CO_2 EMISSION AND LONG-TERM PREDICTION OF CARBON STOCK CHANGE OF THE SOIL IN DIFFERENT SOIL TILLAGE SYSTEMS

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Abstract
Agricultural soils, having been depleted of much of their native carbon stocks, have a significant CO_2 sink capacity. Global estimates of this sink capacity are in the order of 20-30 Pg C over the next 50-100 years. Management practices to build up soil C must increase the input of organic matter to soil and/or decrease soil organic matter decomposition rates. The most appropriate management practices to increase soil C vary regionally, depending on both environmental and socioeconomic factors (Paustian et al., 1997a).
In a complex soil tillage experiment – set at Karcag in 1997, as the element of the investigation of soil reduced and conventional tillage systems, in situ measurements have been carried out since 2002 in order to determine the CO_2-emission of the soil. Calculations by the IPCC methodology were also done to quantify the effect of various soil tillage methods on the carbon stock change in the soil. Period of calculation was 20 years. In addition a comparison was made bases *of the comparison of measured and calculated data by 2008. The results we gained call the attention to the complexity of the correlation between soil tillage and carbon stock change, and also to the utilisation possibilities and limits of the measured and calculated data.*

Keywords: carbon-dioxide, soil, emission, IPCC

INTRODUCTION

Greenhouse gas emission and climate change are important issues to agriculture both because of their potential impacts on agricultural production and because agriculture is a major contributor to build-up of greenhouse gases in the atmosphere. In the 1995 Intergovernmental Panel on Climate Change (IPCC) Assessment, agriculture was estimated to be responsible for 20% of the annual increase in anthropogenic greenhouse gas emission, expressed as radiative forcing potential (Cole et al., 1996). The increase in radiative forcing due to agricultural CO_2 emissions, excluding that associated with land use change (Erickson and Keller, 1997) is relatively modest, c. 5 % of the total.

Soil as planting area serves not only economic purposes, but biodiversity preservation too (Várallyay és Láng, 2000). The adoption of agricultural management practices that sequester C will be constrained both by environmental conditions such as climate and soil types as well as by economic and socio-political factors. The latter constrains including the supply and demand for agricultural products, production, costs, subsidies, incentives to reduce environmental impacts (including reducing CO_2 emissions), and social, aesthetic and political acceptance for changes in the agricultural landscape, may well be the most important factors affecting adaptation rates. However, analyses of these factors are highly complex and such studies, in the context of mitigation of CO_2 emissions, are only nowadays beginning (Cole et al., 1996).

In temperate regions key strategies involve increasing cropping frequency and reducing bare fallow, increasing the use of perennial forages (including N-fixing species) in crop rotations, retaining residues and reducing or eliminating tillage (e.g. no-till). I North-America and Europe, conversion of marginal arable land to permanent perennial vegetation, to protect fragile soils and landscapes and/or reduce agricultural surpluses, provides additional opportunities for C sequestration (Paustian et al., 1997a).

By itself, C sequestration in agricultural soils can make only modest contribution (e.g. 3-6 % of total fossil C emissions) to mitigating greenhouse gas emission. However, effective mitigation policies will not be based on any single 'magic bullet' solutions, but rather on many modest reductions which are economically efficient and which confer additional benefits to society. In this context, soil C sequestration is a significant mitigation option. Additional advantages of pursuing strategies to increase soil C are the added benefits of improved soil quality for improving agricultural productivity and sustainability (Paustian et al., 1997a).

De Jong and Schappert (1972) reported that the highest CO_2 percentages in heavy clay chernozemic soils are at the depth of 15 to 30 cm, and that they declined slowly with further depth. Observations on the CO_2 content of the gaseous phase of agricultural soils relate to the effect of many different soil factors. These include soil genesis (Yugakov and Popova, 1968), diffusion rate (Ovcharenko, 1977), moisture tension (Miller and Johnson, 1964), temperature (Yamaguchi et al., 1964), organic matter application (Epstein and Kohnke, 1957), and cropping system (Abrqsimova et al., 1964).

