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Soil respiration depending on different agricultural practices before maize sowing

Jolanta BOJARSZCZUK[1,*], Jerzy KSIĘŻAK[1], Anna GAŁĄZKA[2]

[1]*Department of Forage Crop Production, Institute of Soil Science and Plant Cultivation – State Research Institute, Puławy, Poland*
[2]*Department of Agriculture Microbiology, Institute of Soil Science and Plant Cultivation – State Research Institute, Puławy, Poland*
**Corresponding author: jolanta.bojarszczuk@iung.pulawy.pl*

ABSTRACT

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The aim of the study was to compare soil respiration depending on different agricultural practices before sowing of maize (*Zea mays* L.). Results of the study were derived from the field experiment that was carried out in 2013–2015; the research indicates that soil respiration depends on cultivation method. The highest soil respiration was recorded in maize cultivation in monoculture using full tillage. The simplifications in maize cultivation caused a decrease of soil respiration, especially in direct sowing. The lowest level of this parameter was recorded in monoculture in direct sowing. Compared with other treatments, such as direct sowing, reduced tillage and crop rotation, soil respiration was higher by 65, 55 and 12%, respectively. The statistically significant differences in soil respiration in the tested agricultural practices were observed in the first date of measurement in all years of the study. The higher soil respiration values were noted in autumn. The yield of maize correlated with soil respiration, but stronger relationship was noted between soil respiration and grain yield of maize than straw yield. The simple regression analysis showed no linear relationship between soil respiration and evaporation, changes in soil moisture and biochemical parameters such as soil dehydrogenase activity, acid and alkaline phosphatase.

Keywords: soil fertility; biological activity; tillage management; carbon dioxide; grain yield

Soil respiration is an important indicator of soil fertility and biological activity, which has a significant impact on the plant yield (Wididana and Higa 1995). The variability of CO_2 emissions depends on the category of soil, cropping system and fertilization (Wyczółkowski et al. 2006, Sainju et al. 2008). The soil emission and absorption mechanisms of CO_2 also influence soil properties such as humidity, temperature, density, reaction and organic matter content (Fang and Moncrieff 2001, Rastogi et al. 2002, Smith et al. 2003).

Reduced tillage or zero tillage have been increasingly used worldwide due to their environmental advantages and lower labour inputs (Kirkegaard et al. 2014). Some studies declared that no-tillage caused a decrease of soil disturbance (Alletto et al. 2010), and lowers CO_2 emission from the soil (Fuentes et al. 2011). Tillage practices influence soil physical, chemical and biological characteristics that, in turn, may alter plant growth and yield (Ozpinar and Cay 2006, Rashidi and Keshavarzpour 2009). The methods of reduced tillage improve soil structure, lower its temperature and limit greenhouse gas emissions (Rutkowska et al. 2017). Tillage system has an influence on soil respiration. Adoption of minimum- and no-tillage practices has partly reversed the trend in soil organic carbon (SOC) losses observed under conventional tillage using mouldboard plough (Fortin et al. 1996, Dao 1998, Curtin et al. 2000).

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Maize is one of the most commonly cultivated crops in no tillage system with leaving plants residues on the surface of the field. In the reduced tillage, stubble cultivators are the most often used for surface cultivation instead of a plough.

The aim of the study was to compare soil respiration intensity depending on different agricultural practices before maize sowing and growing season.

MATERIAL AND METHODS

Field experiment. The field experiment was carried out in 2013–2015 at the Agricultural Experimental Station of the Institute of Soil Science and Plant Cultivation – State Research Institute in Grabów, the Masovian Voivodeship (51°23'N; 21°38'E), Poland. The research was conducted on a grey brown podsolic soil formed from light loam. The ploughing layer of soil was characterized by a low content of magnesium, medium potassium and high phosphorus. The experimental scheme involved following four treatments: maize monoculture in zero tillage (direct sowing), reduced tillage, maize monoculture – full ploughing tillage, cultivation in crop rotation (spring barley-winter wheat-maize). The experiment was established with the scheme of long strips with the mirror image of treatments. The meteorological conditions during the growing season are presented in Figure 1. The results of microbial community diversity and the enzymatic activities were published (Gałązka 2017a,b,c). The effects of different cultivation techniques on grain and straw yields of maize are published in publication (Gałązka et al. 2017b).

