# The effects of tillage and soil mineral fertilization on the yield and yield components of spring barley

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**ABSTRACT**

A field experiment with a malting spring barley crop (2007–2009) was conducted in south-eastern Poland on Cambisols. Conventional (CST) and simplified soil tillage systems (SST) were used in combination with NPK fertilizer enriched with S and Mg. Analysis of the results showed a beneficial effect of CST and NPK fertilization with S and Mg on yield and yield structure. SST and NPK fertilization decreased grain yield by 6.6% and 6.2%. CST increased grain number per ear, grain weight per ear and plant height, while the SST decreased the value of these characteristics by 7.9, 5.7 and 5.3%. Number of ears (standardized regression coefficient $b$ = 0.330), grain number per ear ($b$ = 0.488) and 1000 grain weight ($b$ = 0.360) were found to be significant for predicting grain yield. Significant correlations were found between grain yield and yield components of spring barley. Grain yield per ha was positively correlated with number of ears ($r_{n = 72}$ = 0.330), grain number per ear ($r_{n = 72}$ = 0.488), 1000 grain weight ($r_{n = 72}$ = 0.359), grain weight per ear ($r_{n = 72}$ = 0.528) and plant height ($r_{n = 72}$ = 0.246).

**Keywords**: *Hordeum vulgare* L.; yield formation; influence of weather; sulphur; magnesium; tillage system

In the conditions of central Europe, spring barley yield and yield structure components are influenced by many external factors, especially tillage method, mineral fertilization and weather conditions (Schillinger 2005, Váňová et al. 2006, Machado et al. 2007, Trnka et al. 2007, Barczak and Majcherczak 2008, Hejcman et al. 2013, Sedlář et al. 2013).

A factor currently limiting crop yield in Poland and worldwide is a low content of available sulphur in the soil (Siebielec et al. 2012). In 90% of samples of Polish soils, available S does not exceed 16.5 mg $SO_4^{2-}$/kg, and in 2010 as many as 94% of profiles tested were classified as low in S. Another deficient nutrient in Polish agriculture is Mg. The content of available Mg in 2010 ranged from 0.5 to 38 mg/kg (determined by calcium chloride; of Schachtschabel method, 0.0125 mol/L $CaCl_2$ 1:20; Fotyma and Dobers 2008). The percentage of soil profiles with low or very low available Mg levels was 26%. Many authors claim that cereals should be fertilized with S and Mg. Błaziak (2007) reported that application of fertilizer in the form of $MgSO_4$ provides a large amount of Mg and S, which positively affects the yield of spring barley. Klikocka et al. (2011) claim that cereals should be fertilized with S and Mg at a rate of 20–30 kg/ha for each element. According to Górski et al. (2006), grain yield of spring barley per unit area results from the number of ears, grain number per ear and 1000 grain weight. All of these yield components are determined by the genetic properties of the species and variety, habitat conditions, and agricultural conditions.

The aim of the study was to evaluate the effect of soil tillage methods (conventional and simplified) and mineral fertilizer (NPK with sulphur and magnesium) on grain yield of spring barley and its yield components formation.

## MATERIAL AND METHODS

The subject of the experiment was malting spring barley (*Hordeum vulgare* ssp. *distichon*, cv. Madonna), cultivated on a site where the previous crop was medium-early potato. The first factor was the soil tillage method (ST): A – conventional

Table 1. Description of variables used in the field experiment (2007–2009)

| | | | |
|---|---|---|---|
| Variable I – Soil tillage ($n$ = 2) | | A – conventional (ploughing soil tillage) | B – simplified (soil tillage without ploughing) |
| | in autumn | medium ploughing (20 cm) | cultivation (15 cm) |
| | in spring | harrowing, cultivation, harrowing, sowing | harrowing, cultivation, harrowing, sowing |
| Variable II – Mineral fertilization ($n$ = 3) | | 1 – NPK (40, 17.6, 41.5 kg/ha) | |
| | | 2 – NPK-S (40, 17.6, 41.5, 16 kg/ha) | |
| | | 3 – NPK-S-Mg (40, 17.6, 41.5, 16, 30 kg/ha) | |

(ploughing) (CST); B – simplified (no ploughing, with a cultivator) (SST). The second factor was mineral fertilization (MF): 1 – NPK; 2 – NPK-S; 3 – NPK-S-Mg. The field experiment was carried out in the years 2007–2009 in four replications. A description of the variables is presented in Table 1.

