The impact of five long-term contrasting tillage systems on maize productivity parameters

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Maize productivity is mainly constrained by the climate, meteorological and soil conditions, and agro-technological practice. Reduced primary tillage intensity might be a method to optimize the complex interactions between these conditions. An 8-year field experiment was designed to test this. The aim of the experiment was to establish the influence of deep and shallow ploughing, chiselling, disking and no-tillage systems on parameters of maize productivity. No-tillage resulted in a significant decrease in maize stand density compared with deep and shallow ploughing, as well as chiselling, while maize canopy height and dry biomass was slightly higher in the no-tillage system. Nevertheless, in no-tillage plots the maize yield was insignificantly lower than in deeply and shallowly ploughed plots (on average 3.5–6.4% less). Overall, long-term reduction of primary tillage had less impact on maize productivity parameters than meteorological conditions during the vegetation period.

Key words: meteorological conditions, productivity parameters, tillage, *Zea mays* L.

Introduction

In Lithuania, agricultural crops occupy approximately 32% (2.062 million ha) of the total land area. Cereals account for around 67–70% of the total crop area (Statistics Lithuania 2018). Winter wheat and spring barley are the most widely grown crops. Unfortunately, due to changing climatic conditions (uneven precipitation distribution, lack of sunny days), the quality of grain usually only allows their use as animal feed. However, given that processing maize for feed is inexpensive, there has been a focus on developing methods for maize growing, especially those allowing using the grain for a food crop. In fact, demand for maize for livestock concentrate feeds is around 3–4 times higher than the demand for cereal grains. Therefore, maize might be a very attractive export opportunity for Lithuanian farmers. In addition, given that maize is not grown in the same soil types as wheat, these two crops do not compete for land.

Latitudes between 58 and 54°N (Latvia and Lithuania) are marginal for maize grain production in the Eastern Baltic Sea region (Gaile 2012). In Lithuania, maize grain production (primarily experimental) only began around 15–18 years ago because of its short growing season (approximately 150–160 days), low growing temperatures and a lack of early-maturing varieties. During the last 15 years, the temperatures and the length of the growing season have increased in Lithuania. Since 2008, 75 different varieties of maize have been registered, of which three varieties were FAO 170 and 7 and FAO 180 (SPS 2018), leading to the implementation of maize production. These factors support an increase in the area devoted to maize as well as the total volume of maize production. The area devoted to the production of maize grain has increased from 5.4 thousand ha in 2007 to 13.8 thousand ha in 2018, and the grain yield per ha has increased from 4.8 to 6.0–7.0 t ha^{-1} over the same period (Statistics Lithuania 2018). Currently, new questions have become important e.g. how to most efficiently manage high grain moisture contents (37–40%) at harvest (due to the short growing season and wet autumn), which currently requires high energy inputs associated with drying. And also how to reduce the fuel and labour costs through managing tillage (conversion, minimal, rational or no-tillage) (Baker et al. 2006, Kisic et al. 2010, Kertész and Madarász 2014).

Arvidsson et al. (2013) found that the average yield for non-inversion tillage was only 1–2% lower compared with mouldboard ploughing. Swedish experiments comparing shallow tillage and no-tillage systems in 1983–2012 showed that the spring cereal and spring oilseed rape yields were similar with both methods. Yields of peas, sugar beet, potatoes, and winter oilseed rape were 5–10% lower in shallowly tilled plots. In no-tillage, yields were on average 9.8% lower than with mouldboard ploughing (Arvidsson et al. 2014). Ekeberg and Riley (1997) showed that in southeast Norway reduced tillage could be recommended for all the crops studied, except for fodder beet.

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According to the review of Rasmussen (1999), in Norway, Sweden, Denmark and Finland, crop yields were up to 10% lower under reduced tillage treatments compared with mouldboard ploughing. Van den Putte et al. (2010) found that under European conditions, reduced soil tillage on average reduced the crop yields by 2.7%, while no-tillage by 8.5%. In the humid climate of Northern Europe, no-tillage yields were 5–10% lower compared with ploughing. In Southwestern Europe, the yields were similar or higher (Cannell 1985, Soane et al. 2012, Alakukku et al. 2019). Variation in maize yields were observed worldwide. Under arid or semi-arid climate conditions, conservation tillage and/or no-tillage were found to be superior to ploughing (Tolon-Becerra et al. 2011, Wyngaard et al. 2012, Wang et al. 2012, Botha et al. 2015, Busari et al. 2015, Zhang et al. 2015, Shaoa et al. 2016). Under humid, semi-humid or irrigated conditions mouldboard ploughing resulted in higher or similar yields of maize compared to minimal or no-tillage methods (Jin et al. 2011, Tueche and Hauser 2011, Berhe et al. 2012, Messiga et al. 2012, Qingjie et al. 2014, Li et al. 2018). Other explanations for the observed differences include variation in the types of soil, meteorological conditions, machinery used, methods for weed control, increased soil compaction, etc. (Cullum 2012, Feiziene et al. 2018, Hontoria et al. 2018, Zhang et al. 2018, Jia et al. 2019, Xu et al. 2019).

