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The effect of tillage system and nitrogen fertilization on yield and yield components of winter spelt cultivars (*Triticum aestivum* ssp. *spelta* L.)

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Abstract. The aim of the present paper is to assess the effect of cultivation systems and varied nitrogen fertilisation doses on yield and yield components of two cultivars and one strain of winter spelt. The experiment was conducted on soil is classified as Haplic Cambisol. Three factors were compared in the course of the experiment: factor I – 2 cultivation systems: reduced tillage and conventional cultivation, factor II – 4 nitrogen fertilisation levels, factor III – cultivar/strain. The plants under analysis were two cultivars of winter spelt: German 'Frankenkorn' and Swiss 'Oberkulmer Rotkorn' and strain STH 12. There was no significant difference regarding winter spelt grain yield depending on the cultivation system. Nitrogen fertilisation caused a significant increase in yield to a certain threshold which, when exceeded, resulted in a decrease of grain yield. The highest yield was obtained for STH 12 strain. With respect to thousand grain weight, number of ears per m^2, number of grains yield per ear, and ear yield, there was a significant relationship with the cultivar factor. SPAD values showed no differences between cultivars. The method of cultivation (conventional vs. reduced tillage) did not show differences for the four analysed yield components and SPAD of winter spelt.

Keywords: winter spelt, yield, yield components, tillage system, nitrogen fertilization

INTRODUCTION

Winter spelt wheat commonly known as (*Triticum aestivum* ssp. *spelta* L.), is a very well-known cereal which was cultivated as early as in the Neolithic period and the Bronze Age (8000-3000 BCE). Most likely, spelt originated as a natural hybrid of aegilops (*Aegilops squarrosa*) and Emmer wheat (*Triticum dicoccum)* (Lacko-Bartošová, Otepka, 2001). The European as well as Polish legislation considers spelt wheat to be a separate species (*Triticum spelta* L.).

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In Europe, spelt, though popular for centuries, was replaced in the 19th century by common wheat which was increasingly more intensively cultivated due to its resistance to genetic modifications and ability to retain its original features (Bonafaccia et al., 2000; Capouchová 2001). In the last two decades, spelt has become an increasingly more popular cereal due to the possibility of being cultivated extensively and the general trend towards organic production. Spelt is a hexaploid wheat (genomes AABBDD – 42 chromosomes), with hulled grain of the same genome as bread wheat (Yan et al., 2003; Onishi et al., 2006). Its hulled grain is vitreous, white to red in colour. Spelt is a cereal crop which is characterised by a lack of special requirements regarding soil, climatic conditions or intensive protection (Sliesaravičius et al., 2006; Schober et al., 2006). The highest number of cultivars originates from Germany and Switzerland (Mielke, Rodemann, 2007).

The oldest cultivars originating in Germany were registered before the year 1904, and Frankenkorn cultivar in 1995. Oberkulmer Rotkorn is a Swiss cultivar registered even earlier, i.e. 1948. STH 12 strain is the result of hybridisation of common wheat with spelt and was obtained from Plant Breeding Strzelce, Poland.

The reduced tillage cultivation has been a popular concept for many years (Stošić et al., 2017), and reduced cultivation practices are becoming increasingly more frequent in large scale farming. Nowadays, there is a trend in modern agriculture to replace the traditional soil cultivation system with no-tillage cultivation (reduced tillage). The literature on the subject provides numerous positive, as well as negative, opinions on the effect of the conventional and reduced tillage systems on crop yield and grain quality (Gibczyńska et al., 2002; De Vita et al., 2007; Peigné, 2014; Rachoń et al., 2018). The traditional cultivation system is based on ploughing which destroys the natural structure of soil causing soil drying and increases the mineralisation of organic substance (Morris et al., 2010). The most popular reduced tillage cultivation system (no-tillage) provides numerous benefits such as: water conservation, particularly in the dry years, reduced variations in temperature, limiting the organic matter loss, intensification of soil biological life as well as reduced fuel consumption and gas emission (Melaj et al., 2003; Ozpinar, 2006; Bottinelli et al., 2010). No-tillage cultivation allows plants to grow in autumn, thus allowing for nitrate absorption and consequently reducing nitrate leeching (Małecka, Blecharczyk, 2008). However, there are some disadvantages to the no-tillage system, such as soil compaction in the deeper layers, decreased mineralisation of plant residue and mechanical problems with positioning of seeds (Stošić, 2012). Especially in the initial years, no-tillage cultivation leads to increased soil compaction, which can result in hampered plant germination, poor root system development and, as a consequence, lower crop yield (D'Haene et al., 2008). Out of all agro-technical factors, nitrogen fertilisation has the greatest effect on yield differentiation and grain quality (Mikos, Podolska, 2012; Liu, Shi, 2013; Linina, Ruža, 2018).

