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Effect of Tillage Methods and Nitrogen Levels on Seed Yield, Weed Traits, and Nitrogen use Efficiencies of Maize (*Zea mays*)

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ABSTRACT

Tillage (T) methods and nitrogen (N) rates are influential factors in improving maize yield. An experiment was conducted as a factorial arranged in randomized complete blocks design (RCBD) for two years (2016-2018). In treatments consisting of three tillage methods minimum tillage (MT) (chisel plower and furrower) and conventional tillage (CT) (once moldboard plow+ once disc + furrower), intensive tillage (IT) (two moldboards plow + two disc + furrower) as main plot, and five N levels (0, 50, 100, 150 and 200 kg N ha^{-1}) as subplots. The results showed that MT method had the highest seed yield (7615.9 kg ha^{-1}), an increase of 22.3% and 5.8% over IT and CT methods, respectively. Additionally, the highest seed yield (7484 kg. ha^{-1}) was obtained with 200 kg ha^{-1} of N, an increase of 21% higher than control. Nitrogen use efficiency (NUE) and weed management were affected by N. However, the results showed that weed weight, and the number increased with increasing the N levels. On the other hand, reducing N level reduced seed yield. It is therefore essential to maximize efficiency with good management. Overall, the results revealed that MT method can be recommended as an appropriate agronomic approach and it had higher performance compared to CT and IT methods in the region.

***Keywords**:* Maize, Tillage, Weed, Nitrogen, Yield

INTRODUCTION

As the world's population grows, agricultural production has dramatically increased due to application of machineries, fertilizers, and chemical pesticides (Fathi *et al*., 2022; Hafeez *et al*., 2023; Mosabeygi *et al*., 2023). The world population will reach 10 billion by 2050 (Ghadirnezhad Shiade *et al*., 2023a). Therefore, food security requires a reliable and appropriate supply (Ghadirnezhad Shiade *et al*. 2020; Ghadirnezhad Shiade *et al*. 2023b-c; Mosabeygi *et al*. 2023). Maize is the third most important grain crop in Iran and the world after wheat (Bagheri *et al*., 2020; Fathi *et al*., 2020), barley (Taghavi Ghasemkheili *et al*. 2022; Ghasemkheili *et al*., 2023) and rice (Ghadirnezhad Shiade, Pirdashti, *et al*., 2023). It is grown in many parts of the country, for human nutrition and animal feed. While maize production has significantly increased, its mean seed yield is still far from its genetic potential (Fathi *et al*., 2021). One of the critical operations in the cultivation of maize is using tillage systems (Simić *et al*., 2020). These methods can significantly affect maize's yield and nutritional quality through temperature, humidity, aeration, and soil nutrient availability (Simić *et al*., 2020; Zeidali *et al*., 2022). As climatic conditions change and drought occurs, tillage (T) appropriate to soil types and agricultural and ecological needs may help conserve water and produce higher yields (Bodner *et al*., 2015). One of the main reasons for soil compaction is the frequent use of machinery and T operations. The gradual increase in soil density reduces N uptake by soil, affecting corn seed quality (Wasaya *et al*., 2018). The different T operations affect soil compaction to a different extent. In other words, without T for many years, the soil becomes hard and restricts access to nutrients (Wasaya *et al*., 2018).