Carbon levels in soil are determined by balance of inputs, as crop residues and organic amendments, and C losses through organic matter decomposition. Thus management to sequester C requires increasing C inputs, decreasing decomposition, or both. Most management practices seek to increase the productivity of a crop and therefore nearly all management practices directly affect the input of C to the soil. While increasing productivity may result in an increase in the rate of crop residue return, the magnitude will depend on residue management practices (e.g. straw retention vs. removal) and the C allocation pattern within the crop. Management practices which enhance production, such as fertilization and irrigation, may also influence decomposition rates (Andrén et al., 1993). So the relationship between management as it productivity and SOC is complex. Before every agricultural cultivation intervention knowledge of cultivated area is very important because global problems are solved by understanding local ones (Tamás, 2001).

Biological processes in the soil lead to the accumulation of CO_2 and a concomitant decrease in O_2. The rate of CO_2 accumulation depends both upon soil biological activity and physical characteristics such as porosity, structure, aggregate size, moisture content, and temperature. The composition of the soil air has an effect on soil pH, especially in calcareous soils (Buyanovsky, 1972), on the transformation of organic substances (Wagner, 1975), and on root growth.

Soil respiration is a critical determinant of landscape carbon balance. Variations in soil temperature and moisture pattern are important physical processes controlling soil respiration which need to be better understood (Paustian et al., 1997b).

Good gas exchange between soil and the ambient atmosphere is very important for maintenance of an appropriate soil atmosphere with regard to O_2/CO_2 balance. Low rates of gaseous diffusion in heavy, over-wetted soils result in excessive CO_2 accumulation and lower O_2 in the soil profile (Buyanovsky et al., 1983).

Decomposition of organic matter is influenced by numerous chemical, physical and biological factors controlling the activity of microorganisms and soil fauna (Andrén, 1990; Swift et al., 1979).

Soil temperature and moisture are the most important environmental controls and their influence is fairly well understood. The increase in decomposition rates with increasing temperature, usually is described by power function, is well documented. Optimal moisture conditions in soils are at around 55-60 % water-filled pore space (Doran et al., 1988) with decomposition decreasing as the soil dries. Water contents near or at saturation inhibit decomposition due to reduced diffusion and availability of oxygen. Both moisture and temperature are affected by management including crop type (e.g. water use), cropping intensity, residue management (e.g. surface mulching), irrigation and tillage.

Tillage affects decomposition processes through the physical disturbance and mixing of soil, by exposing soil aggregates to disruptive forces and through the disturbance of crop residues in the soil (Oades, 1984, Elliot, 1986; Beare et al., 1994a).

Tillage also affects soil temperature, aeration and water relation by its impacts on surface residue cover and soil structure (Paustian et al., 1997a). By increasing the effective soil surface area and continually exposing new soil to wetting or drying and freeze or thaw cycles at the surface, tillage makes aggregates more susceptible to disruption and physically-protected inter-aggregate organic material becomes more available for decomposition (Elliott és Coleman, 1988; Beare et al., 1994a). Numerous field studies show increases in macroaggregate stability with reduced tillage, especially with no-till (Kladivko et al., 1986; Beare et al., 1994b).

Crop residues vary in their inherent decomposability due to differences in their physiochemical characteristics (Andrén és Paustian, 1987). So the use of different crop types represents a potential management control on decomposition. Strong correlation has been shown between lignin content and short term decomposition rates of fresh residues (Melillo et al., 1982; Tian et al., 1992). The effects of litter quality also seem to have a more lasting effect on total soil C levels. Experiments with 20-30 years of organic amendments of differing qualities, but in the same amounts, have shown significant long-term effects of litter quality on soil C levels (Sowden és Atkinson, 1968; Paustian et al., 1992). For conventional cropping systems manipulation of litter quality may not be a major option, since most crop residues do not differ greatly in their relative amounts of recalcitrant substances. Most forage and crop residues have lignin contents in a relatively narrow range, usually between 5 and 15 % (Theander 1984 és Åman, 1984).

