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Influence of NPK Fertilization and Cellulose Application on the CO_2 Production of Soils

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With 2 Figures

Summary

A model was worked out by the authors to study the soil respiration kinetics under laboratory conditions. The model was applied to 5 different Hungarian soil types. The CO_2 production was measured from the 2nd to the 90th day. The model was adapted to the respiration data measured in 25 different soils between the 7th and 56th day. The results lead to the conclusion that the study of biological activity in soil by respiration model experiments needs only about 2 weeks. During this period of time the quantity of the CO_2 produced has to be measured twice, because the first measurement (on the 7th day) and the growth between first and second measurement, i.e. the speed of the process, characterize the whole process well. Probably the correlation between rates of growth and soil properties is similarly close or closer than that between rates of growth and CO_2 production.

Zusammenfassung

Es wurde ein Modell erarbeitet, um die Kinetik der Bodenatmung unter Laborbedingungen untersuchen zu können. Das Modell wurde bei 5 verschiedenen ungarischen Bodentypen angewendet. Die CO_2-Produktion wurde vom 2. bis 90. Tag gemessen. Ebenso wurden mit Hilfe des Modells Respirationsdaten, die zwischen dem 7. und 56. Tag gemessen wurden, interpretiert.

Aus den Ergebnissen kann abgeleitet werden, daß zur Erfassung der biologischen Aktivität im Boden für das Respirationsmodell nur ein Zeitraum von 2 Wochen erforderlich ist. In dieser Zeitspanne wird die CO_2-Menge zweimal gemessen, weil durch die erste Messung (am 7. Tag) und das Wachstum zwischen der ersten und zweiten Messung, das auf die Geschwindigkeit des Prozesses deutet, der gesamte Vorgang gut charakterisiert wird.

Wahrscheinlich ist die Korrelation zwischen den Wachstumsraten und den Bodeneigenschaften enger als zu der CO_2-Produktion.

Soil respiration experiments are widely used today and play an important role among the methods aiming at studying the total biological activity of the soil (NOVÁK 1972, 1976, 1977, 1980; KUBAT and NOVÁK 1979; DAMASKA and NOVÁK 1979; SZEGI et al. 1984).

For the characterization of biological activity, mostly the CO_2 quantities produced in a given period are compared. At the same time several investigations study the rate of soil respiration dynamics and try to model them (FREYTAG 1977; CARPENTER 1934; ABU-EL NAGA et al. 1983).

A model was worked out by the authors to study the soil respiration kinetics under laboratory conditions. The model was applied to 5 different Hungarian soil types. The CO_2 production was measured from the 2nd to the 90th day. The model was also adapted to the respiration data measured in 25 different soils between the 7th and 56th day.

Materials and Methods

To determine the CO_2 production of the soil samples, 100 g soil were used in a respiration system. The CO_2 produced in the soil was absorbed in alkaline solution. The produced CO_2 quantity was determined by potentiometric titration. 4 treatments were used in the soil respiration experiments; 1. Control; 2. NPK; 3. Cellulose; 4. Cellulose + NPK.

NPK nutrients were given to the soil in form of solution made of pure chemicals corresponding to 75 ppm N, P_2O_5 and K_2O, respectively. The applied carbon source was cellulose powder corresponding to 1 % of the soil, mixed to the soil samples before moisturing. Water content of the samples was set to a moisture value corresponding to 70 % of the soil, mixed to the soil samples before moisturing. Water content of the samples was set to a moisture value corresponding to 70 % of the water holding capacity. The respiration was conducted in 28 °C thermostat. 3 replications were made.

The experiment was carried on until the CO_2 production set to equal values in the 4 treatment. This means that the last count was done on the 90th day of respiration.

Results and Conclusions

Our previous paper (SZEGI et al. 1984) describes that the CO_2 quantity produced during a given period depends on the physical and chemical properties of the soil. The aim of the kinetic experiments was to gain more information on the factors influencing soil respiration on the basis of detailed analysis and evalution of data. With the help of the obtained information a parameter was selected to characterize the biological activity of the soil. Two parallel formally first order reaction models were used, as the first approximation for describing the CO_2 production in time. The expression in derivated form:

$$\frac{dy}{dt} = k_1(y_{1max} - y_1) + k_2(y_{2max} - y_2)$$

which was used further in integrated form:

$$y = y_{1max}(1 - e^{-k_1 t}) + y_{2max}(1 - e^{-k_2 t})$$

where

$\frac{dy}{dt}$ = rate of CO_2 production

k_1 = rate constant of the quick process

k_2 = rate constant of the slow process

y_{1max} and y_{2max} = the maximum amount of CO_2 — C produced in the course of the quick and slow processes, respectively

y_1 and y_2 = the CO_2 quantity produced during the quick and slow processes by the time of t.