The nutrients were applied in the following forms: N – ammonium nitrate (34% N), P – granulated triple superphosphate (17.4% P), K – potassium salt (49.8% K), S – ammonium sulphate (20% N, 25% S), and Mg – magnesium sulphate (9.6% Mg, 12.8% S).

The field experiment was conducted in south-eastern Poland (50°42'N, 23°15'E) in a randomized split-plot design (with four replications) on Cambisols (WRB 2007) consisting of light silty sand. The soil was slightly acidic (pH = 5.6), with high available phosphorus content, medium content of potassium and magnesium, and low sulphur content.

The area of the plots was 30 $m^2$ for sowing and observation and 20 $m^2$ for harvesting (4.0 m × 5.0 m). Crop protection against fungi was assured by the application of Alert 375 S.C. (flusilazol + carbendazym) – 1.0 kg/ha at the stage BBCH 32/33, and Tilt CB 37.5 (propikonazol + carbendazym) – 1 L/ha at the stage BBCH 58–59 whereas weeds were reduced with the use of Granstar 75 WG (tribenuron methyl) – 20 g/ha at the stage BBCH 28.

The precipitation and temperature distribution significantly affected the variation in the analysed features (Tables 2 and 3). In most months of the years 2007–2009 the air temperature exceeded the average long-term temperature. It was noted, however, that the distribution of precipitation and temperature significantly differentiated the phases of development of the spring barley (Table 4). However, weather conditions did not significantly influenced the spring barley grain yield, as described below.

The number of ears ($m^2$) and plant height were determined before harvesting. In addition, 30 ears of spring barley were collected randomly from the edge of each plot to determine yield components.

Table 2. Sums of precipitation (mm) and mean air temperature (°C) in the years 2007–2009 and in the long-term period 1971–2005 (Zamość Research Station, Poland)

| Year | Month | | | | | | Sum–mean | | |
|---|---|---|---|---|---|---|---|---|---|
| | III | IV | V | VI | VII | VIII | IV–V | VI–VII | III–VIII |
| **Precipitation** | | | | | | | | | |
| 2007 | 41.6 | 21.7 | 41.1 | 54.0 | 118.9 | 31.6 | 62.8 | 172.9 | 308.9 |
| 2008 | 63.1 | 71.5 | 74.8 | 48.9 | 104.6 | 69.7 | 146.3 | 153.5 | 432.6 |
| 2009 | 33.5 | 15.5 | 102.6 | 124.4 | 24.2 | 48.9 | 118.1 | 148.6 | 349.1 |
| 1971–2005 | 26.2 | 44.1 | 65.5 | 78.9 | 98.4 | 54.3 | 109.6 | 177.3 | 367.4 |
| **Temperature** | | | | | | | | | |
| 2007 | 7.4 | 10.0 | 17.6 | 19.8 | 21.1 | 18.6 | 844 | 1284 | 2899 |
| 2008 | 4.7 | 10.7 | 15.5 | 19.4 | 20.2 | 19.7 | 804 | 1207 | 2767 |
| 2009 | 1.2 | 11.3 | 13.8 | 20.2 | 20.0 | 20.1 | 767 | 1224 | 2652 |
| 1971–2005 | 1.6 | 7.9 | 14.1 | 16.8 | 18.4 | 17.8 | 676 | 1076 | 2353 |

Table 3. Regression coefficients and value of $R^2$ in multiple regression equations for spring barley yield