In the future, gradual climatic changes and unstable meteorological conditions will have a major impact on changes in crop production (Abraha and Savage 2006). Intensive soil tillage may cause soil erosion, which can destroy productive agricultural lands, and climate change can deepen this problem (Parajuli et al. 2016). Consequently, one of the most important objectives of future agricultural technologies will be to stabilize soil properties, highly dependent on tillage intensity. Reduced tillage systems will become common practice in a range of different climatic zones.

Reduced tillage systems for maize grain have not been widely investigated in Northern Europe and Lithuania, and no long-term experiments have yet been performed. The hypothesis tested in this experiment is that changing tillage practice from annual conventional deep ploughing to chiselling, disking or no-tillage (direct drilling) will preserve maize grain production despite unstable meteorological conditions. The objective was to evaluate the effect of long-term ploughless tillage systems and meteorological conditions during an 8-year period on the main productivity parameters of maize cultivation.

Materials and methods

Description of the site

A long-term stationary field experiment has been performed at the Experimental Station (54°52′ N, 23°49′ E) of Vytautas Magnus University, Agriculture Academy in Lithuania since 1988. No-tillage (direct drilling) treatment was added in 2001. As cultivated plants in crop rotation, sugar beet crop was grown at this site in the period of 2001–2007, while maize (*Zea mays* L.) was grown in the period 2008–2015. Here, we present the data from study of maize cultivation. The soil at the experimental site was a silt loam (45.6% sand, 41.7% silt and 12.7% clay) *Planosol* (WRB 2014). The agrochemical soil properties at the beginning and at the end of the experiment are presented in Table 1, while the description of its physical and biological properties could be found in Buragiene et al. (2019).

Table 1. Agrochemical soil properties (0–15 cm layer)

Year	pH	C_{org} (g kg^{-1})	N_{total} (g kg^{-1})	P (mg kg^{-1})	K (mg kg^{-1})
2008	6.8±0.2	7.6±0.8	1.5±0.1	181.2±26.9	104.4±25.0
2015	6.7±0.1	7.4±0.9	1.5±0.2	161.0±28.1	106.6±7.0

The climate of the experimental site is subarctic with wet winters and moderate summers. During the last 100 years average annual temperatures at the site increased from 6.3 to 6.7 °C and the precipitation rate – from 590 to 625 mm. The length of the vegetation season with active temperatures (≥ 10 °C) is about 6 months (160–170 days). Even though increased temperature positively affects crop productivity in cold climatic conditions, higher temperatures and an increase of precipitation rates lead to soil degradation. Around 70% of soil in Lithuania is eroded.

Average annual temperatures and rainfall in 2008–2015 are presented in Tables 2 and 3. Additional descriptions of the climate conditions of the experimental site are available in Romaneckas et al. (2015). During eight years of investigation, the average temperature in April was higher than the 40-year average temperature (Table 2).

Table 2. Average temperature and the sum of the active temperatures (SAT) during the maize growing season (April-September) in 2008–2015, Kaunas Meteorological Station

Year \ Month	April	May	June	July	August	September	SAT
2008	8.8	12.1	16.0	18.1	17.9	12.2	2321
2009	8.9	12.7	14.8	18.4	16.9	13.8	2381
2010	7.4	13.7	16.5	21.9	19.7	12.0	2564
2011	8.9	13.1	18.1	19.6	18.1	13.6	2607
2012	7.7	13.7	15.3	19.4	17.1	13.3	2452
2013	5.5	16.1	18.5	18.1	12.1	12.3	2634
2014	9.1	13.2	14.6	20.5	17.8	13.5	2526
2015	7.1	11.4	15.4	17.4	20.3	14.3	2458
Long-term average, 1974–2013	6.9	13.2	16.1	18.7	17.3	12.6	-

