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SOIL BIOLOGY

Effect of Potassium Chloride on the Emission of Carbon Dioxide from Chernozem

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Abstract—The dynamics of carbon dioxide emission from the soil is traced over nine months by the method of microbial succession initiation for characterizing the microbial activity of soil. A twofold decrease of carbon dioxide emission from the fertile chernozem is observed when potassium chloride is used as a fertilizer. The contents of available nitrogen and especially phosphorus decrease in a pot experiment with barley at standard rates of fertilizer application. The reduction in the content of soluble salts (primarily chlorides and nitrates) in the nonsaline soil after leaching increases the microbial activity.

Keywords: carbon dioxide emission, microbial activity, potash fertilizer, potassium chloride

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INTRODUCTION

The application of potassium chloride as a potash fertilizer in combination with nitrogen–phosphorus fertilizers can reduce the biomass of plants [8]. This negative effect was observed for the first time. It was hypothesized that the effect may be related to the decrease in the mineral supply of plants because of the effect of fertilizers on the functioning of the microbial complex in chernozem. No similar effect was observed in an analogous study on a poor soddy–podzolic soil [7].

Thus, the aim of the current work is to study the effect of potassium chloride on the emission of carbon dioxide from chernozem, as well as to assess the relationship between the microbiological activity and some agrochemical and chemical properties of soil.

MATERIALS AND METHODS

The objects of study were mixed soil samples taken from a pot experiment with the application of nitrogen–phosphorus (NP) and nitrogen–phosphorus–potassium (NPK) fertilizers. The experiment was established on April 30, 2010. Soil samples were taken on May 25 at the tillering stage of barley. The soil was sampled from the upper humus–accumulative horizon of virgin ordinary chernozem from the Kamennaya Steppe (Voronezh oblast) with a high humus content (8.1%) and a neutral reaction (pH_{KCl} 6.4), which did not change significantly during the experiment. The soil has an elevated (slightly above the median) level of available phosphorus (11 mg P_2O_5/100 g by the Chirikov's method) and a very high level of exchangeable potassium (25 mg K_2O/100 g). It should be noted that the properties of the Kamennaya Steppe soils are well-studied [2, 11]. Fertilizers were applied at a standard rate of 0.10 g/kg in the forms of ammonium nitrate (N), double superphosphate (P), and potassium chloride (K). The conditions and results of the experiment were described earlier [8].

Numerous soil processes can be most clearly diagnosed through microbiological parameters, which reveal changes at the early stages that cannot be detected by other methods. Of special relevance are gas chromatographic methods of determining the microbial transformation rate of carbon, an essential biophilic element (respiration). Thus, the microbiological activity of soil was assessed from the emission rate of carbon dioxide. A laboratory experiment on the initiation of microbial succession was performed [3, 5, 6]. Soil samples (5 g) were put in serum vials, wetted with 1.5 mL of distilled water, and sealed (eight replicates for each treatment); the accumulation of carbon dioxide in the gaseous phase above the samples was determined after 24 h of incubation; the vials were then ventilated and incubated again. The accumulation of carbon dioxide was estimated on the fifth, seventh, and tenth days of the experiment. The emission was determined by gas chromatography using a chromatograph with a thermal conductivity detector and a column (3 m long) filled with Polysorb-1; the rate of carrier gas (He) was 25 mL/min.

One month after the beginning of the experiment, two treatments were added, in which 5 g of soil from four replicates of each treatment were washed with 10 mL of distilled water. The solution after soil washing was dried at room temperature to determine the

Table 1. Dynamics of CO_2 emission from the soil

Treatment	Measuring interval			
Primary	5–10 days	5–6 weeks	12–14 weeks	34–36 weeks
Washed $(NP/NPK)_{wash}$	–	4–10 days	8–10 weeks	38–40 weeks
All treatments	1 week	1 week/1 month	2/3 months	8/9 months

dry residue of soluble salts, including nitrates. After washing, the soil water content in all vials was leveled and maintained at the initial level, 60% of the maximum field water-holding capacity, during the entire experiment. Thus, one month later, the experiment included four treatments (NP, NPK, NP_{wash}, and NPK_{wash}), with four replicates for each treatment. After washing, the emission of carbon dioxide was measured on the fourth, sixth, eighth, and tenth days. This corresponds to the range of 4–10 days for the primary (unwashed) treatments and 5–6 weeks for the washed treatments. The time intervals during which the measurements were performed are given in Table 1. The measurements were taken in four replicates (daily). The mean emission values within each measuring interval did not differ significantly and were also averaged. This reduced the experimental error; the intervals for all treatments are denoted in Table 1.

