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The Effect of Compost Addition on Chemical and Nitrogen Characteristics, Respiration Activity and Biomass Production in Prepared Reclamation Substrates

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***Abstract*—**Land degradation is of concern in many countries. People more and more must address the problems associated with the degradation of soil properties due to man. Increasingly, organic soil amendments, such as compost are being examined for their potential use in soil restoration and for preventing soil erosion. In the Czech Republic, compost is the most used to improve soil structure and increase the content of soil organic matter. Land reclamation / restoration is one of the ways to evaluate industrially produced compost because Czech farmers are not willing to use compost as organic fertilizer. The most common use of reclamation substrates in the Czech Republic is for the rehabilitation of landfills and contaminated sites.

This paper deals with the influence of reclamation substrates (RS) with different proportions of compost and sand on selected soil properties–chemical characteristics, nitrogen bioavailability, leaching of mineral nitrogen, respiration activity and plant biomass production. Chemical properties vary proportionally with addition of compost and sand to the control variant (topsoil). The highest differences between the variants were recorded in leaching of mineral nitrogen (varies from 1.36mg dm^{-3} in C to 9.09mg dm^{-3}). Addition of compost to soil improves conditions for plant growth in comparison with soil alone. However, too high addition of compost may have adverse effects on plant growth. In addition, high proportion of compost increases leaching of mineral N. Therefore, mixture of 70% of soil with 10% of compost and 20% of sand may be recommended as optimal composition of RS.

***Keywords*—**Biomass, Compost, Reclamation, Respiration.

I. Introduction

THE problem of land degradation and the recovery of degraded land to its original condition is one of great concern in most countries of the world [5], [12]. In Czech Republic research indicates that more than one third of the land surface is degraded in some way (water and wind erosion, influence of mineral fertilizers, human activity etc.). Also, old ecological loadings and landfill reclamation is a considerable problem in the Czech Republic.

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The use of compost as an amendment for soil restoration and regeneration is increasing, not only in the Czech Republic [2]. Compost amendment improves physical, chemical and biological properties of soils, in particular by increasing available nutrients mainly in the organic soil fractions [2], [3], [13]. The application of organic matter to degraded soils is a good environmental practice. Therefore, the application of compost to the soil has become a common environmental practice for soil restoration, maintaining soil organic matter, reclaiming degraded soils, and supplying plant nutrients.

Czech farmers' lack of interest to use compost as organic fertilizer caused that the compost producers can start to use more for the preparation of reclamation substrates (here after RS). But instructions or regulations for preparation or for optimal composition of RS don´t exist in Czech Law.

Also, the application of compost increases the plant cover and stimulates soil microbial growth and activity [12]. On the other hand, if the compost is applied in high doses it can negatively influence desirable groups of microorganisms and reduce yield of crops because unnaturally high proportion of organic matter (and other substances in compost) and undesirable interactions of microorganisms may lead for example to toxicity of the RS for certain groups of microbes [14].

The aim of this paper was to test the hypothesis that high addition of compost for preparation of RS may cause toxicity of RS and leaching of excessive nitrogen. RS were also evaluated in terms of chemical composition and selected indicators – nitrogen bioavailability, microbial respiration (basal and substrate induced) and biomass production (aboveground and underground).

II. Materials and Methods

A. Experimental Design

The experiment was based on the methodology previously detailed by [4].

Experiment was performed in experimental containers with a square floor plan (Fig. 1). Eight seeds of *Lactuca sativa* L. (salad) were planted in each container. Containers were filled with 550g of RS according to respective variants of the experiment. After one week, one germinated seed was left in each experimental container. During the first 10 days, salad was irrigated with 20ml of distilled water every day. In the remaining time of experiment, salad was irrigated with 30mL of distilled water five days a week. During whole experiment, plants were kept in a climate chamber at 22°C with a day length of 16h and a light intensity of 300µmol m^{-1} s^{-1}. After 35 days, both RS and plant material were sampled. Plant sample were dried at 105°C and dry weight of aboveground and belowground was determined. RS samples were stored at 4°C until further analyses.

