Yield of Winter Wheat Grown under Zero and Conventional Tillage on Different Soil Types[5]

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Abstract. In three-year field trials, conducted in West Poland, the growth and development of winter wheat grown under zero tillage (ZT) and conventional tillage (CT) methods on four soils were investigated. The soils were different mainly in grain fraction distribution and content of organic matter. The tested soils were sandy loam (SL), loamy sand (LS-1, LS-2) and sand (S). In GPS-fixed sites, in ZT and CT fields, yield of aerial part biomass in four growth stages: stem elongation, second node, and heading and inflorescence phases, was compared. In addition, yields of grain and straw were tested. On medium and coarse textured soils (SL, LS-1, LS-2), more biomass was produced by wheat under CT than ZT, but on very coarse textured soil (S), the biomass yields obtained from wheat growing under both soil tillage methods were identical. On medium textured soils and on coarse textured (LS-1) soil, wheat under CT contained more N and P as well as much more Ca and Mg in tissues than under ZT. In contrast, on the other coarse textured (LS-2) soil and on very coarse textured soil, wheat plants under ZT were generally characterized by identical or slightly higher nutrient content than plants under CT. Despite periodic fluctuations in biomass yields between ZT and CT for particular growth stages of wheat, the yields of grain and straw were the same for both soil tillage methods, irrespective of the soil type.

Key words: Wheat, zero tillage, yield, growth stages, types of soil

INTRODUCTION

Reduced soil tillage has certain advantages, as it prevents soil erosion, reduces water loss and decreases crop cultivation costs in comparison with conventional soil tillage with a plough. An extreme example of simplified soil tillage is the zero method, also known as the direct drilling method, which involves sowing seeds into unploughed soil using a specialist seed drill. The references suggest that zero tillage (ZT) leads to differentiated results. Yields from zero tillage fields are often higher than those from conventional tillage ones, but there are also cases when no differences appear between zero and conventional tillage fields or when yields under zero tillage are lower (Ernstein & Laxmi, 2008). There are many factors influencing the results of direct sowing, including soil, climate and the duration of ZT implementation (Martinez et al., 2008). Higher crop yields under ZT than under

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CT are typically obtained in dry climate (Wang et al., 2007). In the moderate climate of West Poland, with mean annual precipitation of 550 mm and mean annual temperature of 8.5^{o} C, zero tillage rarely generates higher yields than conventional soil cultivation methods. The advantages of using ZT depend both on the weather, especially distribution of precipitation, and the type of soil. Besides, nitrogen fertilization, forecrop, as well as weed infestation and disease outbreaks can alter the direct effect of ZT on yield volume (Małecka & Blecharczyk, 2008).

The impact of the type of soil on effects of ZT consists in the fact that ZT changes physical properties of soil, particularly soil density together with air and water relationships, as well as soil chemical and biological characteristics in comparison with CT. The extent and intensity of such changes caused by the 'no-plough' method in soil obviously depends on soil texture. In heavier soil, for example, such changes happen faster and reach deeper than in lighter soils.

Some claim that sandy soils are not suitable for zero tillage. In Poland, over 60% of arable land consists of sandy soils. The purpose of this study has been to compare the growth and development of winter wheat grown under zero and conventional tillage on 4 types of soil of different texture.

MATERIAL AND METHODS

The experiment was conducted in 2007-2009 at the Experimental Station in Baborowko near Poznań (West Poland). It involved winter wheat fields, which had been cultivated for three years before the trials under conventional tillage (CT) or zero tillage (ZT) methods. Conventional tillage involved stubble ploughing and seed ploughing to the depth of 25 cm as well as pre-seeding soil cultivation with a power harrow. Zero tillage was performed without mechanical soil tillage, mulching the soil with comminuted straw. Seeds were sown using a special type of seed drill and weeds were controlled with herbicides only. Fertilization was identical for both soil tillage methods. All fields received basic fertilization: N - 30 (autumn) and 120 (spring 80+40), P - 17 and K - 50 kg ha^{-1}.

In GPS-fixed points in ZT- and CT-fields, the biomass yield of aerial parts of wheat plants in 4 growth stages: early stem elongation (I), second node (II), heading (III) and inflorescence (IV), was assessed. In addition, yields of grain and straw were measured. Plant samples were collected by cutting whole aerial parts of wheat growing in an area of 1 square meter.

