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Long-Term Effect of Flocculated Sewage Sludge on Growth of Poplar under Drought Conditions

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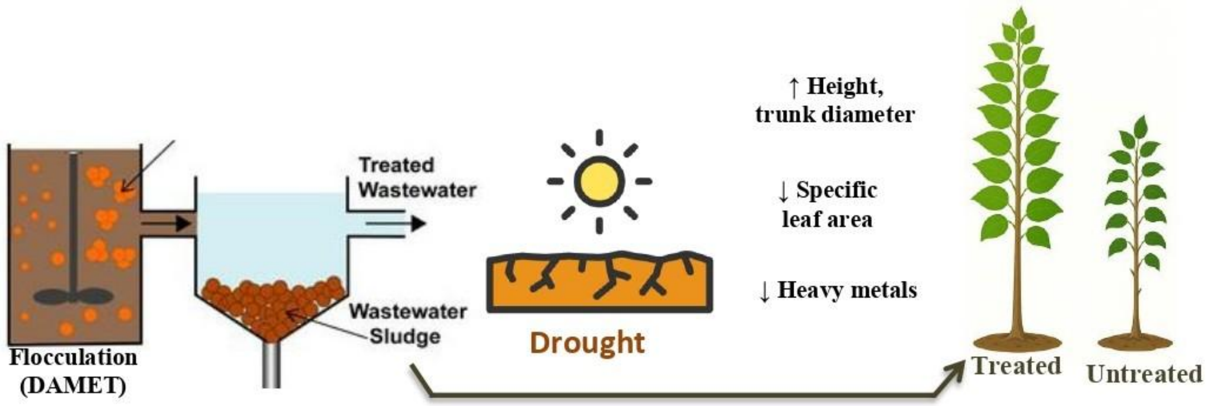
Graphical Abstract

This study proposes a circular and ecological approach to transform flocculated sludge (DAMET) from wastewater treatment plants into a resource that can be used in forestry and sustainable bioenergy. It demonstrates the effectiveness of flocculated sludge in promoting the growth and resilience of *Populus x canadensis* under water stress conditions and in reducing the risk of metal contamination in plant biomass.



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Abstract: Poplar is popular for protective forest plantations and raw material for renewable energy and other industries. A long-term experiment with the *Robusta* clone to determine the effect of untreated and flocculant-treated sewage sludge was established on phyto-remediated loess-like loam at the DSAEU Land Reclamation Research Station in the Dnipropetrovsk region with applications of 20, 40 and 60 t/ha of both untreated and flocculated sludge. In the sixth year, in comparison to the control, the flocculated sewage sludge increased the average tree height and diameter of the three variants by 11 and 19.5%, respectively; somewhat less in the case of untreated sludge. The specific leaf area in the variants receiving flocculated sewage sludge was lower than in those receiving untreated sludge by 13-23%. Under drought conditions, the combination of greater organic matter and nitrogen and lower content of heavy metals in the flocculated sewage sludge was more favourable for the growth of poplar during six years of its cultivation.

Keywords: *Poplar, Growth parameters, Technosol, Heavy metals.*

Introduction

Hybrid poplars (*Populus* sp.) are among the most adaptable and fast-growing trees in Ukraine. Grown in a short-rotation plantations, they can be a reliable source of biomass, even on marginal lands [1,2] and well suited for applications such as the production of fuel briquettes, cellulose, lignin and other bioproducts [3,4]. For phytoremediation of heavy metal pollution, poplar plantations fertilized with sewage sludge reduce the risk of contamination of adjacent areas [5,6]. Even so, poplar is exposed to drought and has certain soil fertility requirements [7,8].

Recent Eastern European studies of poplar for biofuel show the need to take account of the increasing rainfall deficit [9]. Field experiments under irrigation have demonstrated the effectiveness of sewage sludge application which significantly increased production, with the *Beaupré* variety yielding more than *Trichobel* [10].