Improper use of mineral fertilisers, particularly nitrogen, can result in reduced soil fertility due to stimulated soil acidification, disturbed ionic balance of elements, reduced biological activity or induced soil salinity (Vitousek et al., 2009; Stępień et al., 2016). Excessive application of nitrogen can lead to a reduced grain yield and increased nitrogen loss in a wheat-soil system (Wang et al., 2011).

SPAD-502 chlorophyll meter is a simple, mobile diagnostic instrument used for estimating the chlorophyll content in leaves. Zhu et al., 2012 and Naderi et al., 2012 estimate that SPAD readings are positively correlated with destructive measurements of chlorophyll and have been recognized as a useful indicator of plant demand for nitrogen during growth.The value of SPAD chlorophyll and its ratio to common wheat and spelt wheat yield has been poorly measured to date (Islam et al., 2014). Jarecki et al. (2016) based on their results noted that the higher dose of nitrogen caused a considerable increase of leaf area index (LAI) and SPAD indicator. The overwhelming majority of studies on spelt focus on its yield and pays less attention to the relationship between the elements of ear yield and morphological characteristics of plants.

Old spelled cultivars can react differently to tillage systems, and new cultivars are likely to react more intensively to nitrogen fertilization.

The aim of the present paper is to assess the effect of cultivation systems (ploughing vs. reduced tillage) and varied nitrogen fertilisation doses on yield and yield components of two cultivars and one strain of winter spelt.

MATERIAL AND METHODS

Site description

The field experiment was conducted in the period 2009–2011 in Lipnik (53°42'N, 14°97'E), at the Agricultural Experimental Station of the West Pomeranian University of Technology in Szczecin, Poland. The experiment was conducted on brown soil which originated from light loamy sand and is classified as Haplic Cambisol (IUSS Working Group WRB 2015). The soil was characterised by a slightly acidic pH (in 1 mole KCl, on average, pH was 6.5) and the content of floatable particles (diameter ≤ 0.02 mm) was approximately 11–13%. The thickness of the humic layer was from 14 to 25 cm, and the content of humus in soil was at the level of 1.3–1.5%. The content of available microelements was found to be average, the amount of available phosphorus and potassium was: $P_{available}$ = 58; $K_{available}$ = 104 mg kg^{-1} of soil.

Three factors were compared in the course of the experiment: factor I – 2 cultivation systems: (reduced tillage) and conventional (ploughing) cultivation, factor II – 4 nitrogen fertilisation levels (0, 50, 100, and 150 kg N ha^{-1}), factor III – cultivar/strain. The plants under analysis were two cultivars of winter spelt: German Frankenkorn and Swiss 'Oberkulmer Rotkorn' and strain STH 12. The strain is a hybrid of common wheat and spelt and was obtained from Plant Breeding Strzelce Ltd. IHAR Group near Kutno, Poland. The experiment was laid out in split-split-plot system in three replications. The material for the analysis was the grain of winter spelt wheat, obtained as mean from the experimental combinations. Spelt was preceded by oats in each year of study.

Experimental design and management

Phosphorus-potassium fertilisation was applied in autumn after the preceding crop harvesting at a rate of 100 kg ha^{-1} as single superphosphate ($Ca(H_2PO_4)_2$) and 150 kg ha^{-1} in the form of potassium salt (KCl) 60%. Additionally, 25 kg MgO and 50 kg SO_3 was applied in the form of Kieserite. Nitrogen fertilisation (ammonium nitrate) was applied in summer at of 50 kg N ha^{-1} on the following dates: start of vegetation (March 17–19), stage of shooting (April 21–24) and stage of earing (May 17–21). The cultural practices performed prior to sowing included ploughing with Campbell roller in the variants with ploughing system and harrowing using disc harrow with cage roller in the variant with reduced tillage. Sowing was done in the third decade of September using a seed drill with Øyorda type sowing apparatus. The area of the plot was 15.0 m^2, the number of rows was 12 and the spacing between the rows was 12.5 cm. The adopted sowing rate was 350 grains germinating per 1 m^2. Depending on the conditions, herbicide and fungicide treatments were applied. The integrated weed and fungus protection program was adhered to. The grain was harvested at full maturity with the use of Wintersteiger plot harvester.