The experiment was established on four soil types: Haplic Phaeozems, sandy loam (SL); Haplic Arenosols (Brunic), loamy sand (LS-1); Albic Luvisols, loamy sand (LS-2) and Albic Luvisols (Arenic), sand (S). The soils were different in texture, organic matter content and nutrient abundance (Table 1).

The years during which the experiment was conducted were quite different as for weather conditions. The highest average monthly temperatures, exceeding the multi-year mean, were recorded in 2007 (Table 2). Moreover, the year 2007 had the highest total precipitation from March to July, exceeding the multi-year average (Table 3). Noteworthy is an extremely dry April and a very wet May, when over 2.5-fold more rain fell compared to the multi-year average. The year 2008 was characterized by the average monthly temperatures higher than multi-year average. The total rainfall from March to July was the lowest compared to the other analyzed years, yet at a level of the multi-year average. Nonetheless, the distribution of rainfall was less favourable than in 2007, because after very heavy rains in April came very dry May and June. In 2009, higher temperatures were recorded in April, compared to the other years or to the multi-year average, and the rainfall was relatively low. The temperatures in May and June were lower than in the other years, while the rainfall was quite high.

Table 1. Characteristic of experimental soils

Soil	pH KCl	OM	SF I	SF II	SF III	P	K	Mg
		%				mg kg^{-1}		
SL	6.4	1.38	65.8	27.5	6.7	92	116	97
LS-1	6.3	1.34	79.8	14.9	5.3	72	115	95
LS-2	6.2	1.03	83.8	4.8	11.4	67	96	93
S	6.3	1.07	88.3	7.4	4.3	89	84	66

OM-organic matter, SF I-soil fraction 2.0-0.05 mm, SF II-soil fraction 0.05-0.002 mm, SF III -soil fraction <0.002 mm.

Table 2. Mean monthly air temperatures in Baborowko (^{o}C)

Year	Month					
	III	IV	V	VI	VII	Mean
2007	6.7	11.0	16.5	19.8	20.2	14.8
2008	4.4	9.0	15.0	19.4	20.7	13.7
2009	4.1	12.4	14.1	16.2	20.0	13.4
1971-2006	3.1	7.8	13.5	16.4	18.4	11.8

Table 3. Monthly sums of precipitation in Baborowko (mm)

Year	Month					
	III	IV	V	VI	VII	III-VII
2007	55.9	3.8	119.4	59.0	94.7	332.8
2008	50.1	71.4	14.9	18.0	69.5	223.9
2009	50.6	17.2	76.8	91.4	75.8	311.8
1971-2006	29.6	31.0	49.5	59.4	77.3	246.8

Dry matter yield of aerial wheat parts in the consecutive growth stages was determined alongside grain and straw yields from 1m^2 of field. The results underwent analysis of variance. For comparison of the differences between the means, the Tukey test ($\alpha < 0.05$) was applied.

Soil samples were taken for chemical analyses before the trials. Organic carbon in soil was determined by Tiurin method, pH was established potentiometrically in 1 mol KCl dm^{-3}, P and K were assessed using Enger-Riehm method and Mg was assayed by Schachtschabel method.

In all plant samples, after wet mineralization (concentrated H_2SO_4+ 30% solution of hydrogen peroxide), N and P content was determined with flow spectrophotometric method, K with emission spectrophotometry and Ca and Mg with AAS.

RESULTS AND DISCUSSION

The wheat biomass yield determined in the plant's subsequent growth stages differed according to soil tillage method (CT or ZT), depending on the year, which was connected with the weather (Fig. 1).

