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Response of Crops to Conservation Tillage and Nitrogen Fertilization under Different Agroecological Conditions

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Abstract: Effects of soil tillage (CT-conventional, SS-subsoiling, CH-chiselling, DH-disk-harrowing and NT-no-till) and nitrogen rate (reduced N1, optimal N2 and luxury N3) on yield and yield components of maize and winter wheat in two different agricultural subregions of Croatia (Magadenovac and Cacinci site), have been studied in years 2013–2014 as a part of long-term experiment. Maize yield and yield components were influenced by site properties, tillage and nitrogen treatments. The highest yields and yield components were recorded at site Magadenovac on N2 and N3. The lowest values of the yield and yield components of maize were recorded on NT and were significantly lower than CT, SS, CH and DH, among which no significant differences were recorded. Winter wheat yield and yield components were affected by site properties and nitrogen rates while soil tillage treatments had influence only on grain and straw yield and plant height. Winter wheat achieved maximum yield and yield components on a N3 and N2 and at Magadenovac site. Winter wheat grain yield was decreasing in following order: SS > DH > CH > NT > CT. The obtained results indicate the importance of optimal nitrogen fertilization and the possibility of implementation of conservation tillage for maize and winter wheat production in different agroecological conditions.

Keywords: conservation tillage; nitrogen rate; site properties; maize; winter wheat; yield; yield components

Citation: Jug, I.; Brozović, B.; Đurđević, B.; Wilczewski, E.; Vukadinović, V.; Stipešević, B.; Jug, D. Response of Crops to Conservation Tillage and Nitrogen Fertilization under Different Agroecological Conditions. *Agronomy* **2021**, *11*, 2156. https://doi.org/10.3390/agronomy11112156

Academic Editor: Purushothaman Chirakkuzhyil Abhilash

Received: 31 August 2021
Accepted: 25 October 2021
Published: 27 October 2021

1. Introduction

Winter wheat (*Triticum aestivum* L.) and maize (*Zea mays* L.) are crops with around 68% in the total cereal production within the European Union [1]. Grain yield is a complex trait that is highly influenced by many genetic and environmental factors [2] such as climatic conditions, soil properties, water ability [3,4] quantity and availability of plant nutrients, etc.

The global climate change is affecting on all segments of human lives including food production. Climate change makes it difficult to predict weather conditions for accurate and successful agricultural production [5,6]. Given the different water and temperature needs of individual crops, each crop has its own set of environmental conditions under which growth is most efficient [7]. Crop production is particularly sensitive to prevailing weather and climatic conditions at key times of the growing season [1]. Different agricultural subregions of Croatia are characterized by different climate types, edaphic and orographic properties [8]. The structure, stability and outcomes of plant cultivation, and consequently the design of economic policy, directly depend on the natural habitat conditions (agrobiotopes) in the agrosphere. Soil and climate characteristics determine the "ecological framework" of plant cultivation through suitability or limitations, which can be temporary or permanent. In agroecological science, unfavorable soil properties are considered as temporary limitations, and unfavorable climate is considered to be permanent ones [8].

In the prevailing semi-arid and arid conditions that occur as a result of changing climatic conditions, the application of conservation tillage adapted to the type and properties of soil and agroecological conditions in the production area can significantly contribute to water conservation, prevent soil degradation and achieve high and stable yields [9–12]. Conservation tillage is one of the fundamental postulates of conservation agriculture, which is according to FAO [13], an approach to managing agroecosystems for improved and sustained productivity, increased profits and food security while preserving and enhancing the resource base and the environment. Conservation tillage, which include minimal soil disturbance and covering surface by crop residues (at least 30% of the soil surface), have been implemented in many countries around the world [14]. Many research established that conservation tillage improves soil properties and crop yields [15,16]. Conservation tillage practices have been shown to reduce soil organic matter decomposition [17] and promote sustainable crop production systems [18]. Conservation tillage presents a sustainable management option but despite that soil productivity may be reduced. Because of that conservation tillage should be combined with other management practices (i.e., cover crop, crop rotation) to increase soil organic matter, carbon sequestration [19] and nitrogen storage [20].

Crop response to applied nitrogen fertilizer depends on soil type and fertility, soil and crop management practices, time, doses and method of nitrogen application. Nitrogen is key elements in crop productivity which plays role in accelerating yield and its deficiency will constitute in low yield and productivity of cereal crops [21]. Excessive nitrogen rate will result in excessive vegetative mass of crops [22,23], increased plant height [24], which will delay grain ripening and prolong vegetation [25], increase the sensitivity of crops to diseases and pests, decline in photosynthetic capacity [26] and reduce the quality of yield [27]. On the other hand, insufficient amount of N during intense vegetative growth will result in a smaller assimilation surface, reduced synthesis of chloroplast pigments which will affect the photosynthesis process [28,29] and ultimately result in reduced yield. Rationalizing fertilizer application is an important issue for sustainable agriculture because it can reduce the negative effects of agronomy practices on the surrounding environment [30].

The main objective of this study was to compare the yield and yield components of maize and winter wheat under different soil tillage treatments and applied nitrogen dosage in the two agroecological regions to determine the most suitable tillage system and nitrogen rate depending on site properties defined by climatic conditions and soil types.

2. Materials and Methods

2.1. Site Description, Experimental Design and Treatments

This research was conducted in the years 2013–2014 on two experimental fields in two different agricultural subregions of Croatia [8]: Central Pannonian agricultural subregion—Cacinci site (Long. 17.86336 E, Lat. 45.61316 N, Altitude 111 m) and East Pannonian agricultural-cultural subregion—Magadenovac site (Long. 18.17254 E, Lat. 45.67046 N, Altitude 92 m), as a part of a long-term field experiment. According to WRB [31] on both experimental fields determined a different type of soil: Stagnosol at the Cacinci site, and Glaysol at the Magadenovac site (Table 1).

Before setting up experiment, soil samples were collected with soil probe from depths 0–30 cm (for basic soil chemical analysis) and from soil profile (for soil texture determining). Average soil samples were air-dried, homogenized, milled and passed through a 2 mm sieve.

Soil pH was measured electrometrically in a 1:5 (*w*/*v*) soil: water (distilled) extract (pH-H_2O) and 1 mol dm^{-3} KCl (pH-KCl). Plant available P and K were analyzed using ammonium lactate acid extractant [32]. Hydrolytic soil acidity (Hy) was determined by titration where alkaline hydrolytic salts (Ca-acetate) was used to exchange H^+ and Al^{3+}

ions from the soil adsorption complex. Soil organic matter content was measured using modified Walkley-Black method [33]. Soil texture was determined by pipette-method with wet sieving and sedimentation after dispersion with sodium pyrophosphate [34] according to USDA-NRCS [35]. The average annual precipitation and temperature for both experimental sites (30-yr average) are characterized by a wide aberration from 320 to 1240 mm and 9.4–12.9 °C (Table 2).

Table 1. Selected soil properties on experimental sites.

	Sd	pH_{H2O}	pH_{KCl}	P	K	Hy	OM	Sand	Silt	Clay	St
Stagnosol	0–30	5.09	4.03	62	127	2.54	2.49	15.65	55.25	29.10	SiCL
	30–60							18.47	53.23	28.30	SiCL
Gleysol	0–30	5.29	4.27	172	227	4.39	1.45	9.92	71.78	18.30	SiL
	30–60							10.80	66.21	23.00	SiL

Stagnosol—site Cacinci, Gleysol—site Magadenovac, Sd—Soil depth (cm), P—(AL) mg kg^{-1} soil, K—(AL) mg kg^{-1} soil, Hy—cmol(+) kg^{-1}, OM—Organic matter (%), Sand—(2–0.05 mm) %, Silt—(0.05–0.002 mm) %, Clay—(<0.002 mm) %, St—Soil texture, SiCL—Silty clay loam, SiL—Silty loam.

