Effect of tillage and fertiliser treatments on yield of maize (*Zea mays* L.) hybrids

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Abstract: This research was conducted in a spilt-plot design at the University of Debrecen Látókép Research Station, site (N 47°33' E 21°27') in 2015 and repeated in 2016. There were three main plots, each 1.0 ha in size which represents the tillage treatments: moldboard plowing (MT), strip tillage (ST) and ripper tillage (RT). Maize hybrids, Loupiac (FAO 380) and Armagnac(FAO 490) were sown at 80,000 plants ha^{-1} with a row spacing of 76 cm in the main plots which were subdivided to accommodate three fertiliser treatments (N_0 kg ha^{-1} (control); N_{80} kg ha^{-1}; N_{160} kg ha^{-1}) with four replications. The hybrids were harvested at the end of the growing cycle with a Sampo 2010 plot harvester and the grain moisture content was computed at 15% moisture to arrive at the final yield. The findings revealed RT produced the highest yield of 10.37 t ha^{-1}, followed by MT and ST with 10.22 and 9.60 t ha^{-1} respectively. There was no significant difference($p>0.05$) in yield between the RT and MT treatments. However, both the RT and MT were found to be statistically significant ($p<0.05$) when compared to ST treatment. In 2015, a relatively dry year, yield of ST plots were not significantly different compared to MT and RT plots. A positive interaction between tillage and fertilisation was evident, with higher yield variation (CV=40.07) in the non-fertilised (N_0) tillage plots, compared to those which received the N_{80} and N_{160} kg ha^{-1} treatments (CV=22.42). Fertilizer application greatly increased the yield of maize and accounted for 43% of yield variances. The highest yield (11.88 t ha^{-1}) was obtained with N_{160} kg ha^{-1} treatment, followed by N_{80} kg ha^{-1} (10.83 t ha^{-1}), while the lowest yield (7.48 t ha^{-1}) was recorded in the nonfertilised plots(N_0 kg ha^{-1}). Year effect was highly significant with vast variation in yield between the two years, ranging from 8.36 t ha^{-1} in 2015 to 12.43 t ha^{-1} in 2016 for the same set of agrotechnical inputs. In 2016, higher yield was obtained with increase fertiliser dosage due to favourable growing condition which allowed for better fertiliser utilisation. However, with 2015 being a relatively dry year there was no yield increasing effect with higher fertiliser dosage (N_{160} kg ha^{-1}). Loupiac (FAO 380) was the better performing hybrid, with a yield of 11.09 t ha^{-1} compared Armagnac (FAO 490) with 10.60 t ha^{-1} . The adaptability traits of the two hybrids appears very similar, since the yield differential between the two hybrids was almost constant (0.48 vs 0.49) in both years , despite the vast variation in weather condition.
Keywords: maize; mouldboard; strip tillage; ripper tillage; fertiliser; hybrid; year effect

Introduction

In an ever-changing world, improving and achieving sustainable yield requires continuous evaluation of production technologies in order to determine the best combination of inputs which will optimise yield for a given situation. Maize (*Zea mays* L.), is major grain crop in Hungary, cultivated on approximately one million hectares. Besides being an excellent feed source, maize is also a cheap source of energy and raw material for industry (Nagy, 2006a). Annual production over the last decade ranged from 4.8 to 9.3 million tons, with significant fluctuation in yield (Hungarian Central Statistical Office, 2018).

Year effect significantly influences the size of yield of maize and in particular, the amount and distribution of precipitation during the growing season, coupled with the temperature during the winter (Nagy, 2003; Széles et al. 2013). Harmonization of the agroecological (weather and soil), biological bases and agrotechnical factors (crop rotation, nutrient supply, soil cultivation, sowing, plant care, irrigation, harvest, etc.) is critical for optimization and reduction of fluctuation in the yield of maize (Nagy, 2003; Berzsenyi,

2010; Berzsenyi et. al. 2011; Sárvári and Bene, 2012; Pepó and Csajbók, 2013).

