

THE IMPACT OF ALTERNATIVE SOIL TILLAGE ON SOIL RESISTANCE AND CO₂ EMISSIONS

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Abstract: *The alternative soil tillage (CP) and mouldboard ploughing (MP) was applied for five years on a heavy soil under Slovenian agro-ecological conditions. The measurements of horizontal resistance with horizontal penetrometer were performed at 15, 25 and 35 cm layer depth on 375 m long experimental parcel. In the 15 cm layer significant lower resistance was detected in MP15 (40.98 Ncm⁻²) than in CP15 (45.10 Ncm⁻²), while in 25 cm layer higher resistance was measured in CP25 (122.47 Ncm⁻²) than in MP25 (91.66 Ncm⁻²). The measurement of CO₂ emissions from the soil were carried out by the LC pro+ device during the whole year in hourly interval. Significant lower emissions (31.934 Mg/ha day in January and 52.464 Mg/ha day in June) were measured in the CP in comparison with the MP (112.527 Mg/ha day in January and 144.460 Mg/ha day in June).*

Key words: *soil resistance, soil tillage, chisel, mouldboard plough, CO₂ emissions*



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1. Introduction

Soil organic matter (SOM) is crucial for maintaining soil fertility because it stabilizes soil structures against erosive forces and increases water capacity and nutrient availability. Increasing SOM on agricultural land could provide a potential sink for atmospheric carbon whenever alternative soil tillage is applied (Ellert & Janzen, 1999; Reicosky et al., 1999). However, a long-term conventional tillage with mouldboard plough causes severe SOM reduction in agricultural soils (Six et al., 2000) and is responsible for reducing soil organic carbon levels by up to 70% (Lal & Bruce, 1999).

According to the world's scientists and politicians, global warming is mostly caused by greenhouse gases in the atmosphere descend through human activities, which also involves agriculture. In the Slovenian agriculture for processing of one hectare of land on average 184.83 l ha⁻¹ fuel is spent, which released 508.282 kg CO₂ ha⁻¹ when burned. The largest proportion 38 % (70.23 l ha⁻¹) is used for the basic soil preparation. Stajanko et al., 2009a proved that the direct drilling can save between 78.43 % and 81.42 % of fuel as well as alternative tillage can decrease the diesel consumption between 33.29 l ha⁻¹ (48.68 %) and 36.03 l ha⁻¹ (52.00 %) depending on soil type and moisture. In several field experiments the CO₂ emissions was decreased on average for 161.71 kg CO₂ ha⁻¹ in direct drilling and for 103.13 kg CO₂ ha⁻¹ in reduced tillage.

Moreover, the conventional soil tillage with mouldboard plough also emits into the atmosphere important quantities of CO₂ gases as the result of microbial decomposition of the soil humus thus modified methods of tillage can reduce direct emissions of CO₂ significantly. Furthermore undistorted soil can act as a sink for atmospheric CO₂ being produced in industry and traffic. Many authors have confirmed the impact of long-term absence of ploughing on the increase of SOM, which however depend also on soil type. Direct sowing and mulch tillage as two most important alternative tillage methods increases SOM content and organic carbon in the surface layer of soil and microbial biomass. Gregorich et al., 2005 found that direct sowing accumulate 42-50 % more organic carbon in the surface layer of soil than conventional tillage. Furthermore, the minimum tillage and direct sowing can accumulate more organic carbon in the surface layer of soil when compared with conventional treatment. Stockfisch et al., 1999, after 20 years of mulch tillage measured increase in SOM and total microbial biomass. However, the mere one-year change in the conventional treatment, can be completely offset several years accumulation of organic matter.

Cookson et al., 2008, also found more total organic carbon in topsoil in direct sowing and conservation tillage compared with ploughing. However, on the average there was no difference in treatment between all depths. Wang et al., 2008, additionally reported that direct sowing without removal of crop residues can increase not only organic matter in soil by 21.7 %, but also total nitrogen by 51 % and available phosphorus by 97.3 % in the 0-10 cm layer in comparison with conventional treatment of soil by the removal of crop residues. Also Etana et al., 1999, measured in the shallow cultivated soil the increase in

concentration of organic carbon in the surface layer of soil, while in the deeper layers it remains unchanged. Álvaro-Fuentes et al., 2009 found that reducing the intensity of tillage and more diverse crop rotation can increase the organic carbon in soil.

