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EFFECTS OF A CARBONIZATION PRODUCT AS ADDITIVE ON THE GERMINATION, GROWTH AND YIELD PARAMETERS OF AGRICULTURAL CROPS

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The effects of the carbonization product of separated communal waste as an additive to the soil was studied on the germination, quantitative growth and yield parameters of maize (*Zea mays* L.), bean (*Phaseolus vulgaris* L.) and tomato (*Solanum lycopersicum* L.). The product was tested on three soil types with different humus content and mineral composition in doses of 1, 10 and 20 g of additive per kg soil, with application before seeding or after plant emergence, under greenhouse and field conditions. It was found that plants utilized the nutrient content from the carbonization products in both methods of application and that the stimulatory effect on the germination, fresh and dry mass and yield parameters of the treated plants was dependent on the plant species, soil type, dose and method of application. A significant effect of the additive was found on the germination of bean, which increased by 8–22% over the control. Fresh and dry mass increased by 18–62% in maize and by 2–30% in bean when the additive was applied under greenhouse conditions. In the field the additive was found to have a positive effect on the average mass of tomato fruits and maize cobs, and on the yield per plant.

Key words: non-traditional fertilizer, carbonization product, maize, bean, tomato, germination, fresh and dry mass, yield

Introduction

One of the main factors in the intensification of plant production is the appropriate fertilization of plants, which decides the quantity and quality of many agricultural crops (Ložek, 2001; Ankumah et al., 2003; Hlušek et al., 2003; Liua et al., 2003; Márton, 2004). Although the current spectrum of industrial fertilizers in the Slovak Republic is already extensive (Vaneková, 1989; Fecenko and Ložek, 2000), the development of new fertilizers continues (Jahnátek, 2003). This generally depends on the agricultural production and economic potential of individual countries. Nowadays many new and non-traditional fertilizers are being tested. Proteinaceous hydrolysate prepared from tanning waste stimulates the germination and growth of maize, barley and cucumber (Bezák et al., 1989). Zeolite fertilizer (Zeomix) increases the yield of spring barley (Rimár, 1999). Anaerobically digested grey municipal solid waste can serve as a readily available N source to ensure rapid crop development (Makaly Biey et al., 2000). A mixture of organomineral complexes with morphoregulatory and antistress effects shows positive effects on the increase of dry mass in winter wheat (Hudec et al., 2001).

One alternative source potentially utilizable in plant nutrition is the product of the carbonization of separated solid communal waste. Waste has become a critical problem for industrialized society, particularly in big cities and densely populated areas (Grodziska-Jurczak, 2001; Fehr et al., 2002). Therefore new solutions for waste treatment need to be elaborated. It requires research and development throughout the world. According to Bedő (2003), in agriculture, too, only the comprehensive handling of ecological, economic and social challenges can produce a satisfactory answer to the questions involved in sustainable development.

The present study summarizes the results of greenhouse and small-plot field investigations on the carbonization product of communal waste as an additive to the soil. The effects of the additive were examined on the germination and some quantitative growth and yield parameters of three agricultural crops, maize (*Zea mays* L.), bean (*Phaseolus vulgaris* L.) and tomato (*Solanum lycopersicum* L.).

Materials and methods

Preparation of additive

The additive was prepared by carbonizing separated solid communal waste (plant and animal residues) at the Faculty of Mathematics, Physics and Informatics of Comenius University, Bratislava. Carbonization is a thermo-chemical degradation process in the absence of oxygen, so that carbon char is formed instead of ash. A detailed description of the process, additive preparation and its physical properties are described by Morvová et al. (2003). The results of the chemical analysis of the additive are presented in Table 1.