| Regression equation | $R^2$ | Coefficients | | | |
|---|---|---|---|---|---|
| | | $b_0$ | $b_1$ | $b_2$ | $b_3$ |
| $y = b_0 + b_1x_1$ | 0.109* | 2.83[a] (1.10)[c] | 0.004 (0.001) | – | – |
| | | | 0.330[b]** (0.113)[c] | – | – |
| $y = b_0 + b_2x_2$ | 0.238* | 2.82 (0.69) | – | 0.178 (0.038) | – |
| | | | – | 0.488** (0.104) | – |
| $y = b_0 + b_3x_3$ | 0.129* | 2.48 (1.11) | – | – | 0.076 (0.023) |
| | | | – | – | 0.360** (0.111) |
| $y = b_0 + b_1x_1 + b_2x_2$ | 0.483* | –3.23 (1.20) | 0.007 (0.001) | 0.233 (0.033) | – |
| | | | 0.519** (0.090) | 0.641** (0.090) | – |
| $y = b_0 + b_1x_1 + b_3x_3$ | 0.288* | –0.97 (1.478) | –0.005 (0.001) | – | 0.079 (0.022) |
| | | | 0.349** (0.104) | – | 0.371** (0.104) |
| $y = b_0 + b_2x_2 + b_3x_3$ | 0.246* | 0.96 (1.08) | – | 0.152 (0.038) | 0.499 (0.227) |
| | | | – | 0.418** (0.106) | 0.235** (0.106) |
| $y = b_0 + b_1x_1 + b_2x_2 + b_3x_3$ | 0.552* | –4.73 (1.328) | 0.007 (0.001) | 0.210 (0.033) | 0.044 (0.019) |
| | | | 0.507** (0.088) | 0.576** (0.092) | 0.205** (0.088) |

$y$ – dependent variable – grain yield; $x_1$ – number of ears ($m^2$); $x_2$ – grain number per ear; $x_3$ – 1000 grain weight (g); $b_0$ – constant regression value; $b_1$–$b_3$ – regression coefficients ([a]usual; [b]standardized; [c]standard error of coefficient; **significant ($\alpha$ = 0.05)

The grain yield (at 11% moisture content) was calculated after the harvest.

Analysis of variance was performed with the Snedecor's *F*-test. Significance of differences was calculated using the Tukey's test ($P$ = 0.05) followed by post-hoc analysis. The statistical software Excel 7.0 and Statistica (StatSoft Polska'97) was used for the analysis.

## RESULTS AND DISCUSSION

The analysis of the results showed a beneficial effect of conventional soil tillage and NPK fertilization with sulphur and magnesium on yield and yield structure components. The simplified soil tillage and NPK fertilization had the least beneficial

Table 4. Dates of phenological growth phases (BBCH) of spring barley in the experiment

| Year | BBCH | | | | | | |
|---|---|---|---|---|---|---|---|
| | 00 | 10 | 25 | 31 | 51 | 83 | 99 |
| 2007 | 8.04 | 17.04 | 4.05 | 24.05 | 11.06 | 4.08 | 17.08 |
| 2008 | 3.04 | 12.04 | 30.04 | 21.05 | 8.06 | 9.08 | 23.08 |
| 2009 | 31.03 | 11.04 | 5.05 | 27.05 | 15.06 | 17.08 | 25.08 |

Table 5. The influence of soil tillage and mineral fertilization on the structure of spring barley yield (mean for 2007–2009)