On the other hand convention tillage increases also the risk of soil compaction as the number of farm operations and the use of heavier machinery is rising in the modern agriculture. According to Gill & Van den Berg (1968) soil compaction is the process in which the soil particles are rearranged to decrease empty space and bring them into closer contact with one another so increasing the bulk density. The major contributor to forming soil compaction is various loads applied to the surface of unsaturated soils.

Consequently, excessive soil compaction has negative effects on soil structure, reduces crop production, increases runoff and erosion, accelerates potential pollution of surface water by organic waste and applied agrochemicals, and causes inefficient use of water and nutrients due to slow drainage (Johnson & Bailey, 2002).

Quantitative evaluation of soil compaction is necessary to determine its severity and to identify suitable mechanical, chemical, or biological methods of intervention for ameliorating or controlling soil compaction. Two different methods are commonly used for measuring soil penetration resistance. In the first method, soil samples are taken over the field at a certain depth of soil with the help of an open-ended pipe and then the samples are analyzed in the laboratory to determine dry bulk density, dry specific volume, void ratio, and porosity (Hao et al, 2008). In the second method, a specifically sized conical tip is immersed into the ground vertically or horizontally to measure soil strength at a standard speed of 30 mm/s (Jones & Kunze, 2004). Soil strength has been widely used to estimate the degree of soil compaction. By nature, soil strength sensors are of *soil failure-type*. As this type of sensor is moved through the soil, it registers resistance forces arising from cutting, breakage and displacement of soil.

Contrary to the vertical penetrometer, which enables only point measurements of the soil strength, horizontal penetrometer can make instantaneous measurements during driving. Result of the measurement is a signal obtained at a certain distance, which is selected for measurement. The values obtained at a distance which is defined and a constant speed of movement of the tractor allows the evaluation of higher quality data, because one can reduce the impact of soil inhomogeneity due to large amounts of measured values (Jejčič & Poje, 1995).

During 2011 two studies were performed (i) to determine the effect of alternative soil tillage (chisel plough) on the horizontal soil resistance and (ii) to measure the CO₂ emission from the soil which is an important indicator of soil fertility.

In the following chapters we are going to present the result of five-year alternative soil tillage with chisel plough and mouldboard ploughing on horizontal resistance of the soil and the CO₂ emissions from the soil on a silty clay loam soil (Gleyic Podzoluvisol) under Slovenian agro-ecological conditions.

2. Measuring of soil compaction

For our investigation in 2011 a field called 'Center' (Lat. E 15°40'36'' Long N 46°35'58'') was selected. Since 2005 the half of the parcel was conventionally tilled with a mouldboard plough (Lemken, Albatros 5, Fig. 1), while on the other half a chisel Vederstadt Top Down 600, (Fig. 2) was applied in the alternative tillage. The rotation corn - winter raps - winter wheat was the same on both sub parcels.



Fig. 1. Lemken Albatros 5



Fig. 2. Vederstadt Top Down 600

3. Horizontal penetrometer

For measuring soil horizontal resistance a horizontal penetrometer was used (Fig. 3), which is represented in details on Fig. 4. The conical tip of the horizontal penetrometer was made of steel. The load cell bed was formed into the steel tine. The load cell was placed in this section and the top was covered. This prevents possible damage to the load cells under the soil. The data cables of the load cells were transported to the data collection unit, which was placed on the nearby driving vehicle, by being passed through the metal tubes placed behind the penetrometer's

tip. Afterwards, a conical-shaped tip of 30° was placed into the hole, and fixed to the load cell. The surface of the designed conical-shaped tip is 18.08 cm^2 . Insulation seals were used in order to prevent probable leakage of water or soil particles into the holes on the body. An adjustable wheel system was placed behind the penetrometer to ensure a well-maintained depth adjustment and proper running of the machine. By changing the inclination of knife holder of penetrometer and by releasing the hydraulic tractor drawbar we achieve that the penetrometer is buried below the topsoil at the proper depth and guided by a horizontal plane (Jejčić & Poje 1996).



