Municipal solid waste organic fraction (kitchen waste) management via urban green areas fertilization

WP4 Report

Authors:
PhD. Eng. Ksawery Kuligowski,
Prof. Adam Cenian
MSc. Eng. Lesław Świerczek
MSc. Eng. Izabela Konkol

Spis treści

1. The relationship with the ISWM framework

1.1 The solid facts about the solid waste management in Poland

- **12,500 Mt** – the annual production of the municipal waste in Poland,
- **3,269 Mt** – amount recycled (26% on average),
- **1,012 Mt** – amount digested and composted.

In 2018 a statistical Pole has produced 325 kg of waste/year on average per capita, below 200 for rural communes, up to 384 in urban communes; 38% of municipalities produced less than **200 kg** of municipal waste per inhabitant (mainly rural communes), including two communes below 50 kg, and in 53% of municipalities the amount of generated waste was in the range of 200-400 kg per inhabitant. The largest amounts of municipal waste are generated in touristic municipalities - in six of them over **1000 kg** of domestic waste per inhabitant was collected. In comparison, EU avg. is 480 kg per year per capita, the leader is Denmark 780 kg; Poland is the second lowest producer after Romania (280 kg). There are 192 installations of Mechanical and Biological Waste Processing in Poland and 195 installations for bio-waste composting.

In 2018, there were 2144 publicly available points for selective domestic waste collection, of which 37% were located in cities and 63% in rural areas. In 2018, over 3,6 Mt (94 kg/inhabitant) were collected selectively, of which as much as 3,3 Mt from households (29% of the total generated municipal waste amount), which means an increase by 11% in comparison to the previous year.

In 2018, 28% of the total amount of domestic waste it was a biodegradable waste (i.e. around 26 kg/inhabitant - GUS 2018), which includes food waste of plant origin with high biogas potential. It gives over 3,5 Mt of biowaste, and even if composted or anaerobically digested, it is still available for the novel management techniques e.g. fertilisation of urban green areas.

1.2 The use of biowaste as fertilizers

There are many reports in the literature related to the use of biowaste for fertilization purposes. It is known the possibility of using alfalfa and goldenrod (after CO2 extraction) as micronutrient sorbents for purposes fertilizers. The biomass was enriched with Cu2+, Zn2+ and Mn2+ micronutrient ions. Sorption capacity of post-extraction materials increased 54-1700 times compared to raw biomass (Samoraj et al., 2017). In another work, blackcurrant seeds after supercritical extraction were used (Samoraj et al., 2015, 2016) as carriers of micronutrients. The valorization into Cu2+ ions is shown. The determined sorption capacity was 17 mg / g. In turn, Tuhy et al. (2014) presented fertilizers based on peat, bark and residues from supercritical extraction of seaweed. Research related to the biosorption of fertilizing micronutrients and application tests on plants were carried out. Germination tests were carried out on Lepidium sativum. Plants fertilized with enriched biomass were characterized by higher plants bioavailability of micronutrients and higher weight compared to the control group (plants fertilized with inorganic salts).

Waste biomass can also be used as fertilizer without prior enrichment. The microalgae used first for the production of biodiesel (Chlorella variableilis and Lyngbya majuscula) were after extraction applied as a natural nitrogen-rich fertilizer. To assess manure as chemical fertilizer, studies were carried out on maize. Root biomass loss was observed, with no significant effect on leaf biomass or chlorophyll content in plants. The use of natural fertilizer made it possible to obtain a comparable yields as with chemical fertilizer. It was found that post-extraction waste can partially replace micronutrients contained in the chemical fertilizers (Maurya et al., 2016). The promotion of this type of solutions allows to minimize the use of fertilizers from non-renewable sources, as well as the management of valuable waste from various economic directions.

