013).

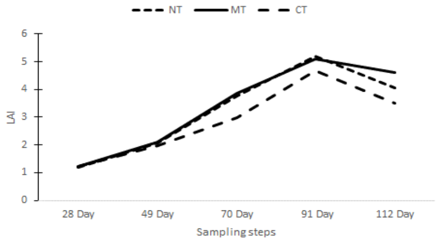

Fig. 3. Effect of tillage treatment on LAI

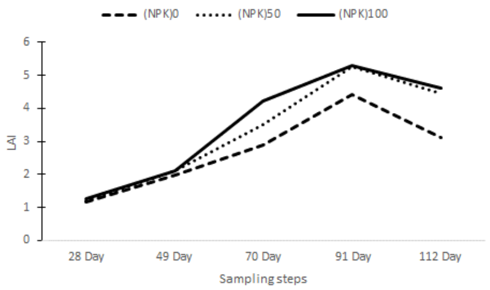

Fig. 4. Effect of fertilizer treatment on LAI

TDM: The results of this study showed that the effect of main tillage and fertilizer treatments had significant effect on TDM, but the effect of year and double and triple interaction (year, tillage and fertilizer) had no significant effect. The results showed that the effect of tillage and fertilizer sources on TDM was significant at 70 and 91 days after planting (Table 3), but at 49 days and 112 days after planting, it had no significant effect. The results showed that the highest TDM was obtained in MT treatment at 4542.7 g/m^2 and the lowest in CT treatment at 4029.2 g/m^2. Also, the highest TDM was observed 91 days after planting in NPK 100 treatment (4562.7 g/m^2), and the lowest TDM in no fertilizer treatment was 3946.4 g/m^2 (Fig.s 5 and 6). Generally, DM accumulation during the growing season is sigmoid in most crops, so the DM accumulation rate is slow and gradual at the beginning of growth. The dryness becomes more positive so that it reaches its maximum at the peak of the curve and then decreases as the DM of the leaves increases and eventually stops. Due to the small size of the plants and slow growth at the beginning of the growing season, there was no difference between different tillage methods in terms of increasing DM accumulation. Still, DM accumulation entered the linear growth stage rapidly about 49 days after planting. It began to grow and reached its maximum level about 91 days after implantation, followed by an almost constant trend. Conservation tillage had more DM accumulation than NT, which could be due to higher leaf area index and consequently light absorption and photosynthesis by corn canopy. Also seen increased crop DM accumulation in conservation tillage methods than CT due to better water availability, better growth conditions and plant residues that provide nutrients during the growing season as an improvement. Nitrogen is one of the nutrients that affect the activity of photosynthetic enzymes and consequently the plant DM accumulation. The presence of plant residues in CT in maize planting resulted in increased soil nitrogen which increased maize growth and ultimately increased DM accumulation in tillage methods, which was consistent with the findings of other researchers (Eshel et al., 2015; Kwaw-Mensah and Al-Kaisi, 2006).