Nutrient levels and soil pH affect decomposition rates and SOM turnover and both are influenced by management practices such as fertilization and liming. However, manipulation of nutrient and pH reduce decomposition rates are unlikely to be effective strategies in most instances. In most agricultural soils, significant nutrient limitation of decomposition would only occur at low nutrient levels, where crop production would be far below the optimum. Similarly, optimal pH levels for decomposition coincide with those best suited for crop production (i.e. 6-7) and decomposition is usually not significantly repressed except in quite acid conditions (Dyal et al., 1939) where crop growth is similarly inhibited.

Overall, the main effects of fertilization and liming on the soil C balance are likely to be manifested through influencing crop production and C inputs to soil.

MATERIAL AND METHODS

Field of in situ CO_2 emission measurements

Reduced tillage is considered to cause lower CO_2 loss from the soil by emission in general, especially higher values measured in conventionally cultivated soils during a certain period after tillage operations. The impact of tillage systems on soil CO_2-emission is a complex issue as different soil types are managed in various ways. In the Department for Soil Utilisation and Rural Development of Karcag Research Institute of the University of

Debrecen, Centre of Agricultural Sciences and Engineering in close co-operation with the Department of Water- and Environmental Management broad examination of new soil tillage methods was started in 1997 based on the research achievements gained in the past decades. The main goal of this research is to reveal the processes that result in the emission of CO_2 from the soil into the atmosphere.

Research involving in situ measurement of CO_2-emission of the soil has been carried out at the Karcag Research Institute of University of Debrecen, Centre of Agricultural Sciences since 2002. The main goal of this research is to reveal the processes that result in the emission of CO_2 from the soil into the atmosphere. Measuring CO_2-emission, the most important (from agricultural point of view) characteristic of the soil can be directly quantified. As the practice of soil cultivation is changing in Hungary nowadays, consequently soil properties also change that result in the change of the microbiological activity, nutrient dynamics and organic matter profile of the soil. All these have a great influence on plant production.

In 2008 tillage systems of reduced tillage based on mulching were compared to the conventional cultivation system based on ploughing where (H-1) 15 ha was divided into two plots. The soil type of the investigated plot is meadow chernozem solonetzic in the deeper layers, a soil type that is characteristic for the Trans-Tisza Region of Hungary. In the case of conventional tillage all the crop residues were baled and removed from the subplot, then millet was sown conventionally. In the reduced tillage treatments direct seeding was used, but three different methods were applied regarding the fate of the crop residues: all residues remained (mulch), remaining mulch and application of a mulch tiller and pure direct seeding with no mulching.

Sets and calculation of in situ measurements

An ANAGAS 98 infrared gas analyser was used in order to measure the CO_2-concentration of the air above the soil surface before and after a 30 minute-long incubation period.

At Karcag special, individually developed sets consisting of a metal frame and a plastic bowl each are used to delimitate the measuring area. In order to have perfect isolation, the metal frame is inserted into the soil (sharpened bottom edge) down to 5.5 cm and the trough around the frame is filled with water. The volume of the plastic bowls is approximately 4,000 cm^3, the diameter of the metal frames is 20 cm (*Fig. 1.*).

Fig. 1: The frame+bowl sets

This set was developed for CO_2-emission measurements in vegetation or on stubbles and can substitute the cylinder method that was used earlier (Zsembeli *et al*., 2005). And these sets were used and described by Kovács and Szőllősi (2007) and Szőllősi et al. (2008) too.

The measured ppm concentration degrees were calculated into CO_2-emission which unit is $g*m^{-2}*h^{-1}$. To calculate the CO_2-emission from soil the following formula was used:

$$F = d * (V/A) * (C2-C1)/t * 273/(273+T)$$

Where:

F: CO_2-flux (kg m^{-2} s^{-1}), d: density of CO_2 (kg m^{-3}, 1.96 for CO_2), V: volume of head space of chamber (m^3) A: area of chamber (m^2), C1: CO_2-concentration at time of start (m^3 m^{-3}), C2: CO_2-concentration at time of end (m^3 m^{-3}), t: duration of measurement (s), T: air temperature (C°). To determine the actual soil moisture contents and temperature TTN-M type probes were used.