Plant material and soil

Biological research on the additive was done on maize (*Zea mays* L. cv. Torena), bean (*Phaseolus vulgaris* L. cv. Unidor F_1) and tomato (*Solanum lycopersicum* L. cv. Tornado). The additive was tested in three soil types (Table 2), which were analysed at the Research Institute of Soil Science and Conservation, Bratislava, where the chemical analysis of the additive was also performed. Soil reaction $pH_{(KCl)}$ was determined according to ISO 10390, carbon (oxidisable) and humus according to ISO/FDIS 14235, hydrolysis of samples according to Kjeldahl, content of mineral elements (Na, K, Ca, Mg, Fe) according to methods F-AAS ISO/DIS 14 869:1998 and ISO/FDIS 11 047:1997, phosphorus by the colorimetric method and total nitrogen according to STN ISO 11261.

Table 1

Chemical analysis of the additive, carried out at the Research Institute of Soil Science and Conservation in Bratislava, Slovak Republic

pH_{KCl}	C_{ox} (%)*	Humus (%)	Content of elements in additive ± SE (g kg^{-1})						
			$N_{Tot.}$	P	Na	K	Ca	Mg	Fe
8.7±0.3	6.3±0.6	10.8±1.0	15.9±1.5	7.1± 0.7	13.4±1.3	14.8±1.4	29.0±2.9	37.7±3.7	25.3±2.5

* Oxidisable carbon

Table 2
Agrochemical analysis of soil types, carried out at the Research Institute of Soil Science and Conservation in Bratislava, Slovak Republic

Soil type	pH	Concentration of elements in soil (mg kg^{-1})*				Humus (%)
		P	K	Mg	Ca	
I	6.6±0.2	39	150	575	11150	8.6±0.9
II	7.8±0.3	12	95	240	15400	0.9±0.1
III	7.7±0.3	644	2285	840	6100	3.8±0.4

* The standard error of the values did not exceed 10%

Characteristics of tested soils

Soil type I had a neutral soil reaction, a low content of available phosphorus, a medium content of available potassium and a very high content of available magnesium and calcium. The content of humus was very high. Soil type II had a highly alkaline soil reaction, a very low content of available phosphorus, a low content of available potassium, a high content of available magnesium and a very high content of available calcium. The content of humus was very low. Soil type III had an alkaline soil reaction with a very high content of all available nutrients (phosphorus, potassium, magnesium and calcium) and a relatively high content of humus.

Greenhouse experiments

The greenhouse experiments were carried out at the Department of Plant Physiology, Faculty of Natural Sciences of Comenius University, Bratislava. The effect of applying the additive before seeding (pre-emergence application) and after planting (post-emergence application) was tested on maize and bean. Twenty seeds of each species were sown in experimental pots containing soil types I and II mixed with the additive in doses of 1 and 20 g kg^{-1}, while the control was soil without additive. In the post-emergence application, pre-grown maize plants at the 2–3-leaf stage and bean at the 1st true primary leaf stage were individually planted in pots with the required amount of additive. Each treatment was carried out in three replications. Both treated and untreated (control) plants were irrigated daily. The influence of the additive on germination was evaluated ten days after sowing, and on the fresh and dry mass of the plants after seven weeks. Fresh and dry mass was evaluated according to Erdelský and Frič (1979).

Field experiments

The field trials were carried out in type III soil at Tvrdošovce (Nové Zámky district, South Slovakia). Before sowing maize or planting tomato, the soil was treated by traditional mechanical means. One kg of soil containing the requisite doses of 1, 10 and 20 g additive per kg soil was distributed in 1 m long rows before sowing maize. In the tomato experiments, 1 kg of soil with the required doses of additive was distributed under the root system of the tomato seedlings at a spacing of 450 × 500 mm. Every variant, with five plants per species, was replicated five times. During the growing season the plants were regularly irrigated. The average number and mass of tomato fruits and maize cobs and the total yield per plant were evaluated.

Evaluation of results

The effect of the additive on germination and on quantitative growth and yield parameters was evaluated. The statistical treatment of the data was done by calculating means ± SE and using Student's t-test.

Results

When the additive was applied to soil types I and II before sowing no significant effect was observed on maize germination under greenhouse conditions. Germination ranged from 99 to 106% of the control in soil type I and from 94 to 100% in soil type II. By contrast, the effect of the additive on bean germination was positive, giving a significant increase of 8–22% over the control.