Soil respiration measurement. Measurements were made at two dates: after sowing (summer) and after maize harvesting in the milk-dough stage (autumn), in four repetitions. Soil respiration (Sr) was measured using the CIRAS-2 (PP-Systems, Amesbury, USA), portable CO_2 analyzer (soil CO_2 flux chamber). The concentration of carbon dioxide is expressed in g CO_2/m/h. The measurement range of SRC-1 is 0–9.99 g CO_2/m^2/h. The chamber has an area of 78 cm^2 and a volume of 1170 cm^3. During the measurement of soil respiration intensity some other characteristics were determined: evapotranspiration (E), the differences in carbon dioxide concentration (ΔCO_2) and changes in soil moisture (ΔM_B).

Soil moisture measurement. The soil moisture measurements were made by soil moisture analyser RHG-131-2 (Krakow, Poland), A-ster company in the depths of 15 cm and 45 cm.

Soil samples. Soil samples were taken for microbiological and biochemical analyses at two dates: before sowing and after harvest of maize. The samples were collected in four replicates from

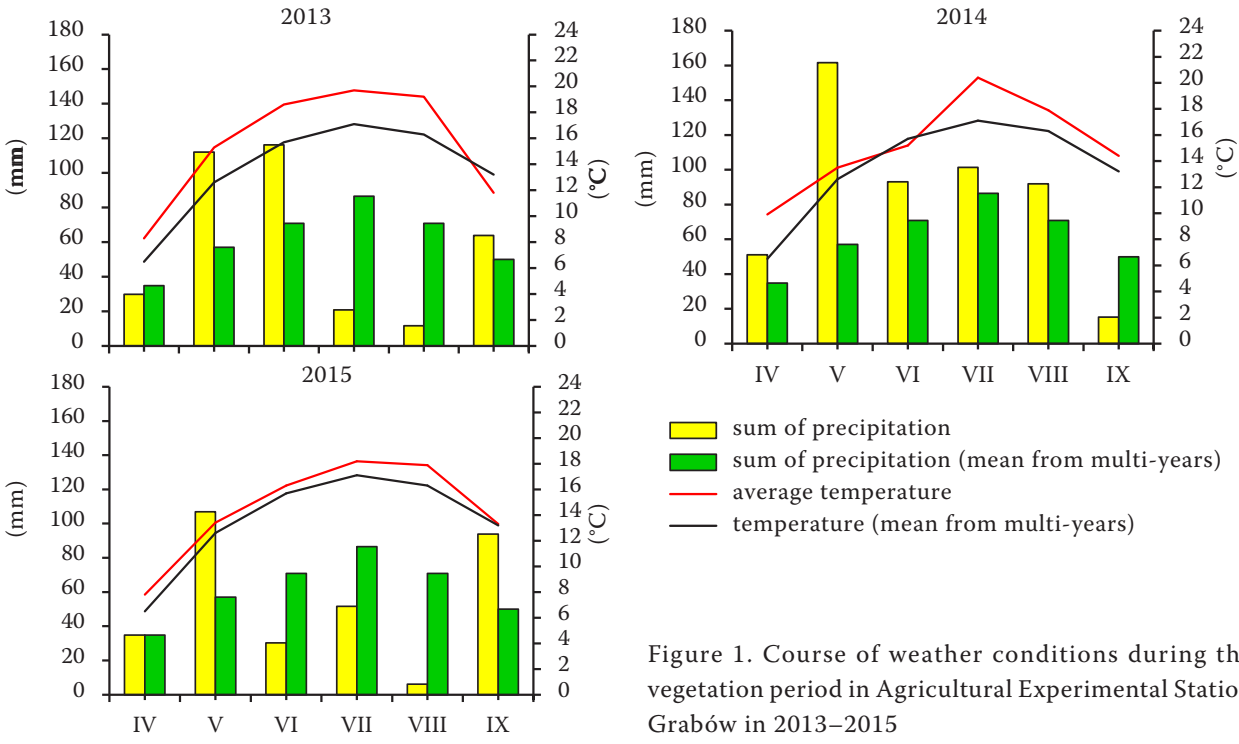

Figure 1. Course of weather conditions during the vegetation period in Agricultural Experimental Station Grabów in 2013–2015

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the 0–25 cm layer, sieved through a 2 mm sieve and stored in a refrigerator (4°C) until analysis.