Tillage is central to the agrotechnical factors which modifies soil structure by changing its physical properties, such as soil moisture content, bulk density and penetration resistance. These changes in soil physical properties, as a result of different tillage practices, influenced seedling emergence, plant population density, root distribution and crop yield (Khan et al., 2001; Iqbal, et al., 2013; Khurshid et al., 2006; Rashidi and Keshavarzpour, 2007).

The effects of basic soil tillage are largely modified yearly by the various levels of water supply (Nagy, 2006a). Under extremely dry conditions the final yield of maize was significantly affected by the soil tillage system (Kristo et al., 2013; Memon et al., 2012). Soil tillage systems had different effects on the preservation of the soil moisture contents, which significantly affected maize yield (Simić et al. 2009) and the most important goals of tillage include preserving the favourable soil attributes and alleviating circumstances leading to detrimental processes (Birkás, 2010).

In Hungary, changing climatic condition and increase frequency of drought years are paving way for alternative tillage methods which can conserve on soil moisture, minimise soil erosion and optimize yield (Birkás, 2015). Mouldboard plowing has been the common tillage practice in Hungary in maize production technology. It provides good depth and improves the water storage capacity of the soil (Nagy,2006a). However, this tillage practice offers minimal soil surface protection with crop residue and has high potential for moisure loss and soil erosion (Birkás, 2010).

Strip tillage (ST) and ripper tillage (RT) are two alternatives which have been identified for evaluation in this research. Unlike the moldboard plow , strip and ripper implements do not completely invert the soil and leaves a higher percentage of the soil surface covered by crop residue. The potential for erosion and moisture loss is therefore considerably less than that of moldboard plowing. Besides, ripper tillage reportedly loosens more soil, compared to conventional and zero tillage and allows for greater aeration and water retention capacity, which are favourable for plant growth (Memon et al. 2012).

Rátonyi et al.(2014) reported higher moisture retention in the soil profile of ST and RT in Hungary, compared to the conventional MT tillage and posited that maize yield in ST treatment can reach similar level as yields of maize in conventional MT treatment on chernozem soil in Hungary. On sites with root-restricting soil layers, deep tillage effects were 20% higher than at sites without such layers (Kuhlmann et al., 1989; Kirkegaard et al., 2007). Successful deep tillage requires soil water content to be below the plastic limit from the topsoil to the maximum tillage depth (Borchert, 1975; Eck and Unger, 1985). In addition to appropriate selection of tillage operations, the improvement in average yield per hectare can be obtained if soil fertility is maintained through proper dose, application method and use of organic and inorganic fertilizers (Mermon et al. 2012). Under favourable conditions fertilisation could improve yield up to 50%, however in excessively dry years, it does not have any yield increasing effect (Pepó, 2007).

The findings of this research will add to the body of knowledge gained from similar research and will serve as an effective tool to analyse trends, generate model and predict the most suitable crop production technologies which can be applied, in order to reduce fluctuation in yields and achieve production sustainability.

Table 1. Monthly temperature(°C) for the examined period (2015-2016).

Year	Temperature (°C)											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2015	1.69	2.00	6.84	11.19	16.10	20.31	23.38	23.33	17.77	10.44	7.06	2.61
2016	-0.64	5.99	7.15	12.88	16.35	21.15	22.50	20.76	18.55	9.86	5.26	-0.38
30-year mean	-2.6	0.2	5.0	10.7	15.8	18.7	20.3	19.6	15.8	10.3	4.5	-0.2

Materials and Methods

The experiment was conducted at the Látókép Research Station Site (N 47°33' E 21°27') of the University of Debrecen in 2015 and repeated in 2016. The soil type was calcareous chernozem soil, consisting of 11% sand, 65% silt and 24% clay in the upper soil layers , with a near neutral pH value (pH_{KCl}=6.46). It has a humus content of 2.8% and humus depth of approximately 80 cm, with good water holding capacity.