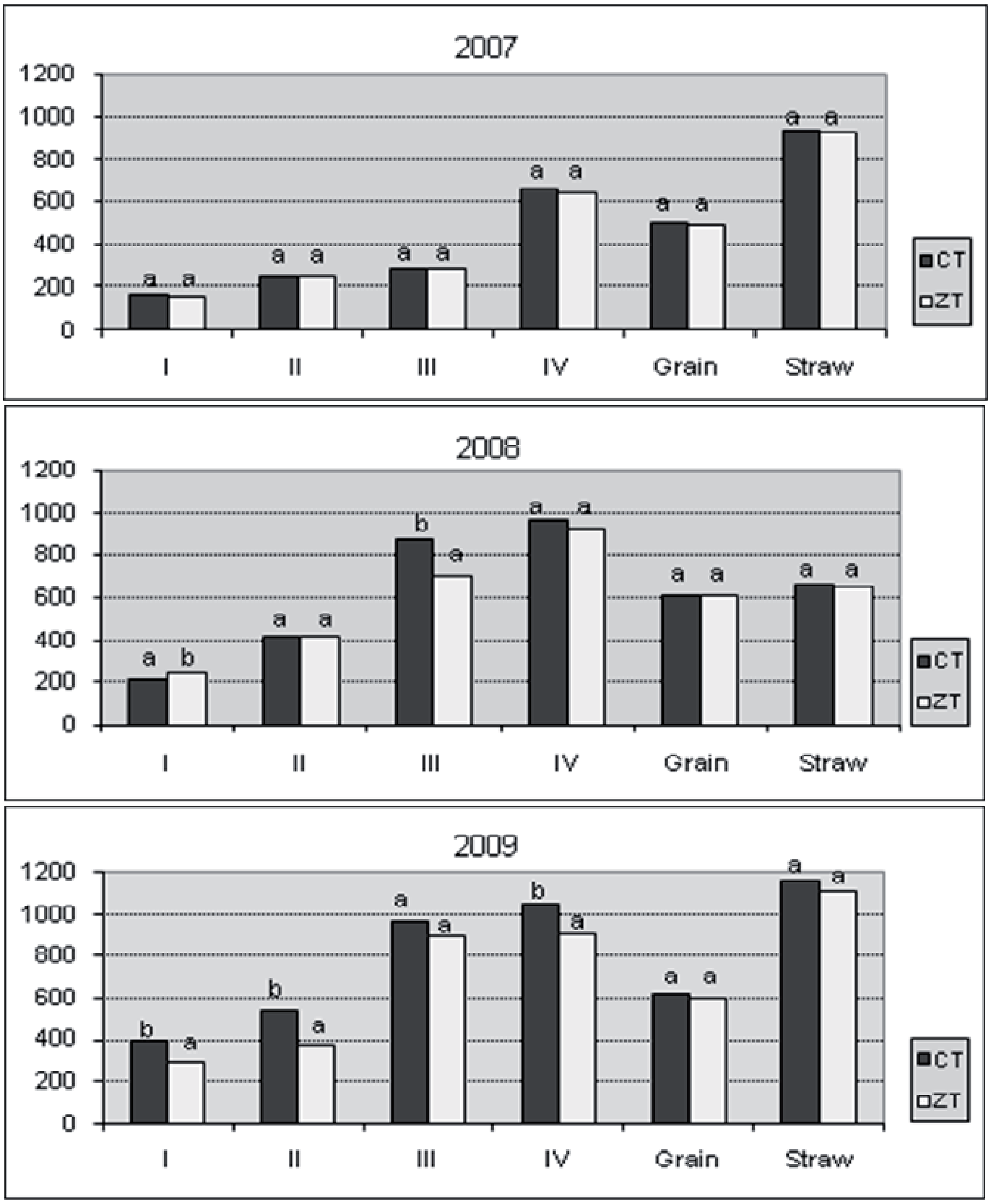

Fig. 1. Yield of wheat dry aerial parts (g m^{-2}) during subsequent growth stages (I – IV) and final yield means of soil types. Identical letters denote lack of differences tested with the Tukey test ($p < 0.05$).