The mass of maize plants was not positively influenced by applying the additive before sowing (Fig. 1A) and ranged from 92 to 95% of the control for fresh mass (i.e. 6.0–6.2 g per plant) and from 84 to 99% for dry mass (i.e. 0.66–0.78 g per plant) in soil type I, and from 96 to 97% (i.e. 4.71–4.75 g per plant) for fresh mass and from 85 to 102% (i.e. 0.56–0.68 g per plant) for dry mass in soil type II. In both soil types a dose of 20 g kg^{-1} of the additive was found to have a retarding effect on the dry mass, which decreased to 15–16% below the control with an average dry mass of 0.66–0.79 g per plant.

In the post-emergence application of the additive to maize a significant stimulatory effect was recorded in both soil types for fresh and dry mass production (Fig. 1B). In soil type I, which had higher humus content (8.2%) and essential elements, the stimulatory effect of the additive was observed at a dose of 20 g kg^{-1} of soil (Table 2). The fresh mass was significantly increased by 62%, with an average mass of 27.45 g per plant, and the dry mass by 56% with 3.39 g per plant. In the control the average fresh mass of maize was 16.92 g and the dry mass 2.16 g per plant. However, in soil type II, which had a very low content of humus (0.7%) and elements, the stimulatory effect of the additive was observed at the lower applied dose of 1 g kg^{-1}. The fresh and dry mass were significantly increased by 35 and 45% (15.94 g of fresh and 2.12 g of dry mass per plant) over the control, with an average fresh mass of 11.8 g and dry mass of 1.46 g per plant in the control. In soil type II at a dose of 20 g kg^{-1} of additive, the fresh and dry mass dropped to 18 and 23% below the control, respectively (Fig. 1B).

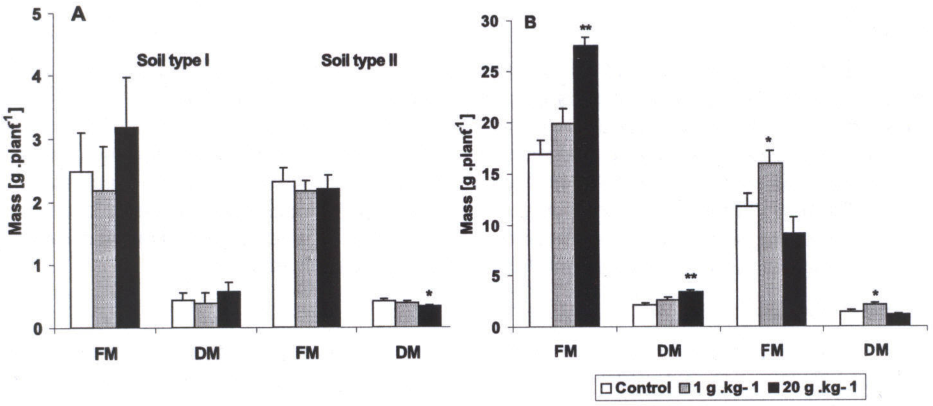

Fig. 1. Effect of additive on fresh (FM) and dry (DM) mass of maize (*Zea mays* L. cv. Torena) after pre-emergence (A) and post-emergence (B) application, determined in soil types I and II under greenhouse conditions. Data represent means ± SE (n=3).* Significant difference at P=0.05, ** Significant difference at P=0.01

The pre-emergence application of the additive to bean (Fig. 2A) in soil type I only had a positive effect on the fresh and dry mass at a dose of 20 g kg^{-1}, where the fresh mass increased by 28% (3.19 g) and the dry mass by 30% (0.56 g) compared with 2.49 g per plant fresh mass and 0.43 g dry mass in the control. In soil type II no positive effect on growth and quantitative parameters was observed. Fresh mass in beans ranged from 2.16 to 2.21 g per plant (93–95% of the control) and dry mass from 0.33 to 0.38 g per plant (79–92% of the control). At a dose of 20 g kg^{-1} in soil type II dry mass decreased significantly by about 21%, from 0.41 g per plant in the control to 0.33 g per plant (Fig. 2A). In post-emergence application the effect of the additive on bean growth was only positive at the higher dose of 20 g kg^{-1}. The fresh mass in soil types I and II increased significantly by 17 and 24% and dry mass increased insignificantly by 4 and 13% in comparison to the control, with fresh mass values of 3.61 to 5.31 g and dry mass values of 0.67 to 1.0 g per plant (Fig. 2B). The dry to fresh mass ratio in both species was enhanced under the greenhouse conditions, indicating water loss from treated and untreated maize and bean plants.