The experiment was set up in a split-plot design with three main plots, each 1.0 ha in size (37 × 272 m) which represents the tillage treatments: Moldboard plowing (MT) – 30 cm depth; Strip tillage (ST) – 30 cm depth; Ripper tillage (RT) – 45 cm depth. The main plots were subdivided to accommodate three fertiliser treatments (N_0 kg ha^{-1} (control); N_{80} kg ha^{-1}; N_{160} kg ha^{-1}) with four replications.

Maize hybrids, Loupiac (FAO 380) and Armagnac (FAO 490) were sown with 80,000 plants ha^{-1} with a row spacing of 76 cm. The crop was harvested at the end of the growing cycle with a Sampo 2010 plot harvester and the grain moisture content was adjusted to 15% moisture to arrive at the final yield. Yield data were analyzed using IBM SPSS-26.0 and treatment means were compared using the Fisher's least significant difference (LSD) test (p<0.05).

Monthly temperature (Table 1) and precipitation (Figure 1) and were recorded for the period 2015-2016 and compared to the 30 year mean. Precipitation during the vegetative period (April to September) was 303.8 mm and 449.9 mm for 2015 and 2016 respectively, against a 30 year mean of 345.1 mm.

Results and Discussion

Cropyear interaction was highly significant with vast variation in yield between the two years, ranging from 8.36 t ha^{-1} in 2015 to 12.43 t ha^{-1} in 2016 for the same set of agrotechnical inputs. Analysis of the meteorological data for the two years (2015 & 2016), revealed major differences, especially the amount and distribution of rainfall during the growing season (April-Sept). According to Nagy (2006a) the most critical period of the growing season in Hungary is between flowering and fertilization (15th July – 15th August) and a period of 3 to 4 days of severe moisture stress at this time can easily reduce final grain yields by 30 percent (Lamm, 2003).

Rainfall in 2015 (303.8 mm) was below the 30-year mean (345.1mm) and specifically in the month of July when the reproductive phase commenced (Figure 1). Unlike 2015, there was adequate rainfall throughout the growing season of 2016, as a result, the yield gain in 2016 was 4.07 t ha^{-1}. Significant effects of the year on the yield and its components were observed very often in long-term field studies due to differences in precipitation and grow degree days accumulation during the vegetative period of maize (Wilhelm
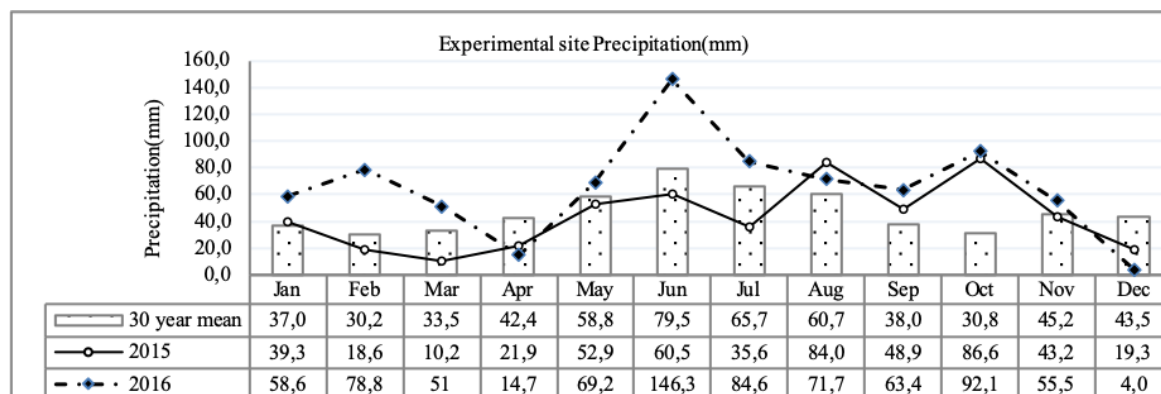
Figure 1. Monthly precipitation for the examined period (mm) (Debrecen 2015-2016).

and Wortmann, 2004; Boomsma et al. 2010). Weather regulates heat and moisture supply of the crop environment and therefore has an effect on material transformation, fertilizer efficiency and nutrient uptake by plants (Kovács, 1982; Nagy, 1996).