Grain yield and yield components

Prior to harvesting, plant samples of the size 4 × 0.125 m^2 were taken from each plot for the assessment of ear density per 1 m^2. The number of ears necessary to assess the number of grains per ear was determined using two-step Stein method for a small sample of unknown variance (Sobczyk, 2019). The conducted analysis showed that for the purpose of assessing the average number of grains per ear, with the permissible estimation error at 5%, 30 ears should be collected from each plot. A thousand grain weight (TGW), was measured in four grain samples, 250 grains each. The measurements were conducted using the automatic seed counter LN-S-50A type. The sample for determining the thousand grain weight was prepared using a 12-channel separator to obtain the representative sample. Ear yield was calculated as the product of the number of seeds per ear and the weight of one caryopsis. Following harvesting with a combine harvester, grain yield obtained from the experimental plots was cleaned in the air separator, and the grain humidity was determined by means of an oven method to calculate the yield into dt ha^{-1} at 15% humidity. The SPAD test (Soil Plant Analysis and Development), also known as the leaf greenness index, allows measurements in a non-destructive way. Chlorophyll meters allow the assessment of the nitrogen nutritional status through measurement of the chlorophyll content on the basis of leaf greenness index. SPAD measurements consist of determination of the quotient of the difference of light absorption by a leaf at the wavelength of 650 and 940 nm. Leaf chlorophyll concentration was estimated with SPAD 502 chlorophyll meter, Minolta, Japan. Chlorophyll content in leaves was measured during the stage of shooting (BBCH 30-31), with the assumption that a given developmental phase was completed by at least 60% of plants. Measurements were made at the middle part of each leaf. The average of 10 measurements was taken as a SPAD value.

Weather conditions of the experiment

The course of the weather conditions in the years of study, i.e. 2009–2011, was varied. The end of 2008 was, on average, by 0.8°C warmer than the long-term average, the year 2009 was warmer by 0.9°C, and 2011 (from January to September) by as much as 1.1°C. The highest thermal variation was identified for the year 2010, as both in January and in December the temperature was well below the norm – by 4.9°C and 5.6°C respectively. In turn, July of 2010 was the warmest month of the whole analysed period. The comparison of the variations of air temperature from the long-term average shows that 2010 was by 0.6°C cooler than the norm. In the analysed period, the maximum precipitation was recorded in the autumn of 2009 and 2010, and in the summer of 2010 and 2011. In the latter two years, heavy rainfall in August and July followed dry periods. The smallest variation in conditions was recorded from September 2008 to September 2009. The year 2010 proved to be the most extreme, as there was a drought from January till the end of April, and following a wet May there was another extreme drought in June followed by a wet July and a particularly wet August. Rainfall deficit was also observed in 2011 when SPI values (standardised precipitation index) in summer (from April to June) amounted to <-1.0, indicating a weak drought.

Statistical analysis

The data of the study were statistically analysed using an ANOVA model for a split-split-plot design for each year and as a 3-years synthesis of the results, using the fixed model. Confidence half-intervals for the purpose of comparing the means were calculated with the use of HSD – Tukey's test at the significance level p=0.05. For grain yield in the subsequent years of the experiment, the ANOVA with regression was calculated. The significance of the effects was assessed with F-Fisher-Snedecor test and second-degree polynomial lines are presented in the graph. Additionally, the maximum of the function was determined, indicating the level of fertilisation which gives the highest yield by comparing the first derivative of the second-degree polynomial equation to zero value. With respect to yield and components of yield of the cultivars under analysis, multiple regression equations were determined, assuming the grain yield (y) to be a dependent variable, and the number of ears, grains per ear, a thousand grain weight (TGW), and grain yield per one ear to be independent variables. The initial analysis of the matrix of Pearson's simple correlation between the variables excluded the yield per one ear from further analysis as it was strongly correlated with the number of grains per ear. Multiple regression analysis was conducted with a stepwise method by including further variables into the equation. The significance of R coefficient was verified with F Fisher-Snedecor test, and the significance of the partial regression coefficients with t-Student test (Mickey et al., 2004). The calculations were made using Statistica 12.0, Software.