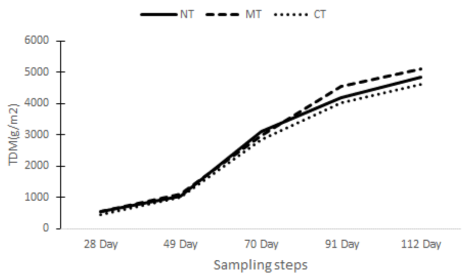

Fig. 5. Effect of tillage treatment on TDM

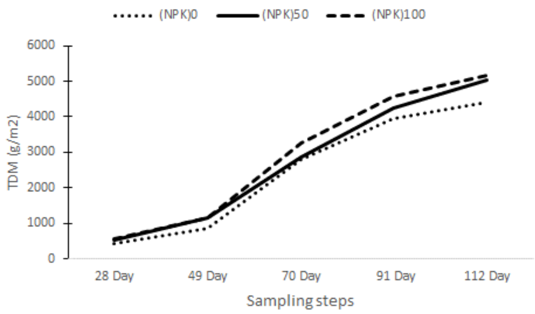

Fig. 6. Effect of chemical fertilizer treatment on TDM

CGR: The results of this study revealed that the effect of tillage and fertilizer sources on CGR was significant at a 1% probability level at 49 and 70 days after planting (Table 3) but at 91 and 112 days post-planting stage significant effect was not observed. The results showed that between the second and third stages the maximum CGR was obtained and from then on, the CGR velocity declined (Fig. 7). The results showed that the highest CGR in 70 days after planting in MT treatment was 73.99 g/m^2 day^{-1} and the highest CGR in chemical fertilizer (NPK) 100 treatment was 62.75 g/m^2 day^{-1} (Fig. 8). The tillage and fertilizer sources interaction in the first stage of sampling was not significant. This can be explained by this possibility that these two factors may not yet have influenced the growth rate because there was not enough time and the plant used more seed reserves for growth. In the last stage, due to the loss of plant DM, the product DM decreased and resulted in no significant effect of these two factors on the CGR. On the other hand, the higher the rate of product growth, the higher the final yield. Since the parts that are added to the plant are structural tissues that are not metabolically active and have no role in photosynthesis (Albayrak & Camas, 2005), this result was obtained. In the late stages of growth, due to the reduction of the current shoot level, and the decrease in photosynthesis rate, the efficiency of material transfer to seed and DM accumulation decreased. Increasing the CGR at the beginning of the growing season is due to the rapid growth of leaves and stems, which requires sufficient nutrients for plant growth and development, especially at critical stages of growth.

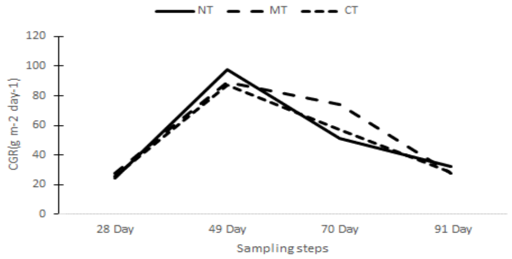

Fig. 7. Effect of tillage treatment on CGR

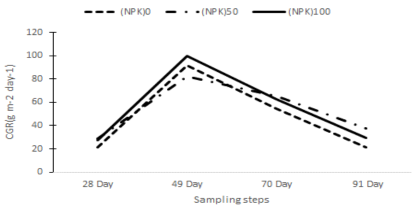

Fig. 8. Effect of chemical fertilizer treatment on CGR

RGR: The results of this study showed that the effect of tillage and fertilizer sources on RGR at 49 and 70 days after planting was significant at 1% probability level (Table 3). At 91 and 112 days after planting had no significant effect. The results showed that the highest RGR was obtained at 70 days after planting in MT treatment with 0.012 g/g day^{-1} and lowest in CT treatment with 0.0083 g/g day^{-1}. The highest RGR in the fertilizer application (NPK) 100 was 0.0142 g/g day^{-1}, and the lowest RGR in the no fertilizer treatment was 0.0077 g/g day^{-1} (Fig.s 9 and 10). It seems that crop RGR trend in different soil methods also showed that the plant had the highest amount of RGR in the early growth period and decreased with time, and reached late growth period. The RGR is the amount of DM accumulated in the plant per unit time. RGR has a decreasing trend in crop life (Karimi & Siddique, 1991). Such a trend would be due to the gradual increase in solar radiation uptake as leaf area increased early in the growing season and due to TDM velocity in plants.

Table 3 (see annex)