When fitting the experimental data, it was found that the model has to be further developed. In the present model the rate of CO_2 produced depends only on the carbon sources remaining in the soil over the experimental period: $(y_{1max} - y_1)$, $(y_{2max} - y_2)$. When developing the model, other factors were considered to be changed too during the period of the experiment. These changes were incorporated into the model, so that k_1 and k_2 originally constant parameters were presumed to be changed during the experiment, and their changes could be described by a maximum function:

$$k_1 = k_1' \left(\frac{1}{1 + e^{-a_1 (t - t_{a1})}} - \frac{1}{1 + e^{-b_1 (t - t_{b1})}} \right)$$

$$k_2 = k_2' \left(\frac{1}{1 + e^{-a_2 (t - t_{a2})}} - \frac{1 - d}{1 + e^{-b_2 (t - t_{b2})}} \right)$$

where k_1' and k_2' are the maximum values of the rate constants of the first and second processes, respectively.

The first term in the bracket is a logistic growth coefficient, the second term is a logistic death coefficient (Biczók et al. 1982). At k_2 rate constant the d coefficient in the numerator of the second term is constant. At the end of the processes at constant equilibrium respiration, k_2 takes the $k_2 = k_2'd$ values.

a_1 is the rate constant of the logistic growing period of the quick process.
b_1 is the rate constant of the death period of the quick process.

t_{a_1} and t_{b_2} are half the time of the growth and death processes, respectively.
a_2 and b_2 as well as t_{a_1} and t_{b_2} are parameters characterizing the slow process.

Table 1. Parameters of the kinetic soil respiration model of the investigated soils. Respiration period 90 d

Origin of soil samples Treatments	$y_{1max} + y_{2max}$ mg C · 100 g^{-1}	k_1' day^{-1}	k_2' day^{-1}	V_{90} mg C · 100 g^{-1} · day^{-1}	Variance
Hosszúhát					
H_2O	89.9	0.127	0.0120	0.220	
NPK + H_2O	85.9	0.125	0.0120	0.220	4.7
C + H_2O	529.9	0.039	0.0044	0.220	
C + NPK + H_2O	529.9	0.060	0.0072	0.220	
Nagyhörcsök					
H_2O	102.5	0.138	0.0133	0.122	
NPK + H_2O	102.5	0.122	0.0135	0.122	9.0
C + H_2O	546.5	0.049	0.0040	0.122	
C + NPK + H_2O	546.5	0.059	0.0076	0.122	
Putnok					
H_2O	82.9	0.115	0.0074	0.150	
NPK + H_2O	82.9	0.118	0.0076	0.150	
C + H_2O	526.9	0.038	0.0057	0.150	17.6
C + NPK + H_2O	526.9	0.068	0.0131	0.150	
Örbottyán					
H_2O	83.2	0.123	0.0105	0.200	
NPK + H_2O	83.2	0.131	0.0112	0.200	8.7
C + H_2O	527.2	0.047	0.0056	0.200	
C + NPK + H_2O	527.2	0.070	0.0110	0.200	
Martonvásár					
H_2O	84.3	0.148	0.0123	0.237	
NPK + H_2O	84.3	0.143	0.0132	0.237	9.4
C + H_2O	528.3	0.050	0.0033	0.237	
C + NPK + H_2O	528.3	0.082	0.0052	0.237	

C = 1 % cellulose; NPK = NPK nutrients; mg C = mg CO_2 — C

Our starting point when creating the model was that NPK fertilization does not increase the available carbon source, but quickens the rate of CO_2 production. According to our hypothesis in the case of cellulose application the available carbon source is the C quantity without the addition of carbon source plus 444 mg C in 100 g soil.

As the data of Table 1 show, mostly k_1' and k_2' values comprise the effects of treatments. However, the other parameters also contain important information. Fitting of the function is demonstrated in Fig. 1. The half-time of the logistic growth phase of the quick process is a very short period, measurable in hours after the moisturing, at least under the given experimental conditions, measured during the 2nd and 90th day and extrapolated. The half-time of the logistic death phase of the quick process is 1—2 d depending on the soil and treatment. In case of the slow process the half-time of the growth phase is between 2—9 d while the half-time of the death phase is about 50—80 d. The rate constants of the growth and death phases were considered independent of the treatments in a given soil. The results of mathematical analysis show that the used model function fits well to the measured data. The rate constants of the quick and slow processes (Table 1) show that in the case of equilibrium, when there is no available carbon source in the soil, are the highest rate constants. In the case of NPK fertilization, the rate constant of the quick process does not change, but the rate constant of the slow process increases. It means that CO_2 production reaches faster its potential maximum. Applying cellulose as carbon source, the system is not in equilibrium further more. The limiting effect of other factors (for example mineral nutrients) causes a great decrease in the value of the rate constants. Applying NPK fertilizers to diminish the limiting effect of nutrients results in the increase of rate constants as the environmental conditions are nearer to the equilibrium. However, in this case their values are far from their equilibrium value. This way the value of the rate constant in a given soil indicates how far the circumstances are from equilibrium conditions. The rate constant of the slow process is practically by one order smaller than that of the quick process.