Table 2. Monthly, annual and 30-yr average precipitation (mm) and air temperature (°C) on both experimental sites (S1—Cacinci site, S2—Magadenovac site).

Site	Year	Month													
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ta	Aa
Precipitation (mm)															
S1	2013	87	101	97	53	80	83	28	99	143	42	102	1	916	
	2014	40	65	49	98	160	64	79	135	108	116	25	78	1017	
	LTA	56	41	54	63	75	95	69	70	77	70	74	65	809	
S2	2013	62	112	113	46	113	54	15	73	97	29	67	1	782	
	2014	52	76	25	69	139	62	82	83	119	143	24	68	942	
	LTA	50	39	46	57	68	86	63	66	69	61	65	56	726	
Air temperature (°C)															
S1	2013	2.2	2.8	5.1	13.1	16.5	19.8	23.3	22.7	15.7	13.6	7.6	2.5		12.1
	2014	4.3	5.5	9.6	12.8	15.4	20.3	21.8	20.3	16.4	11.3	5.8	1.9		12.1
	LTA	0.6	1.8	6.3	11.6	16.3	19.7	21.8	21.1	16.4	11.4	6.0	1.7		11.2
S2	2013	2.0	2.8	4.9	13.3	17.0	19.9	23.3	22.8	15.6	13.3	7.6	1.8		12.0
	2014	3.6	5.2	9.8	13.2	15.7	20.4	22.0	20.4	16.7	12.9	7.5	1.9		12.0
	LTA	0.3	1.8	6.5	12.0	17.0	20.3	22.3	21.8	16.9	11.6	5.9	1.3		11.5

Ta—Total annual; Aa—Average annual; LTA—long term average (1984–2013).

Central Pannonian agricultural subregion extends to the area of western Slavonia, Podravina, Bilogora and central Posavina. The average rainfall ranges from 781 to 798 mm. The average annual air temperature is 10.5 °C. The growing season with average daily temperatures of 5 or more °C lasts about 255 days. The climate of Eastern Pannonian agricultural subregion has characteristics of a typical continental climate with hot summers and very cold winters. The average annual rainfall ranges from 688 to 729 mm, the maximum is in June and the minimum in the off-season. The duration of vegetation with an average daily temperature of 5 °C or more ranges from 255 to 265 days, with a sum of temperatures from 3700 to 3900 °C [8].

The data presented in this paper include part of a multi-year study of the impact of conservation tillage and nitrogen fertilization on crop productivity. The presented data was collected from the part of the second rotation of usual crop rotation in this region, in the years 2013–2014. Previous crop rotation included crops in the following sequence: 2009-maize, 2010-winter wheat, 2011-oilseed rape, 2012-soybean. Maize (*Zea mays* L.) was sown in spring of 2013 (after soybean) and winter wheat (*Triticum aestivum* L.) in autumn of 2013 (after maize). Maize (hybrid PR36V52, FAO 450, plant density recommendation

65 000 plant ha^{-1}) was sown in spring of 2013 (after soybean) and winter wheat (cultivar Lucija—Agricultural Institute Osijek, seeding rate of 650 seeds per m^2) in autumn of the same year (after maize).

The experiment was set up on two agroecologically different areas with five tillage treatments (CT-conventional tillage, SS-subsoiling, CH-chiselling, DH-disk-harrowing and NT-no-till) and three nitrogen levels (N1-30% lower dosage related to the fertilization recommendation; N2-according to the fertilization recommendation) and N3-30% higher dosage related to the fertilization recommendation). The experiment was set up as split-plot with four repetitions. The size of the basic experimental plot for main treatment was 600 m^2 for each individual tillage treatment and 195 m^2 for each individual fertilization as sub-treatment.

Soil tillage was included one conventional tillage and four different conservation tillage treatments:

- CT—ploughing up to 30 cm depth, followed by disk-harrowing (1 pass), pre-sowing surface preparation with rotary harrow + wedge ring roller (2 passes);
- SS—subsoiling up to 35–40 cm depth, pre-sowing surface preparation with rotary harrow + wedge ring roller (1 pass);
- CH—chiselling up to 25 cm depth, pre-sowing surface preparation with rotary harrow + wedge ring roller (1 pass); DH—disk-harrowing up to 10–15 cm depth (2 passes);
- NT—no till (without any soil tillage preparation).

Application of mineral fertilizers (P_2O_5 and K_2O) was uniform for all soil tillage treatments and with the same distribution dynamics on both experimental sites: for maize (140 kg P_2O_5 ha^{-1}, 150 kg K_2O ha^{-1}) and winter wheat (100 kg P_2O_5 ha^{-1}, 110 kg K_2O ha^{-1}). Fertilization nitrogen dosage was variated as follows (i) on Cacinci site for maize: N1-N2-N3/140-200-260 kg N ha^{-1}; for winter wheat: N1-N2-N3/80-115-150 kg N ha^{-1}; (ii) on Magadenovac site for maize: N1-N2-N3/147-210-273 kg N ha^{-1}; for winter wheat: N1-N2-N3/95-135-175 kg N ha^{-1}.

All other details (e.g., tillage, sowing and harvest dates, crop protection) about crop growing practices on this experiment can be found in previously published paper [11].

2.2. Plant Material Sampling and Analysis

Five separated samples of maize each consisting of 20 plants collected in line and diagonally on each tillage and fertilization treatment. Maize plant material was dried in the oven at 65 °C to constant weight to obtain dry matter weight and scaled to hectare. Grain yield was calculated from the same samples after hand harvesting and grain separation from the rest of plant material (cob + stalk + leaves). Calculation of grain yield (t ha^{-1}) was done with grain yield at 14% moisture. Dried mass of stalk, leaves and cobs represent straw yields (t ha^{-1}). Plant height (cm) was measured from ground level to the base of the tassel, after milk stage. From each treatment 20 ears were selected; air dried and maize ear weight was determined by weighing and then averaged. From the same ears grains were manually shelled and weighed on a technical scale to two decimal places after which the average grain weight per cob (g) and the mass of the stalk was air dried and weighed and the average expressed in grams was calculated. Grain weight was determined by weighing 1000 grains randomly taken from the grain lot of each treatment. Hectoliter mass (kg hl^{-1}) was determined by Dickey John GAC 2100 apparatus.

Winter wheat plant material samples were collected using 50 cm × 50 cm frame randomly and diagonally in five repetitions on each tillage and fertilization treatment. W. wheat plant material was dried in the oven at 65 °C to constant weight to obtain dry matter weight and scaled to hectare. Grain yield was calculated from the same samples after hand harvesting and grain separation from the rest of plant material. Calculation of grain yield (t ha^{-1}) was done with grain yield moisture at 12% for winter wheat. Mass of dried stalks and leaves was measured from average of 20 plants and represents straw yield (t ha^{-1}). Plant height was measured (cm) from average of 20 plants. Number of fertile/sterile spikelets per spike and number of grains per spike were counted in 20 spikes and their means were calculated. Thousand-grain weight (g) was calculated from 2 grains subsamples of 2 kg each, collected from the harvested grain mass in harvest; 4 times 500 kernels were counted and weighed. Hectoliter mass (kg hl^{-1}) was calculated from the same 2 grains subsamples, 2 readings of the hectoliter mass and grain moisture has been acquired by Dickey John GAC 2100 apparatus.