Microbial and biochemical properties. Methods of determination of microbial and biochemical properties were described in publications of Gałązka (2017a,b,c).

Statistical analysis. The analysis of variance (ANOVA) was used in a proper model for the experimental design. The Tukey's test was used to evaluate the significance of differences of the means at a significance level of $P \leq 0.05$. Statistical analyses were performed using the Statistica Programme PL (version 6.0) (StatSoft, Krakow, Poland).

RESULTS AND DISCUSSION

Results of the soil respiration studies showed that the highest soil respiration, both after sowing and after maize harvest, was recorded in maize cultivation in monoculture using full tillage (0.38 g CO_2/m/h on average for two dates) (Table 1). Compared with other treatments such as direct sowing, reduced tillage and cultivation in crop rotation, soil respiration was higher by 65, 55 and 12%, respectively. Soil respiration in crop rotation treatment was not much less than in full tillage and amounted to 0.34 g CO_2/m/h (average in three

Table 1. Soil respiration; evapotranspiration; the changes in carbon dioxide concentration, and changes in soil moisture depending on the method of soil cultivation

Cultivation method	Spring				Autumn			
	2013	2014	2015	mean	2013	2014	2015	mean
Soil respiration (g CO_2/m/h)								
Direct sowing (zero tillage)	0.28^a	0.18^a	0.20^a	0.22^a	0.21^a	0.38^a	0.10^a	0.23^a
Reduced tillage	0.33^a	0.16^a	0.22^a	0.24^a	0.24^a	0.40^a	0.11^a	0.25^a
Full tillage	0.44^c	0.33^c	0.32^c	0.36^c	0.43^b	0.42^a	0.36^b	0.40^b
Crop rotation	0.39^b	0.25^b	0.25^b	0.30^b	0.27^a	0.49^b	0.37^b	0.38^b
Mean	0.36^b	0.23^a	0.25^a	0.28	0.29^a	0.42^b	0.24^a	0.32
Evapotranspiration (g CO_2/m/h)								
Direct sowing (zero tillage)	41.3^c	50.5^c	35.3^b	42.4^b	30.1^b	12.0^b	11.4^c	17.8^c
Reduced tillage	35.1^b	40.1^b	36.9^b	37.4^b	24.6^a	11.3^b	13.6^c	16.5^c
Full tillage	31.7^b	30.8^d	30.5^c	64.5^c	22.8^a	9.9^b	9.2^b	14.0^b
Crop rotation	27.0^a	18.3^a	16.8^a	20.7^a	22.7^a	5.6^a	5.8^a	11.4^a
Mean	33.8	47.4	42.5	41.2	25.0	9.7	9.9	14.9
Changes in carbon dioxide concentration (ΔCO_2)								
Direct sowing (zero tillage)	4.37^b	5.30^b	3.20^a	4.29^a	2.43^b	1.97^b	1.47^b	1.96^c
Reduced tillage	4.20^b	4.57^a	3.50^b	4.09^a	1.93^a	1.43^a	1.93^c	1.76^b
Full tillage	3.87^a	7.57^c	3.50^b	4.98^b	1.80^a	1.13^a	1.59^b	1.51^a
Crop rotation	4.27^b	6.17^b	3.43^b	4.62^b	1.87^a	1.70^b	1.07^a	1.55^a
Mean	4.18	5.90	3.41	4.50	2.01	1.56	1.52	1.69
Changes in soil moisture (ΔM_B)								
Direct sowing (zero tillage)	22.3^a	28.7^c	17.9^b	23.0^b	29.2^b	22.0^c	31.1^b	27.4^b
Reduced tillage	25.8^b	22.2^b	19.6^c	22.5^b	18.9^a	18.3^b	23.8^a	20.3^a
Full tillage	22.2^a	18.2^a	18.2^b	19.5^a	19.6^a	14.2^a	21.9^a	18.6^a
Crop rotation	27.0^b	18.3^a	16.8^a	20.7^a	19.0^a	13.2^a	20.6^a	17.6^a
Mean	24.3	21.9	18.1	21.4	21.7	20.2	24.4	22.1

Values followed by a different letter are significantly different ($P < 0.05$)