Table 1 also contains the CO_2 rate values measured on the 90th day. By this time the rate of CO_2 production is the same in soil and independent of the treatments.

According to our previous observations, a process can be better described by measuring its magnitude in a given moment or calculating its rate than by the rate constant and the maximum CO_2 production. In our second experiment the model was applied to the data obtained here.

This soil respiration experiment was carried out with 25 Hungarian soils used in our previous experiments. The first data of CO_2 measurement was the 7th and the last the 56th day, starting the count from the moisturing. The above mentioned model was applied here in shorter period supposing that the first, quick CO_2 production process had mostly passed until the 7th day, and in the slow process the death phase had not started yet, therefore the following function was used:

$$y = y_{1max} + y_{2max}(1 - g \cdot e^{-k_2 t})$$

were g is a time dependent logistic modifier coefficient. Other parameters are the same as before.

Table 2 contains the parameters measured and calculated (y_{1max}, y_{2max}, y_{7days}, y_{56days}, k_2 and v_{10days}).

Fig. 2 demonstrates the meaning of the different parameters well where the fit of the function is shown in case of 4 treatments in the soil taken from Kenyeri.

It can be concluded from the parameters that the values of y_{1max} and y_{7days} generally coincide, while the y_{2max} values are usually higher than the measured

Table 2. Counted and measured parameters of soil respiration. Respiration period 56 d

Origin of soil sample Treatments	y_{1max}	y_{7days}	y_{2max}	y_{56days}	k_2' day^{-1}	V_{10d} mg C · 100 g^{-1} · day^{1}
	mg C · 100 g^{-1}					
Kenyeri						
H_2O	14.78	15.49	49.02	48.64	0.023	1.04
NPK + H_2O	17.09	17.09	46.71	60.53	0.048	1.59
C + H_2O	84.50	90.44	423.31	259.89	0.011	4.28
C + NPK + H_2O	109.70	112.33	398.11	306.78	0.014	5.23

C = 1 % cellulose, NPK = NPK nutrients, mg C = CO_2 — C.

results of y_{56days}. This is obvious since the last measuring point was very far from the end point of the process. Considering the k_2 rate constant values the same is true as in the previous experiments.

Table 2 also comprises the rate values of the CO_2 production calculated on the 10th day. Apparently the speed values of CO_2 production measured on the 10th day follow the actually determined CO_2 production (y_{7days} and y_{56days} or y_{1max} and y_{2max}). In the correlation analysis a close ($r = 0.89$, when $n = 100$) correlation was found between the previously used y_{56days} data and the v_{10days} values.

The results show that the study of biological activity of soil in respiration model experiments needs only about 2 weeks. In this period the quantity of the produced CO_2 has to be measured twice, because the first measurement (on the 7th day) and the growth between the first and second measurement, i.e. the rate of the process, characterize the whole process well.

Probably the correlation between the rate values and soil properties is similarly close or closer than that of the CO_2 production values.