2.3. Data Analysis

All collected data was statistically processed by the statistical package TIBCO Software Inc. [36]. The influence of different soil tillage treatments and different sub-level of nitrogen fertilization on yield and yield components of maize and winter wheat in different agroecological site, was tested by factorial ANOVA design (factors: site properties, soil tillage treatments and nitrogen level). The means were compared by LSD tests upon significant results of F-test at $p < 0.05$ for observed factors. Assumption of homogeneity of variance of all parameters was conducted by the Levene's test; the normality of the distribution of results was examined by the Kolmogorov-Smirnov test. The assumption of the independence was secured by the design of the study (randomized complete block design). The Pearson's linear correlation coefficients according to Mukaka [37] and the value of correlation coefficient ranking by the Roemer-Orphal scale (±0.00–0.30: negligible correlation, ±0.30–0.50: low, ±0.50–0.70: moderate, ±0.70–0.90: high, ±0.90–1.00: very high) according to Hinkle et al. [38] were used to assess the relationships between yield and yield components for maize and for winter wheat.

3. Results

3.1. Maize Yield and Yield Components

Influence of site properties, tillage treatments and nitrogen doses on grain and straw yield and yield components of maize (plant height, ear weight, grain weight per cob, stalk weight, 1000 grain weight, hectoliter mass) are shown in Table 3. Interactions between factors were not statistically significant (*p* value was higher than 0.05).

Table 3. Influence of site properties, tillage treatments and nitrogen doses on yield and yield components of maize in 2013.

		PH (cm)	EW (g)	GWPC (g)	SW (g)	1000 GW (g)	HLM (kg hl^{-1})	GY (t ha^{-1})	SY (t ha^{-1})
S	S1	190.89 ^{b}	283.68 ^{b}	146.88 ^{b}	283.39 ^{b}	299.04	75.61 ^{a}	9.15 ^{b}	35.33 ^{b}
	S2	214.62 ^{a}	385.84 ^{a}	198.01 ^{a}	363.44 ^{a}	302.14	74.14 ^{b}	13.46 ^{a}	50.95 ^{a}
	F_S	38.07	54.55	55.09	47.94	ns	19.31	92.19	91.72
TT	CT	200.50	373.81 ^{a}	189.62 ^{a}	363.32 ^{a}	324.56 ^{a}	75.11	12.43 ^{a}	48.16 ^{a}
	SS	201.06	354.40 ^{a}	183.42 ^{a}	331.97 ^{ab}	305.16 ^{bc}	74.94	12.07 ^{a}	45.12 ^{a}
	CH	206.94	347.09 ^{a}	174.11 ^{a}	331.23 ^{ab}	307.67 ^{ab}	74.34	11.44 ^{a}	44.58 ^{a}
	DH	211.33	336.18 ^{a}	174.80 ^{a}	318.70 ^{b}	289.26 ^{cd}	75.08	11.48 ^{a}	43.06 ^{a}
	NT	193.94	262.30 ^{b}	140.26 ^{b}	271.84 ^{c}	276.30 ^{d}	74.91	9.13 ^{b}	34.77 ^{b}
	F_T	ns	7.65	6.15	6.60	8.59	ns	6.57	7.61
FT	N1	196.67	296.99 ^{b}	152.34 ^{b}	297.26 ^{b}	294.47	74.84	9.98 ^{b}	38.92 ^{b}
	N2	208.20	363.61 ^{a}	186.56 ^{a}	344.72 ^{a}	309.74	75.05	12.23 ^{a}	46.41 ^{a}
	N3	203.40	343.68 ^{a}	178.43 ^{a}	328.27 ^{a}	297.56	74.73	11.71 ^{a}	44.09 ^{a}
	F_F	ns	8.15	8.98	5.79	ns	ns	9.13	7.38
average		202.76	334.76	172.44	323.41	300.59	74.87	11.31	43.14

Values with different letters in a column differ significantly at $p < 0.05$; Note: S: Site (S1: Cacinci site, S2: Magadenovac site), TT: Tillage treatments (CT: conventional tillage, SS: subsoiling, CH: chiseling, DH: disk-harrowing, NT: no-till), FT: Fertilization treatment (N1: reduced nitrogen fertilization, N2: optimal nitrogen fertilization, N3: luxury nitrogen fertilization), F_S: F test for site properties, F_T: F test for soil tillage treatments, F_F: F test for nitrogen treatments, ns: not significant, PH: Plant height, EW: Ear weight, GWPC: Grain weight per cob, SW: stalk weight, 1000 GW: 1000 Grain weight, HLM: Hectoliter mass, GY: Grain yield, SY: Straw yield.

The height of maize plants was significantly influenced by site characteristics (Table 3). Tillage and fertilization treatment did not significantly affect plant height Maize had a higher height on S2 by 12.43% compared to S1.

The weight of maize ear was significantly influenced by site properties, tillage and fertilization treatment (Table 3). The ear weight on S2 was 36.01% higher than on S1. At all tillage treatments there was a significantly higher ear weight compared to NT (on CT the ear weight was 42.51% higher, on SS—by 35.11% higher, on CH—by 32.32% and on DH—by 28.17% higher than NT). No statistically significant differences were observed between CT, SS, CH and DH. Maize on N1 fertilization treatment had a statistically significantly lower ear weight compared to N2 (18.32%) and N3 treatment (13.59%), while differences between N2 and N3 treatment in ear weight were not statistically justified.

The grain weight per cob was significantly influenced by site properties, tillage treatment and fertilization treatment (Table 3). The grain weight per cob was 34.81% higher on S2 than on S1, by 35.19%, 30.77%, 24.13% and 24.63% higher on CT, SS, CH and DH compare to NT; by 22.46% and 147.13% higher on N2 and N3 fertilization treatment compare to N1 fertilization treatment. No significant differences in grain weight per cob was detected among CT, SS, CH and DH tillage treatment nor between N2 and N3 fertilization treatments.

Stalk weight was significantly affected by site properties, tillage and fertilization treatment (Table 3). Maize on S2 had a higher stalk weight (by 28.25%) compared to S1. The highest stalk weight was measured at CT treatment, and the lowest at NT treatment. Statistically significant differences in stalk weight were found between CT, DH and NT treatment (stalk weight on CT was 33.65% higher than on NT, by 14.00% higher than on DH; stalk weight on DH was 17.24% higher than NT); between SS and NT (by 22.12% stalk weight was higher on SS) and CH and NT (maize on CH was higher by 21.85%) and between DH and NT (by 17.24% higher value on DH). Differences in stalk weight among CT, SS and CH was not statistically significantly. Nitrogen levels significantly affected stalk mass and the lowest mass was measured in maize on N1 fertilization treatment, while the highest mass was measured on N2 treatment. Stalk weight on N2 and N3 treatments were by 15.97% and 10.43% higher than N1 treatment, while differences in stalk weight between N2 and N3 treatment were not statistically significant.

The weight of 1000 grains were significantly affected only by tillage treatment (Table 3). Maize on CT had a significantly higher 1000 grain weight if compared to SS (by 6.36%), DH (by 12.20%) and NT (by 17.47%). The weight of 1000 grains on CH were 11.35% higher compared to NT and 6.36% higher compared to DH. On SS, the weight of 1000 grains were 10.45% higher than on NT. Other differences were not statistically significant.

Hectoliter mass was significantly affected only by site properties (Table 3). Maize on S1 had a higher hectoliter mass compared to S2. The impact of tillage and fertilization treatments were not statistically significant.

Grain yield was significantly affected by site properties, tillage and fertilization treatments. Statistically significant differences in yield height between localities were found (maize on S2 had a higher grain yield than S1 by 47.10%), among soil tillage treatments (yield on NT was by 26.55% lower than yield on CT, by 24.36% lower than yield on SS, by 20.19% lower than CH and by 20.47% lower than DH) and among fertilization treatments (yield on N1 was by 18.40% and 14.77% lower than N2 and N3, respectively). Differences between grain yield on CT, SS, DH and CH were not significant nor were differences between N2 and N3.

