Bioefficacy of waste biomass-based fertilizers under drought and salinity stress in model crops

G. Izydorczyk[1], D. Skrzypczak[1], F. Gil[1], M. Mironiuk[1], K. Chojnacka[1], M. Samoraj[1]

[1]Department of Advanced Material Technologies, Wroclaw University of Science and Technology, Wroclaw, Lower Silesia, 50-370, Poland
Keywords: waste biomass, biofertilizers, germination tests, pot tests
Presenting author email: grzegorz.izydorczyk@pwr.edu.pl

Assessing the bioefficacy of newly developed fertilizers is essential to determine their impact on plant growth and development, particularly under abiotic stress conditions such as drought and salinity. In the context of ongoing climate change and rising global temperatures, climate-resilient cropping systems require fertilizers that support physiological tolerance mechanisms in plants exposed to drought and salinity (Francis et al., 2023). Water scarcity and soil salinization are major abiotic stressors contributing to reduced crop yields and soil degradation, particularly in arid and semi-arid regions, negatively affecting both crop quality and agricultural productivity. The shift towards sustainable agriculture is driving the development of fertilizer formulations with optimized nutrient content, organic matter levels, and micronutrient bioavailability. The biological effectiveness of such fertilizers enhances plant resilience to environmental stress, leading to improved yield stability and reduced production losses by promoting osmotic adjustment, antioxidant activity, and micronutrient uptake efficiency (Jacques et al., 2021). Fertilizers enriched with biostimulants or micronutrients that modulate plant metabolism may accelerate adaptive responses to drought and salinity, facilitating measurable improvements in stress-induced biomass losses under controlled and semi-field conditions. This is particularly relevant in organic farming systems, where the exclusion of chemical plant protection products necessitates enhanced abiotic and biotic stress tolerance in crops. The designed fertilizers have the potential to improve crop performance under abiotic stress, contributing to more resilient agricultural practices at the local scale (Penuelas et al., 2023).

This study aimed to develop and evaluate three ecological fertilizer formulations based on waste biomass, each tailored for a specific crop category: cereals (F1), protein crops (F4), and vegetables (F8). The formulations exhibited high contents of organic matter (C_{org}: 25.6±2.6 - 33.6±3.6%), nitrogen (N_{total}: 2.54±0.25 - 2.42±0.34%), phosphorus (P_2O_5: 1.42±0. 28 - 3.85±0.77%), potassium (K_2O: 4.02±0.80 - 5.18±1.04%), and total micronutrients (B, Cu, Mn, Fe, Zn) ranging from 2% to 3%, and all met the criteria for ecological fertilizers.

The biological effectiveness of the formulations was evaluated through pot experiments under simulated drought and salinity stress, using cucumber, lupin, and corn as model plants. Each formulation was tested at three application rates (75%, 100%, 150%) compared to a commercial reference fertilizer and an unfertilized control. After 30 days, plant biomass was harvested and subjected to biometric measurements and elemental composition analysis (Tables 1 and 2).

Table 1. Selected elements content in plants fertilized with F1, F4 and F8 formulations under drought stress

Corn					
Fertilizer/dosage	**F1/75**	**F1/100**	**F1/150**	**REF/100**	**Control**
B (mg/kg)	112±16,8	103±15,4	145±21,7	<1,50±0,23	<1,50±0,23
Cu (mg/kg)	18,4±2,8	14,1±2,1	50,4±7,6	221±33	15,7±2,4
Fe (mg/kg)	193±29	98±14,7	134±20	87,4±13,1	84,7±12,7
Mn (mg/kg)	44,1±6,6	48,1±7,2	67±10,1	30,7±4,6	23,9±3,6
Zn (mg/kg)	56,4±8,5	51,3±7,7	101±15	27,8±4,2	24,8±3,7
Lupin					
Fertilizer/ dosage	**F4/75**	**F4/100**	**F4/150**	**REF/100**	**Control**
B (mg/kg)	20,7±3,1	43,3±6,5	65,8±9,87	4,46±0,67	7,84±1,18
Cu (mg/kg)	9,39±1,41	16,8±2,5	14±2,11	21,5±3,2	9,4±1,4
Fe (mg/kg)	69,2±10,4	71,8±10,8	79,9±12	91,2±13,7	64,4±9,7
Mn (mg/kg)	60,2±9	78,4±11,8	94,4±14,2	69,1±10,4	50,8±7,6
Zn (mg/kg)	41,5±6,2	37,8±5,7	43,8±6,6	27,9±4,2	36,6±5,5
Cucumber					
Fertilizer/dosage	**F8/75**	**F8/100**	**F8/150**	**REF/100**	**Control**
B (mg/kg)	72,9±10,9	98,3±14,7	132±19,9	<1,50±0,23	<1,50±0,23
Cu (mg/kg)	11,2±1,7	14,3±2,1	13,9±2,1	61,5±9,2	8,91±1,3
Fe (mg/kg)	124±19	128±19	98,9±14,8	166±25	87±13,1
Mn (mg/kg)	74,5±11,2	106±16	218±33	96,2±14,4	64,5±9,7
Zn (mg/kg)	46,7±7	52,4±7,9	80,6±12,1	64,8±9,7	46,4±7

Under drought stress, enhanced uptake of boron, manganese, and zinc was observed across all tested species, indicating that the uptake of these micronutrients may be less sensitive to drought-induced reductions in soil water availability (Ahanger et al., 2016).