| Soil tillage (ST) | Mineral fertilization (MF) | Number of ears ($m^2$) | Plant height (cm) | Grain number per ear | 1000 grain weight (g) | Grain weight per ear (g) | Grain yield per ha (t/ha) |
|---|---|---|---|---|---|---|---|
| Conventional soil tillage | NPK | $717^a$ | $59.4^a$ | $18.32^a$ | $48.62^b$ | $0.89^a$ | $6.13^a$ |
| | NPK-S | $723^a$ | $54.5^a$ | $19.14^a$ | $44.63^a$ | $0.86^a$ | $6.37^a$ |
| | NPK-S-Mg | $731^a$ | $56.3^a$ | $18.96^a$ | $45.04^a$ | $0.86^a$ | $6.22^a$ |
| | Mean | $724^A$ | $56.8^B$ | $18.81^B$ | $46.10^A$ | $0.87^B$ | $6.24^B$ |
| Simplified soil tillage | NPK | $716^a$ | $56.8^a$ | $17.21^a$ | $45.78^a$ | $0.80^a$ | $5.43^a$ |
| | NPK-S | $719^a$ | $53.5^a$ | $17.75^a$ | $47.74^b$ | $0.85^a$ | $6.09^a$ |
| | NPK-S-Mg | $725^a$ | $51.0^a$ | $17.04^a$ | $47.19^b$ | $0.81^a$ | $5.97^a$ |
| | Mean | $720^A$ | $53.8^A$ | $17.33^A$ | $46.90^A$ | $0.82^A$ | $5.83^A$ |
| Mean fertilization | NPK | $717^A$ | $58.1^B$ | $17.77^A$ | $47.20^A$ | $0.84^A$ | $5.78^A$ |
| | NPK-S | $721^A$ | $54.0^A$ | $18.45^A$ | $46.19^A$ | $0.85^A$ | $6.23^B$ |
| | NPK-S-Mg | $728^A$ | $53.7^A$ | $18.00^A$ | $46.11^A$ | $0.83^A$ | $6.09^B$ |
| Mean for year of study (Y) | 2007 | $766^c$ | $51.3^a$ | $16.90^a$ | $45.77^a$ | $0.78^a$ | $6.10^a$ |
| | 2008 | $676^a$ | $57.7^b$ | $19.00^c$ | $47.17^a$ | $0.90^c$ | $6.01^a$ |
| | 2009 | $723^b$ | $56.8^b$ | $18.31^b$ | $46.56^a$ | $0.85^b$ | $5.99^a$ |
| Mean | | 722 | 55.3 | 18.07 | 46.50 | 0.84 | 6.03 |
| $LSD_{0.05}$ | | | | | | | |
| ST | | ns | 1.22 | 0.44 | ns | 0.03 | 0.19 |
| MF | | ns | 1.49 | ns | ns | ns | 0.24 |
| ST × MF | | ns | ns | ns | 1.51 | ns | ns |
| Y | | 11 | 1.49 | 0.54 | ns | 0.04 | ns |

Different letters indicate significant differences at $P < 0.05$. ns – not significant

impact, with grain yield 6.6% and 6.2% lower than in the plots with the highest grain yield (Table 5).

Małecka et al. (2004) showed that CST resulted in the highest grain yield of spring barley. Surface tillage (stubble machinery) and direct sowing (no tillage) significantly decreased grain yield in comparison to CST, by 8.4% and 12.4%. According to many authors, there are no conclusive results indicating a direct impact of simplification of soil tillage on grain yield of cereals. Schillinger (2005) reported lower grain yield of spring cereals with no-till (NT) compared with conservation tillage (CT).

The effects of modifications and innovations depend on weather conditions, habitat, cropping measures, soil tillage and mineral fertilization rates (Machado et al. 2007). Klikocka et al. (2011) claim that SST is in some cases economically justified, since the omission of winter ploughing fully compensates the reduction in grain yield of spring barley. A positive effect of S fertilization in the form of simple superphosphate on the yield of spring barley was noted by Potarzycki (2003). Szczepaniak et al. (2013) reported that the balanced nitrogen fertilization with sulphur and magnesium exerted a significantly higher positive effect on yield of spring barley.

CST positively influenced grain number per ear, grain weight per ear and plant height. SST decreased the values of these characteristics by 7.9, 5.7 and 5.3%, respectively. Mineral fertilization with NPK-S and NPK-S-Mg decreased the height of plants in comparison with NPK, on average by 7.3%. The interaction of soil tillage and mineral fertilization significantly influenced the 1000 grain weight. The highest 1000 grain weight was obtained in the case of CST and NPK fertilization. The combination of S and S + Mg with CST

Table 6. Correlation coefficients between variables of yield structure and some environmental factors

| Variable ($n$ = 72) | | Plant height (cm) | Grain number per ear | 1000 grain weight (g) | Grain weight per ear (g) | Grain yield per ha (t/ha) |
|---|---|---|---|---|---|---|
| **Variables of the yield structure** | | | | | | |
| Number of ears (m$^2$) | | –0.231* | –0.295* | –0.036 | –0.248* | 0.330** |
| Plant height | | – | 0.561** | 0.448** | 0.636** | 0.246* |
| Grain number per ear | | | – | 0.297* | 0.879** | 0.488** |
| 1000 grain weight | | | | – | 0.712** | 0.359** |
| Grain weight per ear | | | | | – | 0.528** |
| **Variables of weather** | | | | | | |
| Mean air temperature | March–August | –0.416** | –0.331** | –0.109 | –0.292* | 0.0068 |
| | April–May | –0.411** | –0.325** | –0.106 | –0.287* | 0.067 |
| | June–July | –0.486** | –0.478** | –0.183 | –0.447** | 0.060 |
| Sum of precipitation | March–August | 0.421** | 0.444** | 0.177 | 0.421** | –0.046 |
| | April–May | 0.501** | 0.481** | 0.181 | 0.447** | –0.065 |
| | June–July | –0.482** | –0.418** | –0.147 | –0.378** | 0072 |