The straw yield was under significant influence of site properties, tillage treatment and fertilization (Table 3). Statistically significant differences in straw yield between localities were found (maize on S2 had a higher straw yield than S1 by 44.21%) Straw yield on NT was significantly lower compared to CT (by 27.80%), SS (by 24.35%), CH (by 22%) and DH (by 19.25%), among which no significant differences were detected. Maize on N1 had a significantly lower straw yield compared to other fertilization treatments, among which there were no significant differences.

The results of the study indicate a significant correlation between the examined parameters (Table 4) as follows: very high correlation (Figure 1) was detected between grain yield and ear weight (Figure 1a), grain weight per cob (Figure 1b), stalk weight (Figure 1c) and straw yield (Figure 1d); moderate correlation was observed between grain yield and plant height (Figure 1e) and grain yield and 1000 grain weight (Figure 1f).

Table 4. The Pearson's linear correlation coefficients between yield and yield components of maize for all sites, tillage treatments and nitrogen fertilization treatments.

	PH	EW	GWPC	SW	1000 GW	HLM	GY
EW	0.620 *						
GWPC	0.645 *	0.981 *					
SW	0.601 *	0.949 *	0.915 *				
1000 GW	0.205	0.667 *	0.617 *	0.671 *			
HLM	−0.087	0.015	−0.002	−0.002	0.322 *		
GY	0.663 *	0.975 *	0.993 *	0.908 *	0.579 *	−0.061	
SY	0.643 *	0.984 *	0.962 *	0.974 *	0.633 *	−0.053	0.969 *

Marked correlations with * are significant at $p < 0.05$; Note: PH: Plant height (cm), EW: Ear weight (g), GWPC: Grain weight per cob (g), SW: stalk weight (g), 1000 GW: 1000 Grain weight (g), HLM: Hectoliter mass (kg ha^{-1}), GY: Grain yield (t ha^{-1}), SY: Straw yield (t ha^{-1}).

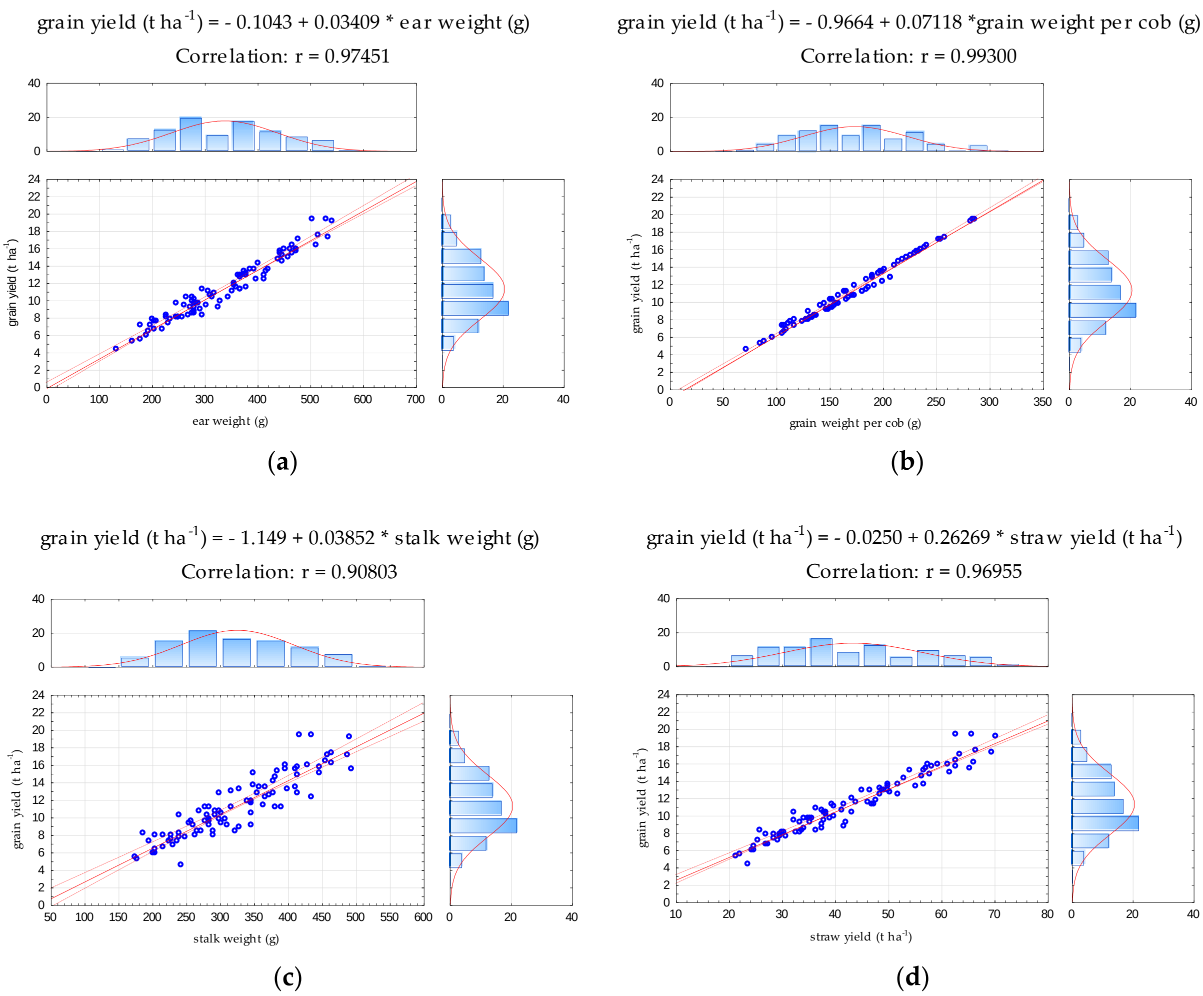
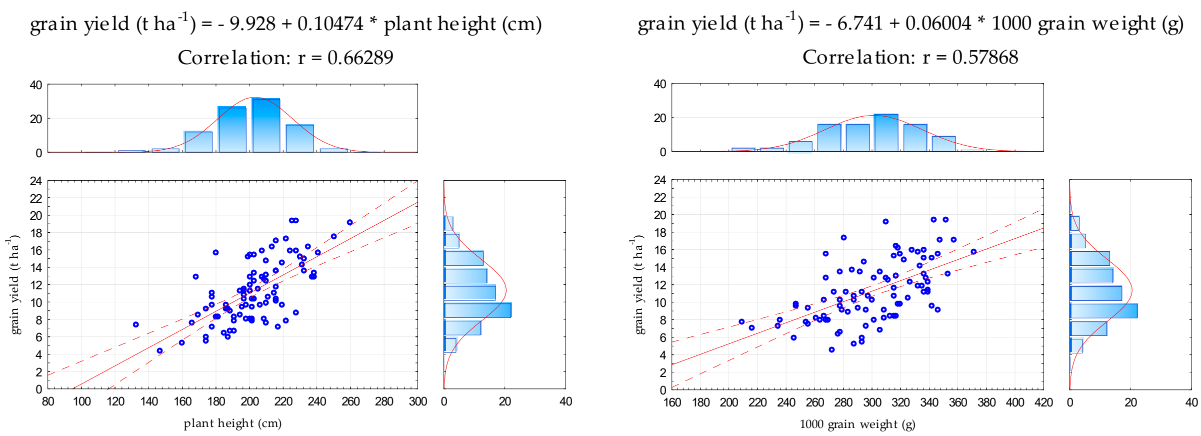


Figure 1. *Cont.*



(e) (f)

Figure 1. Correlation between grain yield with some selected yield components of maize: (**a**) very high correlation between ear weight and grain yield of maize; (**b**) very high correlation between grain weight per cob and grain yield of maize; (**c**) very high correlation between stalk weight and grain yield of maize; (**d**) very high correlation between straw and grain yield of maize; (**e**) moderate correlation between plant height and grain yield of maize; (**f**) moderate correlation between 1000 grain weight and grain yield of maize.