1.3 The relationship between the case and the ISWM framework

Management of the municipal solid waste organic fraction (MSW-OF) by means of fertilization of urban green areas is strictly related with the presented below ISWM framework, namely:

- Stakeholders: Local authorities decide where to fertilize the urban areas, service users do the job, and citizens make the final use of it,
- Waste System Elements: **Treatment** with effective microorganisms on-site, pelletizing and drying (waste collection plant), then **Reuse** as a fertilizer, **Recycling** of nutrients and organic matter into the soil and subsequent **Recovery** of nitrogen, potassium, phosphorus and other microelements by grass.
- Aspects: **Technical** - required pretreatment methods, **Environmental** connected with waste-to-land application, **Financial/ Economic** due to savings in reduced mineral fertilizer usage, **Sociocultural** as citizens see the visible effect with their own eyes, **Institutional** as the municipalities are engaged, **Policy/ legal/ political** as the local authorities need to approve the new waste-based fertilizer

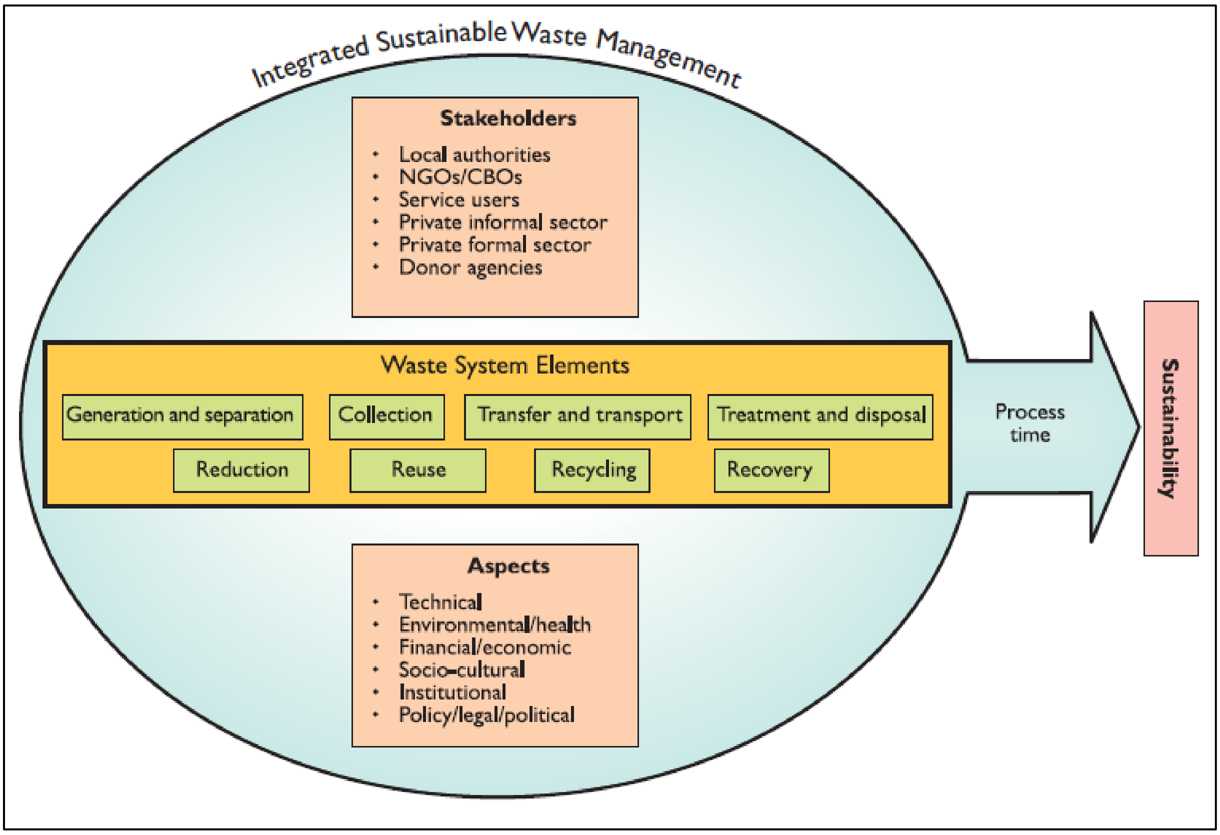


Fig. 1 *The Integrated Sustainable Waste Management scheme developed under the WasteMan Project*