RESULTS AND DISCUSSION

Grain yield and yield components

Grain yield from a given area directly depends on the number of plants, the number of grains in ear and grain weight. The analysis of yield, taking into consideration its structural elements, takes into account intentional stimulating the yield, or limiting it to its optimum size, bearing in mind grain yield and its quality. Unilateral increase in one of the elements, e.g. the number of ears due to fertilisation or overly dense sowing, results in a significant decrease in the other elements, and consequently the effect can be opposite to the desired one. Grain yield and yield components significantly varied in particular years of the study ($p \leq 0.01$) (Table 1), which corresponds with the results presented in the literature on the subject (Wanic et al., 2019). However, the effect of cultivation system on these characteristics was not confirmed here, contrary to the authors (Tolessa et al., 2007; Haliniarz et al., 2013) who claim that the effect of a cultivation system on grain yield and its structure is significant. The levels of nitrogen fertilisation applied to spelt significantly affected grain yield, the number of grains per ear, grain yield per ear, SPAD ($p \leq 0.01$) and the number of ears per m^2, as well as thousand grain weight ($p \leq 0.05$). The yield and its individual elements revealed significant differences between the spelt cultivars ($p \leq 0.01$, $p \leq 0.05$), which is also confirmed by Sulek et al., (2019), who found that wheat yield was highly dependent on the cultivation method and genotype. Similarly, Lacko-Bartošová et al., (2010) confirm the difference in yield of eight spelt cultivars. According to the authors, the highest yield was found for Frankenkorn (67.6 dt ha^{-1}) and the lowest for Ostro (54.9 dt ha^{-1}). A significant genotype-environment interaction points to an inconsistent reaction of cereal cultivars, with respect to a thousand grain weight (TGW), to varied natural and weather conditions (Weber et al., 2009; Linina, Ruža, 2018). This study shows the interaction between the years of study and cultivars with respect to a thousand grains weight ($p \leq 0.05$). Over all characteristics, only the value of leaf greenness index (SPAD) showed a lack of significant dependence on genotype. There was no interaction between fixed factors for yield and yield components of the winter spelt in this study (Table 1).

Attributing the smaller number of caryopses per ear, the yield of spelt is generally lower than that of common wheat. However, Burgos et al., (2001) point to the possibility of obtaining a comparable yield. The wheat model established in 2018 by the Research Centre for Cultivar Testing (COBORU, 2018) gave a yield of 73.9 dt ha^{-1}. The results by Andruszczak (2017) concerning the reaction of winter spelt cultivars to reduced tillage system show the yield of Oberkulmer Rotkorn of 39.6 dt ha^{-1} and 44.8 dt ha^{-1} for Frankenkorn . In the present experiment, spelt yield was lower and ranged from 15.8 to 37.7 dt ha^{-1} with a mean from the experiment at 27.3 dt ha^{-1} (Table 2).

In the present study, no significant effect of cultivation system on winter spelt yield was found (Table 1), which can indicate that the changes in soil properties do not have an unequivocal effect on crop yield as it also depends on climate conditions, crop rotation, applied plant health products or the type of machines used for cultivation or sowing. In the conventional system, the yield of STH 12 was by 22% higher (i.e. 5.7 dt ha^{-1}) than the yield of Oberkulmer Rotkorn and by 9% (i.e. 2.6 dt ha^{-1}) higher than that of Frankenkorn. In the reduced tillage system, the obtained yield was higher by 15% (i.e. 3.6 dt ha^{-1}) and 5% (i.e. 1.4 dt ha^{-1}), respectively. The results of a series of studies conducted so far indicate the varied results of the effect of cultivation system on crop yield – from a beneficial effect of non-tillage system, through lack of effect, to a decrease in yield as compared to traditional cultivation system (Sulek et al., 2019).