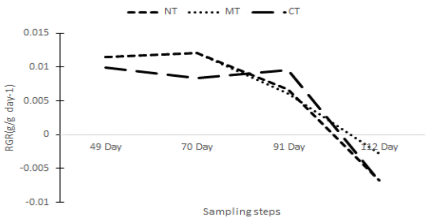

Fig. 9. Effect of tillage treatment on RGR

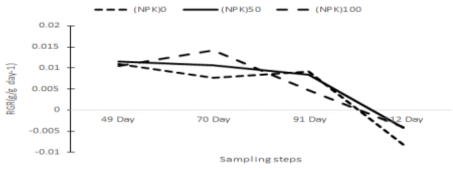

Fig. 10. Effect of fertilizer treatment on RGR

NAR: The results of this study showed that the effect of tillage and fertilizer sources on NAR was significant at 1% probability level at 70 days post-planting (Table 3) but had no significant impact at 49 days and 112 days post-planting. The results showed that the highest NAR was obtained at 70 days after implantation in CT treatment with 16.12 g/m^2 day^{-1} and the lowest in MT treatment with 13.8 g/m^2 day^{-1}. The highest NAR was observed in NPK 100 treatment (14.57 g/m^2 day^{-1}), and the lowest NAR in the no-fertilizer treatment was 13.45 g/m^2 day^{-1} (Fig. 11 and 12). NAR is a suitable criterion for the expression of plant growth characteristics, and since leaves are the primary photosynthetic factor of plants, so expression is based on leaf area. NAR changes in tillage methods and fertilizer sources appear to have been initially upward, possibly due to young leaves and increased photosynthesis, with decreasing net uptake by growing leaves and shading, indicating a downward trend. Gives. In CT, because of the better root system development than in other NAR tillage methods, it was higher. The development of the root system may have absorbed nutrients and nutrients for the plant and increased NAR photosynthesis. The researchers reported that the plant's access to nitrogen fertilizer increased NAR in the early stages of plant growth. They also stated that although 100, 75, and 150 kg ha-1 nitrogen fertilizer had the highest net absorption rate at 75 kg ha-1, there was no significant difference between the different nitrogen levels (Lucas, 1986).

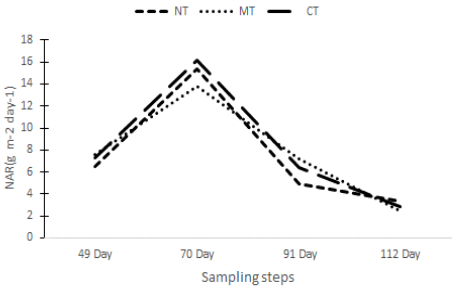

Fig. 11. Effect of tillage treatment on NAR

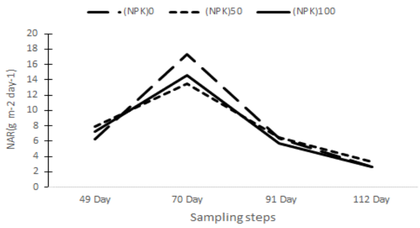

Fig. 12. Effect of chemical fertilizer treatment on NAR

Conclusions

According to the results obtained in this study, it was found that MT had the highest efficiency compared to other tillage methods. It seems that the RGR trend in different tillage methods also showed that the plant had the highest amount of RGR at the beginning of the growing season and decreased with time, and reached the late growth period. MT had higher TDM than NT, due to greater LAI and consequently light absorption and photosynthesis by corn canopy. Based on the results of this study, it can be stated that MT can improve maize grain yield with the highest WUE and increase the characteristics during the growing season.

Author contribution statement

Amin Fathi: research planning, analysis of results, writing and final review.

Davood Barari Tari: research planning, analysis of results, writing and final review.

Hormoz Fallah Amoli: analysis of results, writing and final revision.

Yousef Niknejad: analysis of results, writing and final revision.

Conflict of interest statement

There are no conflicts of interest

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Abbreviations: No-tillage (NT), Minimum tillage (MT), Conventional tillage (CT), Water use efficiency (WUE), Leaf area index (LAI), Total dry matter (TDM), Crop growth rate (CGR), Relative growth rate (RGR), net assimilation rate (NAR), Dry matter (DM)

Annex

Table 3. Effect of tillage and fertilization

	DF	Seed yield	WUE	LAI	TDM	CGR	RGR	NAR
Year(Y)	1	3872782.6*	0.05298*	0.518103 ns	15689.86 ns	1260.47 ns	0.000001 ns	1.7584 ns
R(Y)	6	709203.3	0.00970	0.408036	51399.99	3016.73	0.000016	176.8167
Tillage(T)	2	13088322.8**	0.17904**	0.155351**	55762.36**	750.75*	0.000081**	33.9963 **
T*Y	2	648993.5ns	0.00888ns	0.000007 ns	45.61 ns	1.19 ns	0.000000 ns	0.0022 ns
Error T	12	566566.9	0.00775	0.019545	1640.74	138.41	0.000014	6.7451
Chemical fertilizer(CF)	2	24268037.4**	0.33197**	0.165137**	148129.10**	1828.36*	0.000132	94.3856
CF* Y	2	211508 ns	0.00289ns	0.000004 ns	114.95 ns	2.69 ns	0.000000 ns	0.0186 ns
CF* T	4	1585388.9**	0.02169**	0.024429 ns	917.63 ns	317.97 ns	0.000011 ns	4.2685 ns
CF* T* Y	4	141797.3ns	0.00194ns	0.000001 ns	1.01 ns	0.37 ns	0.000000 ns	0.0189 ns
Error	36	316538.4	0.00433	0.028025	1131.99	179.68	0.000002	8.2307
CV (%)	-	8.4	11.2	8.13	8	14.6	19.4	18.9

*, ** and ^{ns}, respectively, showed significant differences in the level of five percent, one percent and no differences are significant.