2. Motivation

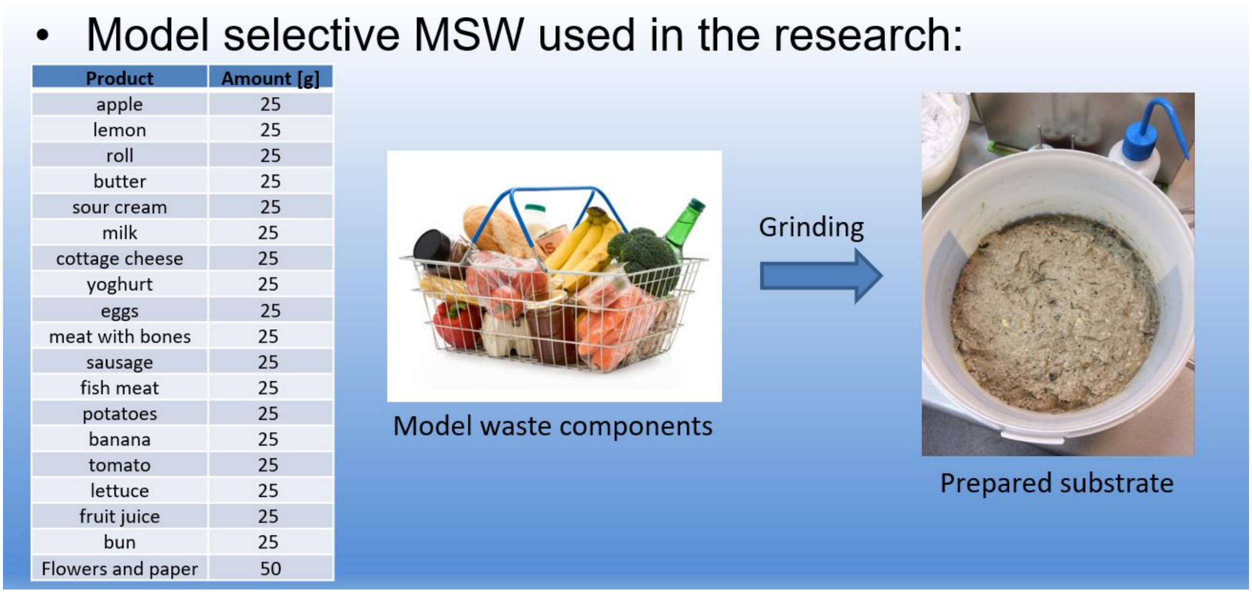
The goal of the study could be characterized by the 3 following subgoals:

1. To verify the MSW-OF modified by Effective Microorganisms as a fertilizer,
2. To compare its efficiency to mineral fertilizer,
3. To evaluate the residual effect on soil after MSW-OF fertilizer application.

3. Methodology

3.1 Waste pretreatment

First, the model waste have been prepared, according to the following recipe presented in Fig. 2. Then such prepared substrate has been ground, treated by effective microorganisms (EMs), pre-dried and pelleted (Fig. 3).



Product	Amount [g]
apple	25
lemon	25
roll	25
butter	25
sour cream	25
milk	25
cottage cheese	25
yoghurt	25
eggs	25
meat with bones	25
sausage	25
fish meat	25
potatoes	25
banana	25
tomato	25
lettuce	25
fruit juice	25
bun	25
Flowers and paper	50

__Fig. 2__ Preparation of the model MSW-OF

__Fig. 3__ Production of the MSW-OF based fertilizer for the glasshouse experiment

3.2 Fertilizer application scenarios

The assumption for the experiment was to determine the response of the grass grown on the soil, where two fertilizers were applied: novel EM-modified MSW-OF and mineral fertilizer commonly accessible on the market. The dosages were carefully planned:

- Normal dose as the one recommended by the mineral fertilizer supplier (20 kg N/ ha)
- Maximum allowable dose according to the Polish legislation (170 kg N/ ha)
- Overdose in order to catch the overfertilization effect.

Table. 1 Fertilizer application scenarios with assumed fertilizer loads, calculated masses of nitrogen and fertilizers.