In 2007, which was characterized by higher than average rainfall during the growing season, especially in May, and relatively high average air temperature, the biomass yield in each growing phase was identical to both soil tillage methods. It was noteworthy that in the driest year, 2008, during the drought in May–June, although the biomass yield tended to be higher under CT than under ZT, the biomass increase between phase III and IV was much higher in the ZT (32%) than in the CT field (11%). In 2009 with a little less rainfall and lower average temperature than in 2007, significant differences were observed in biomass yields in favour of CT method. Higher plant yields from ZT than from CT fields are usually obtained in dry climate or in years with less rainfall (Arshad et al., 1999; Bonfil et al., 1999; De Vita et al., 2007) because in a dry year, plants are less vulnerable to yield loss under ZT rather than under CT method. It is so because more water is accumulated in soil tilled according to zero tillage method, which is a consequence of lower evaporation and changes in the soil's water permeability when no mechanical soil tillage is involved (Rasmussen, 1999; Martinez et al., 2008). An extensive study performed by Erenstein et al. (2008) proves that water productivity indicators in wheat cultivation are higher for ZT than for CT. Also Mrabet (2000) found superior wheat water use efficiency under ZT in a semiarid area.

Although there were certain differences between CT and ZT in wheat biomass yield during the early growing phases, the yields of grain and straw from ZT and CT trials were identical, independent of the year of experiment. This finding is attributable to the fact that in the climate prevailing in West Poland, crops growing under ZT tend to enter the vegetative phase later than plants under CT, which is due to lower temperature of the upper soil layer in early spring. The topmost soil layer, down to 5 cm deep, treated with ZT is more compact and moist than soil receiving CT (Martinez et al., 2008), and consequently, it warms up more slowly. In the later growth stages, the growth and biomass accumulation under ZT can accelerate and the grain yields from fields under both types of soil tillage can become even.

Obviously, apart from the thermal and moisture conditions, the rate of biomass increase is affected by soil type and soil abundance in nutrients. When analyzing differences between CT and ZT applied to different soil types, it was determined that, in general, wheat growing on heavier soils (SL and LS-1), containing more organic matter, had more biomass under CT than under ZT (Fig. 2). On lighter soils with less organic matter (SL-2 and S), wheat under ZT produced as much biomass as wheat plants under CT. The yields of grain and straw, irrespective of the soil type, were identical for both soil tillage methods.

The differences in the biomass yields between CT and ZT could have been caused by the differences in the nourishment of wheat plants during the growing season (Fig. 3).

Wheat under CT on SL and LS-1 soils contained more Ca and Mg as well as more N and P than wheat under ZT. In contrast, on LS-2 and S soils, wheat plants growing under ZT tended to contain the same or slightly higher levels of these nutrients compared to wheat growing under CT.

Many authors report on differences in the distribution of macronutrients in soil, depending on the soil tillage method. Most nutrients appear in higher concentrations in a soil receiving zero tillage than in a soil tilled conventionally, but only in the top 0-5 cm soil layer, and start decreasing along with the depth

(Franzluebbers & Hons, 1996; Martin-Rueda et al., 2007; Tarkalson et al., 2006; Wright et al., 2007). Zech et al. (2000) found varied concentrations of nutrients in soil under CT and ZT depending on a rainy or dry season.