Based on results of long-term experiment, Nagy, (2006b) observed that higher yields were always accompanied by higher precipitation but low yield was not always accompanied by the lowest amount of precipitation. It was evident that the effect of the year (Figure 2) and fertilization (Table 2) on yield of maize was highy significant compared to tillage.

The effect size of tillage on yield of maize was 2.2% for the examined period(2015-2016), compared to fertilizer and year effect with 43.6 and 53.4% respectively. Among the three tillage treatments, ripper tillage (RT) had the highest average yield (10.37 t ha^{-1}) followed by mouldboard plowing (MT) and strip tillage(ST) with 10.22 and 9.60 t ha^{-1}, respectively. Yield difference between RT and MT was not statistically significant (p>0.05), as compared to ST (Table 3).

Although the average yield of strip tillage(ST) was lowest over the two-year period, in 2015, a relatively dry year, the yield of ST treatment (8.27 t ha^{-1}) varied less than

2% when compared to the MT (8.41 t ha^{-1}) and RT(8.42 t ha^{-1}) treatments. It is evident that yield of maize in ST can reach comparable level as maize in the conventional MT, especially under drier condition. Roger et al. (2007) reported that in persistently dry conditions, strip-tilled maize performed better than maize planted with conventional tillage because of better soil moisture conservation. Similar observations were made by Birkás (2010) and Ratónyi et al. (2014).

According to Nagy (1996) & Fenyves (1997) the depth and method of tillage do not significantly influence the yield of maize on well structured soil. It can be inferred based on the results of our tillage treatments, that soil at the experimental site possess good attributes and may not be the ideal location to evaluate the effectiveness of various tillage treatments. Schneider et al., (2014) , found that the yield gains of deep tillage were strongly dependent on site-specific condition and sites with root-restricting soil layers, deep tillage effects were generally 20% higher than at sites without such layers.

A holistic approach will be needed when selecting the most appropriate tillage method since fuel consumption , machine productivity, time and labour are all likely to be varied, inaddition to the yield, and therefore the method with the highest yield gain may not
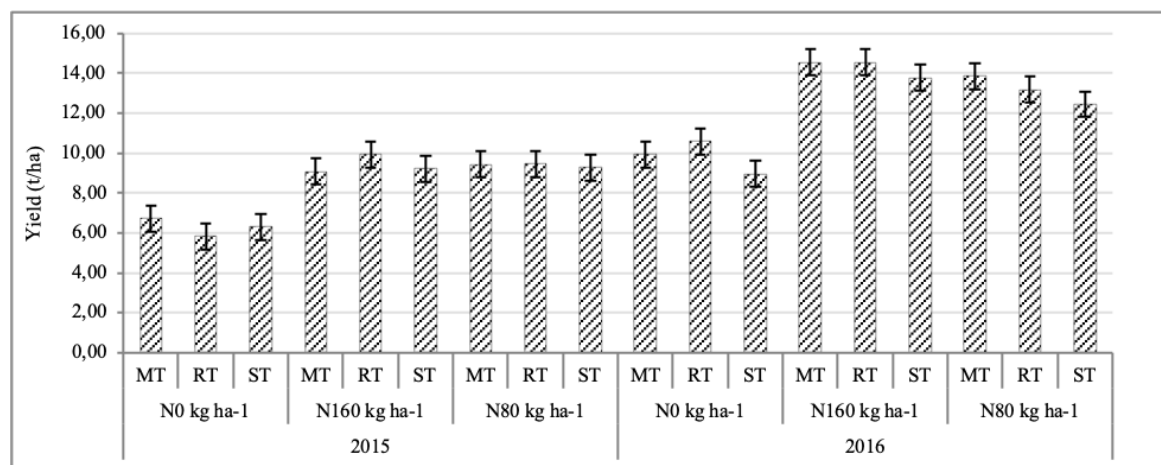
Figure 2. Yield of maize for the tillage and fertiliser treatments (2015-2016) (MT-Mouldboard tillage; RT-Ripper tillage; ST-Strip tillage).

