Characteristics of different urban and rural green wastes

Authors: S. Walk[1], P. Lüssenhop[1], B. M. Elfers[2], I. Körner[1]

Supported by: A. Ananth[1], J. Willruth[1], A. González[1], B. Kuscu[1],

[1]Hamburg University of Technology, Institute of Wastewater Management and Water Protection, Bioresource Management Group

[2]Hamburg University of Technology, Central laboratory for Chemical Analysis

Contact:

Steffen Walk, steffen.walk@tuhh.de, ORCID: 0000-0003-3294-5052

Phillipp Lüssenhop, phillipp.luessenhop@tuhh.de, ORCID: 0000-0002-7056-6988

Ina Körner, i.koerner@tuhh.de, ORCID: 0000-0002-8937-5970

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V1.0: Includes the bioresources leaves mix of autumn 2019, leaves of summer 2020 and wildflower meadow of autumn 2019. The analysis comprises physico-chemical characteristics, elementary composition, nutritional elements, heavy metals and anions and figures for the respective biogas tests.

List of abbreviations

Abbreviation	Meaning
AWW	Institut für Abwasserwirtschaft und Gewässerschutz
BMP	Biochemical methane potential
COD	Chemical oxygen demand
exp.	experimental
FM	Fresh matter
FOS/TAC	Flüchtige organische Säuren/Total anorganic carbon
TAN	Total ammonia nitrogen
TC	Total carbon
th.	theoretical
TN	Total nitrogen
TOC	Total organic carbon
TS	Total solids
VS	Volatile solids

1 Background

The analysis of the characteristics of green waste was conducted within the FLEXIBI project (Grant Agreement No. 031B0610B, funding by FACCE SURPLUS 2, BMBF). The project with partners from Germany, France, Belgium and Finland aims at finding new pathways for the valorisation of selected urban and agricultural bioresources in a biorefinery context. Those pathways include e.g. steam refining and extraction of fibres, extraction of chemical compounds and biogas and compost production. Therefore, it is important to gain knowledge on the chemical and bio-chemical composition of these feedstocks. Furthermore, experiments exploring the biodegradability (BD) and biochemical methane potential (BMP) serve as benchmark.

2 Materials and Methods

This section describes the methodology for the sampling of the bioresources to be analysed and the methods used for their properties and chemical analysis.

2.1 Sampling

2.1.1 Street pruning residues

The material originates from the streets of Hamburg. The sampling took place at the regular tree pruning sessions by professional companies in autumn 2019 and summer 2020. The leaves of both seasons can be distinguished in mostly fallen leaves (autumn) and green leaves still attached to the trees (summer). Hence, sampling in different seasons was carried out to investigate possible differences in chemical composition. The pruning material originates from the tree species linden, oak and maple. Those trees are the most abundant in Hamburg streets with a total share of 59.1% of all roadside trees. Thereof, linden, oak, and maple have a relative share of 40%, 37% and 23%, respectively. The pruning material comprises wood, bark, branches, twigs, leaves and fruits. The sample was separated into those fractions after collection. Only the composition of leaves, as potential feedstock for anaerobic digestion, is considered in the publication of the data analysis.

2.1.2 Wildflower meadow

The material originates from a wildflower meadow field on the TUHH campus next to building M. It was converted from a standard meadow into a wildflower meadow in the year 2018/2019. It consists of a wide range of wildflowers and grasses. It is accompanied by an insect hotel. The samples were taken in September 2019 and 2020 during the regular annual mowing. However, only the sample of 2019 was analysed in debt.

2.1.3 Cucumber agriculture residues

The material originates mostly from the Nantes region in France where most of the country’s cucumber cultivation takes place. The sampling was conducted by INRAE, a partner in the FLEXIBI project. It took place after the cucumber harvesting in autumn 2020. The agricultural residues consist of stems, twigs and leaves and some small cucumber fruits. To have a full dataset, also cucumber fruits were purchased in a supermarket in Hamburg, however, originating from Spain. For the cucumber fruits both, conventionally and organically grown ones were analysed as comparison.