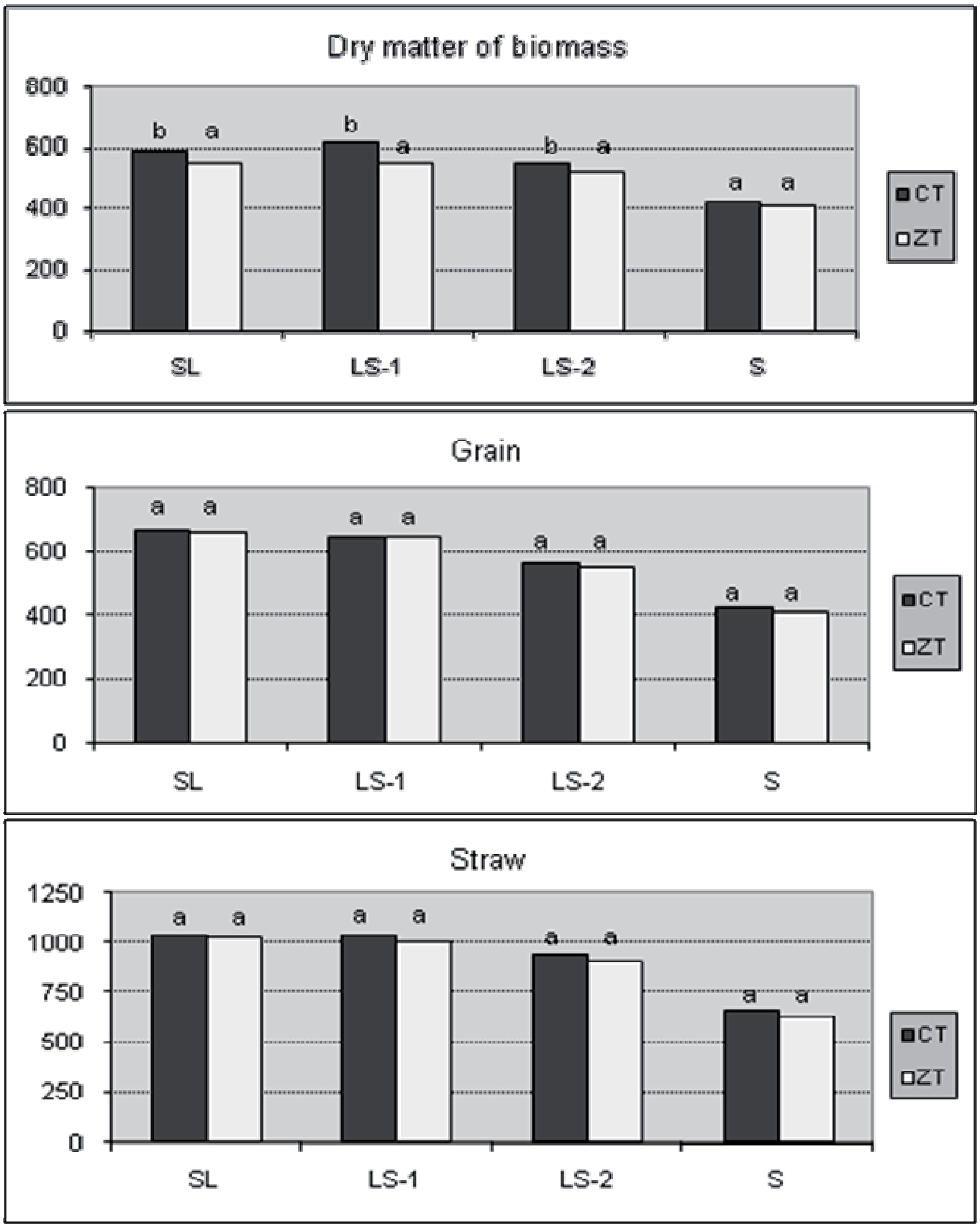

Fig. 2. Wheat yield (g m^{-2}) on different types of soil. Mean biomass for 4 sampling dates and 3 years; for grain and straw – means for three years.

Identical letters denote lack of differences tested with the Tukey test ($p < 0.05$).

In a study conducted by Stanisławska-Glubiak & Korzeniowska (2009), differences appeared in the levels of micronutrients in plants under CT and ZT during the early vegetative season. These concentrations were typically higher under CT, unless there was drought, when more nutrients occurred in plants growing under ZT. Lavado et al. (2001) report that soil tillage methods have a relatively weak influence on the content of micronutrients in plants growing under the soil and climatic conditions prevalent in South America.