Calculation of the carbon balance of the soil

The amount of carbon stored in and emitted or removed from permanent cropland basically depends on the crop type, the management practices, the soil variables and the climate variables. The calculation method we used is based on the default factors given in IPCC Good Practice Guidance for LULUCF (2003). According to this method, the existing carbon stock (from the native soil type and the climate characteristics) and the land use factor (from the land use type, management and input features) must be determined.

The soil type was categorised as High Activity Clay Mineral Soil on the base of AGROTOPO data base. In Hungary these (HAC) soils are dominant and the most frequently used for reduced tillage. Among the soils utilised as croplands chernozems, brown forest soils represent this group. Salt affected soils, which are also characteristic to the region where the investigated area belongs to are also in this group, but they are also used as grasslands, mainly depending on the extent of salinization.

The climatic classing, the determination of the climate zone was done on the base of climate maps made by the Hungarian Meteorological Service. As the mean annual temperature of the investigated area is above 10°C and the annual precipitation is less than the evapotranspiration, the factor of the category Warm Temperate Dry was applied.

To choose the input factor that representing the agricultural practice of the region, the characteristics of crop rotations were taken into consideration. According to the IPCC Good Practice Guidance for LULUCF (2003), the input factors represent the effect of changing carbon input to the soil, as a function of crop residue yield, bare-fallow frequency, cropping intensity, or applying amendments. Therefore Low Input category for conventional tillage, while Medium Input category for reduced tillage were applied for the calculations. As the tool of the calculations, the IPCC Soil Carbon Tool was used (*Fig. 2*.)

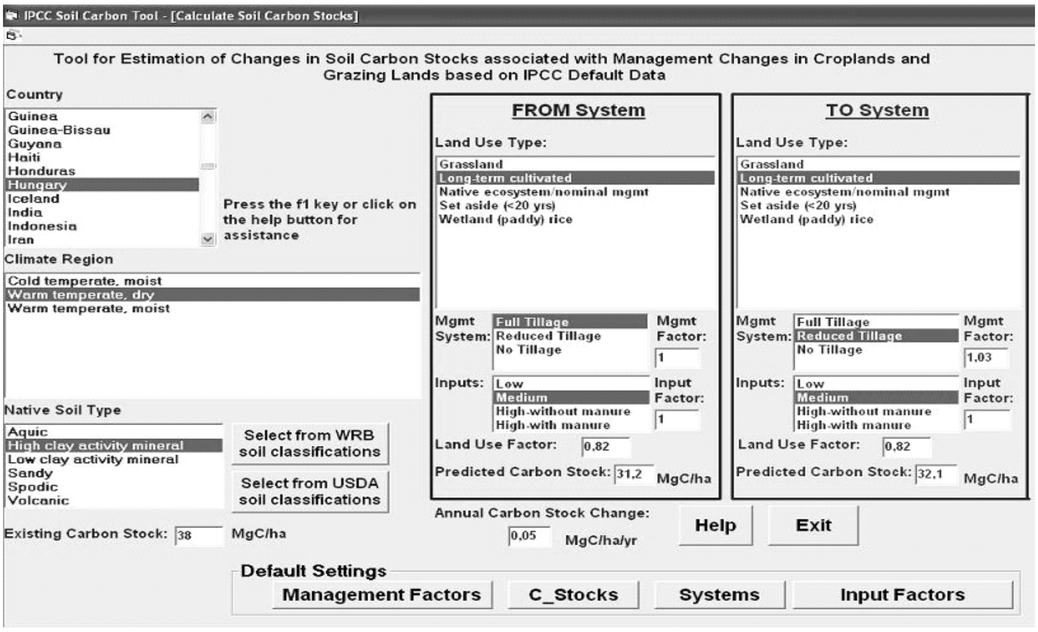

Fig. 2. Display of the IPCC Soil Carbon Tool (sample)