Regardless of the cultivation system or cultivar, the highest yield of winter spelt was obtained following the application of 100 kg N ha^{-1}, on average 32.7 dt ha^{-1}, i.e. by 91% (15.6 dt ha^{-1}) higher than that of the control (0 kg N ha^{-1}). A higher nitrogen dose (150 kg N ha^{-1}) reduced the grain yield by 6% (i.e. 1.9 dt ha^{-1}) (Table 2). Increasing

Table 1. Significance of effects in ANOVA for grain yield and yield components (2009–2011).

Source of variability	Traits: grain yield	number of ears per m^2	number of grains per ear	thousand grain weight	grain yield per ear	SPAD
Y	**	**	**	**	**	**
T	-	-	-	-	-	-
Y × T	-	-	-	-	-	-
N	**	*	**	*	**	**
Y × N	-	-	-	-	-	-
T × N	-	-	-	-	-	-
Y × T × N	-	-	-	-	-	-
C	**	**	**	**	*	-
Y × C	-	-	-	*	-	-
T ×C	-	-	-	-	-	-
Y × T × C	-	-	-	-	-	-

* significance at $p<0.05$, ** significance at $p<0.01$, - no significance
Y – years, T – tillage systems, N – nitrogen fertilization, C– cultivars/strain

Table 2. Effect of tillage systems (T) and nitrogen fertilization (N) on grain yield [dt ha^{-1}] of winter spelt cultivars/strain (C), mean 2009–2011.

Cultivation	Cultivars/strain	Nitrogen fertilization [kg ha^{-1}] 0	50	100	150	Mean
Conventional	Oberkulmer Rotkorn	16.6	27.0	30.5	28.8	25.7
	Frankenkorn	17.1	32.1	34.8	31.2	28.8
	STH 12	19.8	31.3	37.7	36.7	31.4
	Mean	17.9	30.1	34.3	32.2	28.6
Reduced	Oberkulmer Rotkorn	16.2	23.4	27.8	28.8	24.1
	Frankenkorn	15.8	27.4	32.5	29.6	26.3
	STH 12	17.1	30.9	32.9	29.8	27.7
	Mean	16.4	27.2	31.1	29.4	26.0
Mean	Oberkulmer Rotkorn	16.4	25.2	29.2	28.8	24.9
	Frankenkorn	16.5	29.8	33.6	30.4	27.6
	STH 12	18.5	31.1	35.3	33.3	29.5
	Mean	17.1	28.7	32.7	30.8	27.3
$LSD_{0.05}$ for:	T – n.s., N – 3.25, C – 1.89, T×N – n.s., T×C – n.s., N×C – n.s.					

n.s. – no significant difference

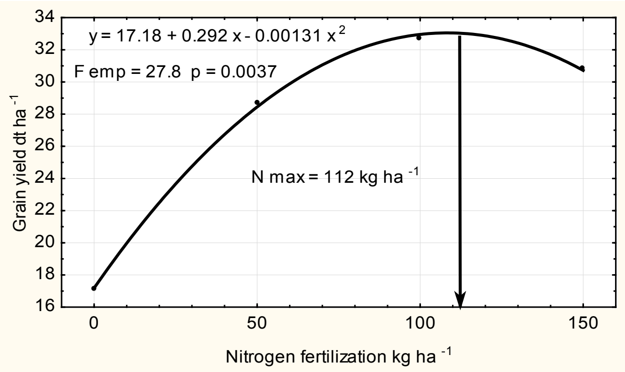

Figure 1. Regression line between nitrogen fertilization and grain yield.

the nitrogen fertilisation dose (to 150 kg N ha^{-1}) resulted in a reduced yield of all the analysed genotypes of winter spelt. The highest yield, determined with second-degree regression equation, was obtained following the application 112 N kg ha^{-1} (Figure 1). A positive correlation between grain yield and nitrogen fertilisation is well documented in the literature on the subject (Linina, Ruža, 2018; Litke et al., 2017; Ma et al., 2019). However, according to Linina, Ruža (2018), application of larger doses of nitrogen fertilisation (more than 60 kg N ha^{-1}) is not justified as it does not result in an increase of spelt wheat yield. In turn, Rüegger, Winzeler (1993) indicate that application of nitrogen fertilisation with respect to spelt does not affect the crop productivity per hectare. The authors also claim that the effect is identified for the dates of sowing. Lower nitrogen demand by spelt, as compared to that by common wheat, is an argument for increasing the acreage cropped to spelt (Koutroubas et al., 2012).