The results of field experiments carried out in soil type III (location: Tvrdošovce) showed that the total yield of maize cobs per plant was not influenced positively by the additive (Fig. 3A). It ranged from 102.9 to 118.6 g per plant, with 118.7 g per plant in the control. The number of cobs per plant decreased to 76–81% of the control (Fig. 3B), though the average cob mass increased significantly by 7–31% over the control.

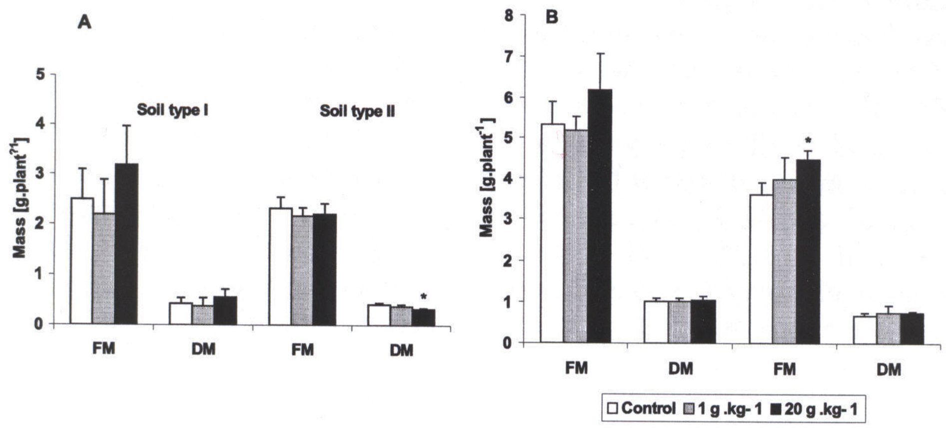

Fig. 2. Effect of additive on fresh (FM) and dry (DM) mass of bean (*Phaseolus vulgaris* L. cv. Unidor F_1) after pre-emergence (A) and post-emergence (B) application, determined in soil types I and II under greenhouse conditions. Data represent means ± SE (n=3). *Significant difference at P= 0.05

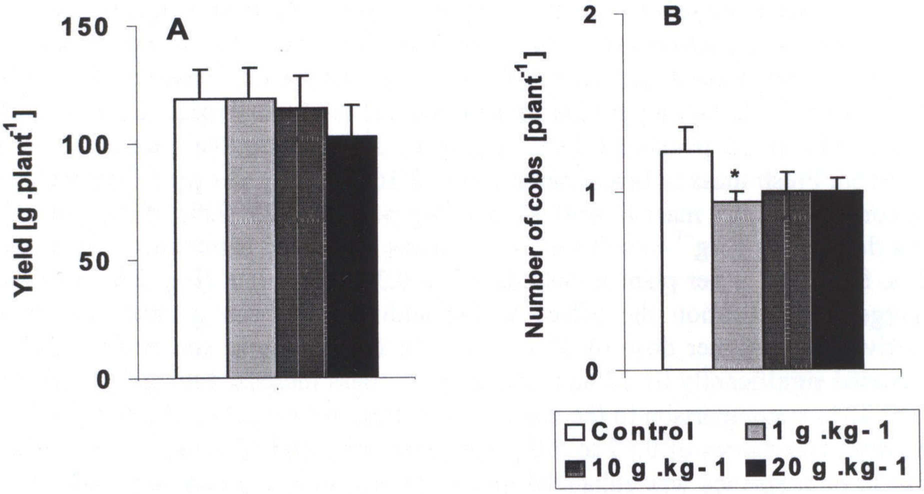

Fig. 3. Effect of additive on yield (A) and number of cobs (B) per plant of maize (*Zea mays* L. cv. Torena) determined in soil type III in Tvrdošovce. Plants were cultivated under field conditions from May 4 to October 6, 2001. Data represent means ± SE (n=5). *Significant difference at P= 0.05