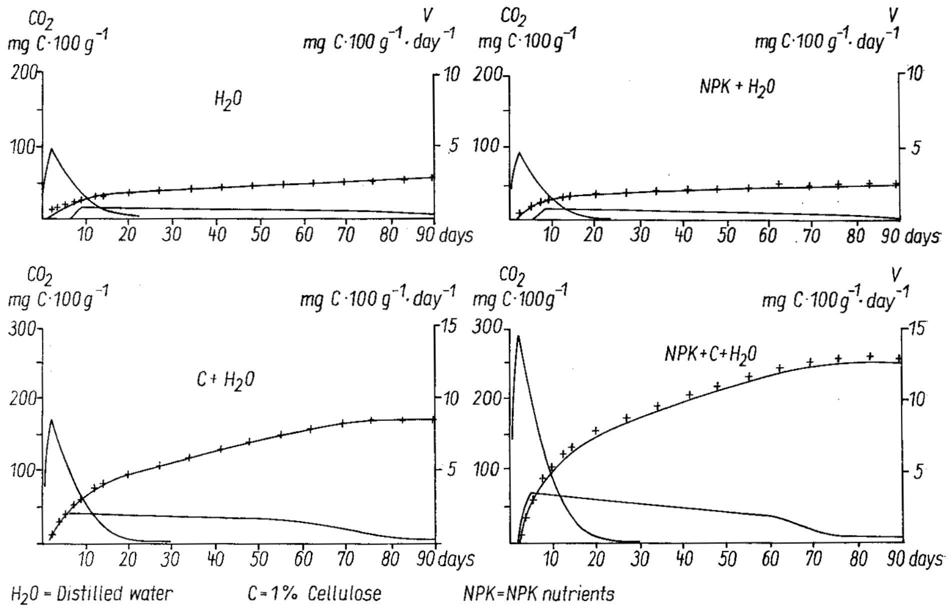

Fig. 1. Effect of fertilization and cellulose application on the soil respiration dynamics. Meadow soil, Hosszuhát. Respiration period 90 d.

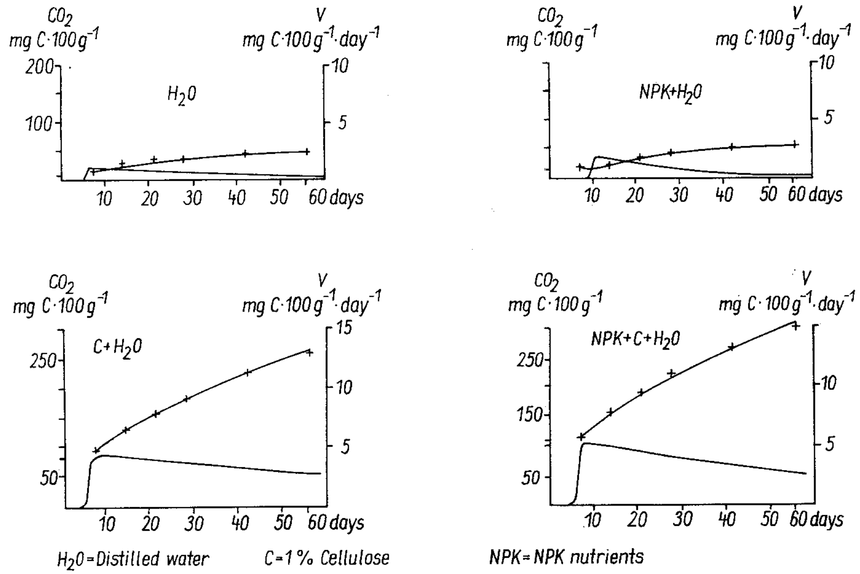

Fig. 2. Effect of fertillzation and cellulose application on soil respiration dynamics. Brown forest soil, Kenyeri. Respiration period 56 d.

References

Abu El-Naga, S. A., Panikov, N. S., Zvyagintzev, D. G.: Kinetical analysis of CO_2 evolution from glucose-amended soils. (In Russian.) Moscow University Soil Science Bulletin **4** (1983), 40—48.

Biczók, Gy., Békési, A., Ruda, M.: Modelling the dynamics of arable crop nutrient uptake MTA SZTAKI. Working paper IV/21 (1982), 1—14.

Carpenter, S. R.: Decay of heterogenous detritus: a general model. J. Theor. Biol. **89** (1981), 539—547.

Damaska, J., Novák, B.: Soil humus and soil respiration relationships. In: Studies about Humus. Transact. Int. Symp. Humus et Planta VII. Brno (1979), 180—184.

Freytag, H. E.: Analyse von Bodenatmungskurven. Zbl. Bakt. II **132** (1977), 452—460.

Kubat, J., Novák, B.: The decomposition of glucose in soil incubated at various temperatures. In: Studies about Humus. Transact. Int. Symp. Humus et Planta. VII. Brno (1979), 189—194.

Novák, B.: Effect of increasing amounts of nitrogen on the microbial transformations of straw in soil. In: Symp. Biol. Hung. (Szegi, J., ed.) **11** (1972), 49—53.

— Effect of inorganic nitrogen and phosphorus on the straw transformation in soil. In: VIIIth International Fertilizer Congress. Vol. II. Moscow 1976, 129—234.

— Effect of fertilizers (with special attention to high doses of nitrogen) on the soil microflora. In: Interaction of Soil Microflora and Environmental Pollutions. Proc. Int. Symp. Pulawy (Poland) (1977), I, 6—22.

— Effect of starch and inorganic nitrogen in microbial transformations of organic compounds in soil. Folia Microbiologica **25** (1980), 140—143.

Szegi, J., Gulyás, F., Füleky, G.: Influence of soil properties on the biological activity. Zbl. Mikrobiol. **139** (1984), 527—536.

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