Spelt is characterised by high adaptability, it shows good tolerance of winter, excess water levels as well as shortage of water, it is more resistant to soil salinity as compared with other cereals (Burgos et al., 2001). Despite the lower demand of spelt in relation to soil and environment, over the years of the study a rather high variability of the yield (17%) was observed (Table 3), which, however, could be due to different weather conditions (Table 1).

Rozbicki et al. (2015) point to a similar relationship, claiming that the environmental conditions (particularly climatic conditions) have a significantly greater effect on common wheat yield than the cultural practices. However, Bujak et al. (2013) find no correlation between the yield and precipitation sums.

According to Żuk-Gołaszewska et al. (2015) the results obtained for spelt confirm its stability in terms of chlorophyll level over the years and greater tolerance to different weather conditions in comparison with common wheat.

Table 3. Mean values of grain yield and yield components in 2009–2011.

Trait	Years			V%
	2009	2010	2011	
Grain yield [dt ha^{-1}]	29.8	30.3	22.0	17.0
Thousand grain weight [g]	35.9	39.6	51.7	19.5
Number of ears per m^2	423	436	351	11.3
Number of grains per ear	19.8	17.8	12.7	21.8
Yield per ear [g]	0.706	0,700	0.674	4.7
SPAD	45.9	44.9	35.3	13.7

V% – variability coefficient

The effect of tillage system and nitrogen fertilization on yield components

Just as in the case of yield, in the third year of the experiment, the lowest SPAD values, in comparison to the first and the second year, were found (Table 3). In the present experiment, SPAD values for particular cultivars were comparable and ranged from 41.4 to 42.9 (Table 4). The analyses did not show differences in SPAD values depending on the cultivar and strain of spelt (Table 5).

Table 4. Yield components of cultivars, mean 2009–2011.

Trait	Cultivar/strain			$LSD_{0,05}$
	Oberkulmer Rotkorn	Frankenkorn	STH 12	
Thousand grain weight [g]	45.7	42.3	39.3	1.95
Number of ears per m^2	365	434	411	34.7
Number of grains per ear	15.5	15.4	19.1	1.59
Yield per ear [g]	0.690	0.638	0.726	0.069
SPAD	41.4	42.9	41.8	n.s.

n.s. – no significant difference

Table 5. Effect of cultivation tillage systems on yield components, mean 2009–2011.

Trait	Tillage system		$LSD_{0.05}$
	conventional	reduced	
Thousand grain weight [g]	42.8	42.0	n.s.
Number. of ears per m^2	405	401	n.s.
Number of grains per ear	17.1	16.1	n.s.
Yield per ear [g]	0.712	0.657	n.s.
SPAD	43.2	41.3	n.s.

n.s. – no significant difference

Pużyński et al., (2015) in their study on the yield of selected spelt wheat cultivars (*Triticum spelta* L.), obtained the highest SPAD value for STH 28-4619 strain i.e., 40.1. Numerous studies confirm that the values of leaf chlorophyll measured with SPAD chlorophyll meter are closely connected with grain yield (Maiti et al., 2004; Islam et al., 2014).

Number of ears per 1 m^2 is the decisive yield constituent affecting grain yield in approximately 50% of cases; however it can result both in an increase as well as a decrease in yield. On the other hand, the number of grains per ear and a thousand grain weight are less important and, therefore, it can be assumed that their effect on grain yield is 25% each.

With respect to the four elements of yield structure: the thousand grain weight (TGW), the number of ears per m^2, the number of grains per ear and ear yield, the study identified a significant dependence on the cultivar factor (Table 4).

Generally, spelt grain has lower values of the thousand grain weight (TGW), as compared to the grain of common wheat – 32.2–50.1 (Konvalina et al., 2012; Wanic et al., 2019). TGW values of spelt cultivated in this experiment ranged from 39.3 to 45.7 (Table 4).