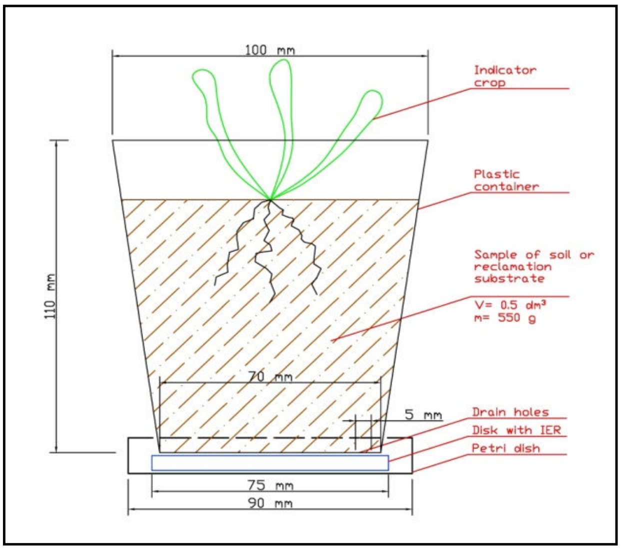

Fig. 1 Experimental container according to [4]

Thirteen variants of the experiment were prepared: C – only arable soil, and RS prepared as mixture of soil, compost and sand in different ratios: K10 – arable soil with addition of 10% (i.e. weight percent) of compost, K20 – addition of 20% of compost, K30 – addition of 30% of compost, K40 – addition of 40% of compost, +S10 – arable soil with addition of compost and with addition of 10% (i.e. weight percent) of sand, +S20 – arable soil with addition of compost and with addition of 10% (i.e. weight percent) of sand.

For the experiment we used soil (topsoil) from the experimental area in Brezovanad Svitavou. Soil sampling was done on the 9th of April 2013. Soil sampling was done in accordance with CSN ISO 10 381-6. Compost (Cernydrak) samples were taken from the Central Composting Plant in Brno on the 10th of April 2013 in accordance with CSN 46 5735. Compost (Cernydrak) is registered (under the Fertilizers Law) for agriculture use in the Czech Republic. Samples of sand were washed thrice in 6% HCl and 10% NaOH solution to remove all organic material which could be contained in sand. Before preparation of RS the soil was preincubated at laboratory temperature for 30 days. All samples were sieved through a sieve (grid size of 2 mm) before preparation of RS. Moisture of the mixing material was: soil (w = 20%), compost (w = 40%) and sand (w = 98%).

B. Chemical Analysis

The pH_{H2O} was measured in suspension of RS and boiled distilled water (ratio in 1:5) in accordance with [16]. The pH_{CaCl2} and available P, K, Ca and Mg were determined according to the method of Mehlich III method [15]. EC was determined in filtrate, which was produced by filtering a suspension of reclamation substrate sample and distilled water (in ration 1:5) according to [17]. Available mineral Nitrogen was determined by distillation and titration method [9] according to [1]. Organic Carbon was determined by colorimetry after oxidation of the organic matter by the excess $K_2Cr_2O_7$ according to [18].

C. Measurement of the Leaching of Mineral Nitrogen

Mineral nitrogen (NH_4^+-N and NO_3^--N) leached from the RS was captured by special discs with mixed IER (Ion Exchange Resin), which were located under each experimental container (Fig. 2).

Fig. 2 Plastic disk with IER [4]

The discs were made from plastic (PVC) tubes. Each disc was 75mm in diameter and 5mm thick. From both sides of each disc, nylon mesh was glued (grid size of 0.1mm). Mixed IER (CER– Cation Exchange Resin and AER– Anion Exchange Resin in ratio 1:1) were then placed into the inner space of annular flat cover [8].

For the quantification of N_{min} trapped by the resin (CER and AER), the IER were allowed to dry at room temperature. Captured N_{min} was extracted from resin using 100ml of 1.7 M NaCl. Released N_{min} was determined by distillation and titration method [9]. The results obtained from the Ion Exchange Discs were expressed in mg of N_{min} dm^{-3} of soil.