Fig. 3. Horizontal penetrometer during measuring on the field in May 2011

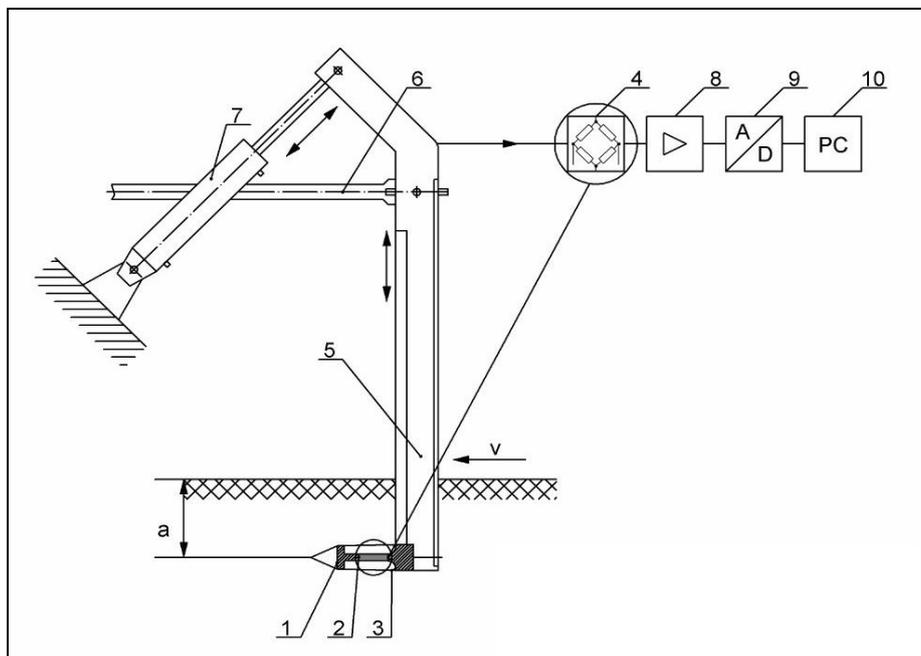


Fig. 4. Horizontal penetrometer: 1 – conical tip, 2 – sensor of compressive force, 3 – protective armour, 4 – strain gauges, 5 - medium, 6 - tractor drawbar, 7 - hydraulic cylinder for adjusting tilt, 8 - magnifying glass, 9 - A/D converter, 10 – personal computer (Jejčić & Poje 1996)

3.1 Average horizontal soil resistance

Fig. 5 shows measurements of the horizontal resistance on the field parcel in May 2011, which was ploughed in the last years. Additional statistics may be seen in Tab. 1, which shows the highest average horizontal soil resistance in the depth of 35 cm (124.77 Ncm⁻²) and the lowest in the depth of 15 cm (40.98 Ncm⁻²). In the deepest layer the maximum soil resistance (184.36 N/cm²) was also detected, but it did not differ significantly from the maximum point in the 25 cm layer. On the other hand, in the 15 cm layer the values remains minimal during all the measurements.

Depth (cm)	Average (Ncm ⁻²)	Standard deviation (Ncm ⁻²)	Maximum (Ncm ⁻²)	Minimum (Ncm ⁻²)
15	40.98 ^a	10.76	77.00	16.26
25	91.67 ^b	29.10	183.28	31.45
35	124.77 ^b	15.66	184.36	84.59

^{a, b} statistically significant difference at p < 0.05 (Duncan test)