Table 2. Analysis of variance: Tests of Between-Subjects Effects.

Dependent Variable: Yield

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	6255.982[a]	35	178.742	48.380	.000
Intercept	93539.493	1	93539.493	25318.145	.000
Year	3484.418	1	3484.418	943.120	.000
Fertilization	2526.592	2	1263.296	341.934	.000
Tillage	52.366	2	26.183	7.087	.001
Hybrid	10.991	1	10.991	2.975	.085
Year * Fertilization	60.586	2	30.293	8.199	.000
Year * Tillage	44.888	2	22.444	6.075	.002
Year * Hybrid	4.260	1	4.260	1.153	.283
Fertilization * Tillage	13.674	4	3.418	.925	.449
Fertilization * Hybrid	3.359	2	1.679	.455	.635
Tillage * Hybrid	5.975	2	2.988	.809	.446
Year * Fertilization * Tillage	30.408	4	7.602	2.058	.085
Year * Fertilization * Hybrid	.558	2	.279	.076	.927
Year * Tillage * Hybrid	11.290	2	5.645	1.528	.218
Fertilization * Tillage * Hybrid	1.614	4	.404	.109	.979
Year * Fertilization * Tillage * Hybrid	5.001	4	1.250	.338	.852
Error	3059.099	828	3.695		
Total	102854.574	864			
Corrected Total	9315.081	863			

a. R squared = .672 (Adjusted R squared = .658)

necessarily be the most economical one. It is the expressed views of several researchers, that the effects of tillage systems on yield cannot be evaluated on the basis of a single season and that long-term experiments of many years are required.

Table 3. Analysis of variance: Tests of Between-Subjects Effects.

Dependent Variable: Yield
LSD

| (I) Tillage | (J) Tillage | Mean Difference (I-J) | Std. Error | Sig. | 95% Confidence Interval | |
					Lower Bound	Upper Bound
MT	ST	.60*	.130	.000	.35	.86
	RT	.00	.130	.995	-.25	.26
ST	MT	-.60*	.130	.000	-.86	-.35
	RT	-.60*	.130	.000	-.86	-.35
RT	MT	.00	.130	.995	-.26	.25
	ST	.60*	.130	.000	.35	.86

Based on observed means.
The error term is Mean Square(Error) = 3.660.
*. The mean difference is significant at the .05 level.

Table 4. Analysis of variance - Fertilizer treatments.

Dependent Variable: Yield
LSD

| (I) Fertilization | (J) Fertilization | Mean Difference (I-J) | Std. Error | Sig. | 95% Confidence Interval | |
					Lower Bound	Upper Bound
0 kg N/ha	80 kg N/ha	-3.22*	.130	.000	-3.48	-2.97
	160 kg N/ha	-3.79*	.130	.000	-4.05	-3.54
80 kg N/ha	0 kg N/ha	3.22*	.130	.000	2.97	3.48
	160 kg N/ha	-.57*	.130	.000	-.83	-.32
160 kg N/ha	0 kg N/ha	3.79*	.130	.000	3.54	4.05
	80 kg N/ha	.57*	.130	.000	.32	.83

Based on observed means.
The error term is Mean Square(Error) = 3.660.
*. The mean difference is significant at the .05 level.

Fertilizer application significantly increased the yield of maize and accounted for 43% of yield variances. Yield differences between fertilizer treatments was highly significant (Table 4). The highest yield (11.88 t ha^{-1}) was obtained with N_{160} kg ha^{-1} treatment, followed by N_{80} kg ha^{-1} (10.83 t ha^{-1}), while the lowest yield (7.48 t ha^{-1}) was recorded in the nonfertilised plots(N_0 kg ha^{-1}).