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years of the study). The simplifications in maize cultivation caused a decrease of soil respiration, especially in direct sowing. The lowest level of this parameter was recorded in monoculture in direct sowing (zero tillage) (average 0.23 g CO_2/m/h). The highest soil respiration occurred in 2013 on the first date of measurement (after sowing) and in 2014 in the second term of measurement (autumn). The soil respiration had similar patterns for the first term in 2014 and 2015. Values of soil respiration in those years ranged from 0.23 to 0.25 g CO_2/m/h. The statistically significant differences in soil respiration in the tested agricultural practices were observed in the first date of measurement (spring) in all years of study. The treatments with full tillage and crop rotation caused a significantly increased soil respiration. In addition, in the first date of measurement there were no significant differences between average soil respiration under maize cultivated in direct sowing and reduced tillage, while in the second term of the measurement (autumn) the significant differences were not observed between soil respiration under maize cultivated in full tillage and crop rotation system. The results obtained by Runowska-Hryńczuk et al. (1999) show that the simplification of the crop cultivation results in a decrease in soil respiration. Hryńczuk and Weber (2004) reported higher values of soil respiration in cultivation with full tillage compared to direct sowing. A similar trend was observed by Alvarez et al. (1995) and Runowska-Hrynczuk et al. (2000). The research results obtained by Lamptey et al. (2017) showed that zero-tillage significantly decreased soil respiration compared to conventional tillage. According to those authors, a significant soil respiration decrease in direct sowing treatment may be related to the improvement of soil properties as seen in the increases in porosity and saturated conductivity.

A comparative analysis of the three years of study showed that a 32% higher level of soil respiration was recorded after harvest of maize plants. Wielgosz and Szember (2006) noted that the evapotranspiration process (Table 2) was most strongly influenced in maize cultivated in monoculture in full tillage, but the least when maize was cultivated in crop rotation. Significantly higher levels of this indicator were found in the term after sowing.

The differences in carbon dioxide concentration were the highest in the term after sowing in maize cultivated in monoculture in full tillage, especially in the second year of the study (2014). However, in the third year of the study, the value of this parameter at the same term was the smallest at all sites compared to the other two years (Table 1).

The highest changes in soil moisture at both dates were found after maize sowing in the treatments in direct sowing while the lowest in crop rotation and in treatment with full tillage (Table 1). Comparison of those values in all years of the study revealed that the highest changes in soil moisture in the term of measurement after sowing were noted in the first year of study, while in the term after harvest it was in the third year of the study.

Table 2. Average of moisture soil value (%, v/v) in the 0–35 cm soil layout (mean 2013–2015)

Cultivation method	2013	2014	2015	Mean
Direct sowing (zero tillage)	15.1^b	12.6^b	21.1^c	16.3^c
Reduced tillage	12.9^a	10.2^a	16.8^a	13.3^a
Full tillage	13.6^a	12.1^b	19.5^b	15.1^b
Crop rotation	13.7^a	14.1^c	17.2^a	15.0^b
Mean	13.8	12.3	18.6	14.9

The lowest significant difference (*LSD*) (α = 0.05) for: years = 0.56; for: cultivation techniques = 0.56; interaction: years × cultivation = 1.04

Table 3. Correlation of soil respiration with the evapotranspiration; soil moisture; soil dehydrogenase activity; acid phosphatase; alkaline phosphatase; total bacteria; ammonifying bacteria; fungi and grain and straw yields

Cultivation method	Soil respiration
Evapotranspiration	–0.887
Soil moisture	0.015
Changes in soil moisture	–0.790*
Soil dehydrogenase activity	–0.326
Acid phosphatase	–0.574
Alkaline phosphatase	–0.409
Total bacteria	–0.069
Ammonifying bacteria	–0.439
Fungi	–0.132
Grain yield of maize	0.871*
Straw yield of maize	0.539*