Tab. 1. Average horizontal soil resistance on the parcel ‘plough’ in May 2011

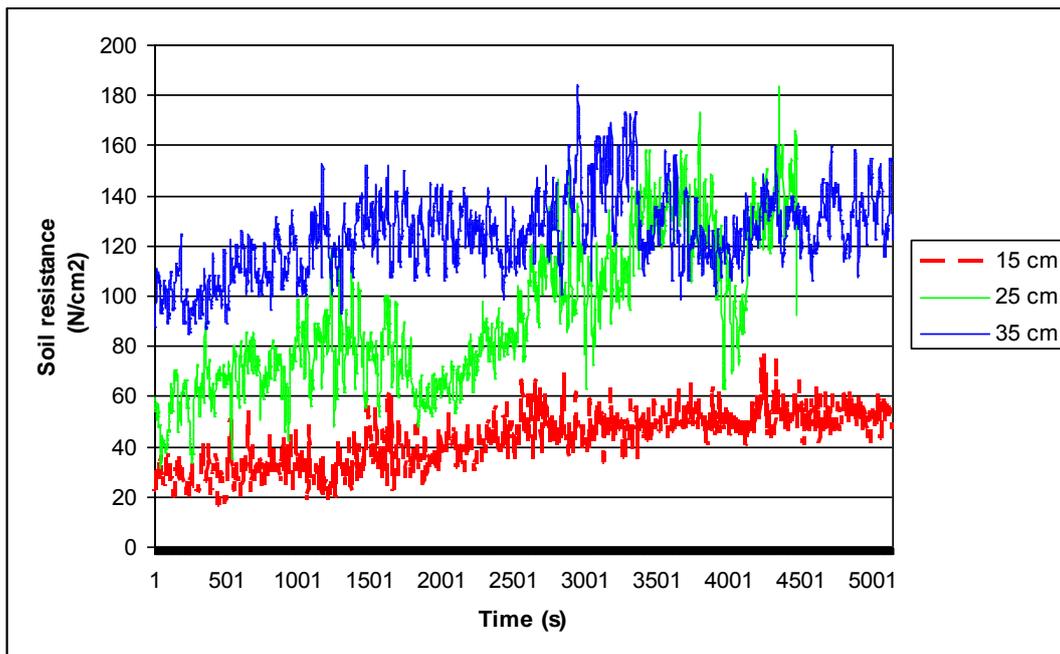


Fig. 5. Horizontal soil resistance in three soil layers on the subparcel ‘plough’ in May 2011

Fig. 6 represents measurements (May 2001) of the horizontal resistance on the part of field, which was chiselled with Vederstadt Top Down 600 in the last five years. In the Tab. 2 additional statistics is shown. Again the highest average horizontal soil resistance was measured in the deepest depth of 35 cm (120.05 Ncm⁻²) and the lowest in the depth of 15 cm (62.57 Ncm⁻²). In the deepest layer we did also detect the maximum soil resistance (161.59 Ncm⁻²), but it did not differ significantly

from the maximum value in the 25 cm layer. The minimum values remained during all the measurements in the 15 cm layer.

h Dept (cm)	Average (Ncm ²)	Standard deviation (Ncm ²)	Maximum (Ncm ²)	Minimum (Ncm ²)
15	62.57 ^a	11.01	98.69	31.45
25	91.67 ^b	29.10	135.56	33.62
35	120.05 ^b	15.97	161.59	60.73