A positive interaction between tillage and fertilisation was observed, with higher yield variation (CV=40.07) in the non-fertilised (N_0) tillage plots, compared to those which received the N_{80} and N_{160} kg ha^{-1} treatments (CV=22.42). Similar observations were made by Győrffy, (1976) who postulated that effects of tillage depth as well as the number of interventions are reduced or compensated for by fertilization.

In 2016, higher yield was obtained with increase fertiliser dosage due to favourable growing condition which allowed for better fertiliser utilisation. However, 2015 being a relatively dry year with less than optimum water supply, there was no yield increasing effect with higher fertiliser dosage (N_{160} kg ha^{-1}). Similar observation was made by
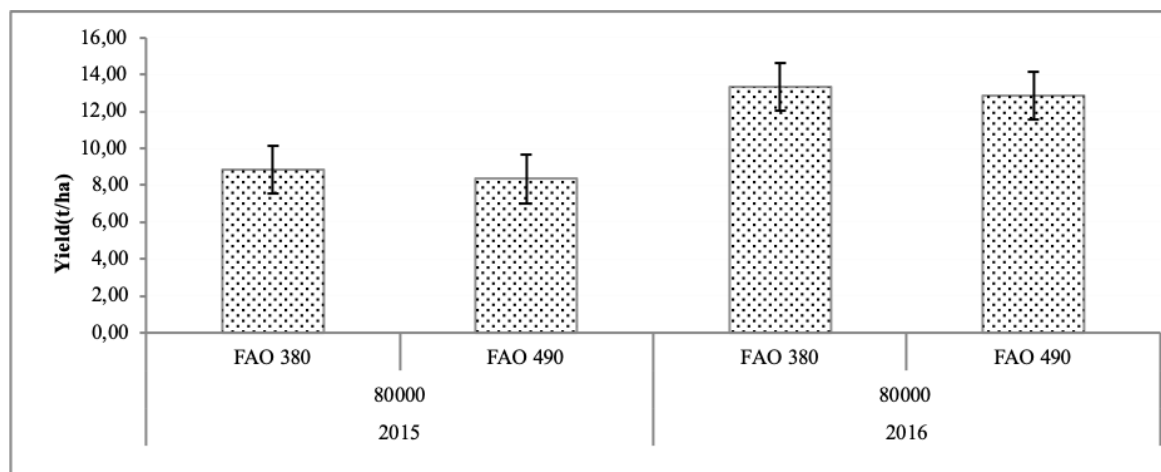
Figure 3. Yield of maize hybrids for the three fertiliser treatments (2015-2016).

Nagy (2006a, 2007) who concluded that a positive correlation exists between fertiliser and water suppy and both factors must be increased or decreased simulataneously inorder to realise optimum benefits. According to Berzsenyi & Dang (2003) in dry years, lower fertiliser dosage had higher stability while in wet years higher fertiliser dosage results in more stable yield.

Maize has high productivity, but it is very sensitive to the agroecological and agrotechnical conditions. When these conditions are optimal, the amount of yield is determined by the differences between the hybrids; but in the case of unfavourable weather conditions or shortcomings in the agrotechnique, the most important factor is the adaptability of the hybrids (Gardner et al. 1990; Marton et al. 2005).

Loupiac (FAO 380) was the better performing of the two hybrids, with an average yield of 11.09 t ha^{-1} compared Armagnac (FAO 490) with 10.60 t ha^{-1} . The adaptability traits of the two hybrids appears to be very similar, since the yield differential between the two hybrids was almost constant (0.48 vs 0.49) in both years , despite the vast variation in weather condition (Figure 3).

Conclusions

Loupiac (FAO 380) was the better performing hybrid compared to Armagnac (FAO 490). Lower dosage of fertiliser produced optimum results in drier year with limited water supply. Ripper tillage and strip tillage can be suitable alternatives for the conventional mouldboard tillage, especially in drier conditions. The best combination of treatments for optimum yield was Lopiac (FAO 380), cultivated under rip tillage (RT) with N$_{80}$ kg ha^{-1} fertiliser.

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