	Control	MINERAL FERTILIZER				EM MODIFIED OFMSW			
Scenario	kg N/ha	kg N/ha	g N/pot	g d.m. fertilizer/pot	mg N/kg soil d.m.	kg N/ha	g N/pot	g d.m. fertilizer/pot	mg N/kg soil d.m.
1 (Normal Dose)	0	20	0,033	0,75	0,024	20	0,033	0,97	0,024
2		70	0,116	2,63	0,083	70	0,116	3,38	0,083
3		120	0,198	4,50	0,142	120	0,198	5,79	0,142
4 (Max in PL)		170	0,281	6,38	0,201	170	0,281	8,21	0,201
5		220	0,363	8,25	0,260	220	0,363	10,62	0,260
6		270	0,446	10,13	0,319	270	0,446	13,04	0,319

The soil for each of 39 pots was prepared by mixing the pre-sieved sand with peat in 5:1 gravimetric ratio. Then the prepared micronutrients were added (Table 2) and soils were incubated for 4 days at Field Capacity (22% w/w). Subsequently fertilizers were added according to the amounts given in Table 1 (Figure 4), then 80 seeds (ca. 0.5 g) of grass were placed on top and covered with the topsoil. Afterwards everything was watered to each the Field Capacity.

Table. 2 Micronutrients added to the pots

Salt	Concentration (g/l)	ml/kg soil	ml/ pot	Application
K_2SO_4	42	6.7	12	** At the beginning and 6 weeks later
$CaCl_2{\cdot}2H_2O$	90	3.3	6	
$MgSO_4{\cdot}7H_2O$	24	3.3	6	
$MnSO_4{\cdot}H_2O$	6	3.3	6	
$ZnSO_4{\cdot}7H_2O$	5.4	3.3	6	
$CuSO_4{\cdot}5H_2O$	1.2	3.3	6	
H_3BO_3	0.42	3.3	6	
$CoSO_4{\cdot}7H_2O$	0.16	3.3	6	
$Na_2Mo_4{\cdot}2H_2O$	0.12	3.3	6	

MAINTAINANCE: Soil moisture maintained at Field Capacity (ca. 35% cm^3 H_2O/cm^3 soil e.g. 22% w/w) by watering with deionised water.

INTERIM POINTS: Harvesting after 30, 90, 180 days of growth for biomass yield and NPK uptake analysis.

END: Residual soil properties analysis (NPK, pH, EC)**.**

Figure. 4 Fertilizer application to the soil (a) and (b) EM-MSW-OF, (c) mineral fertilizer

3.3 Soil and plants used

The table 3 shows basic characterization of the applied fertilizers and the soil (Fig. 5). As shown, the background NPK concentrations of the soil were very insignificant, thus it was expected to find a visible effect of fertilizer being applied to soil and plants. The total N content in both mineral and organic fertilizers were similar, however EM-MSW-OF was much poorer in P and K.

Table 3 *Soils and fertilizer basic analysis.*

Material	dm (%)	Total N (g/ kg dm)	Total P (g/ kg dm)	P (Olsen) (g/ kg dm)	Total K (g/ kg dm)	K (Olsen) (g/ kg dm)
Soil	85	1,26	0,19	0,019	0,626	0,067
Mineral Fertilizer	100	44,00	40,00	26,35	158,00	NA
OFMSW (Raw/ Dried)	25/ 100	34,18	1,51	0,048	8,48	5,72

Figure. 5 *Soil preparation by mixing the pre-sieved sand with peat (5:1 w/w) – left and grass seeds weighing – right.*

3.4 Experimental setup

Below (Fig. 6) the experimental setup is shown in a laboratory glasshouse facility, located 37 km from the Institute. Such setup allowed to test 2 fertilizers, 6 application rates and 3 repetitions for each scenario.

3.5 Expected results

In general one could expect the slower mobilization of nutrients from the organic fertilizer than from the mineral one and right-shifted grass-to-fertilizer response curve for the organic one. This is because of the nutrients bound in the organic forms. However some things are still unknown, e.g.

- The effect of winter conditions on plant growths for both fertilizers; which fertilizer will resist it better?
- The overfertilization effect – where and at what level of growth it will occur?

- The nitrogen uptake inhibition effect – will it be dependent on fertilizer application rate or the level of impurities?