Table 2. Selected elements content in plants fertilized with F1, F4 and F8 formulations under salinity stress

Corn					
Fertilizer/dosage	**F1/75**	**F1/100**	**F1/150**	**REF/100**	**Control**
B (mg/kg)	40,9±6,1	48,2±7,2	82±12,3	<1,50±0,23	<1,50±0,23
Cu (mg/kg)	22,1±3,3	22,4±3,4	23,2±3,5	5,65±0,85	14,2±2,1
Fe (mg/kg)	151±23	103±15	109±16	84,7±12,7	80±12
Mn (mg/kg)	41±6,1	43,8±6,6	54,8±8,2	25,9±3,9	21,5±3,2
Zn (mg/kg)	58,3±8,7	53,1±8	59,6±8,9	25,9±3,9	22,4±3,4
Lupin					
Fertilizer/ dosage	**F4/75**	**F4/100**	**F4/150**	**REF/100**	**Control**
B (mg/kg)	24±3,6	35,1±5,3	46,3±6,9	4,49±0,67	7,35±1,1
Cu (mg/kg)	9,21±1,38	11,4±1,7	9,49±1,42	10,4±1,6	10±1,5
Fe (mg/kg)	78,1±11,7	93,7±14,1	75,9±11,4	102±15	69,3±10,4
Mn (mg/kg)	60,2±9	49,6±7,4	88,6±13,3	70,2±10,5	43,6±6,5
Zn (mg/kg)	39,9±6	39±5,9	42,2±6,3	32,6±4,9	32,4±4,9
Cucumber					
Fertilizer/dosage	**F8/75**	**F8/100**	**F8/150**	**REF/100**	**Control**
B (mg/kg)	65,9±9,9	59,2±8,9	110±17	3,6±0,54	<1,50±0,23
Cu (mg/kg)	10±1,5	29,7±4,4	10,5±1,6	13,2±2	8±1,2
Fe (mg/kg)	88,9±13,3	134±20	121±18	115±17	79,1±11,9
Mn (mg/kg)	78,7±11,8	80,6±12,1	103±15	87,4±13,1	58,6±8,8
Zn (mg/kg)	42,6±6,4	51,9±7,8	58,4±8,8	56,7±8,5	49,9±7,5

Salinity stress also influenced micronutrient accumulation, though no clear dose–response relationship was found between fertilizer application rate and elemental content in plant tissues. This variation may be attributed to species-specific metabolic responses to salinity, reflecting differential activation of micronutrient-dependent physiological pathways (Hussain et al., 2018).

The findings indicate that targeted fertilization with compositionally optimized formulations can effectively mitigate the adverse effects of abiotic stress. The inclusion of micronutrients and biostimulants in these formulations offers a promising strategy for enhancing stress resilience in organic farming systems. The formulations have been upscaled and are currently undergoing biological efficacy validation in field trials under real-world agronomic conditions. The trials aim to evaluate the season-long effects of the fertilizers on biomass production, micronutrient uptake, and stress response under variable field condition throughout the cropping season.

Acknowledgements

This work was financed by the National Centre for Research and Development under project no. LIDER13/0290/2022 entitled: “Innovative comprehensive ecological fertilizers based on waste biomass”.

References

Ahanger, M. A., Morad-Talab, N., Abd-Allah, E. F., Ahmad, P., & Hajiboland, R. (2016). Plant growth under drought stress. *Water Stress and Crop Plants: A Sustainable Approach*, *2–2*, 649–668. https://doi.org/10.1002/9781119054450.CH37

Francis, B., Aravindakumar, C. T., Brewer, P. B., & Simon, S. (2023). Plant nutrient stress adaptation: A prospect for fertilizer limited agriculture. *Environmental and Experimental Botany*, *213*, 105431. https://doi.org/10.1016/J.ENVEXPBOT.2023.105431

Hussain, S., Khalid, M. F., Hussain, M., Ali, M. A., Nawaz, A., Zakir, I., Fatima, Z., & Ahmad, S. (2018). Role of micronutrients in salt stress tolerance to plants. *Plant Nutrients and Abiotic Stress Tolerance*, 363–376. https://doi.org/10.1007/978-981-10-9044-8_15/TABLES/2

Jacques, C., Salon, C., Barnard, R. L., Vernoud, V., & Prudent, M. (2021). Drought Stress Memory at the Plant Cycle Level: A Review. *Plants 2021, Vol. 10, Page 1873*, *10*(9), 1873. https://doi.org/10.3390/PLANTS10091873

Penuelas, J., Coello, F., & Sardans, J. (2023). A better use of fertilizers is needed for global food security and environmental sustainability. *Agriculture and Food Security*, *12*(1), 1–9. https://doi.org/10.1186/S40066-023-00409-5/METRICS