SAT = sum of active temperatures (≥ 10 °C)

In approximately 50% of the years studied, May, June and July were warmer than usual, while August and September were warmer in approximately 70% of cases. These data highlight the trend of increasing air temperature in the Baltic region over the last several years. Early maize grain hybrid productivity requires temperatures of no less than 2000 °C SAT. Since 2000, SATs have continuously increased in Lithuania and, in the period 2008–2015, reached a range of 2300–2600 °C. Juhola et al. (2017) suggest that an increase in temperature and precipitation in spring and summer could increase the yields in Northern countries.

The precipitation variance for every month studied is presented in Table 3.

Table 3. Precipitation (mm) during the maize growing season (April-September) in 2008–2015, Kaunas Meteorological Station

Year \ Month	April	May	June	July	August	September	Sum
2008	32.1	35.5	83.2	43.0	99.3	27.0	320.1
2009	8.6	42.0	107.4	83.8	87.5	28.3	357.6
2010	58.5	84.8	127.0	101.0	112.0	63.3	546.6
2011	25.2	46.9	82.7	144.0	152.4	73.9	525.1
2012	72.3	50.3	93.4	112.8	69.2	67.2	465.2
2013	56.5	63.8	45.9	118.5	47.2	104.3	436.2
2014	21.3	84.2	49.4	52.5	111.3	20.7	339.4
2015	46.0	43.8	16.4	72.4	6.9	56.6	242.1
Long-term average, 1974–2013	41.3	61.7	76.9	96.6	88.9	60.0	425.4

Four growing seasons were more arid than usual, two were extremely humid and two were similar to the long-term average, based on the sum of precipitation. A moderate positive correlation between SAT and the sum of total precipitation was found during the maize growing seasons (r = 0.602).

Experiment design and tillage management

In this long-term field experiment five tillage methods were used: 1) conventional deep ploughing with a mouldboard plough (DP); 2) shallow ploughing with a mouldboard plough (SP); 3) deep cultivation with a chisel cultivator (DC); 4) shallow cultivation with a disc harrow (SC); and 5) no-tillage (direct drilling) (NT) (Table 4).

Table 4. Tillage methods used in the experiment

Tillage system	Stubble tillage	Primary tillage	Implement	Depth of tillage (cm)	Pre-crop residue cover (%)
DP	Yes	Inversion	Mouldboard plough	22–25	3–4
SP	Yes	Inversion	Mouldboard plough	12–15	5–8
DC	Yes	Non-inversion	Chisel cultivator	25–30	20–22**
SC	Yes, twice	No	Disc harrow	10–12	16–17**
NT	No	No	None	0	30–81**

DP = deep ploughing; SP = shallow ploughing; DC = deep cultivation; SC = shallow cultivation; NT = no-tillage (direct drilling); ** = significant differences from the control treatment (DP) at $p \le 0.01$

The distribution of experimental plots was randomized. There were four replications, and the total number of plots per crop was 20 (Fig. 1). The primary size of each experimental plot was 126 m^2 (14 × 9 m), and the sampled area was 70 m^2 (10 × 7 m). The pre-crop in all these plots was winter wheat, while the crop rotation in this experiment was winter wheat, maize, spring barley, and spring oilseed rape. Since 2001, only mineral fertilization of experimental plots was made. Legumes and cover crops were not grown.

Fig 1. Experimental site

A special plot harvester (Wintersteiger AG, Austria) was used for pre-crop harvesting. After harvesting, the stubble was shallow cultivated (disked) in all the experimental plots, except for NT (Fig. 2). The only factor that varied across the treatments was the tillage method (except for weed control in NT plots). In NT plots, the herbicide Roundup (glyphosate 360 g l^{-1}, 4 l ha^{-1}) was used. Primary tillage was performed in late October, with a Gamega PP-3-43 plough (Laumetris, Lithuania) with semi-helical shellboards, chisel cultivator KRG-3.6 and Väderstad Carrier 300 disc harrow. In spring, mineral fertilizers were broadcast with an Amazone-ZA-M-1201 fertilizer spreader (Amazone, Germany). Pre-sowing tillage was performed with a complex cultivator KLG-3.6 (Laumetris, Lithuania). A strip sowing method was employed using a Vaderstad Rapid 300C Super XL drill (Vaderstad, Sweden). The distance between the rows in each strip was 12.5 cm, and the distance between the strips was 50 cm. The maize was sown at a rate of 100000 seeds per ha (approximately 21–23 kg ha^{-1}) at a depth of 6–7 cm. Early maturing (FAO 180, Germany) maize hybrids were used. A single application of herbicide was used in the maize crop (Amazone UF-901 sprayer, Germany). The maize crop was sprayed with Maister herbicide (foramsulfuron 22.5 g l^{-1}, 1.5 l ha^{-1}) and additionally fertilized with ammonium nitrate (N60). Given that there was a low incidence of pests and disease, other pesticides were not used. Harvesting of the maize was initiated when the kernels contained more than 60% dry matter. Additional information on the experimental methodology is available in Avižienytė et al. (2013) and Romaneckas et al. (2015).