The grain of Oberkulmer Rotkorn showed the highest TGW values – 45.7, the value usually representative of wheat grain (Table 4). At the same time, for this cultivar, the lowest number of ears per m^2 was obtained which, owing to the smaller plant density, indicates better conditions for growth. In comparison with the data from the first year of the experiment, in the third year the values of TGW were higher by 44% (Table 3). According to Weber et al., (2009), unfavourable weather conditions determine the values of this yield constituent. In a broad sense, high inheritance (reproducibility) obtained in the series of experiments, indicates that this characteristic is strongly genetically determined. A large number of ears per m^2 can reduce the number of grains per ear. The spelled variety STH 12 had a grain yield per ear, equal to 0.726 g, so the yield of the ear was the highest, (Table 4).

The analysis of the reaction of the reduced tillage and chemical plant protection with respect to spelt by Andruszczak (2017) shows different values of ear yield – 0.92 g for Oberkulmer Rotkorn and 1.08 g for Frankenkorn. In the last year of the experiment, the following values were also found to be the lowest: yield per ear and the number of grains per ear – by 5% and 36% respectively, in comparison with the first year of the experiment which was marked by the highest values of the analysed characteristics. Additionally, the number of ears per m^2 was significantly lower in the last year of the experiment, by 19%, as compared to the second year of the experiment (with the highest values).

Multiple regression equation shows a significant relationship between yield (y) and the number of ears per m^2 (x_1), the number of grains per ear (x_2) and a thousand grain weight (x_3). Correlation coefficients for individual cultivars were high (Oberkulmer Rotkorn, r = 0.998, Frankenkorn, r = 0.944, STH 12, r = 0.985). An increase of the thousand grain weight by one unit was accompanied by the increase of the yield of Oberkulmer Rotkorn by 0.552 dt ha^{-1}. An increase in the number of grains by one unit resulted in the increase in grain yield of Frankenkorn by 1.712 dt ha^{-1}. A higher number of ears per m^2 by one unit caused the increase in STH 12 by 0.0714 dt ha^{-1} (Table 6).

A decrease in grain yield in a non-tillage cultivation system generally resulted from a decrease in the number of ears per area unit (Sulek et al., 2019). The authors' own study did not confirm statistically significant differences in the number of ears per area unit between the particular cultivation systems. Moreover, there were no significant differences between the individual elements of yield structure of spelt wheat cultivated in the conventional and reduced system (Table 5).

A significant, nitrogen fertilization-dependent increase in the yield of winter spelt was observed, that affected the values of four grain parameters: thousand grain weight (TGW), number of ears per m^2, number of grains per ear and yield of ears. The above parameters continued to increase only up to the rate of 100 kg N ha^{-1} (Table 7). Winter spelt grain harvested from the treatment fertilised with 100 kg N ha^{-1} was characterised by higher values of: the thousand grain weight (by 8%), the number of ears per m^2 (by 10%), the

Table 6. Multiple regression equation between yield (y) and number of ears per m^2 (x_1), number of grains per ear (x_2) and thousand grain weight (x_3) for cultivars (n = 72).

Cultivars/ strain	Regression equation	R	p
Oberkulmer Rotkorn	$y = -43.2 + 0.0621x_1 + 1.592x_2 + 0.552x_3$	0.998	<0.000
Frankenkorn	$y = -49.4 + 0.0624x_1 + 1.712x_2 + 0.543x_3$	0.994	<0.000
STH 12	$y = -53.7 + 0.0714x_1 + 1.542x_2 + 0.624x_3$	0.985	<0.000

R – multiple correlation coefficient, p – level of significance

Table 7. Effect of nitrogen fertilization on yield components, mean 2009–2011.

