学位論文内容の要旨

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学位論文題名

Effect of digestate application replacement to chemical fertilizer on the growth, quality and salt stress resistance of vegetables

（消化液の化学肥料の代替が野菜の成長、品質および塩ストレス耐性に及ぼす影響に関する研究）

Anaerobic digestion technology, which is extensively used for commercial processing of agricultural and other wastes worldwide, only a small part of digestate reused directly or indirectly. If this excess digestate cannot be properly managed, new environmental issues will arise. From a circular economic perspective, the application of digestate as organic fertilization is an interesting scenario. With the goal of chemical fertilizer reduction and organic fertilizer replacement of chemical fertilize in sustainable agriculture, it is important and urgent to explore the reasonable application of organic fertilizer and chemical fertilizer in the production of vegetables in facilities.

In this study, the effect of digestate as a fertilizer alternative or partial replacement of chemical fertilizer growth, yield and fruit antioxidant substances of tomato and soil properties was investigated in tomato production. In addition, the application of digestate substitute for chemical fertilizers on salt stress in lettuce was explored.

1. Digestate fertilization with reduced rates of chemical fertilization improves on the growth, yield and fruit quality of tomato

This is first tested the digestate as an alternative or partial replacement to chemical fertilization for tomato production. Digestate was added to agricultural soil, either individually or along with inorganic fertilizer, and tomato plants were cultivated under open field and plastic greenhouse conditions. Inorganic fertilizer alone was also applied, with unfertilized soil used as a control. The impact of three fertilization strategies at same nitrogen dose and a control on growth and yield was investigated under both cultivation environments. The results showed that the application of digestate significantly increased growth of tomato including height, stem diameter, leaf chlorophyll content index and photosynthetic rate of tomato plant and sugar-acid ratio, protein, and ascorbic acid of fruit as well as decreased nitrate concentration in fruit compared to chemical fertilizer and untreated plants. Combined digestate to chemical fertilization had the greatest increase in tomato yield, which is up to 174.28% and 67.37% under field and greenhouse conditions, respectively, compared to untreated control.

2. Bioactive compounds and antioxidant activity of tomato fruits as affected by digestate fertilization

In order to further elucidate the effect of digestate replacement of chemical fertilizers on tomato quality, bioactive compounds and antioxidant capacity in tomato fruits were analyzed. This study investigated the sugars, organic acids and phenolic compound levels, total phenolic (TP) and antioxidant capacity (TEAC) of four different fertilizer applications. Analysis of sugars, organic acids, phenolic compounds, TP and TEAC levels in tomato fruit

showed statistically significant differences under fertilizer applications. Chlorogenic acid was the predominant phenolic compounds found in tomato fruit of both cultivation environments. The highest chlorogenic acid value (41.04 mg kg^{-1}) was found in the application of digestate and the lowest (18.35 mg kg^{-1}) in control under greenhouse condition. Fructose and glucose were the predominant saccharides found in all treatments. Citric acid content was the dominant organic acid in tomato fruits, with the highest citric acid value found in the application of digestate. TP and antioxidant levels were significantly higher in the application of digestate as compared to other fertilization strategies.

3. Variation in soil chemical properties and enzymatic activities under addition of digestates and chemical fertilization

This part of work investigated the effect of digestate replacement of chemical fertilizers on soil soil chemical properties and enzymatic activities after the tomato harvest. The results showed that the application of digestate significantly increased the activities of urease, sucrase, protease and nitrate reductase in the soil. Also, the application of digestate neutralized the soil pH and increased the soil organic carbon content. In addition, the application of digestate also increased the soil nitrogen and ammonium nitrogen content. Fertilization with digestate increased soil fertility, including nitrogen and carbon levels, and enhanced soil enzyme activities. In short, the combined use of digestate along with chemical fertilizer allows for reduced inorganic fertilization while maintaining tomato fruit yield, enhancing tomato fruit quality, and improving soil characteristics.

4. Comparative effects of chemical fertilizer and digestate on growth, antioxidant system, and physiology of lettuce under salt stress

Experimental treatments comprised application of two types of fertilizer (chemical fertilizer and digestate) and three NaCl concentrations (0, 3, and 7.5 dS m^{-1}). High NaCl concentrations resulted in significantly lower photosynthesis, growth, and physiological indices compared with those under no NaCl addition. However, under the 7.5 dS m^{-1} NaCl condition, digestate application (DA) increased the fresh weight (42%), dry weight (27%), photosynthetic pigment contents and photosynthesis (20%) of lettuce compared with that under chemical fertilizer application (CFA). Accumulation of reactive oxygen species was markedly lower, and the membrane stability index was therefore higher, under DA compared with under CFA within the same salinity level. Lipid peroxidation was lower under DA compared with under CFA in all salinity treatments. Salt stress up-regulated the antioxidant system and DA further increased the enzymatic and non-enzymatic antioxidant capability compared with that under MFA. In addition, the total water use was lower and water-related indices were higher under DA compared with under CFA.

The overall results obtained the highest yield of tomatoes from digestate fertilization and achieved higher fruit quality while promoting the growth in the tomato plant. The synthesis of bioactive compounds (including sugar, phenolic components and some acids) and antioxidant capacities in tomato fruits were also enhanced under application of digestate. Moreover, digestate was found to neutralize soil pH significantly increase soil C, N, and enzyme activities. In addition, the application of digestate replacement of chemical fertilizer could be a promising practice to alleviate the negative impact of salt stress on the productivity and physiological characteristics of lettuce plants.