2.2 Storage and preparation

Samples were stored at -20 °C and only thawed before they were used in an experiment. For each experiment, samples were roughly crushed mechanically.

2.3 Parameter analysis

Table 1 summarises the basic distinction of characteristic, the specific characteristics which were analysed, the place where those were analysed and the reference of the methodologies. The designation of the basic characteristics, is based on the use for anaerobic digestions. Therefore, the designation as nutritional element refers to the elements capability to influence the process.

Table 1: Analysed characteristics and their methods.

Basic Characteristic	Specific characteristics	Reference
Physicochemical[a,b]	TS	[1]
Physicochemical[a,b]	VS	[2]
Physicochemical[a]	FOS/TAC	[3]
Elementary composition[b]	TN, TC, TOC, H, S	[4]
Nutritional elements[a]	TAN	[5]
Nutritional elements[b]	Mo, Zn, P, K, Ca, Mg, Na, Mn, Fe	[6], [7]
Nutritional Elements (Anions)[b]	NO_3^-, PO_4^{3-}	[8]
Heavy metals[b]	Pb, Cd, Cr, Cu, Ni, Si	[6], [7]
Heavy metals[b]	Hg	[9]
Anions[b]	F^-, Cl^-, Br^-, $[SO_4]^{2-}$	[8]
Physicochemical[a]	pH	[10]
Physicochemical[a]	BMP	[11]
Physicochemical[a]	COD	[12]

[a]AWW laboratory, [b]Central TUHH laboratory

The non-complex analyses of the total and the volatile solids were simultaneously determined within the central laboratory of TUHH and the laboratory of Institute of Wastewater management and Water protection (AWW). The approach of the central laboratory was to freeze-dry the samples in order to restrain any volatile components for the chemical analysis. In addition, the TS and VS determined in the AWW lab, were measured before and after the Biochemical Methane Potential test (BMP). TS was determined at 105 °C incubated for 24 hours [1] and VS and ash in both laboratories were determined at 550 °C according to the loss of ignition method [2].

The buffer capacity via FOS/TAC analysis was determined by endpoint titration using the device FOS/TAC 2000 by Pronova. It was determined after finishing the BMP test by analysing the digestate.

Total nitrogen and carbon as well as hydrogen and sulphur were determined using the NCHS-Analyzer *Vario Macro Cube* by *Elementar* [4]. For the analysis of the total organic carbon (TOC), dried samples were previously treated with hydrochloric acid to remove inorganic carbon.

Total Ammonia Nitrogen (TAN) was determined according to DIN 38406-5 [5] using a *Jasco V-550* photometer. Fresh samples were prepared via $CaCl_2$ extraction.

Further elements, either nutritional elements (Mg, Fe etc.) or heavy metals (Pb, Cd etc.), were, according to their concentration, either determined by *inductively coupled plasma mass spectrometry* (ICP-MS) [6] or by *inductively coupled plasma optical emission spectrometry* (ICP-OES) [7]. The detection limit for the ICP-MS is usually within the range of µg/L and that of the ICP-OES usually in the range of mg/L. For ICP-MS determinations a *Perkin Elmer Modell*

NexION 300 D or *350 D* [6] and for ICP-OES determinations a *Perkin Elmer Modell Optima 8300 DV* [7] were used. Previously, the samples were disintegrated in the microwave using HNO_3 and H_2O_2 [13].

Anions (Cl^-, Br^-) were determined using ion chromatography with the device *Dionex ICS 1100* by *Thermo Fischer Scientific* [8].

Mercury was determined by atomic absorption spectroscopy (AAS) with the device *Perkin Elmer Pinaacle 900Z* and flow injection mercury system (FIMS) with the device *Perkin Elmer FIMS 400* [9].

The pH of the samples was analysed according to the method described in DIN 38404-5 with an initial disintegration of the individual substrates into liquid or semi-liquid form. For the BMP test the medium including inoculum and substrate was measured before and after the test. The pH was determined using the device *WTW-Multi 9620 IDS* [10].