Nitrogen is an essential nutrient for maize plants, and its inadequacy can limit their growth (Fathi, 2022; Ghadirnezhad Shiade *et al*., 2024). Crop production and development are negatively affected by low and high N consumption (Eyni *et al*., 2023; Taheri *et al*., 2021; Zamani *et al*., 2023). Over the past four decades, increased agricultural food production worldwide has been accompanied by a sevenfold increase in N fertilizer application (Ghadirnezhad Shiade *et al*., 2024; Rahimizadeh *et al*., 2010). Reduced maize yield can be attributed to the low crop growth rate at the beginning of the growing season, the long distance between planting rows, and the rapid establishment of weeds (Subedi *et al*., 2009). In modern agriculture, herbicide application is the primary method of controlling weeds due to its effectiveness and ease. Researchers, however, strive to integrate weed management and reduce herbicide application due to concerns about groundwater and surface water pollution (Svečnjak *et al*., 2009). Weed management may also be affected by the source of N fertilizer. Nitrogen application has improved seed yield by affecting photosynthesis, increasing dry matter production, transport, uptake, and grain filling (Liu *et al*. 2009; Qiu *et al*. 2015). It has been reported that N consumption improves the yield components of maize (Sharifi *et al*., 2009), since N application resulted in a 22% increase in biomass production and a 24% increase in grain yields (Amanullah *et al*., 2009). The T system and N application are significantly correlated (Fathi *et al*., 2021). Several studies investigated the crop yield response to N fertilizer under different T methods (Jug *et al*., 2019; Liu *et al*., 2020). The effect of T on maize yield is very variable. Although no difference in maize yield was found between MT and CT (Barari Tari *et al*., 2020), some studies identified a decreased maize yield in MT compared with CT practices (Afzalinia and Zabihi, 2014; Javeed and Zamir, 2013). Therefore, since it is critical to achieve the sustainable agricultural objective, this study aimed to reduce N fertilizer application, maintain soil structure, and evaluate the effects of T methods and N fertilization on maize seed yield, weeds traits, and indicators of NUE.

MATERIALS AND METHODS

Site Description

This experiment was carried out for two cropping seasons (2016-2018) in Darreh-Shahr city of Ilam province (33° 11'N longitude, 47° 21'E latitude, and 620 m above sea level).

Chemical and physical properties of soil were analyzed prior to planting at depths of 0-30 cm, including soil texture, electrical conductivity (EC), soil acidity (pH), total nitrogen (N), available potassium (K) and available phosphorus (P). The results of two years indicated as: soil pH 7.7/7.6, EC = 1.73/1.88 (dS m^{-1}), total nitrogen (N) = 0.09/0.08 (%), available potassium (K) = 520/534 (mg kg^{-1}), available phosphorus (P) = 4.2/4.76 (mg kg^{-1}) and the soil texture was sandy loam for the whole period.

Experimental design

This experiment was conducted as a split-plot arranged in RCBD with three replications. Treatments consisted of three tillage methods minimum (MT) (chisel plower and furrower), conventional (CT) (one moldboard plow + one disc + furrower), and intensive tillage (IT) (two Moldboard plow+ two discs + Furrower) as main plots, and five N levels (0, 50, 100, 150 and 200 kg N ha^{-1}) (urea with 46% N) as subplots. Plowing soil depth were between 10 and 12 cm in MT, in CT and more than 20 cm in CT and more than 30 cm in IT methods.

Crop management

Dimensions of main plots were 15 × 5 m, and the sub-plots were 5 × 5 m. The seed was planted at a rate of 25 kg. ha^{-1}, and the cultivation operations were carried out in both years in the second week of July immediately after the first irrigation. To achieve proper plant density, after the four-leave stage, the plants were thinned. Nitrogen fertilizer was applied as urea at three growing stages and triple superphosphate (150 kg. ha^{-1}) before planting. Based on the soil test, potassium fertilizer was not required. This field was fallowed the year prior to the experiment. During the first year, 30% of the residues were preserved at the soil surface, and in the second year, the treatments were continued in the exact location. Then, the soil surface was collected from the first year's residues for CT and IT methods.

Measurements

All plots were manually harvested simultaneously after observing the signs of physiological maturity of the seeds. Each plot was harvested by removing the side rows and 50 cm from the beginning and end, and then selecting 1 m^2 from the middle (including 5 plants). To measure weed traits at the time of weeding (70 days after planting) was marked using a plot of 0.5 × 0.5 m, and then weeds were collected from the soil surface and counted. Then, they were kept at 70 °C until dry weight was established, and their weight was measured with a digital scale. N was measured by the Kjeldahl method.