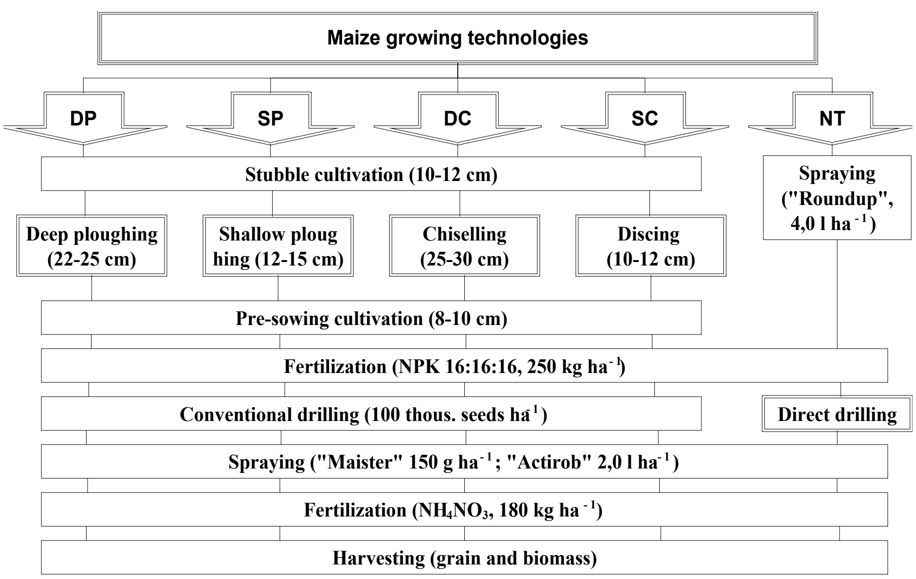

Fig. 2. Technological scheme for maize cultivation according to Šarauskis et al. (2014)

Methods and analysis

In order to evaluate the properties and the texture of the soil, soil electric conductivity was first tested with a mobile machine Veris 3150 MSP (Veris Technologies, USA) (Fig. 3). This machine is able to test soil electrical conductivity at depths of 0–30 and 0–90 cm and is equipped with a GPS system. Mapping of electrical conductivity was performed with the computer program "SMS Advanced"(Ag Leader, USA). Samples for evaluation of soil properties were taken with an agro-chemical auger in 15–20 spots per plot with the dominant colour. This method limits variation of the chemical and physical soil properties. Chemical soil properties were analysed as follows: pH was measured with a potentiometer, phosphorus and potassium using the Egner-Rim-Doming (A-L) method and total nitrogen using the Kjeldahl method.

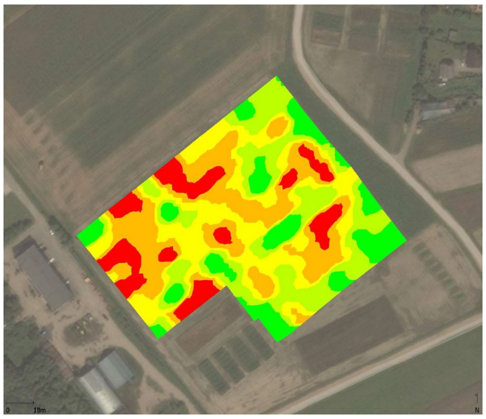

Fig. 3. Experimental site mapping with Veris 3150 MSP

The same coordinates were used for the evaluation of maize crop density, biometric and productivity parameters. Maize canopy samples were taken from 10 separate spots in each experimental plot before harvesting. The total sampled area was 3.1 m^2 per plot. Each plant and cob in the sample were measured and weighed. Four separate samples from each plot were calculated for evaluation of the 1000-grain weight.