The BMP was determined in batch tests according to the method described by VDI [11]. The method used was according to DIN 38414-8 – Gas volume measurement with the eudiometer tube in a self-made device. Biogas quality was measured using *Geotech Biogas 5000* by QED.

Chemical oxygen demand (COD) was determined according to ISO 15705:2002 [12].

2.4 Calculations

2.4.1 Oxygen

The share of oxygen of a substrate was calculated by a simple mass balance performed in g/kg on TS basis. Therefore, the amount of C, N, H, S and the ash were subtracted from the maximum of 1000 g/kg TS.

2.4.2 Theoretical Chemical oxygen demand

In order to compare the measured COD, the theoretical one was calculated using the molar masses of the elements C, N, H and S with eq. (1),

$$COD_{th} = \frac{8 * (4n + a - 2b - 3c)}{12n + a + 16b + 14c} \qquad \left[\frac{mg\ COD}{mg\ C_n H_a O_b N_c}\right] \qquad (1)$$

where n, a, b and c are the molar masses of total carbon, hydrogen, oxygen and total nitrogen, respectively. The values calculated are respective to the chemical composition of the sample.

2.4.3 Theoretical Biochemical methane potential

BMP was calculated in theory using the elementary composition and eq. (2) according to Buswell [14].

$$BMP_{th} = \frac{22400 * \left(\frac{n}{2} + \frac{a}{8} - \frac{b}{4} - \frac{3c}{8}\right)}{12n + a + 16b + 14c} \qquad \left[\frac{mL_{CH4}}{g_{VS}}\right] \qquad (2)$$

Thereof, n, a, b and c represent the molar masses of C, H, O and N respectively of the chemical composition of the sample.

The calculations for the experimentally derived BMP were conducted according to VDI [11] subtracting the BMP originating from the inoculum from the total measured BMP.

2.4.4 Experimental Biochemical methane potential

The reactor bottles have a working volume of 800 mL and it was aimed to have a substrate to inoculum (S/I) ratio of 0.5 based on VS. No additional supplements were added. The temperature of the water bath was set to 37 °C. Ambient temperature and pressure were recorded each time of the gas volume measurement. Each sample was tested at least in duplicates if homogenous, mostly in triplicated. For each BMP test a set of blanks containing only inoculum from a wastewater treatment plant was added.

To calculate the fresh matter of inoculum to be added to the reactors eq. (3) was used,

$$V_I = \frac{V_{bottle} * VS_S}{\left(\frac{S}{I} * VS_I * \left(1 + \left(\frac{VS_S}{\frac{S}{I} * VS_I}\right)\right)\right)} \qquad [g] \tag{3}$$

where V_I is the volume of inoculum, V_{bottle} is the maximum working volume (mL), VS_S and VS_I is the share of volatile solids of the substrate and inoculum, respectively, in relation to its fresh mass (% of FM) and S/I is the substrate to inoculum ratio (-) as mentioned previously. It is assumed a density of 1000 g/L as conversion of mass to be added. To calculate the amount of substrate to be added, one only has to subtract V_I from V_{bottle}.

Gas accumulation was calculated from daily readings. Gas quality was measured when at least 300 mL of gas were produced. In order to calculate the absolute BMP, the readings of the biogas production combined with the readings from the biogas quality were applied to the following procedure.

First the daily readings were summed up to the generate the accumulated gas quantity produced. It is followed by the conversion of the produced gas under norm conditions following eq. (4),

$$V_{dry,N} = V * \frac{(p - p_w) * T_N}{p_N * T} \qquad [mL] \tag{4}$$

where $V_{tr,N}$ is the volume of dry gas under norm conditions at time t (mL), V is the accumulated volume at time t (mL), p the gas pressure at time t (hPa), p_w is the vapor pressure of the water as function of the ambient temperature (hPa), T_N is the norm temperature (273.15 K), p_N is the norm pressure (1013 hPa) and T is the temperature of the gas or ambient temperature (K).

p_w can be calculated following the *Magnus equation* (5),

$$p_w = 6.11231 * e^{\frac{17.5043 * T_C}{241.2 + T_C}} \qquad [hPA] \tag{5}$$

where p_w is the vapour pressure (hPa) and T_c is the temperature of the gas or ambient temperature (°C).

p can be calculated using eq. (6),

$$p \; = p_A + p_w \qquad [hPa] \qquad (6)$$

where p_A is the ambient pressure (hPa) and p_w is the pressure from the water column of the eudiometer (hPa) which can be calculated according to eq. (7),

$$p_w = h * 98.0665 \qquad [hPa] \qquad (7)$$

where h is the hight (m) of water column at the moment of gas reading.