^{a, b} statistically significant difference at $p < 0.05$

Tab. 2. Average horizontal soil resistance at chisel in May 2011

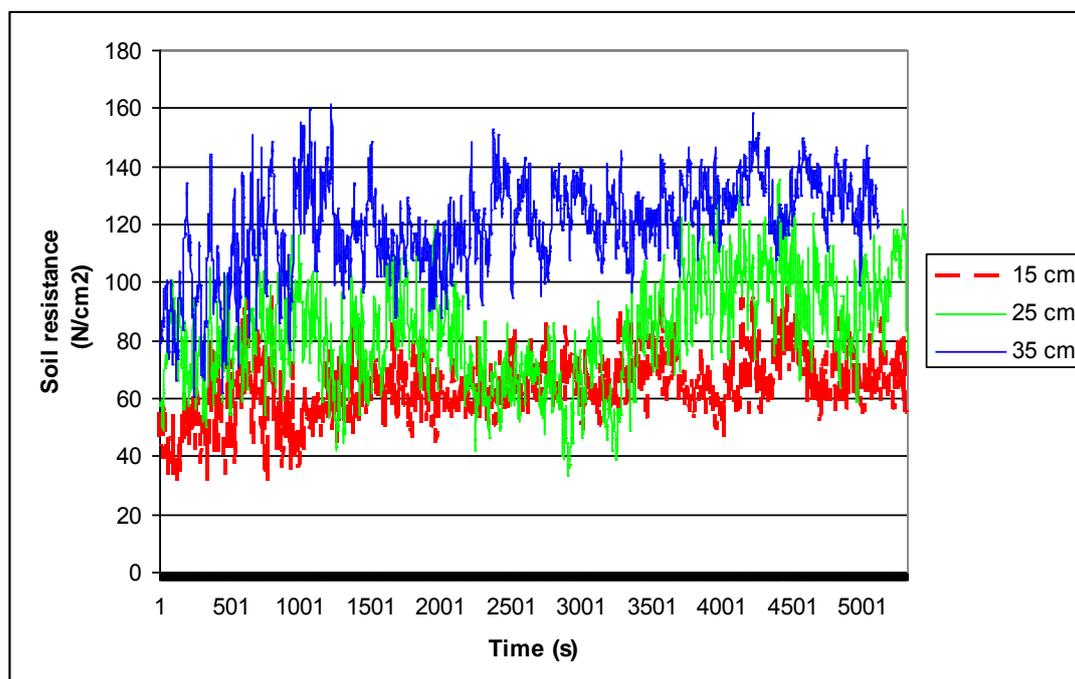


Fig. 6. Horizontal soil resistance in three soil layers on the sub parcel 'chisel' in May 2011

4. CO₂ monitoring

The CO₂ soil/air gas exchange monitoring was measured by using the infrared device (LC PRO, Fig.7a) and the soil hood (Fig.7b). Soil hood represents a chamber with incorporated enclosed volume used for the measurement of gas exchange. The LC uses the principal of Non Dispersive Infrared (NDIR) for the CO₂ measurement in the range of 0-2000 ppm. This relies on the fact that CO₂ absorbs energy in the infrared region in a proportion related to the concentration of the gas.

The dynamics of CO₂ exchange from the soil in 2011 is represented in Fig. 8, which shows very small CO₂ emissions in January and February, however a rapid increase followed in March, which is closely related to the temperature. Then on the plough and chisel plots values remained even from the end of March till late May and

late June (control), respectively. The maximum 6.8 and 6.5 $\mu\text{mol}/\text{m}^2\text{s}$ were measured on control plots.

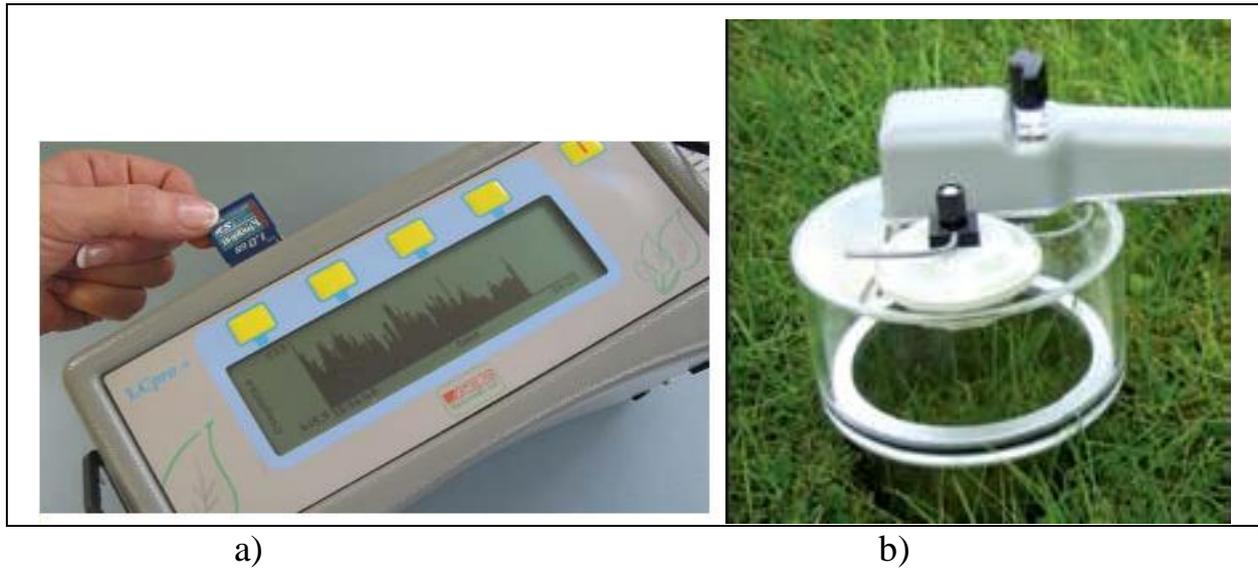


Fig. 7. LC pro + device for measuring CO_2 gas exchange (left), soil hood for collecting the gases from the soil (right)