D. Ammonium Production during Waterlogged Incubation

In this method, soil N availability is estimated from NH_4^+-N produced during a 7 days waterlogged incubation. Method is based on the determination of difference between the original and final content of mineral nitrogen (ammonia and nitrate nitrogen at the beginning and ammonia only after the incubation) in the soil solution. This difference is proportional to the amount of nitrogen that was presumably stored in the original microbial biomass before the incubation. The only anaerobic as well as facultative anaerobic thermophiles (these bacteria constitute a minority in the original soil environment) can survive this extreme conditions of waterlogged incubation at 40°C. Organic N from original microorganisms is mineralized during the incubation and accumulated as ammonia nitrogen (NH_4^+-N) [1].

20g of field-moist RS was weighed into 125ml incubation bottle. 50ml of distilled water was then added into each bottle. All variants (V1-V5; K1-K5) were prepared in three individual replications. The bottles were placed in an incubator at 40°C. After 7 day incubation 50ml of 4M KCl was added and filtration was performed. The ammonium was determined by distillation and titration method according [9].

The content of mineral nitrogen was estimated before the incubation. From each replication 20g of soil sample was taken and it was shaken for 60 minutes with 2M KCl. After shaking the determinations of ammonia and nitrate nitrogen (main compounds of mineral nitrogen) were made. This determination was performed using the same methods as for the determination of ammonia nitrogen after incubation.

The results obtained from the determination of mineral nitrogen (before incubation) and ammonia nitrogen (after incubation) was expressed in mg of N_{min} kg^{-1} and in mg of NH_4^+-N kg^{-1} of soil.

E. Determination of Basal and Substrate Induced Respiration

Basal respiration (BR) was determined by measuring the CO_2 productions from RS incubated in serum bottles for 24h. Field-moist RS (15g) was weighed into each of five 120-ml serum bottles. Bottles were sealed with butyl rubber stoppers and incubated at 25°C. After 3 and 24h, a 0.5-ml sample of the internal atmosphere in each bottle was analyzed by gas chromatography (Agilent Technologies 7890A, equipped with a thermal conductivity detector). Respiration was calculated from the increase in CO_2 during 21-h incubation period (24-3h). At the end of measurements, the total headspace volume for each replicate bottle was determined by measuring the volume of water required to fill the bottle. The measured amounts of CO_2 were corrected for the gas dissolved in the liquid phase. The results are expressed per gram of dry matter and hour [11].

Substrate induced respiration (SIR) was determined by measuring the CO_2 production from the RS incubated in serum bottles for 3 h after addition of glucose. Field-moist RS was added to 3 replicate serum bottles as described for the determination of BR in the previous paragraph, and 2ml of a glucose solution was added to each bottle (4mg C g^{-1}). Bottles were sealed with butyl rubber stoppers, and incubated at 25°C. After 2 and 4h, a 0.5-ml sample of the internal atmosphere was analysed by gas chromatography (see previous paragraph). SIR was calculated from the CO_2 increase during the 2-h incubation period (4-2 h). The bottles were further processed as described for BR measurement [11].

F. Statistical Analysis

Differences in the amount of leached mineral nitrogen, nitrogen availability, respiration and biomass production were analyzed by one-way analysis of variance (ANOVA) in combination with the Tukey´s test. All analyses were performed using Statistica 10 software.

III. Results and Discussion

The subject of our interest was to determine influence of compost addition to RS on chemical properties, leaching of mineral nitrogen, nitrogen availability, respiration and plant biomass production.

Obtained results are divided into five sections: chemical analysis, leaching of mineral nitrogen, ammonium production during waterlogged period, plant biomass production and basal and substrate induced respiration.

A. Chemical Analysis

Chemical properties of the RS are shown in Tables I and II. Soil used in experiments was collected in experimental area in Brezová. Soil has sandy loam texture and it was classified as Cambisol, pH(H_2O) is slightly acid, pH ($CaCl_2$) is moderately acid and the salinity class (EC) is nonsaline for C variant in accordance with [10]. Addition of compost change pH to neutral class or slightly alkaline (variant K40+S20), EC is still nonsaline in all variants. The amount of organic carbon and mineral nitrogen vary depending on the addition of compost and sand.