Nitrogen use productivity seed yield (NUP SY)

In terms of seed yield, the ratio of total seed yield (SY) (kg ha) to the amount of fertilizer input (46% urea fertilizer) plus the amount of soil (kg ha) has been calculated (Feilinezhad *et al*., 2022) according to equation 1: NUP SY=SY/ Nf+Ns.

Nitrogen uptake efficiency (NU_PE)

The distribution of stored N (NY) (kg ha) on the amount of N in the soil plus the net amount of element was done through input fertilizer (N) (kg ha). The amount of N in the fertilizer treatment was calculated based (Feilinezhad *et al*., 2022) according to equation 2: NU_PE=NY/N.

Seed N-utilization efficiency (seed-NutE)

The physiological efficiency of N per seed (NUtE) was calculated by dividing seed yield (SY) (kg ha) by seed nitrogen uptake (NU) (kg ha), according to equation 3: seed-NutE=SY/NU

Nitrogen uptake index (NHI)

The nitrogen uptake index (NHI) was obtained by dividing the stored N of the seed by the stored N of the whole shoot.

Statistical analysis

We used SAS v9.3 software to analyze the data variance, and the LSD test was used at a level of 5% probability to compare the means of the traits. Random-year effects were considered in this study.

RESULTS AND DISCUSSION

Seed yield

A combined data analysis revealed that the effect of T and N fertilizer and the interaction between years for T was significant for seed yield (Table 1). Moderate tillage method had the highest seed yield (7615.9 kg ha^{-1}), an increase of 22.3% and 5.8% over IT and CT, respectively (Table 2). Schillinger *et al*. (2010) found that MT could yield of wheat as much or even more than CT. As for N treatment, the highest seed yield was achieved with application of 200 kg. ha^{-1} (7448.1 kg. ha^{-1}), an increase of 21% compared with no N fertilizer (Table 2). In crops, N plays an important role achieving high yields both quantitatively and qualitatively (Ertiro *et al*., 2022). In this study, higher N fertilizer increased the plant's ability to absorb and transfer the element throughout the plant. Remobilization of nutrients increases seed yield after completion of reproductive growth processes, such as the grain filling stage(Fathi *et al*., 2016; Fathi *et al*., 2023; Ghadirnezhad Shiade *et al*., 2024). N increases plant yield because of its essential role in promoting vegetative growth.

Alternatively, maize's capability to use nitrogen efficiently is of special importance related to its efficient photosynthetic system. The increase in fertilizer rate is therefore reflected in the increase in yield by increasing 1000 seeds and their weight. The positive effect of N on crop yield can also be attributed to leaf area expansion and their better persistence leading to improved photosynthetic reserves.

Table 1. Combined analysis of T methods and N fertilizer levels on maize seed yield, weed traits and nitrogen use efficiencies.

	Df	Seed yield	Dry weight of weeds	Total number of weed plants	Number of weed species	NUP SY	NU_pE	seed-NutE	NHI
Year (Y)	1	863805.41ns	148913.97*	22.5*	4.01*	0.042ns	0.0201*	351.80*	0.0011ns
R(Y	4	3248190.46	12429.59	11.46	0.54	0.015	0.0166	93.82	0.0064
Tillage (T)	2	23275184.6**	195959.57*	282.43**	35.24**	0.014 ns	0.0969 ns	167.10 ns	0.0002 ns
Y*T	2	18192802.58**	1947878.33*	5.43ns	4.04*	0.039*	0.0822**	182.52 ns	0.0113*
Error	8	1612841.53	40144.29	26.20	0.86	0.009	0.0075	43.04	0.0015
Nitrogen (N)	4	7618982.04**	161115.43**	63.32**	10.10**	0.039**	0.0074*	181.77**	0.0005 ns
Y*N	4	191459.3ns	1685.52ns	0.28ns	0.68ns	0.001 ns	0.0009 ns	9.01 ns	0.0009 ns
T*N	8	987819.5ns	11552.91ns	2.78ns	1.59ns	0.003*	0.0030*	10.96 ns	0.0008 ns
Y*T*N	8	287016.95ns	193.26ns	0.17ns	0.92ns	0.001 ns	0.0009 ns	33.62 ns	0.0004 ns
Total error	48	1151299.4	26142.69	3.82	0.99	0.012	0.0036	72.62	0.0022
C.V	-	15.54	14.67	12.18	18.03	11.36	16.23	10.79	14.29

** ,* and ns, respectively, showed significant differences at the 1%, 5%, and non-significant, respectively. .

Table 2. Effects of the T methods and the N levels on maize seed yield, weed traits and nitrogen use efficiencies.