3.2. Winter Wheat Yield and Yield Components

Effects of site properties, tillage treatments and nitrogen doses on yield (grain and straw yield) and yield components of winter wheat (plant height, number of fertile spikelets per spike, number of sterile spikelets per spike, number of grains per spike, 1000 grain weight, hectoliter mass) are shown in Table 5. Interactions between factors were not statistically significant (*p* value was higher than 0.05).

Table 5. Influence of site properties, tillage treatments and nitrogen doses on yield and yield components of w. wheat in 2014.

		PH (cm)	NFS	NSS	NGPS	1000 GW (g)	HLM (kg hl^{-1})	GY (t ha^{-1})	SY (t ha^{-1})
S	S1	61.81 ^{b}	16.17 ^{a}	2.12 ^{b}	36.50 ^{a}	28.81 ^{b}	65.73 ^{b}	5.21 ^{b}	6.44 ^{b}
	S2	63.16 ^{a}	14.69 ^{b}	3.67 ^{a}	30.47 ^{b}	35.32 ^{a}	68.38 ^{a}	6.53 ^{a}	7.26 ^{a}
	F_S	4.60	17.68	37.22	12.04	71.70	21.77	41.98	10.39
TT	CT	63.99 ^{b}	15.08	3.23	31.27	32.43	67.16	5.27 ^{c}	7.33 ^{b}
	SS	66.23 ^{a}	15.90	2.67	35.44	32.52	67.44	6.69 ^{a}	8.54 ^{a}
	CH	62.01 ^{b}	15.79	3.07	35.04	31.10	67.19	5.68 ^{bc}	5.72 ^{c}
	DH	63.73 ^{b}	15.28	2.76	32.61	32.43	66.86	6.09 ^{ab}	6.27 ^{c}
	NT	56.46 ^{c}	15.11	2.77	33.06	31.85	66.62	5.62 ^{bc}	6.41 ^{c}
	F_T	27.42	ns	ns	ns	ns	ns	5.69	15.15
FT	N1	55.18 ^{c}	14.75 ^{b}	3.50 ^{a}	29.76 ^{b}	33.45 ^{a}	67.41	4.64 ^{b}	5.61 ^{c}
	N2	67.10 ^{a}	15.86 ^{a}	2.59 ^{b}	35.49 ^{a}	31.28 ^{b}	67.20	6.31 ^{a}	7.15 ^{b}
	N3	65.17 ^{b}	15.69 ^{a}	2.60 ^{b}	35.20 ^{a}	31.47 ^{b}	66.55	6.66 ^{a}	7.80 ^{a}
	F_F	137.52	3.88	5.62	4.60	3.24	ns	36.87	26.31
average		62.48	15.43	2.90	33.48	32.06	67.05	5.87	6.85

Values with different letters in a column differ significantly at $p < 0.05$; Note: S: Site (S1: Cacinci site, S2: Magadenovac site), TT: Tillage treatments (CT: conventional tillage, SS: subsoiling, CH: chiseling, DH: disk-harrowing, NT: no-till), FT: Fertilization treatment (N1: reduced nitrogen fertilization, N2: optimal nitrogen fertilization, N3: luxury nitrogen fertilization), F_L: F test for site properties, F_T: F test for tillage treatments, F_F: F test for nitrogen treatments, ns: not significant, PH: Plant height, NFS: Number of fertile spikelets per spike, NSS: Number of sterile spikelets per spike, NGPS: Number of grains per spike, 1000 GW: 1000 Grain weight, HLM: Hectoliter mass, GY: Grain yield, SY: Straw yield.

The height of winter wheat plants was significantly influenced by nitrogen doses, soil tillage treatments and site properties. The plants on the N2 fertilization treatment were highest, and the lowest on N1. Differences between plant heights on N1, N2 and

N3 were statistically significant (Table 5). The height of the plants on the N2 treatment was 21.60% higher than the N1 treatment and 2.96% higher than the N3 treatment. On the N3 winter wheat was 18.10% higher than wheat on the N1. Among all tillage treatments SS gave maximum plant height as compared to other tillage treatments. On CT, CH and DH the plant height was statistically significant lower in relation to SS (by 3.38%, 6.37% and 3.77%, respectively) and significantly higher in relation to NT (by 13.34%, 9.83% and 12.88%, respectively). The difference in plant height between SS and NT was the largest (by 17.30% higher on SS than NT). Comparing the plant height averages at the different site showed that wheat achieved significantly higher plant height at S2 compared to S1.

The number of fertile spikelets per spike was significantly influenced by site properties and fertilization treatment. The tillage treatments did not significantly affect on number of fertile spikelets per spike. The number of fertile spikelets per spike on N1 was significantly lower compared to N2 (by 7%) and N3 (by 6.78%), while comparison of number of spikelets per spike indicated the non-significant difference among N2 and N3 treatments (Table 5).

The number of sterile spikelets per spike was significantly influenced by site properties and fertilization treatment while influence of tillage treatments was non-significant (Table 5). Contrary to the number of fertile spikelets, a larger number of sterile spikelets had wheat on S2 than S1 (by 73.11%). The number of sterile spikelets per spike on N1 was significantly higher compared to N2 (by 35.14%) and N3 (by 34.62%), while the number of sterile spikelets per spike on N2 and N3 was almost identical.

The number of grains per spike was significantly influenced by site properties and fertilization treatment (Table 5). Maximum number of grains per spike was detected on S1 and on N2 fertilization treatment W. wheat on S1 and on N1 treatment gave minimum number of grains per spike (Table 5). The difference in NGPS between the fertilization treatments were statistically significant only in relation to the N1 treatment, while difference between number of grains per spike on N2 and N3 was not statistically significant.

The weight of 1000 grain was statistically significantly affected by fertilization treatment and site properties while the impact of tillage was insignificant (Table 5). The maximum grain weight was recorded on S2 and on N1 fertilization treatment and minimum grain weight was recorded on S1 and N2 The weight of 1000 grain on N1 was higher by 6.94% than on N2 treatment and by 6.29% than on N3 treatment. Difference in 1000 grain weight between N2 and N3 was non-significant.

The hectoliter weight was significantly influenced by site properties (Table 5). The maximum hectoliter weight was recorded on S2 Differences in hectoliter weight between tillage treatment and nitrogen doses were not statistically significant.

The variation in grain yield, was significantly affected by site properties, nitrogen doses and tillage treatment. Higher grain yields were achieved on S2 compared to S1 (by 25.34%). The maximum grain yield was recorded on N3 which was 43.53% higher than the lowest grain yield achieved on N1. Difference between grain yield on N3 and N2 was non-significant, while difference between N2 a N1 was statistically significant (Table 5). Comparison of grain yields average by tillage treatments indicated that SS treatment exhibited highest grain yield as compared to other four tillage treatments. Significant differences in the grain yield according to tillage treatments were found as follow: grain yield on SS was higher by 26.94% than on CT, by 17.78% higher than on CH and by 19.04% higher than on NT. The difference in grain yield between SS and DH was non-significant. Grain yield on DH was significantly higher than on CT (by 15.56%), while differences in yield between other tillage treatment was not significant.