4.1 Development of CO_2 gas exchange on different soil tillage

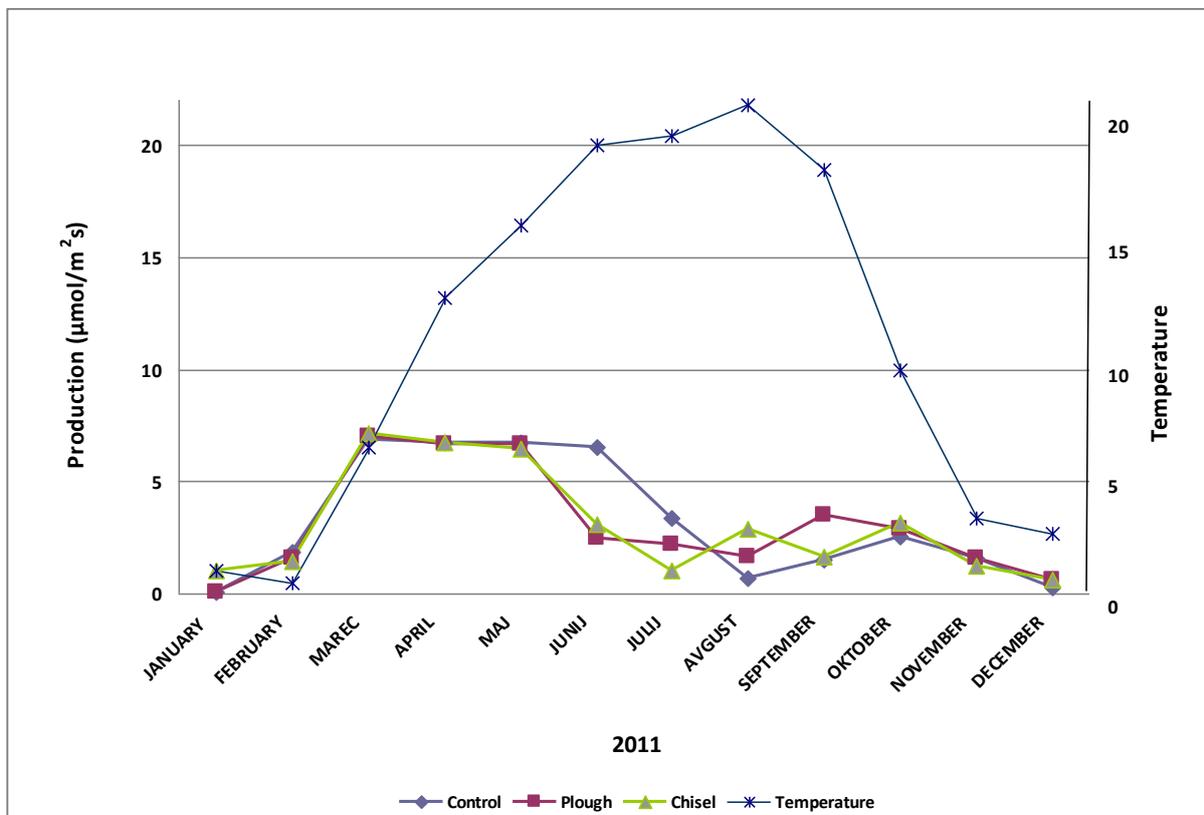


Fig. 8. The influence of different soil tillage on the CO_2 gas exchange during 2011 on the silty clay loam soil

In June and July all values showed again tendency of falling, whereby on the control parcel the same pattern was detected one month later than on chisel and plough parcels. In September and October the CO₂ exchange raised for the second time because the soil was prepared for sowing of winter raps. So, it reached the maximum of 3.54 $\mu\text{mol}/\text{m}^2\text{s}$ on the plough parcel and 1.54 $\mu\text{mol}/\text{m}^2\text{s}$ on chisel parcel, respectively, but it did not exceeded the maximum spring values. In the last colder months of the year all values were falling little by little and reached their minimum in December.

Daily dynamics of CO₂ exchange on January 20th 2011 (Fig. 9) shows on the average 2.96 $\mu\text{mol}/\text{m}^2\text{s}$ (112.527 Mg/ha day) CO₂ production on the parcel 'plough' and 2.12 $\mu\text{mol}/\text{m}^2\text{s}$ (80.593 Mg/ha day) on the parcel 'chisel' during the 24 hours observation with average soil temperature 3.7°C. According to t-test ($p < 0.05$) a significant lower emissions was measured by the alternative soil tillage in comparison to conventional tillage, which resulted in 31.934 Mg/ha day smaller emissions.