The data were analysed using two-way ANOVA and correlation with factor A being the tillage and factor B seasonal meteorological conditions during the experiment. Statistical analysis was implemented with the program SigmaStat.

Results

Maize productivity parameters

The effect of the tillage treatments on maize stand density varied throughout the years. Across the five growing seasons, there were no significant differences in the effects of the different tillage methods on maize stand density (Table 5).

Table 5. The impact of tillage systems on the density of maize crop before the harvest (thousand ha^{-1})

Tillage system (F_A)/Year (F_B)	DP	SP	DC	SC	NT	Average F_B
2008	74.2a	70.8ab	68.8ab	72.5ab	44.2b	66.1C
2009	50.4a	44.2a	48.8a	46.7a	45.0a	47.0D
2010	75.2a	77.3a	77.2a	70.8a	71.2a	74.3C
2011	65.6b	65.6b	85.6a	68.8b	56.0c	68.3C
2012	70.0a	68.0a	70.4a	66.8a	68.4a	68.7C
2013	60.4a	59.6a	51.6a	52.0a	50.0a	54.7D
2014	84.3a	93.1a	87.5a	77.8a	81.9a	84.9B
2015	119.2a	115.2ab	108.0ab	95.2ab	84.0b	104.3A
Average F_A	74.9a	74.2a	74.7a	68.8b	62.6b	15.9*

DP = deep ploughing; SP = shallow ploughing; DC = deep cultivation; SC = shallow cultivation; NT = no-tillage (direct drilling). Different lowercase letters within rows and uppercase letters within columns mean significant difference at $p \leq 0.05$. F_A = factor A (tillage system); F_B = factor B (seasonal meteorological conditions during the experiment); * = $F_A \times F_B$

Significantly lower density in NT plots was observed mainly in the years with dry growing seasons (2008 and 2015). SC and NT treatments, on average (Factor A), resulted in significantly lower stand densities. Significant differences between the growing seasons were found. For stand density, the most favourable seasons were in 2014 and 2015.

The maize canopy height was an important indicator, closely related to other productivity parameters. The reduction of tillage intensity had different impacts on the height of the maize canopy. In only two of the eight years DP plots yielded the highest canopy (Table 6).

Table 6. The impact of the tillage systems on the height of maize canopy (cm)

Tillage system (F_A)/Year (F_B)	DP	SP	DC	SC	NT	Average F_B
2008	218.6a	212.5a	211.0a	218.8a	212.8a	214.7C
2009	243.4a	252.8a	251.3a	237.6a	251.8a	247.4B
2010	202.2a	200.8a	175.9bc	194.6ac	212.7a	197.2DE
2011	304.3a	300.5a	281.4b	284.4b	299.3ab	294.0A
2012	216.8a	187.4b	167.2c	186.3b	209.0ab	193.3DE
2013	169.8b	166.7b	184.2ab	209.3a	209.4a	187.9E
2014	210.7a	212.7a	204.3a	198.3a	208.3a	206.9CD
2015	168.9ab	152.6b	158.7ab	174.1a	166.2ab	164.1F
Average F_A	216.8a	198.3a	204.3a	212.9a	221.2a	35.1*

DP = deep ploughing; SP = shallow ploughing; DC = deep cultivation; SC = shallow cultivation; NT = no-tillage (direct drilling). Different lowercase letters within rows and uppercase letters within columns mean significant difference at $p \leq 0.05$. F_A = factor A (tillage system); F_B = factor B (seasonal meteorological conditions of experiment); * = $F_A \times F_B$

In most cases, the lowest height of maize canopy was found in the DC plots. The NT plots never yielded the lowest height of maize canopy. On average, the highest maize plants were found in NT, while the shortest in the SP plots. On average, the highest canopy of maize was found in the warmest season, in 2011, and this difference was statistically significant. The height of canopy was the index with high variability within experimental years.

Different primary tillage methods had similar effects on the length of the maize cobs. However, SP and/or DC led to a decrease in cob length compared with DP, which was not the case with NT (Table 7).