Treatment	Levels	Seed yield (kg h^{-1})	Dry weight of weeds (g m^2)	Total number of weeds (m^2)	Number of weed species (m^2)	NUP SY (kg kg^{-1})	NU_PE (kg kg^{-1})	seed-NutE (kg kg^{-1})	NHI (kg kg^{-1})
Y	First	6803.34a	1142.4a	16.53a	5.73a	0.953a	0.35a	80.92a	0.326a
	Second	6999.28a	1061.04b	15.53b	5.31b	0.996a	0.38b	76.97b	0.333a
T	MT	7615.9a	1191.27a	19.5a	6.70a	0.996a	0.42a	76.25a	0.33a
	IT	5917.2b	1079.69b	14.93b	5.30 b	0.953a	0.31a	80.64a	0.33a
	CT	7170.8a	1034.2b	13.67b	4.57c	0.976a	0.38a	79.94a	0.33a
N (kg.h^{-1})	0	5877.7d	951.15c	13.44d	4.56c	0.922b	0.369ab	83.16a	0.327a
	50	6690.8c	1071.38b	14.78c	5.11bc	0.935b	0.384a	80.27a	0.337a
	100	7069.7b	1137.18ab	16.56b	5.78b	0.975ab	0.381a	78.16ab	0.330a
	150	7384.2ab	1160.76a	17.67a	5.61b	1.016a	0.377a	74.45b	0.329a
	200	7484.1a	1188.13a	17.72a	6.56a	1.026a	0.334b	78.68ab	0.323a

The same letters in each column of the LSD test did not show a significant difference at the 5% level.

The highest seed yield (8554.1 kg ha^{-1}) was obtained by MT in the second year, while the lowest one (5872.32 kg. ha^{-1}) was obtained with IT in the second year, (Table 3). The availability of nutrients to the plant during the early years of CT is more significant, which leads to a higher fertility rate and a higher conversion of florets into seeds. In the MT system, plant residues on the soil surface slowly decomposes, and nutrients cannot be provided to the plant in the first year. Consequently, nutrient deficiency reduces plant fertility during the pollination stage. In the second year, the highest yield in MT was achieved due to decomposition of residues and providing more nutrients to the plant.

Table 3. Effects of T methods on maize seed yield, weed traits and nitrogen use efficiencies in two years.

Year	T	Seed yield (kg h^{-1})	Dry weight of weeds (g.m^2)	Number of weed species (m^2)	NUP SY (kg kg^{-1})	NU$_P$E (kg kg^{-1})	NHI (kg kg^{-1})
First	MT	6677.62c	1160.97ab	6.53ab	0.99a	0.352c	0.31c
	IT	5962.10d	1221.58a	6.87a	1.00a	0.492a	0.36a
	CT	7770.29b	1103.73ab	5.87b	0.89b	0.300d	0.33abc
Second	MT	8554.10a	1055.64b	4.73c	1.02a	0.318cd	0.33abc
	IT	5872.32d	1162.49ab	4.80c	0.98a	0.411b	0.34ab
	CT	6571.40c	905.91c	4.33c	0.97a	0.342cd	0.32bc

The same letters in each column of the LSD test did not show a significant difference at the 5% level.