For the calculation of the concentrations of methane (CH_4) and carbon dioxide (CO_2) in the biogas, the influence of the headspace gas, especially at the beginning of the experiment can be corrected. It is considered, only CH_4 and CO_2 are produced as described in eq. (8),

$$C_{CH_4,dry} = \; C_{CH_4(CO_2)} \frac{100}{C_{CH_4} + C_{CO_2}} \qquad [\%] \qquad (8)$$

where $C_{CH4,\ dry}$ (%) is the concentration of methane in the dry biogas, and $C_{CH4(CO2)}$ is the measured concentration of CH_4 (or CO_2) in the moist gas.

To calculate the volume of produced CH_4, the share calculated from eq. (8) is multiplied with the dry gas volume that was produced from the inoculum or the inoculum-substrate mixture until the measurement of the concentration of the different gas components.

In order to calculate the volume of CH_4 that was produced only by the substrate in the inoculum-substrate mixture, the amount of CH_4 produced from the inoculum has to be subtracted. If the mass of inoculum used in the blank (inoculum only) differs from the mass of inoculum in the inoculum-substrate mixture, the share of inoculum-derived biogas is calculated according to eq. (9),

$$V_{IS(korr.)} = \frac{\sum V_I * m_{IS}}{m_I} \qquad [mL] \qquad (9)$$

where V_{IS} (mL) is the corrected methane (or biogas) volume in the inoculum-substrate mixture, $\sum V_I$ (mL) is the sum of volumes produced in the blank test at time t, m_{IS} (g) is the mass of inoculum added in the inoculum-substrate mixture and m_I (g) is the mass of inoculum added in the blank. Hereinafter, $V_{IS(korr.)}$ is subtracted from the original volume of methane (or biogas) produced in the substrate-inoculum mixture.

For the final calculation of the BMP, the produced methane is divided by the substrate mass of VS added at the beginning of the experiment according to eq. (10),

$$BMP \; = \frac{\sum V_n}{m_{S_{VS}}} \qquad [\frac{mL\ CH_4}{g\ VS}] \qquad (10)$$

where BMP is the biochemical methane potential $\sum V_n$ is the dry and corrected gas volume at time t (mL) and m_{SVS} is the mass of substrate added based on VS (g VS).

2.4.5 Biodegradability

Biodegradability was calculated in two ways. One method uses the share of experimentally derived BMP (section 2.4.4) and theoretically derived BMP (section 2.4.3) in percent.

In the second method, the total volume of CH_4 and CO_2 produced during the test is converted into mass which is then divided by the substrate mass, according to eq. (11),

$$BD = \frac{m_{biogas}}{m_{S_{VS}}} \qquad [\%] \qquad (11)$$

where BD is the biodegradability, m_{biogas} is the mass of biogas and m_{SVS} is the mass of the substrate initially added based on VS.

The mass of biogas is calculated according to eq. (12),

$$m_{biogas} = \frac{p * (M_{CH_4} * \sum V_{CH_4} + M_{CO_2} * \sum V_{CO_2})}{R * T} \qquad [g] \qquad (12)$$

where m_{biogas} is the mass of biogas (g), p is the standard atmospheric pressure (kPA), M_{CH4} and M_{CO2} are the molar masses of CH_4 and CO_2 (u), $\sum V_{CH4}$ and $\sum V_{CO2}$ are the total volumes of CH_4 and CO_2 produced at the end of the experiment (L), R is the universal gas constant $\left(\frac{kg\ m^2}{s^2\ mol\ K}\right)$ and T is the standard temperature (K).