Table 7. The impact of the tillage systems on maize cob lengths (cm)

Tillage system (F_A)/Year (F_B)	DP	SP	DC	SC	NT	Average F_B
2009	14.8a	14.8a	14.2a	14.8a	15.8a	14.9A
2010	12.1a	10.4b	8.3bc	10.8ab	11.9ab	10.7C
2011	14.9b	13.5b	17.7a	15.8ab	16.1ab	15.6A
2012	13.0a	12.5a	12.2a	12.4a	12.6a	12.5B
2013	13.2ab	11.5b	12.2ab	12.7ab	13.9a	12.7B
2014	13.4a	12.6a	12.8a	13.1a	14.0a	13.2B
2015	13.6ab	12.8b	13.2ab	13.3ab	14.1a	13.4B
Average F_A	13.6ab	12.6b	12.9b	13.3ab	14.1a	2.0*

DP = deep ploughing; SP = shallow ploughing; DC = deep cultivation; SC = shallow cultivation; NT = no-tillage (direct drilling). Different lowercase letters within rows and uppercase letters within columns mean significant difference at $p \leq 0.05$. F_A = factor A (tillage system); F_B = factor B (seasonal meteorological conditions of experiment); * = $F_A \times F_B$

On average, the longest cobs (14.1 cm) were observed in the NT plots. The differences were not statistically significant compared with DP. However, the maize cobs in NT were significantly longer compared with SP and DC (by 1.2 to 1.5 cm, respectively). Significantly, the longest cobs of maize (15.6 cm) were found in the warmest season in 2011.

The total dry biomass of the maize canopy varied strongly throughout the years (Table 8).

Table 8. The impact of the tillage systems on the total dry biomass of the maize canopy (Mg ha^{-1})

Tillage system (F_A)/Year (F_B)	DP	SP	DC	SC	NT	Average F_B
2008	10.47ab	10.69ab	10.60ab	11.43a	8.50b	10.34C
2009	8.26a	8.29a	8.16a	7.06a	8.34a	8.02D
2010	8.47b	8.33b	6.38c	8.08b	11.40a	8.53D
2011	21.28a	21.84a	23.25a	22.51a	20.49a	21.87A
2012	16.00a	11.80b	10.56b	11.40b	14.27ab	12.81BC
2013	7.57a	6.77a	6.31a	8.55a	8.91a	7.62D
2014	13.72a	14.11a	12.46a	11.60a	13.85a	13.15B
2015	12.82a	10.32a	10.43a	10.64a	13.08a	11.46BC
Average F_A	12.32a	11.52a	11.02a	11.41a	12.36a	3.10*

DP = deep ploughing; SP = shallow ploughing; DC = deep cultivation; SC = shallow cultivation; NT = no-tillage (direct drilling). Different lowercase letters within rows and uppercase letters within columns mean significant difference at $p \leq 0.05$. F_A = factor A (tillage system); F_B = factor B (seasonal meteorological conditions of experiment); * = $F_A \times F_B$

The highest total biomass of canopy was found in control plots (DP) only in one year, 2012. In five years, the highest biomass was found in the NT plots. However, these differences were not significant. On average, the highest dry biomass (12.36 Mg ha^{-1}) was produced in the NT plots. The warmer than usual vegetative season in 2011 was the most favourable for canopy development; the biomass of the canopy was 2–3 times higher that year compared with the other seasons. This result demonstrated the higher potential for maize productivity under unstable meteorological conditions if global warming continues. However, in humid warm climate conditions, the complex effects of climate change and tillage practices have not had a significant influence on crop yields (Parajuli et al. 2016).

During the eight years of investigation, the grain maize yield varied significantly, from 2.10 to 12.98 Mg ha^{-1}. The yields depended on the condition of grain maturity as maturity was delayed in some years. The control treatment (DP) resulted in the highest yield in only two years, but its average yield was the highest (6.21 Mg ha^{-1}). However, the differences between the tillage treatments were not significant (Table 9).