Trait	Nitrogen fertilization [kg ha^{-1}]				$LSD_{0,05}$
	0	50	100	150	
Thousand grain weight [g]	40.8	42.8	44.2	42.0	2.75
Number of ears per m^2	376	402	415	420	42.1
Number of grains per ear	11.8	17.6	18.9	18.4	3.40
Yield per ear [g]	0.467	0.733	0.807	0.733	0.141
SPAD	36.0	42.6	45.6	43.9	2.92

number of grains per ear (by 60%) and the yield per ear (g) (by 73%), as compared with spelt harvested from the treatment without nitrogen fertilisation. This study also shows that the highest dose of nitrogen (150 kg N ha^{-1}) reduced the values of the analysed yield components (Table 7). Litke et al., (2017) confirm that increasing the dose of nitrogen fertilisation resulted in lower values of the elements of wheat yield. According to Kołodziejczyk et al., (2012), in the process of cereal production, a nitrogen fertilisation-dependent increase in grain yield is mostly the result of an increase in ear density and only to a lower extent of the grain weight per ear. However, the results obtained in the present experiment indicate that, owing to nitrogen fertilisation, (at 100 kg N ha^{-1}) the highest values were recorded for grain yield per ear (Table 7).

Depending on plant requirements, the rate of nitrogen fertilisation is of crucial importance for the efficiency of the nitrogen applied (Islam et al., 2014). Nitrogen management on the basis of chlorophyll meter allowed the rate of N fertilization to be reduced without compromizing efficiency (Hasan et al., 2016). Measurements of chlorophyll content under field conditions allow for quick and non-invasive control of nitrogen content in plants, therefore limiting the risk of inadequate or excessive crop fertilisation. Chlorophyll content in the leaves of the analysed winter spelt, measured with SPAD meter, was significantly higher in plants fertilised with 100 kg N ha^{-1} – on average by 27%, as compared with spelt cultivated on plots without nitrogen fertilisation. SPAD readings were lower following the application of the highest dose in the amount of 150 kg N ha^{-1} (Table 7).

Numerous studies (Gonzalez et. al., 2007; Maiti et. al., 2004; Islam et al., 2014) suggest that there is a positive correlation between nitrogen uptake, nitrogen concentration in leaves, chlorophyll content in leaves and grain yield. Furthermore, these relationships indicate that it is possible to efficiently manage nitrogen use in crop production by means of measurements of relative chlorophyll content in leaves. Similarly to the results by Żuk-Gołaszewska et al., (2015), the present experiment shows that chlorophyll content was correlated with winter spelt yield. There was a straightforward relationship between the grain yield and SPAD content (Figure 2). Correlation coefficient was found to be high (r=0.88) which indicates that the readings of SPAD meter were strongly correlated with winter spelt grain yield. Coefficient of determination between SPAD value and grain yield was high and amounted 0,774. The values of regression coefficient demonstrate that an increase in chlorophyll content by one SPAD unit translates into an increase in grain yield by 1.078 dt ha^{-1}.

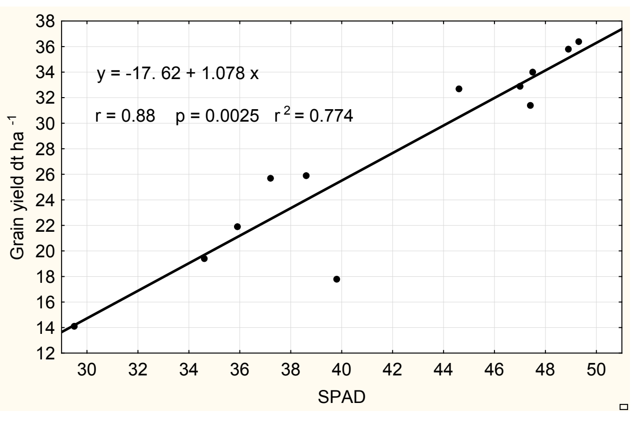

Figure 2. Regression line between SPAD and grain yield (n = 12).

CONCLUSION

1. The present study finds no significant dependence of winter spelt grain yield on the cultivation system.
2. Nitrogen fertilisation, as the factor affecting the yield to the greatest extent, caused a linear significant increase in yield to a certain threshold which, when exceeded, resulted in a decrease of grain yield. The study identifies a relationship between the obtained yields and spelt cultivar – the highest yield was obtained for STH 12 strain.
3. With respect to the four elements of yield structure, i.e. thousand grain weight (TGW), number of ears per m^2, number of grains per ear, and ear yield, there was a significant relationship with the cultivar factor. SPAD values showed no differences between cultivars.
4. The method of cultivation (conventional vs. reduced tillage) did not show differences for the four analysed yield components and SPAD of winter spelt. As a result of nitrogen fertilisation, there was a significant increase in the four yield parameters and SPAD .

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