3 Results

3.1 Data tables

The following tables include the data that has been measured and calculated for the different substrates. For the summer leaves mix, only the values in Table 2 and Table 3 have been measured. The other values were calculated using the share of the abundant tree species as mentioned in section 2.1.1.

Table 2: Physico-chemical characteristics 1.

Parameter	th. COD	exp. COD	th. BMP	exp. BMP	CH_4	BD_{BMP}	BD_{VS}
Unit	g(COD) $g(C_nH_aO_bN_c)^{-1}$	g(COD) $kg(FM)^{-1}$	$mL(CH_4)$ $g(VS)^{-1}$	$mL(CH_4)$ $g(VS)^{-1}$	% of biogas	% of th. BMP	% of substrate VS
Autumn leaves, mix	1.61	322	538.05	207.49	-	38.56	-
Summer leaves, mix	1.54	405	510.63	220.02	67.70	43.09	36.36
Summer leaves, oak	1.54	225	511.35	226.19	68.60	44.23	36.54
Summer leaves, maple	1.54	552	518.69	215.92	67.00	41.63	36.35
Summer leaves, linden	1.52	488	505.36	268.58	67.60	53.15	44.55
Wildflower meadow	1.45	-	496.69	208.02	58.8	41.88	43.45

Table 3: Physico-chemical characteristics 2.

Parameter	pH of substrate	pH at beginning	pH at end	Alkalinity[a]	Water	TS	VS	Ash
Unit	-	-	-	-	%FM		%TS	
Autumn leaves, mix	-	7.20	7.00	0.10	50.12	49.88	92.36	7.64
Summer leaves, mix	-	7.21	7.15	0.16	50.72	49.28	93.90	6.10
Summer leaves, oak	5.62	7.21	7.15	0.19	48.90	51.10	94.30	5.70
Summer leaves, maple	4.82	7.21	7.14	0.21	47.60	52.40	93.60	6.40
Summer leaves, linden	5.01	7.21	7.18	0.17	54.20	45.80	93.70	6.30
Wildflower meadow	-	7.29	7.04	0.10	54.62	45.38	90.06	9.94

[a]Alkalinity was measured at the end of the BMP test

Table 4: Basic elementary composition.

Parameter	TC	TOC	TN	H	S	O	C/N
Unit	g/kg TS						(-)
Autumn leaves, mix	470.00	429.00	17.70	70.19	2.08	363.63	26.55
Summer leaves, mix	483.47	457.57	20.93	61.24	< 2	373.36	23.10
Summer leaves, oak	485.00	458.00	23.10	62.10	< 2	372.80	21.00
Summer leaves, maple	494.00	477.00	16.80	58.20	< 2	367.00	29.40
Summer leaves, linden	476.00	446.00	21.30	62.20	< 2	377.50	22.35
Wildflower meadow	430.00	396.00	7.70	67.40	1.80	393.70	55.84

Table 5: Nutritional elements.

Parameter	TAN	TP	K	Ca	Mg	Na	Mn	Fe	Mo	Zn
Unit	g/kg TS						mg/kg TS			
Autumn leaves, mix	0.11	2.98	5.96	8.14	1.14	0.60	-	98.70	0.49	40.00
Summer leaves, mix	0.00	2.00	9.89	13.66	-	-	94.60	233.66	-	< 50
Summer leaves, oak	0.00	1.96	9.94	13.20	-	-	150.00	267.00	-	< 50
Summer leaves, maple	0.00	1.83	11.20	13.30	-	-	46.70	129.00	-	< 50
Summer leaves, linden	0.00	2.14	9.10	14.30	-	-	70.90	263.00	-	66.30
Wildflower meadow	-	3.22	6.37	23.74	2.15	1.63	154.00	388.00	2.30	91.00

Table 6: Heavy metals.

Parameter	Pb	Cd	Cr	Cu	Co	Se	Ni	Hg	Si
Unit	mg/kg TS								
Autumn leaves, mix	0.91	< 0.2	2.80	7.20	-	-	< 1	< 0.01	-
Summer leaves, mix	< 50	< 50	-	16.16	-	-	-	-	1.25
Summer leaves, oak	< 50	< 50	-	14.00	-	-	-	-	1.09
Summer leaves, maple	< 50	< 50	-	< 10	-	-	-	-	1.87
Summer leaves, linden	< 50	< 50	-	21.70	-	-	-	-	1.04
Wildflower meadow	1.80	0.91	1.30	10.00	-	-	2.40	0.30	-

Table 7: Anions.