The objective of our present case study was to highlight the effect of long-term application of flocculated sludge on the growth of poplar on technosol under drought conditions.

Materials and Methods

Annual precipitation and air temperature data for the growing season (April-October) for 2019-2025 (Tables 1 and 2) indicate increasing aridity. Temperatures are rising but precipitation is not:

Table 1. Annual precipitation in Dnipropetrovsk region, mm

Year	2019	2020	2021	2022	2023	2024	2025
Precipitation	385	362	536	473	518	359	345

Table 2. Annual air temperature in the Dnipropetrovsk region, ^{o}C

Year	2019	2020	2021	2022	2023	2024	2025
Day	26.7	26.0	26.9	26.1	26.0	27.6	29.0
Night	14.1	13.3	14.9	13.9	13.8	14.3	14.8

Research on the long-term effect of application of sewage sludge on the growth of poplar on technosol was conducted at the DSAEU Land Reclamation Research Station in the south of the Dnipropetrovsk region. A field experiment with the *Robusta* clone began in the spring of 2020. Untreated and flocculant-treated (F) sewage sludge (SS) was introduced into pits prepared with a powered auger according to the scheme of control and (in t/ha) 20SS, 40SS and 60SS; and 20SSF, 40SSF and 60SSF. The sludge was treated with DAMET flocculant during the final stage of sludge formation at a waste water treatment facility in Dnipro. The flocculent is a cationic electrolyte at an optimal concentration for the specific quality of the suspension and an aqueous solution of a structuring additive containing high-molecular-weight polyethylene oxide, propylene glycol, glycerin, silicon dioxide, and sodium and calcium salts. A key feature of the polyethylene oxide-based additive is that the treated sludge is structured, forming a stable spatial system of through-flowing channels and cavities that retains its properties during secondary wetting. Ensuring high porosity of the sludge was key to its dewatering. As a result, the content of total organic matter and nitrogen in the flocculated sewage sludge became 1.4-1.5 times higher than in the original form, and the concentrations of manganese, zinc, copper, chromium and lead were 1.4-3.3 times lower [11].

The technosol is phyto-remediated loess-like loam with a humus content of 1.5%.

Six-year-old trees were measured by height and trunk diameter at height of 1.3m, and specific leaf area was determined as the ratio of the total leaf area to the total dry mass of leaves per plant: an indicator of leaf density or fineness expressed in units of area per mass. The content of heavy metals in leaves was determined using a mass spectrometer ICP MS.

Results and Discussion

Figures 1 and 2 summarize the two main morphometrics after six years.

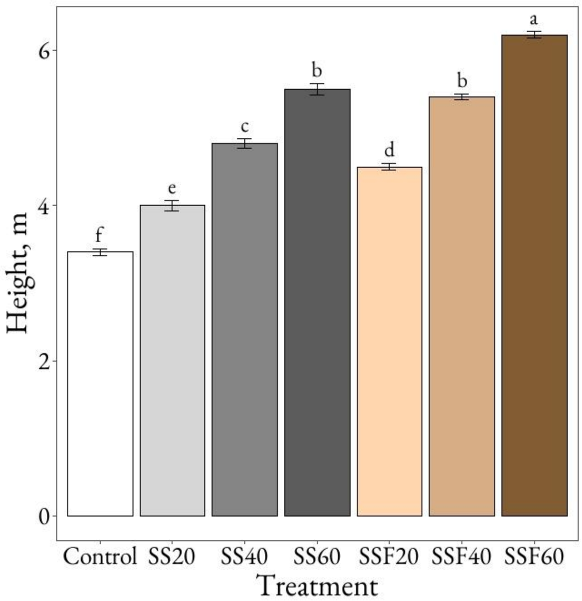

Figure 1. Height of poplar plants, m

Values are expressed as means ± standard error (n=5). Different lowercase letters (a–f) indicate significant differences between groups (treatments) at $p < 0.05$. Statistical differences were determined using analysis of variance (ANOVA) followed by Tukey's HSD test.