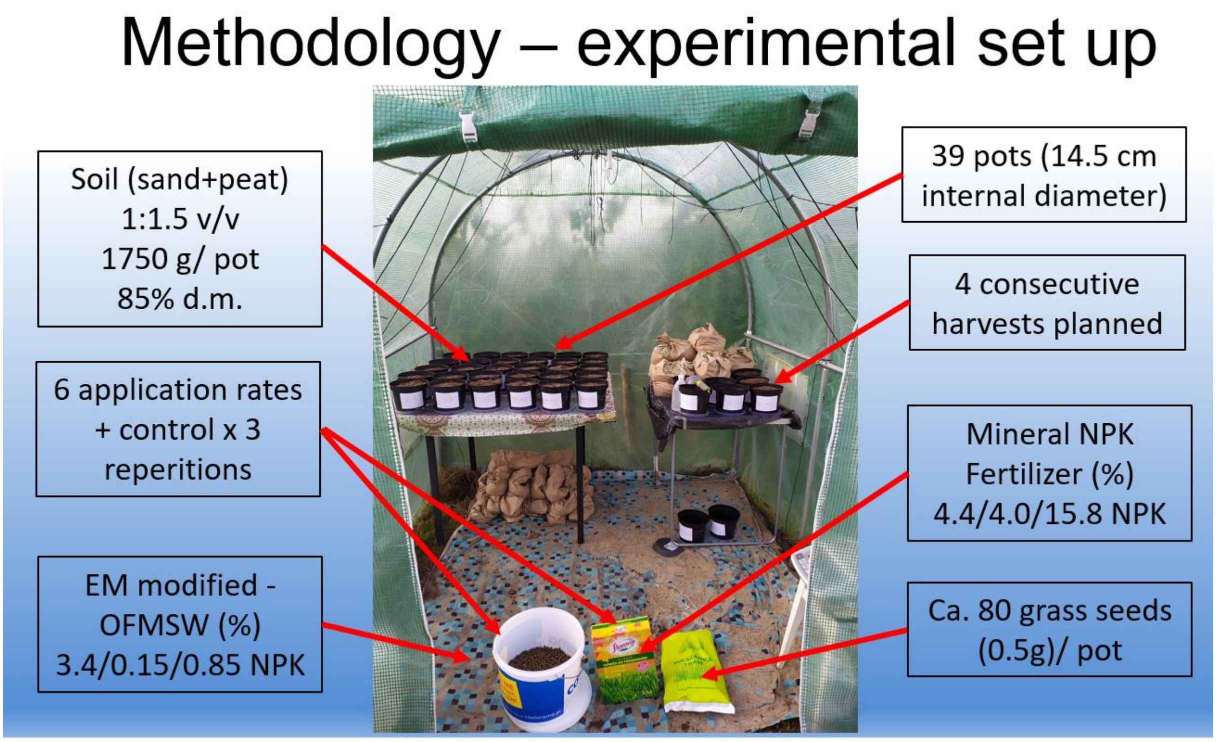


Figure. 6 *The laboratory glasshouse with all prepared materials and indicated amounts.*

Nevertheless, it is desirable to obtain the following results of the given experiment:

- **Plant biomass increase** as a function of fertilizer load, i.e. g d.m. of the plant = f (kg NPK/ha),
- **NPK uptake** by the plant as a function of fertilizer load, i.e. mg NPK/kg d.m. of the plant or kg NPK/ha raised = f (kg NPK/ha applied),
- NPK uptake efficiency expressed as plant biomass increase as a function of NPK uptake, e.g. kg d.m./ha = f (g NPK/ha raised),
- **Soil residual properties**: Soil pH, Soil conductivity, Soil NPK content.

4. The effect of MSW-OF on growth rate of grass during winter

In general the findings after 180 days of growth indicate what was expected in terms of slower mobilization of nutrients from the organic fertilizer and subsequent gradual growth of grass biomass over time (maximum after Harvest 2) and across the application rates (maximum at 170 kg N/ ha and then 15% higher than the mineral fertilizer). This was in opposition to the mineral fertilizer, which provided the fast growth of the grass in the very beginning but only up to 70 kg N/ ha (Harvest 1 and 2), after which the response curve show slow decline (the grass has not grown bigger any more after 70 kg N/ha). The exception was noticed after Harvest 3, where relative maximum growth for the mineral fertilizer was noticed at 120 kg N/ ha, maybe due to nitrogen reservoir that was maintained in the soil over long-lasting frost that was noticed in February and March. In general the discussion could be divided into 2 sections:

1. Harvest 1 (30 days): **Dynamic growth** up 0.18 g d.m./ pot for 70 kg N/ha for the mineral fertilizer and **gradual growth** of grass grown on the EM-MSW-OF with rapid acceleration at 120 kg N/ ha, curves cross at ca. 100 kg N/ ha
2. Harvest 2 (next 60 days, 90 days in total): Opposite situation, **gradual growth** for the mineral fertilizer up 0.13 g d.m./ pot for 70 kg N/ha and **dynamic growth** of grass grown on the EM-MSW-OF up to 0.15 g d.m./ pot (higher than the mineral one!), curves cross at ca. 100 kg N/ha
3. Harvest 3 (next 90 days, 180 days in total): **Dynamic growth** up 0.15 g d.m./ pot for 120 kg N/ha for the mineral fertilizer and **gradual growth** of grass grown on the EM-MSW-OF with rapid acceleration at 120 kg N/ ha, but only up to 0.07 g d.m./ pot at 170 kg N/ ha, curves cross at ca. 160 kg N/ ha.
4. Overfertilization for mineral fertilizer: YES for all 3 harvests after 70 kg N/ ha, EM-MSW-OF: NO for all 3 harvests.

Figure. 7 *The response of the grass to the application of mineral fertilizer (upper row) and EM-MSW-OF fertilizer (lower row). The picture taken right before the 2nd harvest (60 days after the 1st harvest and 90 days after start).*

The figure above taken after the 2nd harvest clearly shows the positive effect of higher organic fertilizer application rates on grass growth than for mineral fertilizer.

GRASS BIOMASS INCREASE

The Figure 8 (upper plots) shows the cumulative amounts of grass harvested over the 3 harvests (upper plots) both for fresh matter (left) and dry matter (right). The growths were varying from **0.15 to 0.42 g d.m./ pot** for the mineral fertilizer and from **0.20 to 0.35 g d.m./ pot** for the organic fertilizer with maximums reaching ca. **0.40 g d.m./ pot** at 70 kg N/ ha for the mineral and 170 kg N/ ha for the organic fertilizer. The most important conclusion is that the EM-MSW-OF based fertilizer has reached the response plateau, thus its application rate at which the overfertilization starts, has not been found. That gives much more buffer capacity to apply such material on land without harm to the plants.

NITROGEN UTILISATION

The Figure 8 (lower plots) shows that the N content in the grass samples on average varied between **32 and 75 g N/ kg d.m.** and its concentration was increasing linearly with growing fertilizer application rate. Between 70 and 200 kg N/ ha it seems that plants grown on mineral fertilizer had more N (up to 65 g N/ kg dm.) than the ones grown on the organic fertilizer (less than 55 g N/ kg d.m.). However calculating the total N uptake per area and comparting it to the fertilizer application rate, it was concluded that the both fertilizers provided equal N uptake (**12 kg N/ ha**) at 120 kg N/ ha application rate (ca. 10%), but organic fertilizer had much better effects on N uptake at higher dosages (**16 to 19 kg N/ ha** for the organic one as compared to **14 to 9 kg N/ ha** for the mineral one).