TABLE I
Selected Chemical Properties of Reclamation Substrate

Variants	pH (H_2O)	pH ($CaCl_2$)	EC µS cm^{-1}	Corg (g/kg)	Nmin (mg/kg)
C	6.45	5.83	103.6	60.3	14.1
K10	6.62	6.72	532	99.4	29.2
K20	6.86	7.08	935	133.7	68.1
K30	6.92	7.22	1223	160.7	15.6
K40	7.11	7.31	1607	171.1	229.1
K10+S10	7.10	7.02	520	96.2	27.4
K20+S10	7.07	7.27	963	107.5	69.0
K30+S10	7.08	7.29	1488	125.0	134.1
K40+S10	7.23	7.34	1624	147.1	216.2
K10+S20	7.09	7.11	559	91.3	15.8
K20+S20	7.05	7.27	910	100.0	63.7
K30+S20	7.13	7.32	1308	118.9	87.5
K40+S20	7.26	7.40	1565	135.4	132.3

Content of available nutrients are shown in Table II. Results were evaluated using 5 level scale of nutrient availability where very low, low, satisfactory, optimal, high and very high level is distinguished. Evaluation of C variant: P-high content, K-satisfactory content, Ca-satisfactory content, Mg-low content according to [15]. Compost addition changed availability of P and K to very high content class. Available Ca changed from optimal content (all variants with 10 % of compost and K20+S20) to high content (remaining variants). Available Mg change from satisfactory content (all variants with 10 % of compost) or optimal content (all variants with 20 % of compost), to high or very high content (remaining variants).

Positive effect of compost addition on soil physical-chemical properties confirmed by some studies [3], [4], [6].

TABLE II
AVAILABLE NUTRIENTS ACCORDING MEHLICH III

Variants	P (mg/kg)	K (mg/kg)	Ca (mg/kg)	Mg (mg/kg)
C	182.8	167.3	1444	53.4
K10	309.3	658.2	2468	158.8
K20	373.1	1173	3397	258.3
K30	406.5	1564	4127	344.9
K40	465.4	2140	4610	468.7
K10+S10	272.3	600.9	2104	134.1
K20+S10	361.3	962.3	3346	243.1
K30+S10	403.6	1540	4092	343.4
K40+S10	446.2	2384	4576	454.2
K10+S20	288.6	679.7	2512	153.0
K20+S20	321.0	945.7	3071	216.3
K30+S20	362.3	1222	4110	319.2
K40+S20	407.1	2023	4816	444.7

B. Leaching of Mineral Nitrogen

Leaching of mineral nitrogen was determined as the capture of ammonium and nitrate forms on the Ion Exchange Resin (mg N_{min} $dm^{-3}$of soil). Expression of results was explained in the preceding section.

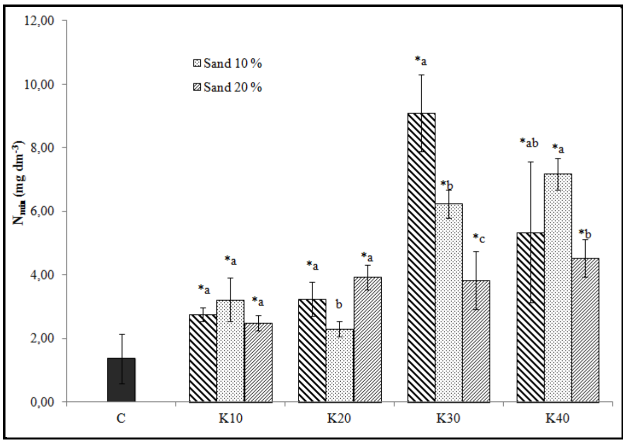

Fig. 3 Detection of mineral nitrogen in the soil (C) and in RS with different amount of compost and sand. Values are means and standard errors of three replications. Different letters indicate significant differences (ANOVA, P < 0.05) and * indicate significant differences between C and other variant with RS

Fig. 3 indicates significant difference between the RS variants (without K20+S10) and C variant in amount of detected mineral nitrogen. The highest leaching of N_{min} was measured in variant K30 (9.09mg dm^{-3}) which is 6 times more than in C variant. On the other hand leaching of N_{min} in variants with compost addition is similar (K30) or lower (other variants) as leaching of N_{min} with addition of mineral fertilizer (NPK fertilizer) used in [4].