The straw yield was significantly influenced by nitrogen doses, tillage treatments and site properties (Table 5). The significant difference was measured between sites: and between all fertilization treatments highest straw yield was recorded on N3 which is higher by 39.22% than N1 and 9.09% than N2. Straw yield on N2 was higher by 27.45% than on N1. Among tillage treatments also was significant differences recorded: straw yield on SS was 49,30% higher than on CH, 36.20% higher than on DH, 33.23% higher than on NT and 16.51% higher than on CT. Straw yield on CT was 28.15 % higher than on CH, 16.91%

higher than on DH and 14.35% higher than on NT. The differences in straw yield between CH, DH and NT were not statistically significant.

Mutual correlations between the examined parameters are shown in Table 6. Very high positively correlation was detected between number of grains per spike and number of fertile spikelets per spike (Figure 2a) and high negative correlation between sterile spikelets per spike and number of grains per spike. Low positively correlation was detected between plant height and (i) number of grains per spike (Figure 2b), (ii) number of fertile spikelets per spike (Figure 2c) and (iii) grain yield (Figure 2e) while correlation with straw yield was moderate (Figure 2d). A low positive correlation was observed between 1000 grain weight and number of sterile spikelets per spike; and between grain and straw yield (Figure 2f). The correlation between 1000 grain weight and hectoliter mass was moderate.

Table 6. The Pearson's linear correlation coefficients between yield and yield components of w. wheat for all sites, tillage and nitrogen fertilization treatments.

	PH	NFS	NSS	NGPS	1000 GW	HLM	GY
NFS	0.347 *						
NSS	−0.201	−0.738 *					
NGPS	0.345 *	0.927 *	−0.783 *				
1000 GW	0.065	−0.208	0.465 *	−0.230			
HLM	0.035	−0.089	0.291	−0.112	0.641 *		
GY	0.491 *	0.227	−0.126	0.290	0.284	0.258	
SY	0.568 *	0.192	−0.076	0.223	0.110	0.065	0.480 *

Marked correlations with * are significant at $p < 0.05$; Note: PH: Plant height (cm), NFS: Number of fertile spikelets per spike, NSS: Number of sterile spikelets per spike, NGPS: Number of grains per spike, 1000 GW: 1000 Grain weight (g), HLM: Hectoliter mass (kg ha^{-1}), GY: Grain yield (t ha^{-1}), SY: Straw yield (t ha^{-1}).

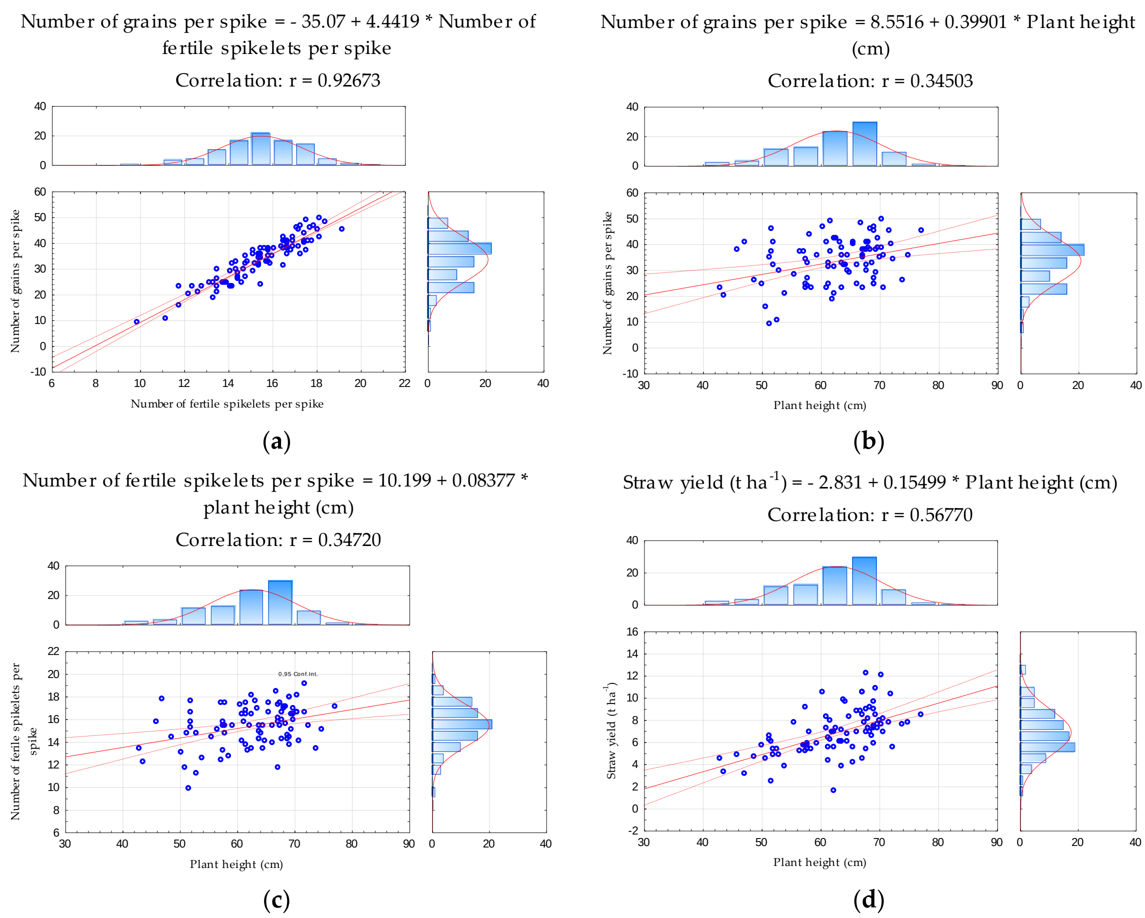
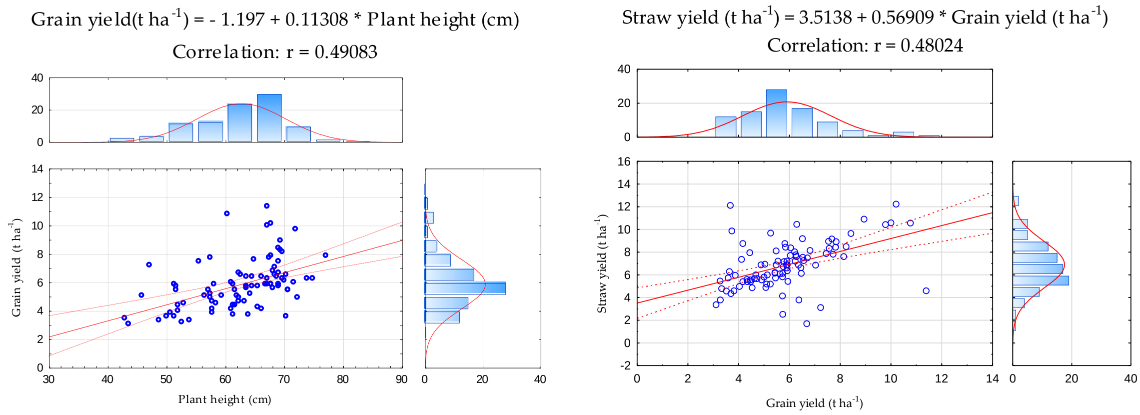


Figure 2. *Cont.*



(**e**) (**f**)

Figure 2. Correlation between some selected yield components of winter wheat: (**a**) very hight correlation between number of fertile spikelets per spike and number of grains per spike; (**b**) low correlation between plant height and number of grains per spike; (**c**) low correlation between plant height and number of fertile spikelets per spike; (**d**) low correlation between plant height and straw yield; (**e**) low correlation between plant height and grain yield; (**f**) low correlation between grain and straw yield.