Table 9. The impact of the tillage systems on the grain yield (Mg ha^{-1})

Tillage system (F_A)/Year (F_B)	DP	SP	DC	SC	NT	Average F_B
2008	5.45a	5.23a	5.16a	5.60a	3.42b	4.97D
2009	3.93a	4.24a	3.62a	3.44a	3.62a	3.77E
2010	3.62b	3.30b	2.10c	3.53b	4.68a	3.45E
2011	11.22b	11.94ab	12.98a	11.70ab	11.17b	11.80A
2012	8.20a	6.14ab	5.69b	6.39ab	6.02b	6.49B
2013	4.93ab	5.06ab	4.10b	5.15ab	5.84a	5.02D
2014	6.31a	7.25a	5.89a	5.52a	6.14a	6.22BC
2015	5.99a	5.01a	5.22a	4.85a	5.58a	5.33CD
Average F_A	6.21a	6.02a	5.60a	5.77a	5.81a	1.71*

DP = deep ploughing; SP = shallow ploughing; DC = deep cultivation; SC = shallow cultivation; NT = no-tillage (direct drilling). Different lowercase letters within rows and uppercase letters within columns mean significant difference at $p \leq 0.05$. F_A = factor A (tillage system); F_B = factor B (seasonal meteorological conditions of experiment); * = $F_A \times F_B$

In the NT plots the lowest yield was found only twice of the eight years investigated. On average, the lowest yield was recorded in the DC plots, even though these differences were not statistically significant. As mentioned previously, warm vegetation conditions in 2011 resulted in the highest grain yield (11.80 Mg ha^{-1}). In 2010, the grain yield was the lowest, due to the humid vegetation conditions (especially in the spring) and late maize maturity.

The impact of the tillage systems on 1000-grain weight was mostly not significant (Table 10). However, on average, DP and NT plots had the highest 1000-grain weights, which was significantly higher than in the DC plots.

Table 10. 1000-grain weight (g) of maize using different tillage systems

Tillage system (F_A)/Year (F_B)	DP	SP	DC	SC	NT	Average F_B
2008	193.95a	200.47a	188.47a	203.37a	189.74a	195.50E
2009	211.30ab	230.60a	197.50b	205.60b	206.00b	210.20D
2010	153.95a	142.36a	101.99b	144.77a	165.76a	141.77F
2011	252.03b	254.73b	250.56b	247.38b	269.41a	254.82C
2012	224.30a	222.95a	212.03a	222.44a	209.55a	218.25D
2013	340.25a	313.90a	325.65a	323.05a	321.95a	324.96A
2014	299.55a	295.02ab	264.95b	266.65b	290.92ab	283.42B
2015	200.79ab	198.86ab	206.52ab	191.34b	220.95a	203.69DE
Average F_A	234.52a	232.36ab	218.46b	225.58ab	234.29a	27.66*

DP = deep ploughing; SP = shallow ploughing; DC = deep cultivation; SC = shallow cultivation; NT = no-tillage (direct drilling). Different lowercase letters within rows and uppercase letters within columns mean significant difference at $p \leq 0.05$. F_A = factor A (tillage system); F_B = factor B (seasonal meteorological conditions of experiment); * = $F_A \times F_B$

On average, the grains were the largest in 2013. The vegetative period of 2013 differed from the other years in the high sum of active temperatures (SAS) and significantly lower maize stand density. The lowest 1000-grain weight was observed in 2010 due to the unfavourable meteorological conditions as previously discussed.

Interactions between meteorological conditions and maize productivity

Reduction of soil tillage intensity lead to significant reductions of stand density in the NT plots. Calculation of Fisher's criterion showed a significant impact of meteorological conditions on the maize stand density. Correlation analysis illustrated that the surplus precipitation rates (especially in June-August) had a negative influence on the crop stand density, while other maize productivity parameters were positively affected. Significant effect on the height of canopy was observed in August (Table 11).

Table 11. Correlation between meteorological conditions and maize productivity parameters in 2008–2015

Meteorological conditions (*x*)	Month	Maize productivity parameters (*Y*)				
		Crop density (thousand units ha^{-1})	Canopy height (cm)	Total dry biomass of canopy (Mg ha^{-1})	Grain yield (Mg ha^{-1})	1000-grain weight (g)
Precipitation rate (mm)	May	n	–0.253	n	n	n
	June	–0.567	0.423	n	n	–0.564
	July	–0.318	0.392	0.413	0.531	0.221
	August	–0.327	0.796*	0.531	0.478	n
	September	n	n	n	0.242	0.344
	Total	–0.402	0.402	0.275	0.319	n
Average air temperature during 24 hours (°C) SAT °C	May	–0.517	n	–0.225	n	0.574
	June	–0.299	0.265	0.239	0.412	0.377
	July	n	n	n	n	–0.277
	August	0.667	n	0.277	n	–0.756*
	September	0.390	n	0.401	0.339	n
	Total	n	n	0.287	0.389	0.488

* = significance at p ≤ 0.05; SAT = sum of active temperatures; n = weak correlation

Higher temperatures in May and June negatively affected crop stand density. It should be noted that in Lithuania, as in other Northern countries, rapid development of maize starts when the length of the light period shortens (from the beginning of July). During this period, the impact of the temperatures was positive, except for the 1000-grain weight (Table 11).