C. Ammonium Production during Waterlogged Period-Index of Nitrogen Availability

Ammonium N, which was determined in filtered extracts, indicates the amount of NH_4^+-N in the microbial biomass.

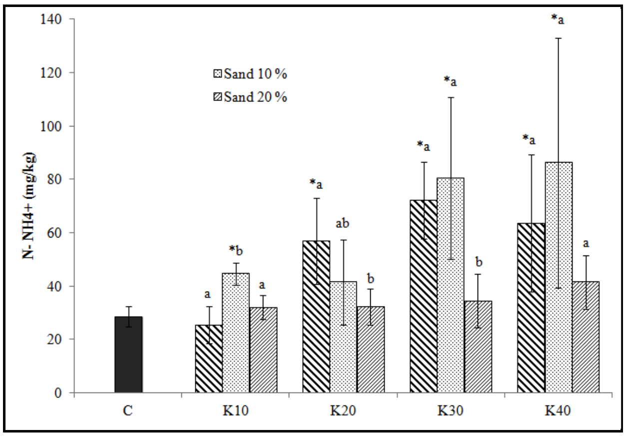

Fig. 4 Ammonium production during waterlogged period. Values are means and standard errors of three replications. Different letters indicate significant differences (ANOVA, P < 0.05) and * indicate significant differences between C and other variant with RS

Fig. 4 shows that the largest stockpile of NH_4^+-N was detected in variants with the 30% and 40% of compost + 10% of sand (K30, K40, K30+S10, K40+S10). Addition of sand (20%) eliminated effect of compost addition on N production. Positive effect of compost addition on nitrogen availability is described for example by [7], [4].

D. Plant Biomass Production

Production of plant biomass was chosen as the main indicator of the impact of RS on plant vitality. The largest biomass production was achieved in variants with the higher addition of compost. But the highest addition of compost (40%) and addition of sand (20%) had negative effect on plant production as you can see in variant K40+S20. It supports our hypothesis, that high level of compost may be toxic to plant.

Consider Fig. 5 which shows a difference between the variants with addition of compost and with addition of compost and sand. The horizontal axis indicates variant of experiment and the vertical axis shows the plant biomass (ing).

The graph is composed of two parts, which presents data relating to production of aboveground and underground biomass. Indicator crop was grown 35 days.

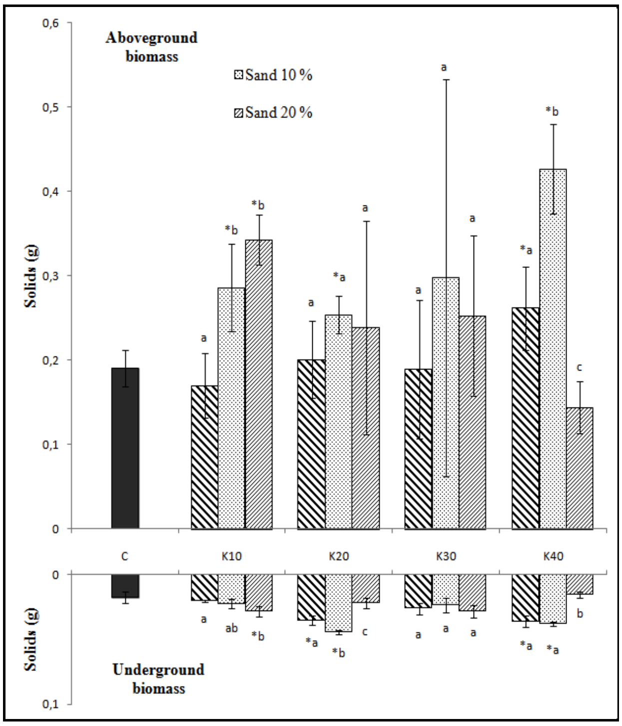

Fig. 5 Production of plant biomass. Values are means and standard errors of three replications. Different letters indicate significant differences (ANOVA, P < 0.05) and * indicate significant differences between C and other variant with RS

The above values show that the addition of compost in combination with/without addition of 10% sand has a positive effect on plant biomass production.