In tomato plants the number of fruits per plant over the whole season (Fig. 4B) depended on the dose. At 1 g kg^{-1} the positive effect was about 12% over the control with 38.3 fruits per plant, but at 20 g kg^{-1} the additive had a negative effect, with 26.4 fruits per plant, which was 23% less than the control, where there were 34.2 fruits per plant. The influence of the additive on the total yield of tomato fruits per plant was similar (Fig. 4B). The additive had a positive effect on the number of fruits per plant and on the total yield in the first two harvests (Fig. 4A). The increase in the number of fruits per plant was 10% (6.8 fruits per plant) at 20 g kg^{-1} and 42% (8.8 fruits per plant) at 10 g kg^{-1}, while the total yield increased by 13% (253 g per plant) and 50% (337 g per plant), respectively, over the control, where 6.2 fruits and a yield of 224 g per plant were recorded after the first two harvests (Fig. 4A).

Discussion

At present, the production of good quality food products is impossible without intensification factors such as fertilizers that influence the yield potential of agricultural crops (Novoa and Loomis, 1981; Fecenko and Ložek, 2000; Kismányoky and Ragasits, 2003; Ramachandrappa et al., 2004). According to Bujnovský et al. (1998), the requirements of crops for essential elements are supplied from many sources, e.g. soil reserves, application of organic fertilizers, fixation of nitrogen by microorganisms. The tested additive, which is a product