4. Discussion

4.1. Maize Yield and Yield Components

Grain yield and grain quality in maize are a result of the interaction of genetic, environmental, and agronomic management factors [39]. Grain yield in maize is the result of different component traits. It is indirectly calculated by the number of kernels formed in each ear, test weight and number of ears per plant [40]. Plant height, ear weight, grain weight per cob, stalk weight, grain and straw yield were significantly higher at site Magadenovac, while hectoliter mass was higher at site Cacinci. Plant growth is modified by the environmental factors which surround the plant. Maize growing is extremely sensitive to environmental conditions, especially to abiotic factors such as rainfall, available soil moisture, air and soil temperature, soil type, etc. [39–42]. During the whole maize growing period and especially during the most critical growing period (April–August) in both experimental sites, air temperature most often was higher than the multi-year average. In the period from April to August, the total precipitation in Cacinci site was by 7.77% lower than the multi-year average in the same period and by 3.11% lower than multi-year average in Magadenovac site. A higher amount of precipitation was measured at the Cacinci site (by 12.24%) compared to the Magadenovac site. During the entire vegetation there was a constant change of extremely humid and dry periods. The stages of maize susceptible to water deficiency are the vegetative, silking and grain filling stage, where yield loss may be as high as 25%, 50%, and 21%, respectively [43]. Although significant aberrations were recorded in the amount of precipitation and temperature regime (especially in tasseling-silking phenological stages) there was no change in the water regime of the plant, which ultimately resulted in a satisfactory grain yield. Although the amount of precipitation in Cacinci was higher, and the temperature was almost 0.2 degrees lower than in Magadenovac, lower yields in Cacinci are probably the result of poor water infiltration due to the typical impermeable layer on Stagnosol. On Stagnosol, in conditions of increased precipitation, oxygen deficiency occurs due to stagnation of precipitation water [44].

Nitrogen is a key element for creating yields, and maize, as a plant that produces a large plant mass in a short time, also has high nitrogen needs that cannot be met by the natural reserves in the soil. The application of nitrogen fertilizers is one of the main agricultural practices which is able to stabilize or even increase maize yield [45]. Although the maize productivity can be maintained under reduced nitrogen doses, high N fertilization rates were used in most high yielding intensive agricultural maize production systems [46]. It is generally known that nitrogen deficiency causes many biochemical and physiological disorders that lead to a decrease in the rate of cell division and disturbances in the process of photosynthesis. On the contrary, excessive nitrogen fertilization is a major problem for agriculture production and environment [47]. Excessive application of nitrogen fertilizer has negative effects on crops [48] and causes significant losses by nitrate leaching and groundwater contamination [49–51], release of greenhouse gases, soil acidification, or biodiversity reduction [52]. The obtained results are expected because insufficient nutrition of crops with nitrogen results in reduced leaf area, reduced chlorophyll concentration and thus lower intensity of photosynthesis, which results in reduced yield [53]. Additional effects of nitrogen deficiency are reduced resistance to disease, reduced resistance to stress caused by drought and significantly lower yields [54]. This condition can be avoided by appropriate nitrogen fertilization, intervention top-dressing and balanced addition of other nutrients [54]. The differences in the investigated parameters between optimal and excessive nitrogen fertilization were not significant, which is probably a consequence of nitrogen leaching into deeper soil layers due an increase in rainfall in the vegetation period. Similar results were obtained by Majid et al. [55] in their study where nitrogen application at 345 kg ha^{-1} produced the highest maize yield and yield traits, but in most of the cases it was statistically similar with 230 kg N ha^{-1}. Thousand grain weight is a yield component of cereal crops and a contributing factor upon which crop yield potential is dependent. Although 1000 grain weight is parameter which frequently measured to evaluate grain yield response to nitrogen fertilization management [56,57], in this research different doses of nitrogen did not significantly affect this parameter. The results obtained are consistent with the Anwar et al. [58] which in their research of effect of nitrogen rates and application time on growth and yield of maize reported no significant differences in 1000 grain weight at 120, 160 and 200 kg N ha^{-1}. Plant height was also not affected by the amount of nitrogen applied. The similar results were also found by Anwar et al. [58] who did not find significant differences in plant height in fertilization that exceeded 160 kg N ha^{-1}. Hectoliter mass is most commonly used to assess maize grain quality. Hectoliter mass is a highly inherited property, so it is an indicator of potential differences between hybrids in chemical composition and energy content of the grain. In general, hectoliter mass is a quality parameter that responds to nitrogen fertilization although no significant differences in fertilization treatments were observed in this study, which is in contrast to research done by Barrios Sanchez et al. [59].

Crop productivity significantly depends on the applied tillage because it is noted that on soils prone to compaction lower yields occur most often as a result of interactions between soil penetration resistance, soil oxygen concentration, soil moisture, root growth and plant access to water and nutrients [60]. Ear weight, grain weight per cob, stalk weight, 1000 grain weight, straw and grain yield was under significant influence of soil tillage treatment. The lowest values of the examined parameters were recorded on NT and were significantly lower than all other tillage treatments which corresponds to Ramadhan [61]. The lowest grain mass per ear, stalk weight, grain and straw yield for NT could be due to a compacted soil layer causing reduced uptake of essential nutrients due to poor infiltration and limited root system penetration. These results are in agreement with those of Khan et al. [62], Khurshid et al. [63] and Yusuf [64], who concluded that tillage practices significantly affect crop yield and growth. Differences in ear weight, grain weight per cob, straw and grain yield between CT, SS, CH and DH were not significant. Wang et al. [65] studied the impact of conventional and conservation tillage on some physical soil properties, yield, and maize yield components during 2016–2017. Significantly higher yields and yield components were recorded on conservation treatment (SS) at a depth of 35 cm. Mafongoya et al. [66] showed that grain yields on NT treatment were significantly lower than at the CT treatment which is consistent with our results. The response in the yield components that originated from soil physical properties amelioration implementing adequate soil tillage probably reflected on maize yield which increased under CT, SS, DH and CH treatments. Tillage treatment did not significantly affect variations in plant height and hectoliter mass, which is contrary to research Ramadhan [61] and Anjum et al. [67]

who reported that higher plants were recorded in deep tillage and lower plant height was found in minimum tillage in maize.

The results of the research indicate a significant correlation between the examined parameters. A very high correlation between grain yield and ear weight and grain mass per cob is in line with the results of the research by Marković et al. [68]. A moderate correlation between grain yield and plant height is consistent with Jattot et al. [69].

Khazaei et al. [70] reported highly significant and positive correlation between grain yield with ear number, 1000 grain weight and grain number per ear.

4.2. Winter Wheat Yield and Yield Components

All investigated parameters were significantly influenced by the site properties and the level of applied nitrogen, while the influence of tillage was significant only for plant height and in the formation of grain and straw yield.

Plant height, number of sterile spikelets per spike, 1000 grain weight, hectoliter weight, straw and grain yield were significantly higher on site Magadenovac, while number of fertile spikelets and grain per spike were higher on site Cacinci. These yield components are directly related to wheat productivity [71], which can vary under different environmental factors and different soil management practices [72]. During the winter wheat vegetation, the amount of precipitation and air temperature deviated if compared with the 30-year average. Deviations from the average in the amount of precipitation were most pronounced during April-June in the period most intense and critical for growing winter wheat. During the vegetation air temperatures were higher in comparison with the multi-year average by 0.5 °C (Magadenovac) to 0.9 °C (Cacinci). The obtained results indicate a noticeable influence of climatic conditions on the examined properties, which is in line with research by Jug et al. [72]. All stages of wheat development are significantly affected by higher temperatures. Higher temperatures accelerate the onset of flowering [73–76], reduce the period of spike development resulting in a shorter spike, reduced number of spikelets and grains per spike [77], and adversely affect pollen development [78]. According to Talukder et al. [79] the flowering period, which lasts for about 20 days before flowering and 10 days after anthesis, endure a temperature of a maximum of 31 °C without any decline in the number of grains.