CUMULATIVE GRASS GROWTH AND NITROGEN UTILISATION AFTER 180 DAYS

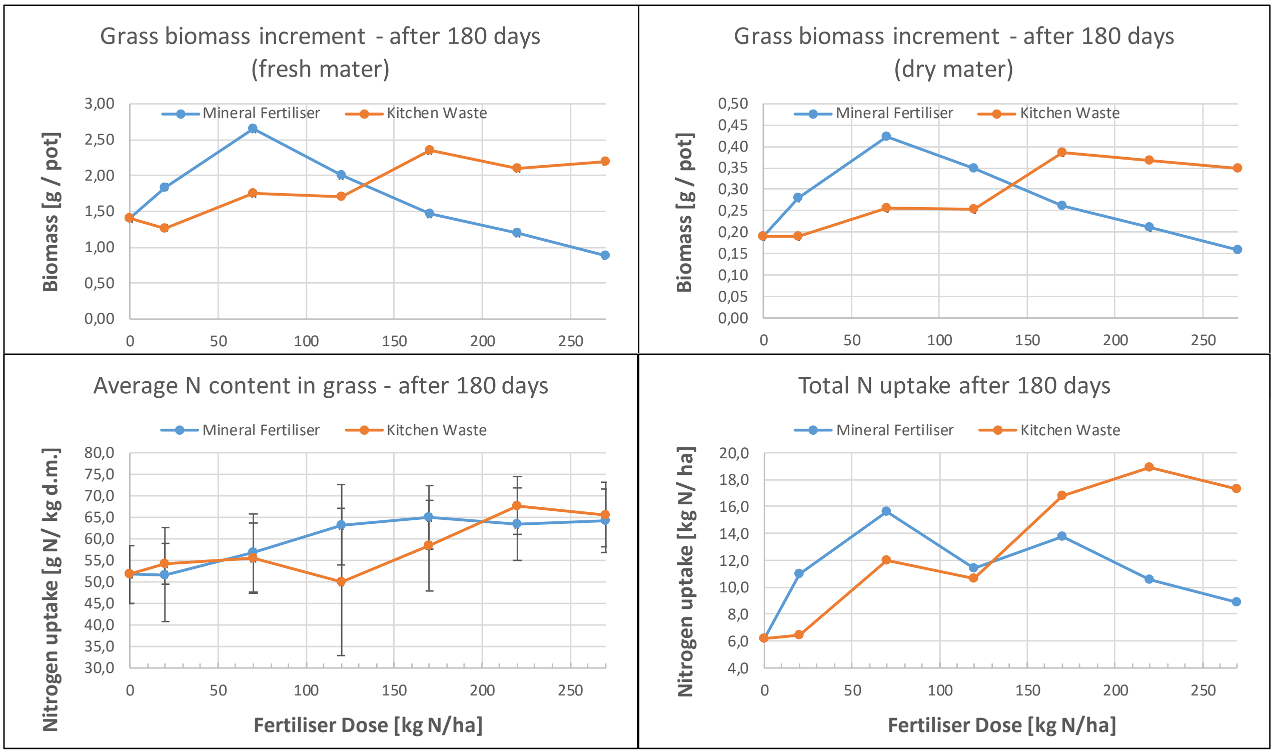


***Figure. 8** Cumulative grass growth and nitrogen utilization after 180 days of the glasshouse study.*

5. The effect of MSW-OF on soil after 6 months

After the 180 days of growth, fertilizers were not providing significant growths to the plants, also due to intensive winter season (long-lasting frosts and limited sunlight), thus the experiment was shut down, and the residual effects on soil were examined. These are:

1. The residual Nitrogen content in soil was much higher after the EM-MSW-OF application (**0.7-1.2 g N/ kg d.m.**) than for the mineral one (0.5-1.0 g N/ kg d.m.) with the maximum at 220 kg N/ ha fertilizer application rate. The more fertilizer applied, the more N left in the soil.
2. In general the calculated total N amount in soil per area is better visible after organic fertilizer application. For small application rates, it is slightly higher than the nitrogen taken up from the mineral fertilizer, and varies from **0.04-0.06 kg N/ ha** up to 120 kg N/ ha application rates, then it rapidly increases after 120 kg N/ ha application rate to the value of **0.1 kg N/ ha** what is even maintained further on at higher application rates.

3. This (above) indicates that this substantial bank of probably organically bound, remained N in the soil, still provides maximum growths at very high application rates for the organic fertilizer.
4. The residual N in soils amended with the mineral fertilizer is rather stable over the whole spectrum of fertilizer application rates, what is connected with its fast mineralization, uptake and water and air emissions. Even though this is not reflected in better grass growths in the whole range of dosages.
5. pH (unlike EC) remains rather stable with increased organic fertilizer application rate, whereas it drops from 8.45 to 7.80 after application of mineral fertilizer,
6. Electrical conductivity of soil increases from **245 to 420 μS/ cm** for the mineral fertilizer application, whereas the application of the organic fertilizer provides very insignificant drop of EC (from **120 down to 80 μS/ cm)** due to organic compounds, that are not leaching any significant amounts of anions to the soil solution.