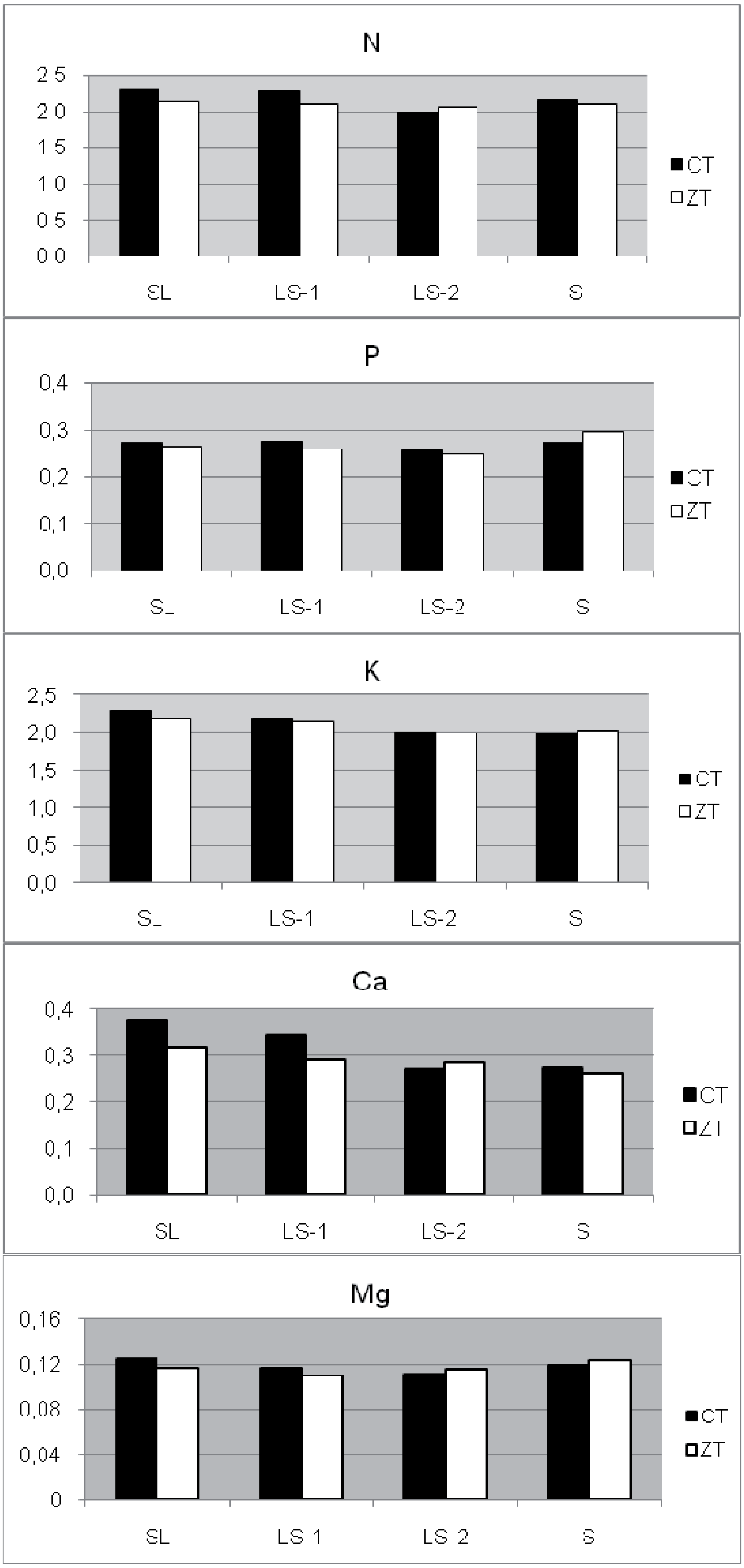

Fig. 3. Content of macronutrients (%) in dry matter of wheat aerial parts on different types of soil – means for 4 sampling dates and 3 years.

It seems, however, that among the many factors which modify the differences between CT and ZT in the content of macronutrients in soil and plants, soil type can also play a role. It can be expected that under inferior moisture conditions, typical of lighter soils, wheat under ZT takes up nutrients from the soil more easily than wheat growing on CT soil, which has manifested itself in terms of biomass formation as well as grain and straw yield.

CONCLUSIONS

1. Under the moderate climatic conditions prevailing in West Poland, small and periodically occurring (from the stem elongation to the inflorescence phase) differences between zero and conventional soil tillage methods were found in terms of winter wheat biomass yields. Such differences, generally in favour of CT, were shaped by the soil and weather conditions.
2. The type of soil produced an effect on the nourishment of plants with basic nutrients, as well as on the volume of biomass yields obtained until the inflorescence phase. On medium and coarse textured soils, wheat growing under CT obtained more biomass, whereas on very coarse textured soil, the wheat biomass yields under ZT and CT were identical.
3. During insufficient rainfall, wheat biomass increase was higher under ZT than under CT. However, when precipitation was moderate, more biomass was produced by wheat growing under CT.
4. Periodically occurring fluctuations in biomass yield produced under CT and ZT did not have any influence on the later grain and straw yield, which was identical for both methods of soil tillage, independently from the soil type. This finding supports the idea of using zero tillage in agricultural practice in West Poland, both for economical and environmental reasons.

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