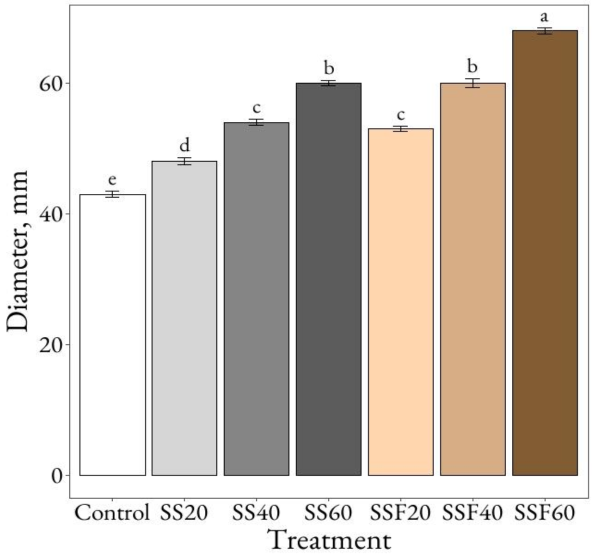

Figure 2. Poplar trunk diameter, mm

Analysis of data on stem height and diameter showed two trends. The first is associated with an increase in height and diameter according to the amount of applied sewage sludge; the second trend is an even greater effect of using flocculated sewage sludge as a soil additive. Application of flocculated sludge resulted in an increase in height and diameter values for three SSF treatments by an average of 11 and 19.5% compared to nontreated variants.

The specific leaf area in the treatments with the initial introduction of flocculated sludge at 20, 40 and 60 t/ha was less than with untreated sludge by 13, 18.4 and 23%, respectively (Fig. 3).

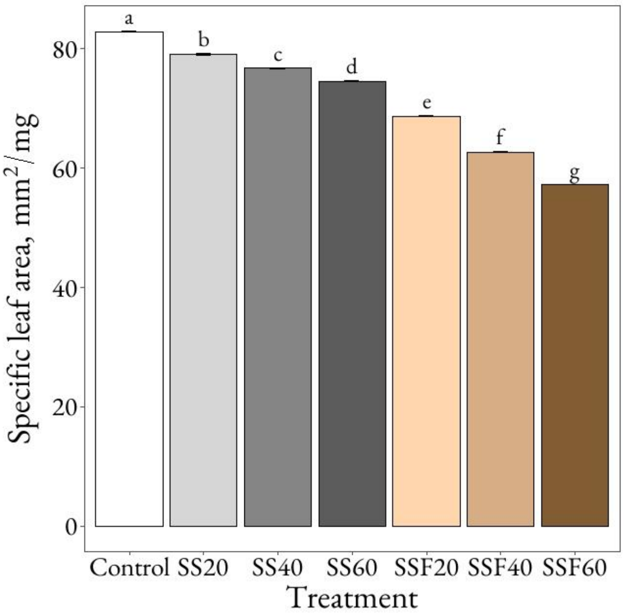

Figure 3. Specific leaf surface area, mm^2/mg

Moreover, the sludge soil amendment contributed to an increase in the concentration of manganese, zinc and copper in the leaves (Fig. 4). Compared to the control, the increase in manganese content in leaves at a sludge dose of 20 t/ha was 8.6-8.8%; at 40 t/ha, 12.8-16.8%, and at 60 t/ha, 17.2-22.3%. The concentration of zinc in leaves increased with the same sludge doses by 40.2%, 60.7% and 81.4%, respectively. The application of flocculated sludge had a lesser effect; the concentration of zinc in leaves increased by 14.6%, 49.6% and 55.9%, respectively.