Dry weight of weeds

The main effect of the year of T ($p < 5\%$), N fertilizer ($p < 1\%$) and the interaction between years on T on weeds dry weight was significant ($p < 5\%$) (Table 1). The highest dry weight of weeds (1142.4 g m^2) was achieved in the first year, an increase of 7.12% compared with the second year (Table 2). The MT treatment had the highest dry weight of weeds (1191.27 g m^2) and was higher than IT and CT, which showed an increase of 9.3% and 13.1%, respectively (Table 2). In deep tillage, the seeds are transferred to the depth of the soil, which reduces weeds emergence, and of MT methods increase the weed density by transferring the seeds to the soil surface. Similarly, Santín-Montanyá *et al*., 2016 found that weed banks grew faster in MT than in CT systems (Santín-Montanyá *et al*., 2016). By moving seeds and weeds to multiple soil profiles, returning debris, and changing nutrient cycles, T significantly affects the weed community (Nichols *et al*., 2015). According to the comparison of N treatment, the dry weight of weeds increased with 200 kg ha^{-1} of N by 19.9% compared to zero of N treatment (Table 2). Furthermore, comparing the annual interaction in T showed that the highest (1221.58 g m^2) and lowest (905.91 g m^2) dry weight of weeds were obtained in in the first year and IT tand in the second year and CT (Table 3). Increasing the N application stimulates weed growth to a great extent and weeds produce more biomass. Sweeney *et al*. (2008) found that weeds absorbed chemical fertilizers faster than crops (Fathi *et al*., 2021; Sweeney *et al*., 2008).

Total number of weeds

The effect of the year of T and N fertilizer application on the total number of weeds was significant. Moreover, none of this trait's dual and triple interactions were significant (Table 1)., The highest total number of weeds (16.53 m^2) were found in the first year, an increase of 6% compared to the second year (Table 2)., Moderate tillage practice had the highest number of weeds (19.5 m^2), representing an increase of 23.4% and 29.8%, respectively (Table 2). Moreover, the highest number of weeds (17.72 m^2) was obtained with 200 kg. ha^{-1} of N fertilizeran increase of 24.15% compared to no N application. (Table 2). Weed management is an important strategy in sustainable agriculture. More than ten nutrients are crucial for the growth and development of maize, among which N holds a special place and a deficiency is a limiting factor. As a result, the need to use it as a chemical fertilizer seems crucial to reducing this limitation and improving growth and development conditions. In maize fields, weed control is significant since reports have shown that weeds can reduce corn yield by more than 80% if they are not controlled (Baghestani *et al*., 2007).

Number of weed species

The effect of the year T, N fertilizer, and the interaction between years on T at the level of 5% probability was significant for number of weed species (Table 1). The highest number of weed species (5.73 m^2) was in the first year, an increase of 7.32% compared with the second year (Table 2). In addition, the highest number of weed species (6.7 m^2) was obtained with MT method, an increase of 20.8% and 31.7% compared with IT and CT, respectively (Table 2). Controlling weeds is one of the most challenging aspects of MT operation (Krauss *et al*., 2010). Weed population dynamics changes in MT methods (Santín-Montanyá *et al*., 2016). Weed diversity and density can change depending on the type of T operation too (Demjanová *et al*., 2009). There have been reports of rapid weed infestations and a large weed seed bank in MT methods (Moyer *et al*., 1994). The highest number of weed species (6.56 m^2) was achieved with 200 kg N ha^{-1} (Table 2). Fertilizers may stimulate plant and weed growth, but invasive species are expected to dominate (Sweeney *et al*., 2008). The highest number of weed species (6.87 m^2) was obtained in the first year and IT method and, the lowest number (4.33 m^2) was and CT method in second year (Table 3). (Chovancova *et al*., 2020), reported that the highest weed infestation in corn fields, mainly perennial plants, was recorded in no-till treatments. In contrast, a rich variety of annual weed species were observed in the MT method, Specific soil treatments affected how weeds emerged and the properties of the soil.