*means significant differences at $P < 0.05$

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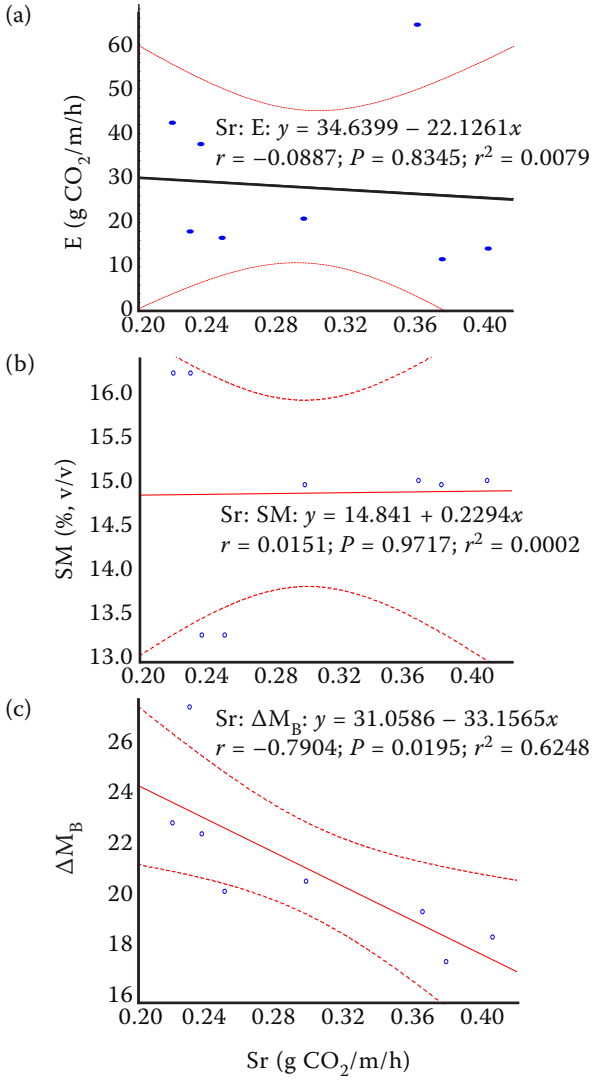

Figure 2. The simple regression analysis on soil respiration (Sr) and (a) evapotranspiration (E); (b) soil moisture (SM) and (c) changes in soil moisture (ΔM_B)

In 2014, where the sum of precipitation in the vegetation period was 448 mm, the soil moisture under maize with full tillage was lower than in direct sowing. In contrast, in 2015, when the sum of precipitation was almost 3 times lower (188 mm), soil moisture content in maize cultivated in full tillage was also lower than in direct sowing (Table 2). In the studies of Lamptey et al. (2017), soil water content increased under no-tillage soils compared with conventional treatment.

The soil respiration was correlated with its biological activity and biochemical parameters (Table 3). The simple regression analysis showed no linear relationship between soil respiration and parameters such as evaporation and changes in soil moisture (Figure 2). The strongest relationship was found between soil respiration and changes in soil moisture, which is confirmed by the value of coefficient of determination (R^2 = 62%). According to Cook and Orchad (2008), to compare the effect on respiration, a measurement of the soil-water status is required.

Statistical analyses also presented that no linear relationship was found between soil respiration and biochemical parameters as soil dehydrogenase activity, acid phosphatase and alkaline phosphatase activity (Figure 3). Dehydrogenase and phosphatase activities are good indicators of changes of soil