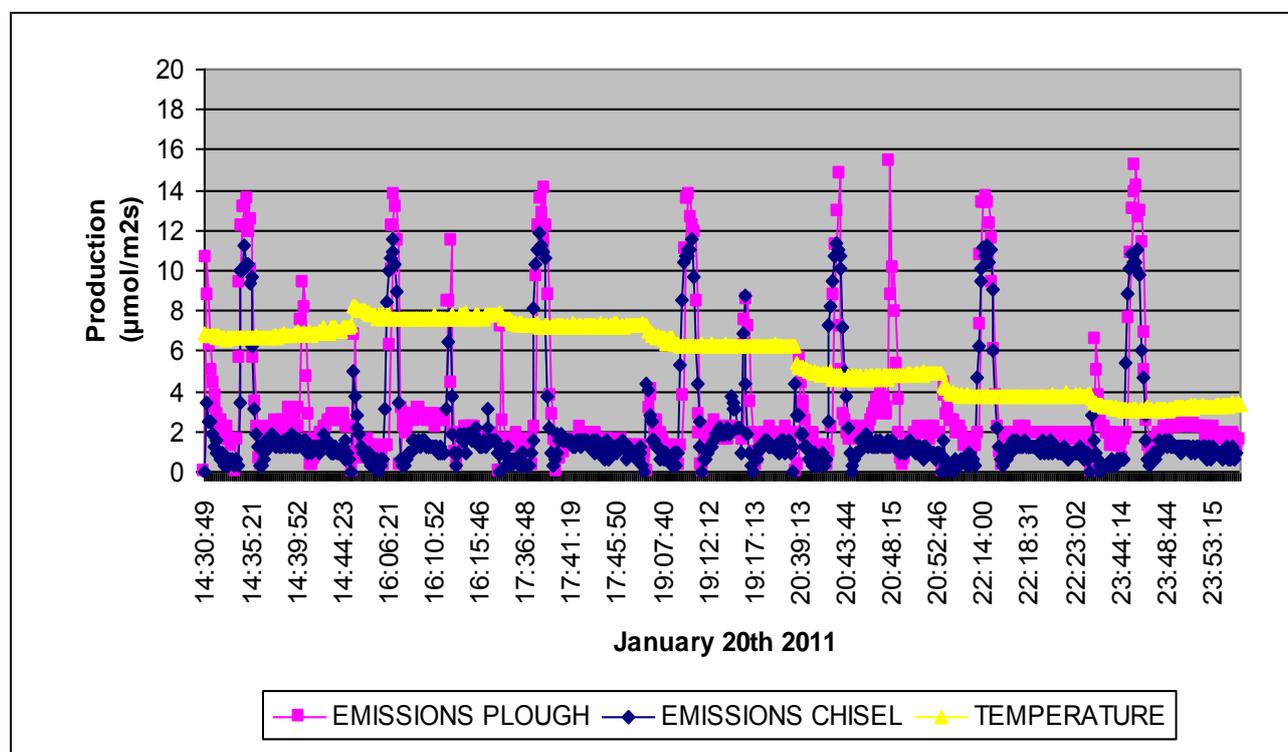


Fig. 9. 24-hours CO₂ soil emissions on the warm winter day

In the summer the same pattern was measured again on June 6th 2011. On the average 3.80 $\mu\text{mol}/\text{m}^2\text{s}$ (144.460 Mg/ha day) CO₂ soil emissions was measured on the parcel 'plough' during 24-hours measurements (Fig.10). On the warm summer day with the average soil temperature of 24.87°C this value is significantly higher in comparison with the 'chisel' parcel (2.42 $\mu\text{mol}/\text{m}^2\text{s}$). From this reason a 52.464 Mg/ha day CO₂ less emissions was caused by the alterative tillage.