E. Basal and Substrate Induced Respiration

Basal respiration is defined as a production of released CO_2 from the soil (RS) for a time without the addition any substrate. The CO_2 production was determined during the 21h production and under the laboratory condition.

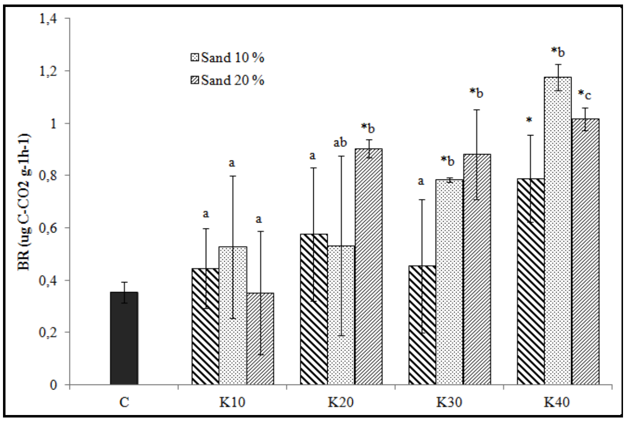

Fig. 6 Basal respiration (BR). Values are means and standard errors of three replications. Different letters indicate significant differences (ANOVA, P < 0.05) and * indicate significant differences between C and other variant with RS

Fig. 6 presents results of basal respiration (BR). We can see that the CO_2 production increase with increasing amount of compost. Highest peaks of CO_2 production are shown with the 40% compost addition. There is a contrast between control variant (C = 0.35 µg C-CO2 $g^{-1}h^{-1}$) and K40+S10 (1.18µg C-CO2 $g^{-1}h^{-1}$). BR is influenced of the amount of C_{org}. Organic carbon represents the energy for microorganisms, which use it for their development. The growth in microbial activity is reflected in rise of their respiration. Substrate induced respiration method uses the soil organism´s physiological respirations reactions to substrate addition, as a means of quantifying microbial biomass in soils.

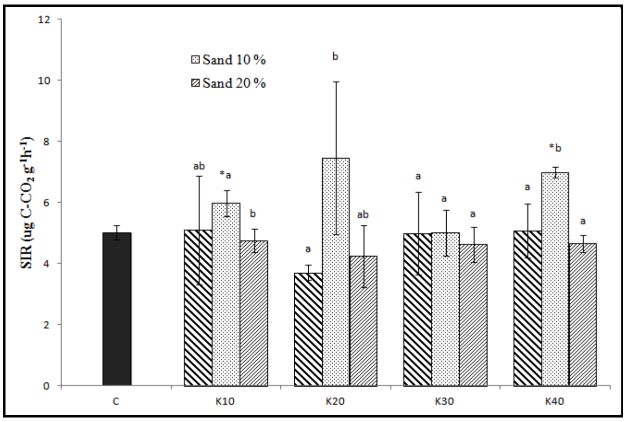

Fig. 7 Substrate induced respiration (SIR). Values are means and standard errors of three replications. Different letters indicate significant differences (ANOVA, P < 0.05) and * indicate significant differences between C and other variant with RS

The CO_2 production was determined during the 2h production and under the laboratory condition. There were no major differences between individual RS in SIR. Comparison with basal respiration suggests that compost addition stimulates microbial activity with limited effect on biomass. It contradicts results of waterlogged incubation (Fig. 3). However, both methods measure different parts of microbial biomass.

IV. Conclusions

Addition of compost to soil improves conditions for plant growth in comparison with soil alone. However, too high addition of compost may have adverse effects on plant growth. In addition, high proportion of compost increases leaching of mineral N. Therefore, mixture of 70% of soil with 10% of compost and 20% of sand may be recommended as optimal composition of reclamation substrate.

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