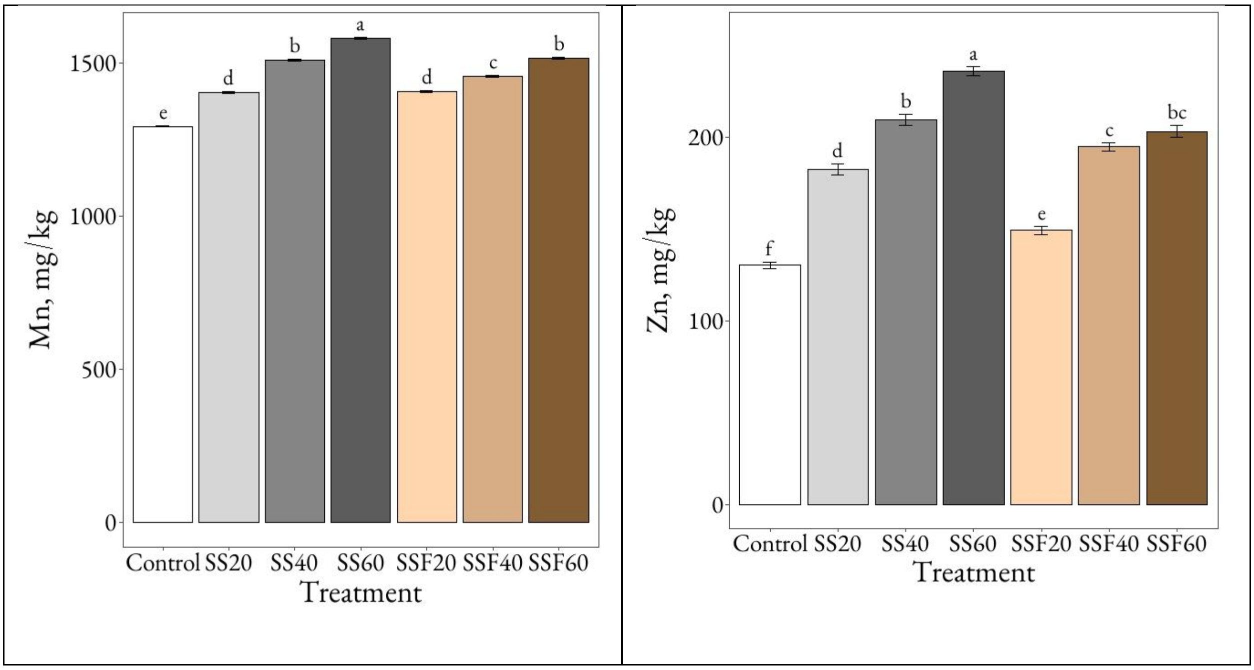

Figure 4. Mn and Zn content in leaves

A change in copper content in poplar leaves was significant only at the higher sludge doses (Fig. 5); the concentration of copper in leaves increased by 21.1-50.0% but the effect of untreated sewage sludge was more pronounced.