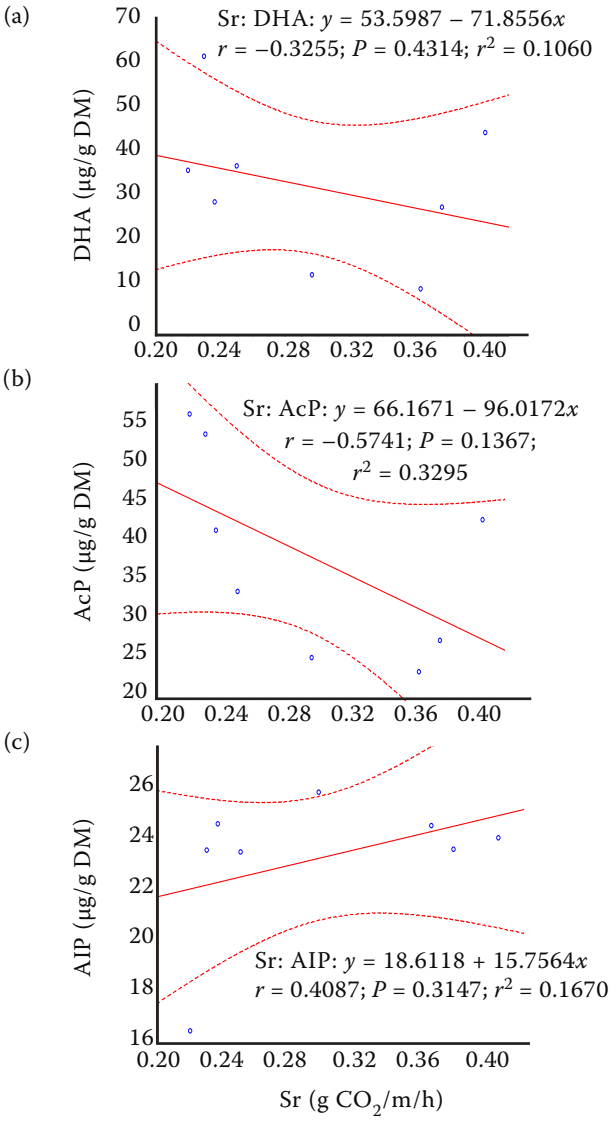

Figure 3. The simple regression analysis on soil respiration (Sr) and (a) soil dehydrogenase activity (DHA); (b) acid phosphatase (AcP) and (c) alkaline phosphatase (AlP). DM – dry matter

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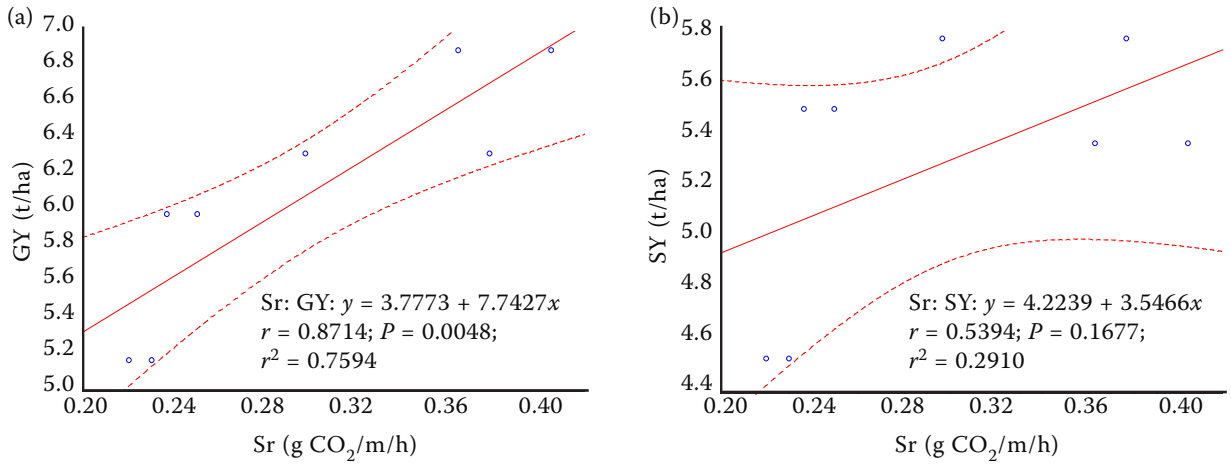

Figure 4. The simple regression analysis on soil respiration (Sr) and yield of (a) grain and (b) straw. GY – grain yield; SY – straw yield

parameters and widely used microbial parameters of soil biology (Wolińska et al. 2013). The dehydrogenase activity was statistically significantly higher in soil under maize cultivated in direct sowing. The highest acid and alkaline phosphatase activities were observed in soil under maize in monoculture with zero tillage (Gałązka 2017a). The activity of phosphatase showed the highest correlation with soil microbial community (Gałazka 2017a).

In the studies of Turski and Wyczółkowski (2008), soil respiratory activity and dehydrogenase activity decreased in a short time after abandonment and were correlated with organic carbon content in the soil. Mijangos et al. (2006) observed higher values of dehydrogenases in zero tillage treatment compared to conventional cultivation.

The yield of maize (grain, straw) correlated with soil respiration (Table 3). Stronger relationships were noted between soil respiration and grain yield of maize than straw yield, which is confirmed by determination coefficient (R^2 = 87%) (Figure 4).

The 3-year research period seems too short to state definite conclusions in this regard. Further research is thus needed to determine soil respiration variations under maize grown using different cultivation practices in long term.

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