RESULTS AND DISCUSSION

In situ CO_2 emission measurements

The CO_2-emission values calculated for the soil tillage experiment are summarised in *Fig. 3*. The highest values were detected in the case of the reduced tillage system, in other words ploughed plot, and this highest value was not characteristic all along the investigated period. Just after the tillage operation, high emission value was detected on the plot of mulch+direct seeding as well, while the conventional tillage plot had much lower values. Of course the shortness of the investigated period and the high amount of precipitation fallen during the investigated time cannot let use to conclude general conclusions, but there is no doubt that we gained remarkable results about the correlation between the soil status and the CO_2-emission from the soil. These results motivate us to continue our investigations.

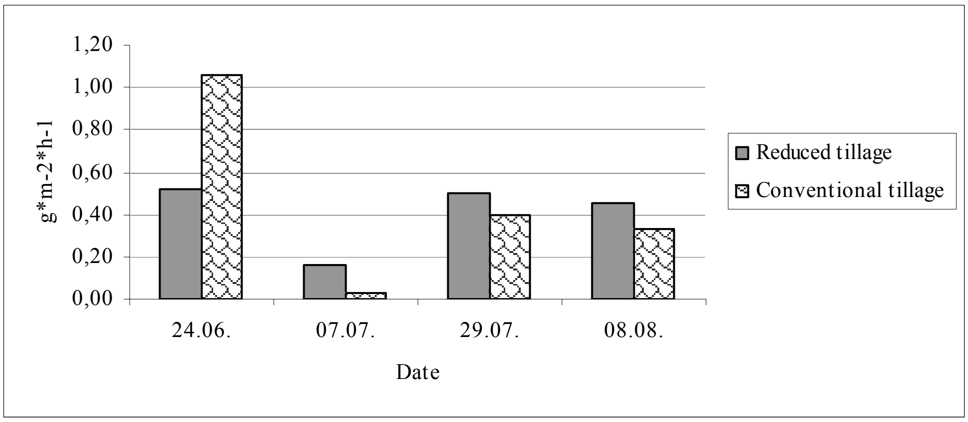

Fig. 3. CO_2-emissions in the soil tillage experiment

Calculation of carbon stock change in soils

According to the estimation method described in the IPCC Good Practice Guidance for LULUCF (2003), first the soil organic C stocks (SOC) were estimated for the beginning and end of the inventory time period using the relevant default reference carbon stocks (SOC_{ref}) and the default stock change factors (F_{LU}, F_{MG}, F_I). The change in soil organic C stocks in mineral soils was calculated by subtracting the C stock in the last year of an inventory time period (SOC_0) from the C stock at the beginning of the inventory time period ($SOC_{(0-T)}$) and dividing by 20, the time dependence of the stock change factors (D). *Tables 1-2.* show the predicted soil carbon stocks for the treatments of the experiment for the default duration of 20 years.

Table 1

Predicted carbon stock change for conventional till

	1997	**2017**
Native soil type	High activity clay	High activity clay
Climate region	Warm, dry	Warm, dry
Reference carbon stock	38 t/ha	38 t/ha
Land use type	Long-term cultivated	Long-term cultivated
Land use factor	0.82	0.82
Management system	Full tillage	Full tillage
Management factor	1.0	1.0
Organic C-input	Low	Low
Input factor	0.92	0.92
Predicted carbon stock	**28.7 t/ha**	**28.7 t/ha**
Annual carbon stock change	**0.0 t/ha**	

Beyond the obvious *full tillage*, we classified *direct seeding* as no tillage system with low input, the *mulch+direct seeding* treatment as no tillage with medium input and the *mulch+mulch tiller+direct seeding* treatments we classified as reduced tillage management system.