NUP SY

The effect of N fertilizer (%) p < 1 and the interaction between year and T on N fertilizer at the level of 5% probability on NUP SY (Table 1). The effects of T and N fertilizer interaction showed that the highest NUP SY (1.069 $kg.kg^{-1}$) was found in MT method combined with application of 200 kg. ha^{-1} N, while the lowest one (0.884 $kg.kg^{-1}$) was achieved in the IT method and no N application (Table 4). When N rates was increased, productivity changes were observed, and the type of T had a lower effect on productivity, although its effect on N was significant. Minimal soil residues remain at the soil surface in MT method, which makes fertilizer application hard to manage in a short term. On the other hand, because N is released gradually, productivity and efficiency may increase over time (Freeman *et al*., 2007).

Table 4. Effects of T methods and N levels on NUP SY

T	N ($kg.h^{-1}$)				
	0	50	100	150	200
MT	0.950cdef	0.942cdef	0.975bcde	1.045ab	1.069a
IT	0.884f	0.910ef	0.964cdef	0.990abcde	1.017abc
CT	0.934def	0.954cdef	0.985bcde	1.013abcd	0.992abcd

The same letters in each column of the LSD test did not show a significant difference at the 5% level.

NU_PE

The effect of years and N fertilizer and the interaction between year and of T for T and N fertilizer (p < 5%) on NU_PE were significant (Table 1). The highest NU_PE (0.438 kg kg^{-1}) was achieved in MT method, accompanied by application 150 kg. ha^{-1} N fertilizer and, the lowest one (150 kg. ha^{-1}) was obtained in IT method with application of (Table 5).

Table 5. Effects of T methods and N levels on NU_pE.

T	N (kg.h^{-1})				
	0	50	100	150	200
MT	0.436ab	0.433ab	0.435ab	0.438a	0.368bcde
IT	0.329def	0.324ef	0.303ef	0.293f	0.295f
CT	0.343cdef	0.395abcd	0.403abc	0.400abc	0.340cdef

The same letters in each column of the LSD test did not show a significant difference at the 5% level.

Absorption efficiency of nutrients can be improved by increasing nutrients and improving plant performance per unit area, increasing fertilizer productivity. As a result, combining these factors can lead to an increase in yield or dry matter per food consumed.

Seed-NutE

The effect of years and N fertilizer was significant for seed-NutE (Table 1). The highest seed-NutE (83.16 kg.kg^{-1}) was obtained with the no N application, an increase of 10.4% compared with 150 kg h of N (Table 2). The loss of N can explain this result in different ways in the field and the lack of linear increase in yield and N uptake in the plant in proportion to the increase in N application in the soil. Similarly, the researchers reported that high levels of nitrogen application significantly reduced the seed-NutE of maize and wheat (López-Bellido *et al*., 2005; Momen *et al*., 2018).

NHI

The main effects of none of the treatments on NHI were significant. We found that the interaction between years and T was significant at 5% probability level on NHI (Table 1). The highest (0.36 kg.kg^{-1}) and lowest (0.31 kg.kg^{-1}) NHI were recorded in the IT method and MT methods of the first year, respectively (Table 3). This finding can be attributed to the fact that with higher plowing depth, in a certain range, the transfer of N to the seeds will cease, similar to the absorption of more N from the soil. In MT, most of the N is used to decompose crop residue rather than plant seeds. While in deep T, more N is transferred to the seed, eventually resulting in a higher NHI. In cereals, NHI is often measured as the efficiency of nitrogen remobilization from plant vegetative forms to seeds (Muurinen *et al*., 2007). Therefore, the higher the NHI, the higher the nitrogen transfer to the seed.

CONCLUSION

In this study, nitrogen levels and tillage methods were important in the relationship between NUE and weed management. Nevertheless, increasing N increases weeds' number, weight, and variety. On the other hand, reducing the levels of N reduces the maize seed yield. Effective management is therefore vital to increasing efficiency—compared with CT and IT methods, MT implementation significantly improved the efficiency of N relationships. The increase in efficiency was even higher than CT and IT in some instances. It is suggested to use nanoparticles or mycorrhiza in addition to nitrogen fertilizer for future research. In line with sustainable agriculture, future studies should be conducted to reduce nitrogen consumption in response to tillage methods.

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