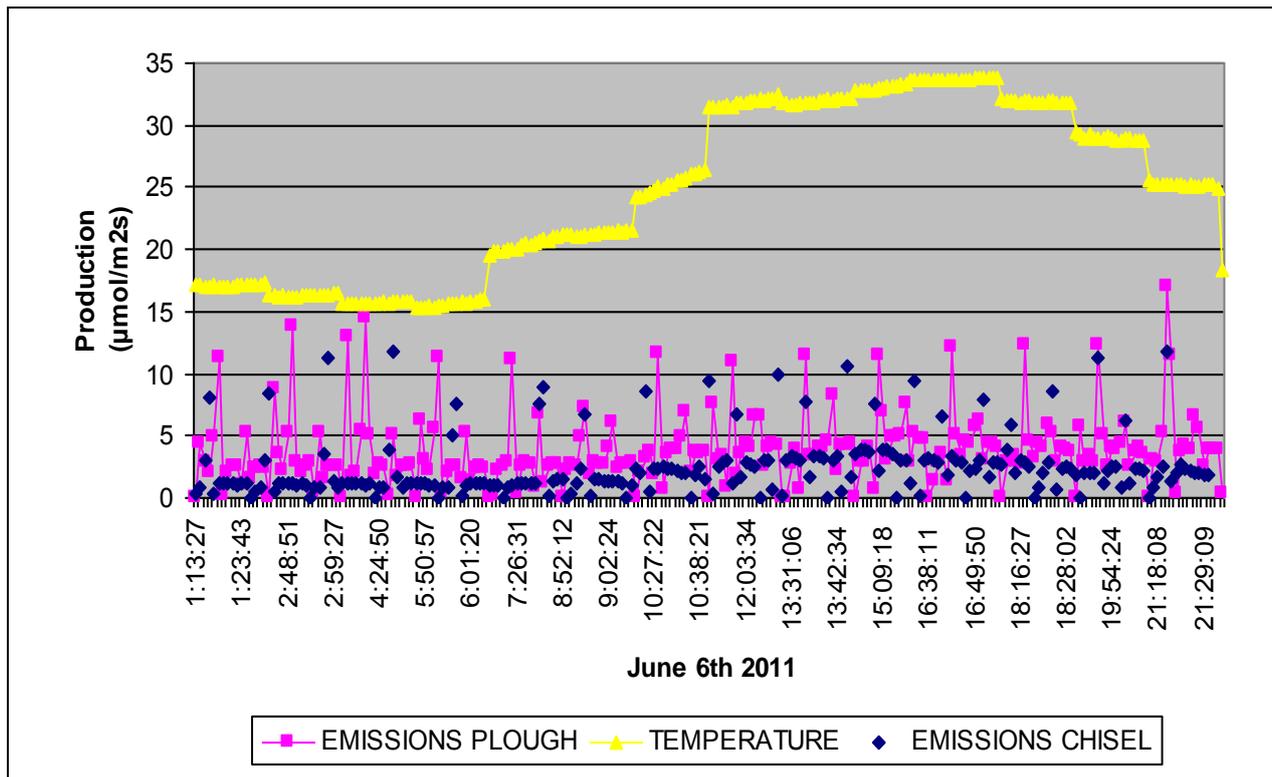


Fig. 10. 24-hours CO₂ soil emissions on the warm summer day

5. Conclusions

Alternative soil tillage with chisel plough in comparison with mouldboard ploughing was proved in some previous experiments (Stajanko et al., 2009b) to reduce significantly the fuel consumption on the heavy silty clay loam soil (Gleyic Podzoluvisol). Subsequently the direct seeding system can decrease the CO₂ emission up to 44.30 kg ha⁻¹ and the alternative tillage system up to 107.05 kg ha⁻¹, respectively.

The result of penetrometer measurements in May 2011 showed that using of alternative tillage (chisel Vederstadt Top Down 600) for five years increased the average soil resistance for 21.09 N/cm² in the top 15 cm soil layer in comparison with mouldboard plough. Contrary, in 25 cm and 35 cm layer no significant difference in the average horizontal resistance was determined between 'chisel' and 'plough' parcels.

In addition, the alternative tillage of the heavy silty soil with chisel showed also significant lower CO₂ emissions in comparison with conventional tillage with mouldboard plough. For this reason a daily dynamics of CO₂ exchange on January 20th 2011 was on average 2.96 µmol/m²s on the parcel 'plough' and 2.12 µmol/m²s on the parcel 'chisel' during the 24 hours observation. This means that an important reduction of CO₂ fluxes from the soil can be achieved even during the winter periods with relatively small precipitations and mild temperatures, which usually increase speed the CO₂ emissions.

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