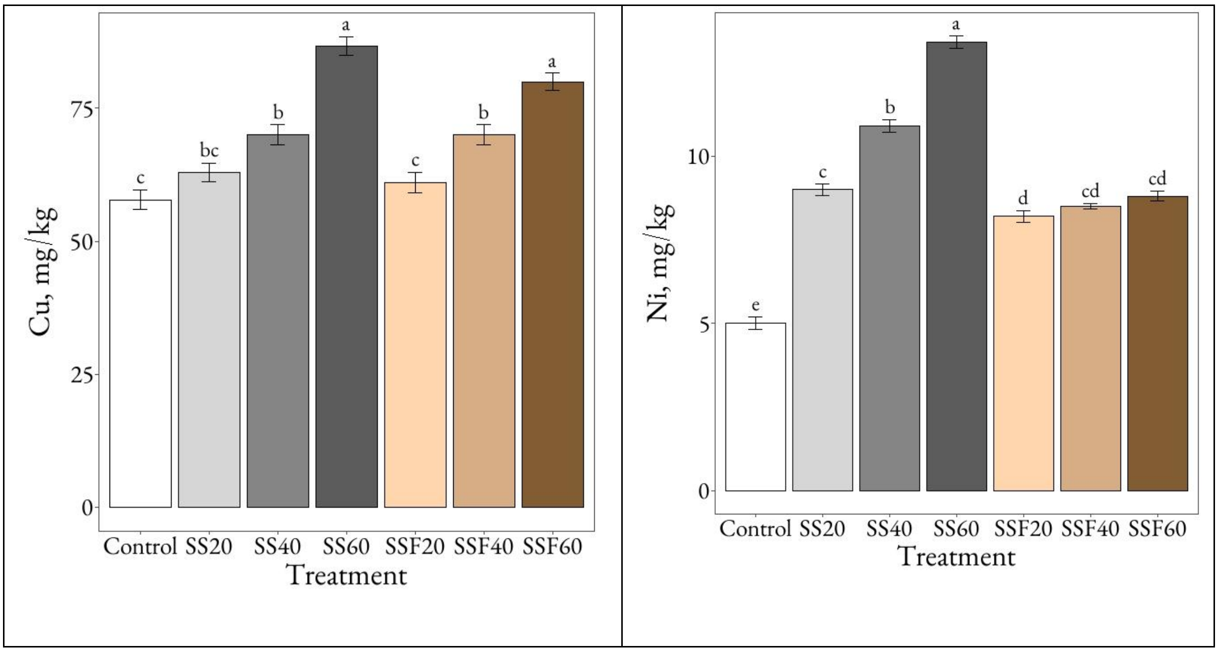

Figure 5. Cu and Ni content in leaves.

The addition of untreated sewage sludge increased the nickel content in the leaves by almost 80% at a dose of 20 t/ha, by 2.2 times at a dose of 40 t/ha, and by 2.7 times at a dose of 60 t/ha. The effect of flocculated sludge was much smaller: the nickel content increased by 64-76%, depending on the dose. The lesser heavy metal accumulation in poplar leaves under the application of flocculated sewage sludge is a good thing, and suggests a more normal physiology.

Discussion

In Ukraine, global heating has markedly increased droughts from south to north [12,13]. The destruction of the Kakhovka Dam in June 2023, together with the destruction of many protective forest belts by military action [14], has further aggravated soil degradation and drought in the southeast of the country [15] but, over the past two years, the natural overgrowth of the Velikiy Lug at the bottom of the Kakhovka Reservoir has underscored the adaptive abilities of poplar [16].

Even so, it is necessary to assess the most resilient poplar clones in relation to scarcity of moisture and nutrients, unfavourable soil texture and soil contamination. In Croatia, the survival rate of the ten poplar clones in experimental plots after four growing seasons ranged from 52.5 for the *Koreana* clone to 92% for the *SV885* and *SV490* clones [17]. In Slovakia, the *Pannonia* clone of Canadian poplar (*Populus × canadensis* Moench) demonstrated greater resistance at air temperatures of about 40°C, having a smaller specific leaf area than the *Gigant* clone [18].

Our data over six years with three levels of flocculated sewage sludge application showed that a smaller specific leaf area made for greater resistance of plants to high air temperatures, as demonstrated by the increase in the height and trunk diameter of young trees. The use of flocculated sewage sludge as a soil additive promoted an increase in tree height and girth according to the dose of soil amendment (20, 40 and 60 t/ha) on average by 11 and 19.5%. The specific leaf area in experimental variants with the initial application of flocculated sewage sludge was lower than in the one where the sludge was not treated with a flocculant, respectively, by 13, 18.4 and 23%.

Thus, it becomes clear that a greater content of organic matter and nitrogen and a lower content of heavy metals in the flocculated sewage sludge were more favourable for the growth of poplar during six years of its cultivation in droughty conditions.

Acknowledgement

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