Yield and yield components heavily depend on growth conditions, soil fertility, fertilizer application, water ability and genotype. In addition to climatic conditions specific to the study site, soil properties played an important role in creating yield. Stagnosol (Cacinci site) has a specific layer in which stagnant water in soil and reduction conditions. That may cause a weak infiltration of water with stressful conditions for wheat crops (the gas exchange of roots with the atmosphere is inhibited). Excessive amount of water in the soil leads to additional negative conditions such as the accumulation of carbon dioxide, ethylene and other compounds in the root zone, most often in combination with a lack of nutrients [80]. Such conditions have a negative effect on plant development which ultimately leads to reduced yields.

Excessive nitrogen fertilization will result in excessive vegetative mass of crops [81], will delay grain ripening and prolong vegetation, increase the sensitivity of crops to diseases and pests, and reduce the quality of yield [48]. On the other hand, insufficient amount of N during intense vegetative growth will result in a smaller assimilation surface and reduced synthesis of chloroplast pigments, which will affect the photosynthesis process and ultimately result in reduced yield. Nitrogen fertilization significantly affects the grain and straw yield as well as all yield components, except hectoliter weight. Nitrogen significantly increased number of grains per spike, number of fertile spikelets per spike and plant height, which is in line with the results Dargie et al. [82]. More grains per spike at optimal and luxury nitrogen doses may be due to higher availability of N. The mass of 1000 grains were the highest on reduced nitrogen fertilization, which is probably a consequence of better grain filling of significantly smaller number of grains per class, which was recorded in reduced N fertilization. Rahman et al. [83] reported that nitrogen application at the rate of 100 kg ha^{-1} in three equal splits produced significantly higher 1000 grain weight than nitrogen rate of 120 kg ha^{-1}. According to same authors, the result indicated that kernel size of wheat was more responsive to method and timing of N application rather than amount of N fertilization.

The highest grain yield was achieved on luxurious nitrogen fertilization, although the difference in relation to the grain yield achieved on the optimal fertilization was insignificant. Grain yield on reduced fertilization was significantly lower in comparison to luxurious and optimal nitrogen fertilization which indicates the role and importance of nitrogen as a yielding element for achieving high and stable yields. The results revealed that straw yield increased linearly with increase in N rate and maximum straw yield recorded were achieved at luxurious nitrogen fertilization. The increase in grain and straw yield at higher doses of nitrogen can be attributed to increased content of chlorophyll in the leaf, larger and wider leaves, which ultimately increased dry matter production [84]. Excessive fertilization is often the result of overestimated production opportunities in conditions where nutrient availability is not a limiting factor in production. The optimal N use for growth and maximizing yields is determined by physiological processes in plants, plant traits, environmental conditions and nutrient management [85]. In the conducted research, there was no negative effect of luxury nitrogen fertilization, which is probably due to the increased amount of precipitation that resulted in nitrogen leaching.

Soil tillage significantly affected grain yield, straw yield and plant height. The highest grain and straw yield, and plants height were recorded on SS treatment and there were significantly higher in comparison to grain and straw yield as well as plant height on CT, CH, DH and NT treatments. The assumption is that subsoiling treatment improved water infiltration and soil water capacity, which influenced increased plant height and consequently increased wheat grain and straw yield. Schnieder et al. [86] analyzed the effects of subsoiling on soil properties and crop yield and found that the mean crop response to deep tillage was significantly positive. Their results suggest that deep tillage increases the availability of subsoil nutrients to plants, which increases crop yield. According to same authors, on soils with stable soil structure and root-restricting layers, deep tillage can be an effective measure to mitigate drought stress and improve the resilience of crops under climate change conditions. Wang et al. [87] reported that under subsoiling tillage treatments, significantly higher grain yield was obtained in two experimental years, and that subsoiling made winter wheat more resilient to adverse weather.

This research results indicate the interrelationship of the investigated parameters: the number of grains per spike is related to the number of spikelets per spike, fertile and sterile, and plant height According to Knezevic et al. [88] the number of grains per spike is also related to the number of flowers per spike, pollination efficiency and seed development in flowers. Plant height was positively correlated with the number of fertile spikelets per spike as well as with straw and grain yield. According to Álvaro et al. [89] increasing of number of spikelets potentially related to increasing of number of grains, which was also confirmed in this study. Philipp et al. [90] found that spikelets number per spike in wheat was not correlated with grain yield which is in line to the results obtained in this study. Sterile spikelet numbers have significant effect on thousand grain weight and grain number per spike.

5. Conclusions

The results obtained in this research indicate a significant influence of site properties, tillage and nitrogen treatments on maize and winter yield and selected yield components.

Higher plant height, ear weight, grain weight per cob, stalk weight, straw and grain yield were recorded on maize in agroecological conditions of the Magadenovac site compared to Cacinci site. Maize achieved uniform yields on all tillage treatments, except on NT treatment, where grain and straw yields were significantly lower. These results indicate possibility of applying conservation tillage as well as conventional tillage in maize production. The highest yields, as well as yield components, were measured on the treatment with the optimal amount of nitrogen, which indicates the need to conduct soil analysis in order to make fertilization recommendations, which reduces production costs and environmental pollution by nitrates.

Winter wheat achieved higher plant height, weight of 1000 grains and grain and straw yield in agroecological conditions of the Magadenovac site compared to Cacinci site. The highest winter wheat grain yields on tillage treatments were recorded as follows: SS > DH > CH > NT > CT. Significantly higher wheat grain yields were recorded on SS and DH indicating that these treatments may be the most appropriate tillage systems for the investigated agroecological conditions. The highest yield, plant height and weight of 1000 grains were measured at a luxurious and optimal amount of nitrogen, while the reduced nitrogen fertilization gave significantly lower values of the investigated parameters. The obtained results indicate the importance of using fertilization recommendations because an insufficient dose of nitrogen reduces the yield, while luxury fertilization does not increase the yield at the cost of raised environmental nitrogen pollution.

The obtained results indicate the importance of optimal nitrogen fertilization and the possibility of implementation of conservation tillage in maize and winter wheat production in different agroecological conditions, thus reducing soil degradation processes, conserving soil and water by reducing their losses, reducing environmental pollution and achieving high and, maybe more important, stable yields.

Author Contributions: Conceptualization, I.J., B.B., B.Đ., V.V. and D.J.; methodology, I.J., B.B., B.Đ. and D.J.; software, I.J., B.B., B.Đ., B.S. and D.J.; validation, I.J., E.W. and D.J.; formal analysis, I.J. and D.J.; investigation, I.J., B.B., B.Đ., V.V., B.S. and D.J.; resources, I.J., E.W. and D.J.; data curation, I.J., B.B., B.Đ., V.V. and D.J.; writing—original draft preparation, I.J. and D.J.; writing—review and editing, I.J., B.S. and D.J.; visualization, I.J.; supervision, I.J., B.S. and D.J.; project administration, D.J.; funding acquisition, I.J., E.W. and D.J. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the Croatian Ministry of Agriculture (VIP Project: "Conservation soil tillage as a measure for climate change mitigation", research grant number 2012-11-55).

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Acknowledgments: We would like to thank the owners of the farm "Zora" in Magadenovac and the farm "Knežević" in Cacinci for their support during this study.

Conflicts of Interest: The authors declare no conflict of interest.

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