NT treatment, on average, slightly increased the height of maize, the length of cobs and the canopy dry biomass. Lower stand density negatively influenced the height of the plant (r = –0.472) and positively influenced the yield of the dry biomass (r = 0.636**) (Table 12).

Table 12. Correlation between the maize productivity parameters in 2008–2015

Independent variable (x)	Dependent variable (Y)		
	Canopy height (cm)	Total dry biomass of canopy (Mg ha^{-1})	Grain yield (Mg ha^{-1})
Canopy height (cm)	1.000	0.636**	0.632**
Crop stand density (thousand units ha^{-1})	–0.472	0.232	n
Total dry biomass of canopy (Mg ha^{-1})	0.636**	1.000	0.371*
1000-grain weight (g)	n	n	0.632**

* = significance at p ≤ 0.05; SAT = sum of active temperatures; n = weak correlation.

Discussion

Wang et al. (2006) reported that growing conditions might play a significant role in the success of no-till systems. In our experiment, correlation analyses showed positive relationships between the height of the canopy and the precipitation rates in June-August (Table 10). Likewise, precipitation rate, temperature and SAT also influenced biomass in different periods of the growing season (Table 10).

Conventional deep ploughing was, on average, the most successful treatment with respect to the grain yield, however it was not statistically significant. Moreover, the highest yield was observed only twice in the DP plots (in 2012 and 2015) during the eight years of the investigation. Similar results were found in NT as well, but in different years (in 2010 and 2013). According to Arvidsson et al. (2013), the average yield in non-inversional tillage was only 1–2% lower than that in ploughed soils. Similarly, in our earlier on-farm experiment, under conditions of well-balanced fertilization and weed control, the soil tillage systems had no significant effect on maize productivity parameters (Romaneckas et al. 2010). Conversely, in semi-arid conditions, chiselled plots resulted in more grain and dry matter yield (23 and 8%, respectively) compared with ploughed plots (Wasaya et al. 2017). Gathala et al. (2016) highlighted that the most limiting factors in maize growing technologies are poor drainage, low quality of land, and delayed planting. Thus, the future of conservation agriculture (including conservation soil tillage) in Europe, based on the yield response, is optimistic (Kertész and Madarász 2014).

In Mediterranean conditions, Seddaiua et al. (2016) established that there was a negative effect of high temperatures in June and drought in July on the maize yield. In Lithuania, in June and July, the temperatures were lower (from 15 to 22 °C). We found positive correlations between the yields of grain, the SAT and the precipitation rates in July-September (Table 10). The highest yields in DP were observed under lower precipitation and SAT, while the opposite was found for NT. The grain yields mainly depend on the height of maize canopy and the total canopy dry biomass, and less on the 1000-grain weight (Table 10). In our previous investigations, canopy height was also related to infestation by perennial weeds (Avižienytė et al. 2013). A similar conclusion was reported by Gruber et al. (2012).

Lampurlanés et al. (2016) found a strong linear relationship between soil water storage and yield. Contrarily, Arvidsson et al. (2013) established a weak correlation between precipitation rates and crop yield.

The impact of the tillage system on 1000-grain weight was uneven. We found a trend for a negative impact of deep cultivation on grain mass. The highest 1000-grain weight, which was not significant, was found in the DP plots, and was similar to the findings of Salem et al. (2015).

Conclusions

Long-term reduced primary tillage had less impact on maize productivity parameters than meteorological conditions during the vegetation period. In tilled treatments, the maize productivity parameters (canopy height and dry biomass, length of cobs and grain yield) were not significantly different. No-tillage treatment lead to a significant decrease in crop stand density (except for shallow cultivation), but slightly improved the development of maize plant (canopy height and dry biomass, and length of cobs). The grain yield in no-tillage was, on average, from 3.5 to 6.4% lower compared with the shallow and deeply ploughed soils, respectively. Nevertheless, the differences among all the tillage methods were not significant. Correlation analysis illustrated that surplus precipitation had a negative influence on the crop stand density. However, other maize productivity parameters (canopy height, total dry biomass and grain yield) were positively affected.

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