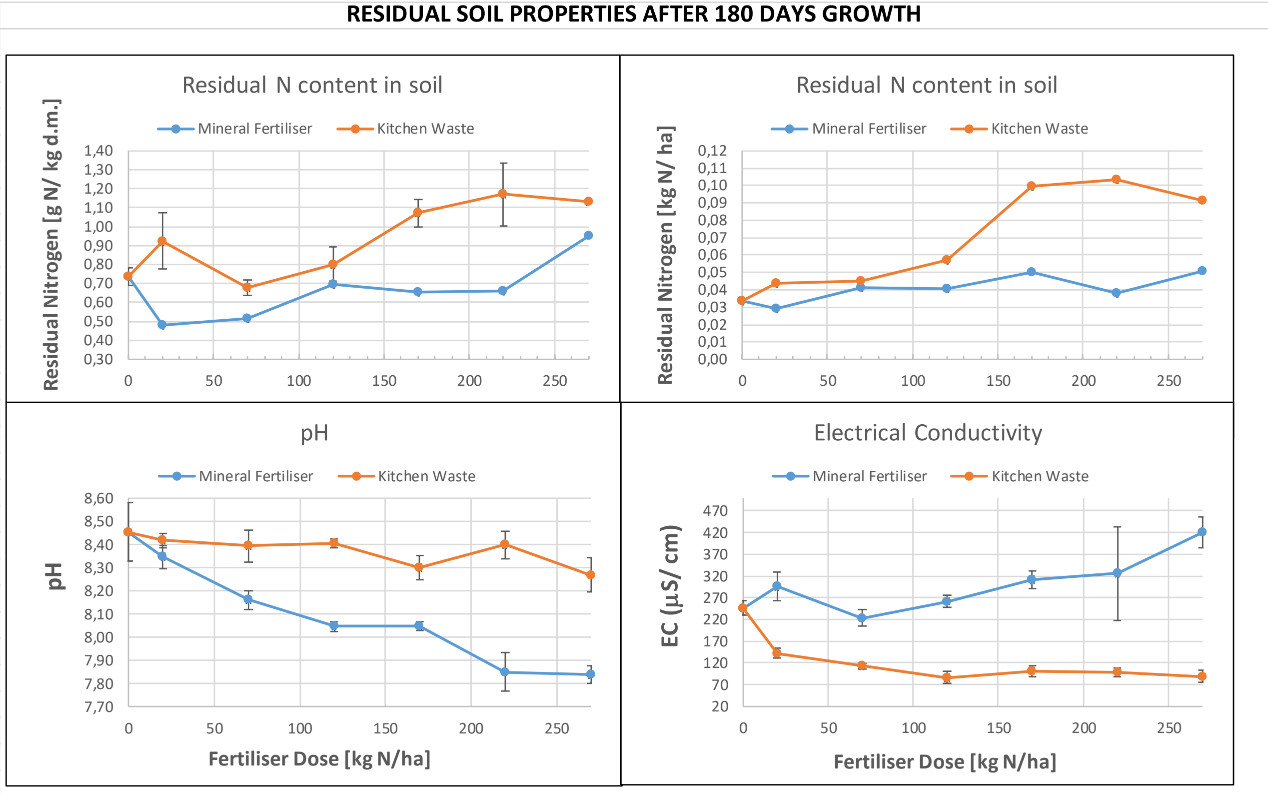


Figure. 9 *Residual soil properties after 180 days of the glasshouse study.*

6. Future recommendations

- Further analogical experiment carried out under spring conditions would be required (planned),
- Comparison to the effect of the real-scale organic fraction from the municipal organic waste (sorted at plant, not at source), maybe anaerobically digested, on grass growth to check for any inhibiting effects (microplastic, heavy metals, organic pollutants effect on grass growth and its uptake),
- Possible application of humic acids for enhancing the bioavailability of nutrients contained in the organic waste,

- Large-scale experiment in the field would be required for evaluation of the possible upscaling effects,
- Possible modeling of the nutrients uptake could be done and compared to the experimental data,
- Application of more acidic soils could probably improve the growths on organic fertilizers, but also could reveal new (potential toxic) elements to the soil solution (eg. Al) and activate faster growth and maybe some inhibiting effects.