RESULTS AND DISCUSSION

The agrochemical characterization of the soil samples is given in Table 2. The content of nitrogen in the nitrate form (14–15.6 mg N (or 62–69 mg NO_3)/100 g) exceeds that added to the nitrogen fertilizers before planting (10 mg N/100 g) by 1.5 times, which indicates the intense mobilization of the element from the soil with the high content of organic matter. Therefore, the contribution of nitrates to the increase in the total content of soluble salts in the soil exceeds that of the chlorides applied as potassium chloride (7.5 mg Cl/100 g or 0.0075%). In the virgin chernozems of Kamennaya Steppe, the content of chlorides is no more than 0.002%, and that of dry residue mainly composed of calcium bicarbonate is 0.06% [2, 11]. Therefore, it should be emphasized that this soil is not saline even according to the strictest criteria. The minimum content of chlorides in the low-saline soils is estimated at 0.01 [1] to 0.05 [4]. The content of dry salt residue, including nitrates, did not exceed 0.15% (or <0.1% without nitrates) in the soil samples from both treatments. The maximum value of this parameter without nitrates for the nonsaline soils is from 0.3 [1] to 0.1% [4]. The content of soluble salts in the soil for this period of the pot experiment should be considered as close to the maximum values, which determined the time of soil sampling for the examination. After the tillering stage, the plants will rapidly accumulate biomass, intensively uptake nutrients and soluble compounds, and reduce the concentration of the soil solution.

Table 2. Agrochemical characterization of soil, mg/100 g

Treatment	Mobile forms		Mineral nitrogen	
	P_2O_5	K_2O	NO_3^-	NH_4^-
NP	15.1	19.4	15.6	1.2
NPK	11.6	22.3	14.0	0.9

After the addition of potassium chloride, the content of exchangeable potassium (Table 2) increases by almost 3 mg K_2O/100 g but remains on the high level of potassium supply of soil [9]. The decrease in the level of available nitrogen forms at the application of potassium fertilizers can be considered insignificant compared to their high total content. It is more important that the content of available phosphorus decreases under the effect of the added potassium chloride. The soil supply with phosphorus decreases by a gradation, from high to elevated (close to average). Under these conditions, the content of available phosphors can be considered as a limiting factor for mineral nutrition and microorganisms. Hence, the addition of potassium chloride increases the content of exchangeable potassium in the soil but decreases the content of mineral nitrogen and especially available phosphorus; i.e., it can reduce the level of mineral nutrition of plants. The unidirectional changes in the mobility of nitrogen and phosphorus directly point to their relationship with microbiological activity, which plays an important role in the mobilization of both elements from soil organic matter. The assessment of the functional diversity, abundance, and structure of the soil microbial community even for the ecosystems of fallow lands (removed from agricultural use) showed a reliable difference between the self-restored ecosystems (after the former application of the complete mineral fertilizer) and the undisturbed forest ecosystem [10].

It can be seen (Table 3) that a regular decrease of carbon dioxide emission and, hence, soil biological activity occurs with time in all the experimental treatments. However, the rate of this decrease, i.e., the difference between the neighboring intervals, varies

Table 3. Dynamics of CO_2 emission, μmol/g soil daily

Treatment	1 week	1 week/1 month	2/3 months	8/9 months
NP_{wash}	–	3.4	2.6	1.47
NP	3.9	3.0	2.2	1.10
NPK	2.7	1.4	1.0	0.57
NPK_{wash}	–	2.3	1.4	0.78
HCP0.05	0.7	0.5	0.4	0.2

Table 4. Dynamics of CO_2 emission, % of NP treatment

Treatment	1 week	1 week/1 month	2/3 months	8/9 months
NP_{wash}	–	116		134
NP	100			
NPK	69	48		
NPK_{wash}	–	77	67	
HCP0.05	17			

among the treatments. The emission in the NP treatment decreased relatively uniformly (with similar differences): from 3.9 to 3.0 μmol/g soil daily in the first month and from 3.0 to 2.2 μmol/g soil daily in the two next months. In the NPK treatment, the decrease is nonuniform: the emission of carbon dioxide abruptly decreased from 2.7 to 1.4 μmol/g soil daily in the first month; the rate of decrease in the next two months was lower: from 1.4 to 1.0 μmol/g soil daily. However, if a longer period of observation (three months) is considered, the effect of these changes is leveled and the difference between the treatments is stabilized at a value of 1.7 μmol/g soil daily in both treatments. Therefore, long-term measurements (over 9 months) were necessary for obtaining substantive results.

The data presented in percentage of the NP treatment are very suitable for analysis (Table 4). The relative values vary less significantly than the absolute values, as is confirmed by the stabilization of the relative experimental error at a level of 17%. The values in the neighboring intervals frequently differ insignificantly and may be averaged. This makes it possible to level the appearing irregularities and simplifies the analysis of the data. The microbiological activity of soil decreased almost twofold under the effect of potassium chloride. The washing of soil with water and the decrease in the concentration of soluble salts enhanced the biological activity in the treatments with the addition of potassium chloride and in the treatment with the background application of NP fertilizers. The similarity of the effects of washing in the two treatments indicates a significant contribution of nitrates to the negative effect. Apparently, the entire effect of soluble salts on the CO_2 emission should be considered. This also emphasizes the decisive role of the chloride ion, rather than the potassium ion, which is strongly fixed by chernozem, in the negative effect of potassium chloride. Nonetheless, the increase of CO_2 emission in the NPK treatment after washing did not compensate the negative effect of potassium chloride even to the level of the NP treatment without washing. The stability of the negative effect after washing can be indicative of significant changes in the microbial complex of soil. This hypothesis undoubtedly needs further experimental testing.

Thus, the negative impact of potassium chloride on the content of plant-available nitrogen and phosphorus forms in chernozem is related to both the negative effect of chloride ions on the activity of microorganisms and the elevated content of nitrates in the soil, which enhances this effect.

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