Table 2

Predicted carbon stock change for mulch+mulch tiller+direct seeding

	1997	**2017**
Native soil type	High activity clay	High activity clay
Climate region	Warm, dry	Warm, dry
Reference carbon stock	38 t/ha	38 t/ha
Land use type	Long-term cultivated	Long-term cultivated
Land use factor	0.82	0.82
Management system	Full tillage	Reduced tillage
Management factor	1.0	1.03
Organic C-input	Low	Medium
Input factor	0.92	0.92
Predicted carbon stock	**28.7 t/ha**	**29.5 t/ha**
Annual carbon stock change	**0.05 t/ha**	

As the tables show the conversion of conventional tillage into energy saving conservation systems affects carbon stocks. Carbon stocks in soils can be significant and changes in stocks can occur in conjunction with most management practices, including crop type and rotation, tillage, drainage, residue management and organic amendments. The annual increase of the carbon stock (*Fig. 4.*) can be up to 0.29 $t*ha^{-1}$ if the conversion to reduced tillage system takes place.

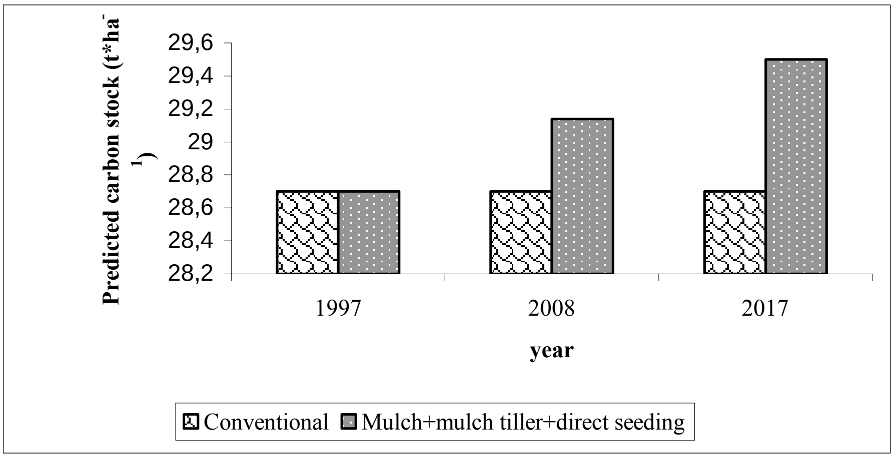

Fig. 4 Predicted carbon stock of the soils of the investigated tillage treatments (t*ha-1)

The differences are considerable, hence all farmers who still follow conventional soil tillage should think over whether the sustainability of crop production would not requires the conversion into a soil protective, energy- and soil carbon stock saving management practice.

CONCLUSIONS

The process of CO_2-circulation between the soil and the atmosphere is very changeable in time and space! There are several factors influencing CO_2 production and emission from the soil. External factors as the seasonal effect and other factors like the manipulation of soil environmental conditions, tillage system, management, irrigation, fertilizer and manure application, all could have an effect on CO_2 production and emission.

Soil inversion by ploughing regularly induces a great carbon dioxide emission from croplands. Intensive tillage results in the reduction of carbon stocks (30-50%), mainly due to the breaking of the soil.

Information from long-term field experiment and simulation modelling shows the main strategies are to rise the time under which the soil is vegetated, reduce soil tillage, that boost primary production and the return of organic matter to soil and increase the use of legume as forage crops, green manures and crop residues.

Studying the effect of different soil utilisation/cultivation methods on the carbon stocks and the CO_2-emission from soil is indisputably actual and needs more efforts as it can contribute to the correct assessment of environmental loads originating from different agricultural habitats and of the microbiological activity corresponding to the actual soil state.

In addition tax benefits, more subsidies, and joint implementation projects could help to motivate farmers and agricultural firms to adopting new practices.

On the whole these data can not be compared because in situ measurements were carried out in different date in period of a year, contrast to calculation by IPCC method which was covered one year period or rather 20 years period. However in the future C balance will be compiled in different conditions and tendencies to become suitable for annual/20 years comparisons to IPCC method.

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