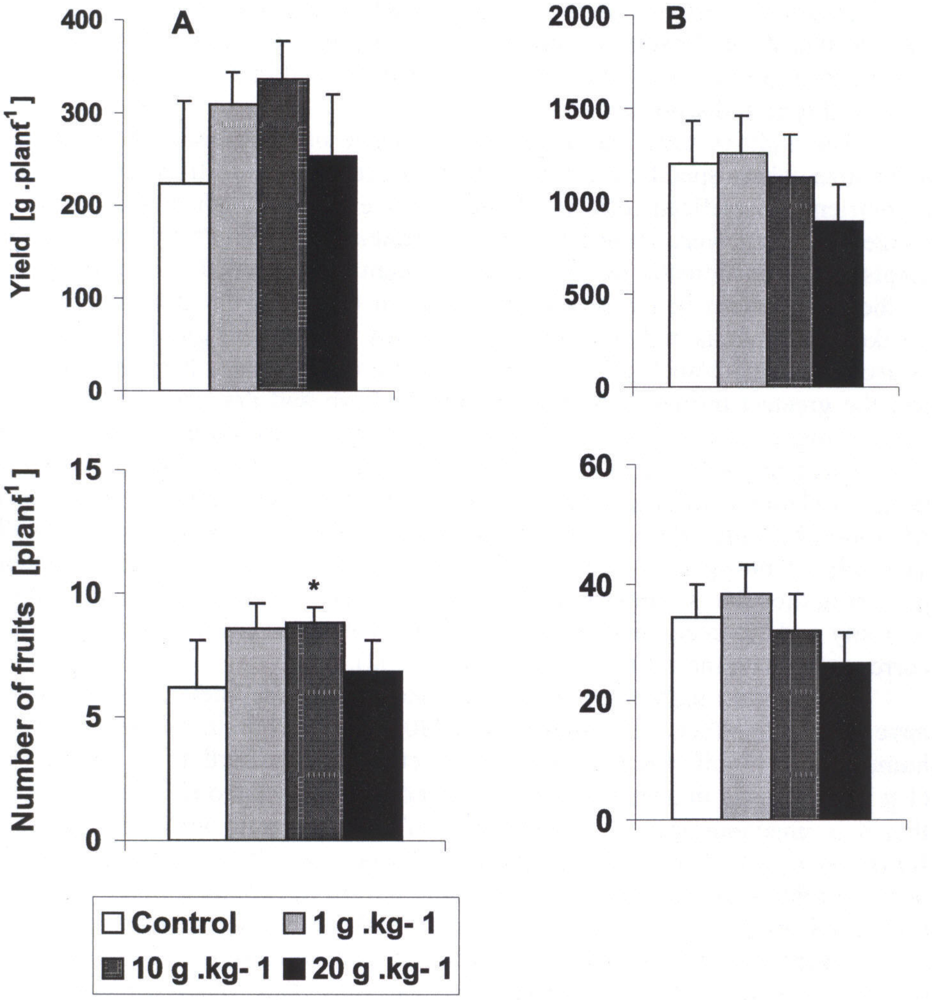

Fig. 4. Effect of additive on yield and number of fruits per plant of tomato (*Solanum lycopersicum* L. cv. Tornado) determined in soil type III in Tvrdošovce. Plants were cultivated under field conditions from May 5 to September 23, 2001. The first two harvests were made on July 8 and 15, 2001. Data represent means ± SE (n=5). A = Parameters after the first two harvests / per plant B = Parameters over the whole growing season / per plant * Significant difference at P= 0.05

of the carbonization of plant and animal food wastes, ranks among the non-traditional and as yet unverified sources of prospective plant fertilizer. The method developed for the carbonization of communal waste offers an effective way of utilizing it. Infrared spectrum analysis (Svetková, 2002; Morvová et al., 2003) confirmed that the additive contains a wide spectrum of mineral elements, the exact amounts of which were determined by atomic absorption analysis. No heavy metals were found to be present.

Biological research on the additive under greenhouse and field conditions showed that its application to the soil had both positive and negative effects on quantitative growth and yield parameters in the tested crops, depending on the dose, soil type and crop species.

The additive only had a positive influence on seed germination in bean and maize, where specific differences were observed in its utilization as a source of nutrients. Significant effects of the additive on the fresh and dry mass of maize and bean were recorded under greenhouse conditions when pre-grown plants with a sufficiently developed root system were planted. The good quality of the root system in maize and bean has an effect on the intensive nutrient uptake of the plants and significantly increases quantitative growth parameters, as ascertained by Vaněk et al. (2003) in several crop species. Nitrogen probably had the greatest influence on the increase in fresh and dry mass of maize and bean. A higher level of nitrogen is generally regarded, according to Masoni et al. (1990), as a major factor in the quantity of biomass and yield of crops, being the essential element with the greatest effect on photosynthetic intensity, the content of chlorophyll pigments and the accumulation of organic matter (Nátr, 1997). The role of nitrogen and the relationship between all the biogenic elements present in the additive appears to have had the greatest impact on photosynthetic intensity and the accumulation of fresh and dry mass of maize and bean, which corresponds with the results of Sabo et al. (2002).

In soil with higher humus content (soil type I) the additive was found to have a positive effect at the highest dose (20 g kg^{-1}), while in soil with very low humus content (soil type II) a positive effect was determined at the lowest dose (1 g kg^{-1}). This is in agreement with the findings of Fecenko (2003), who stated that it is uneconomical to fertilize soils of lower fertility with high doses of fertilizers or soils of good fertility with lower ones. It is suggested that the positive effects of the additive on soil type I were due, among other factors, to higher soil microorganism activity coupled with higher humus content and the good greenhouse conditions. The carbon in the additive could be a suitable source of energy for the production of CO_2 and other substances by microorganisms. According to Marendiak et al. (1987) microorganisms are very important for the cycles of other biogenic elements. The present results showed that the quality and structure of the soil, which are a function of various physical, chemical and biological properties, have a considerable influence on the regulation of nutrient uptake by plants from the soil and the additive, as also indicated by the results of Bedrna (1988) and Pechová et al. (2003).

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