Singificant (*$P$ = 0.05–0.231; **$P$ = 0.01–0.302)

significantly decreased the 1000 grain weight. The opposite tendency was found for the interaction of SST and NPK fertilization; here the 1000 grain weight was significantly lower than in the case of application of S and S + Mg (Table 5).

The weather conditions over the course of the study did not influence the 1000 grain weight or grain yield. However, they had a significant impact on the distribution of characteristics. The growing season in 2008 and 2009 favourably influenced plant height, grain number per ear and grain weight per ear. The weather conditions in 2007 led to a higher number of ears (Table 5).

Grain yield per ha was positively correlated with the number of ears ($r_{n = 72}$ = 0.330), grain number per ear ($r_{n = 72}$ = 0.488), 1000 grain weight ($r_{n = 72}$ = 0.359), grain weight per ear ($r_{n = 72}$ = 0.528) and plant height ($r_{n = 72}$ = 0.246) (Table 6). Therefore, to calculate the contribution of components to grain yield, features most often reported in the literature were chosen (Górski et al. 2006). The following factors significantly contributed to the grain yield: number of ears ($b$ = 0.330), grain number per ear ($b$ = 0.488) and 1000 grain weight ($b$ = 0.360). The analysis conducted shows that these components of yield structure can be used to calculate grain yield (Table 3, Figure 1). For this reason the coefficient of determination was calculated, which was $R^2$ = 0.109, $R^2$ = 0.238 and $R^2$ = 0.129 for the components listed above, respectively (Table 5). When all components of the regression equations are taken into account, their relationship with the grain yield of spring barley becomes closer. The value of $R^2$ for all of the yield components in the multiple regression equation was $R^2$ = 0.552. The number of ears (per m$^2$) and grain number per ear had the highest significant effect in this equation ($b$ = 0.507 and $b$ = 0.576, respectively). The 1000 grain weight also had a significant impact on grain yield, but its effect was weaker ($b$ = 0.205).

The yield of spring barley is described by the following regression equation (a – usual regression coefficients; b – standardized regression coefficients determining the contribution of the independent variable to prediction of the dependent variable):

$$\text{(a) } Y = -4.73 + 0.007x_1 + 0.210x_2 + 0.044x_3$$
$$\text{(b) } Y = -4.73 + 0.507x_1 + 0.576x_2 + 0.205x_3 \quad (1)$$

Where: $x_1$ – number of ears (m$^2$); $x_2$ – grain number per ear; $x_3$ – 1000 grain weight (g).

Potarzycki (2003) claims that spring barley yield depends on the number of ears and grain number per ear and on the relationship between the size of the grain yield and its structure, increased by S fertilization. Szczepaniak et al. (2013) reported that the grain number per plant was a more sensitive component of yield structure response to balanced nitrogen fertilization with sulphur and magnesium than 1000 grain weight of spring barley.

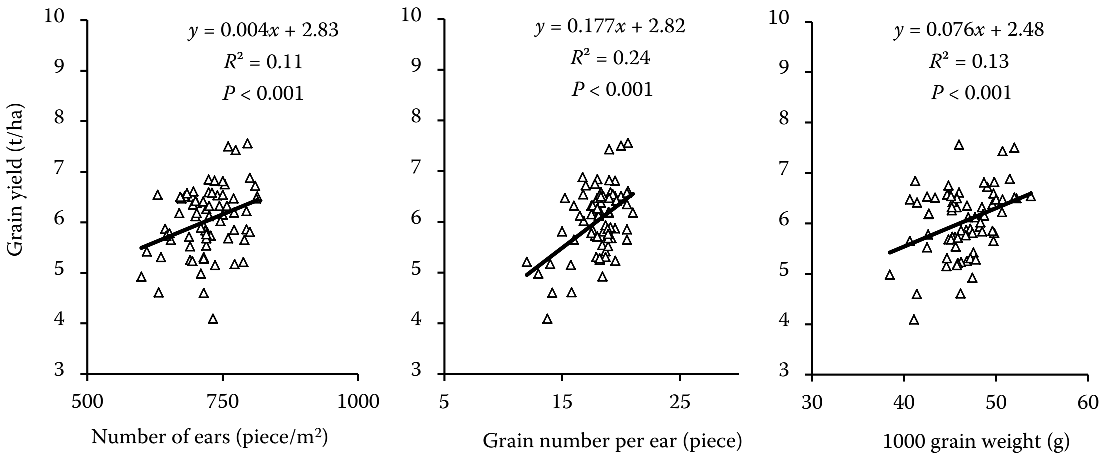


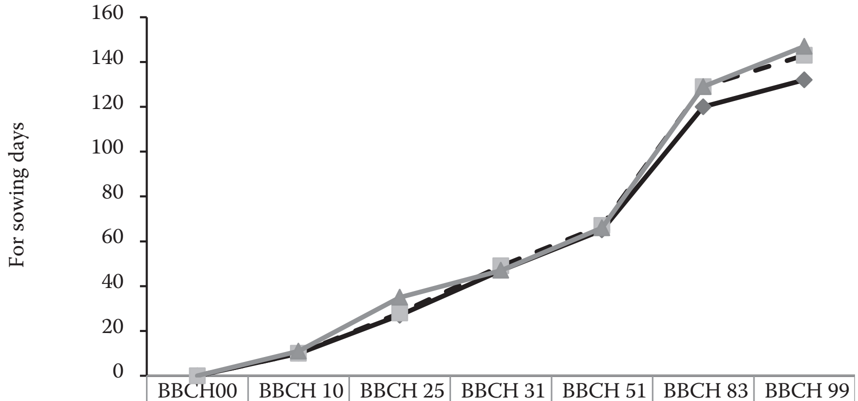

Figure 1. Relationship between grain yield of spring barley and the components of yield ($n$ = 72)

The present study demonstrated numerous interdependencies between components of the spring barley yield (Table 6).

Significant correlations were found between grain yield and yield components of spring barley and selected elements of weather conditions as well (Table 6). The number of ears per $m^2$ correlated negatively with mean air temperature in March to August ($r$ = –0.416), April–May ($r$ = –0.411) and June–July ($r$ = –0.486). The number of ears per 1 $m^2$ correlated positively with the sum of rainfall in March–August ($r$ = 0.421) and April–May ($r$ = 0.501), and negatively in June–July ($r$ = –0.482). Similar correlations were found between the weather and grain number per ear and grain weight per ear. No significant correlation was found between meteorological conditions and 1000 grain weight or grain yield.

In the present study precipitation and temperature influenced the key phenological stages, such as germination, tillering, stem elongation, and earing (Tables 2 and 3, Figure 2).

Schelling et al. (2003) studied phenological and meteorological impact on yields and yield components of malting barley. Mean daily temperature and relative air humidity were the best estimators of grain yield. An optimum temperature ranging between 14°C and 18°C was determined. Assuming a linear relationship, yield reductions between 4.1% and 5.7% were calculated for every 1°C decrease in the mean daily temperature. The results of this study suggest that relative humidity during grain filling can be a more suitable parameter than precipitation to describe drought stress effects from heading to yellow ripeness or from January 1 to yellow ripeness.




| | BBCH00 | BBCH 10 | BBCH 25 | BBCH 31 | BBCH 51 | BBCH 83 | BBCH 99 |
|---|---|---|---|---|---|---|---|
| 2007 (8.04) | 0 | 10 | 27 | 47 | 65 | 120 | 132 |
| 2008 (3.04) | 0 | 10 | 28 | 49 | 67 | 129 | 143 |
| 2009 (31.03) | 0 | 11 | 35 | 47 | 66 | 129 | 147 |

Figure 2. Lenght of phenological growth phases (BBCH) of spring barley depending on days for sowing

Trnka et al. (2007) found that the seasonal water balance (April–June) significantly influenced spring barley production in 51 out of 62 evaluated districts in the Czech Republic. The authors report that in the conditions of Central Europe prolonged periods of rainfall deficit combined with extremely high summer temperatures may significantly affect spring barley yield and cause changes in the agroecosystem.

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