Parameter	Fluoride	Chloride	Bromide	Nitrate	Phosphate	Sulphate
Unit	g/kg TS	g/kg TS	g/kg TS	g/kg TS	g/kg TS	g/kg TS
Autumn leaves, mix	0.01	1.35	< 0.002	< 0.003	0.55	0.65
Wildflower meadow	< 0.001	1.9	0.01	0.03	0.8	1.6

3.2 Figures

The figures indicate the biogas production corrected for the substrate only. The influence of the inoculum has been excluded.

3.2.1 Biogas production and BMP of wildflower meadow

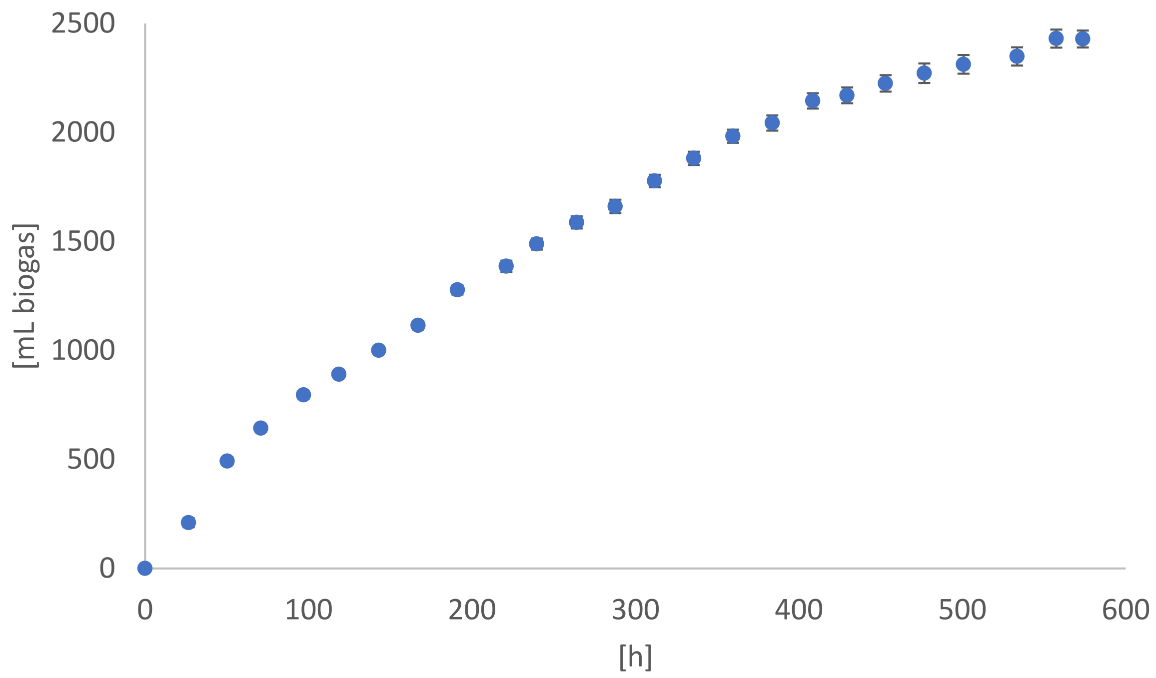

Figure 1: Biogas production of wildflower meadow

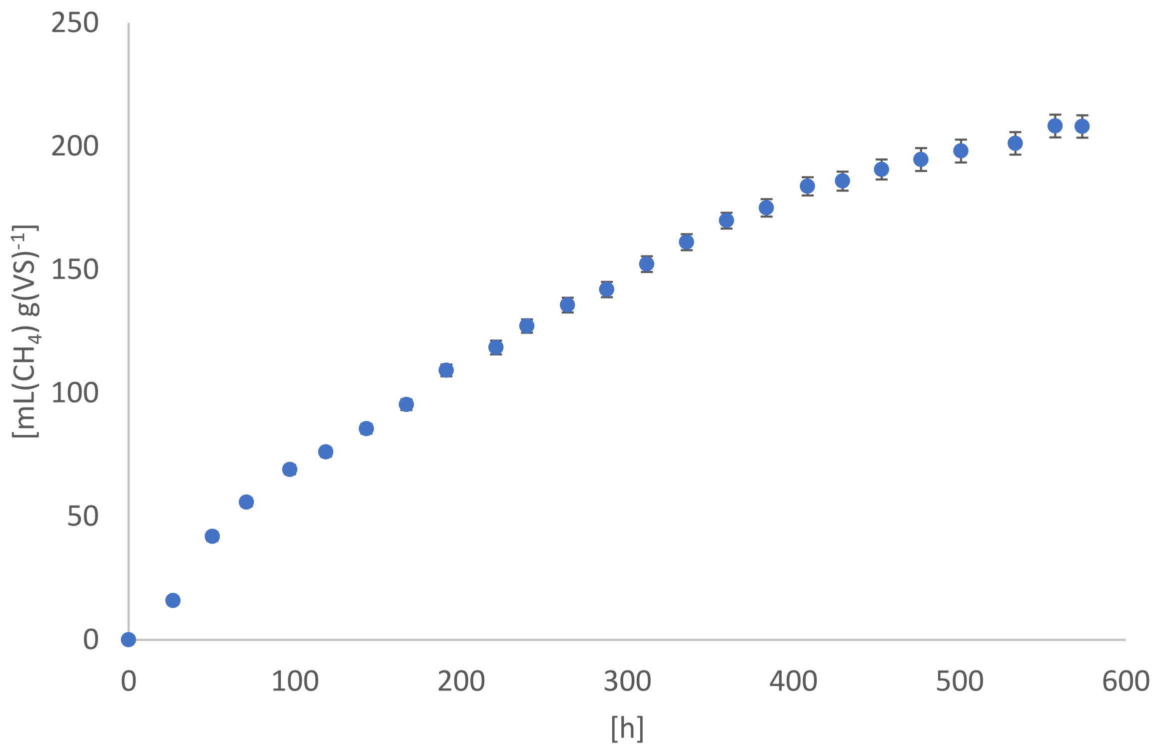

Figure 2: BMP of wildflower meadow

Table 8: Data of wildflower meadow BMP test

Time	Average biogas production	Standard deviation	Average BMP	Standard deviation
h	mL	mL	mL(CH_4) g(VS)$^{-1}$	mL(CH_4) g(VS)$^{-1}$
0.00	0.00	0.00	0.00	0.00
26.70	209.74	20.65	15.85	1.56
50.40	492.56	18.41	41.87	1.78
70.92	643.33	15.54	55.77	1.72
97.02	795.85	16.09	68.99	1.88
118.68	890.50	17.09	76.09	1.86
143.10	1000.70	16.72	85.50	1.95
167.15	1115.07	19.44	95.27	2.19
191.18	1277.73	20.96	109.17	2.39
221.07	1386.46	25.80	118.46	2.77
239.67	1488.04	25.57	127.14	2.74
264.13	1587.38	27.85	135.63	2.98
287.73	1660.85	30.58	141.90	3.12
311.82	1777.21	28.79	152.23	3.19
335.78	1881.35	30.41	161.15	3.24
359.78	1982.86	30.12	169.84	3.21
383.82	2043.38	34.81	175.03	3.51
408.57	2145.07	35.08	183.74	3.71
429.57	2170.07	36.20	185.88	3.86
453.07	2225.07	37.75	190.59	4.05
476.82	2271.97	44.61	194.61	4.65
500.82	2312.30	43.03	198.07	4.64
533.57	2348.46	41.74	201.16	4.59
557.57	2430.67	41.53	208.21	4.61
573.82	2428.48	39.00	208.02	4.55

3.2.2 Methane production and BMP of mixed autumn leaves

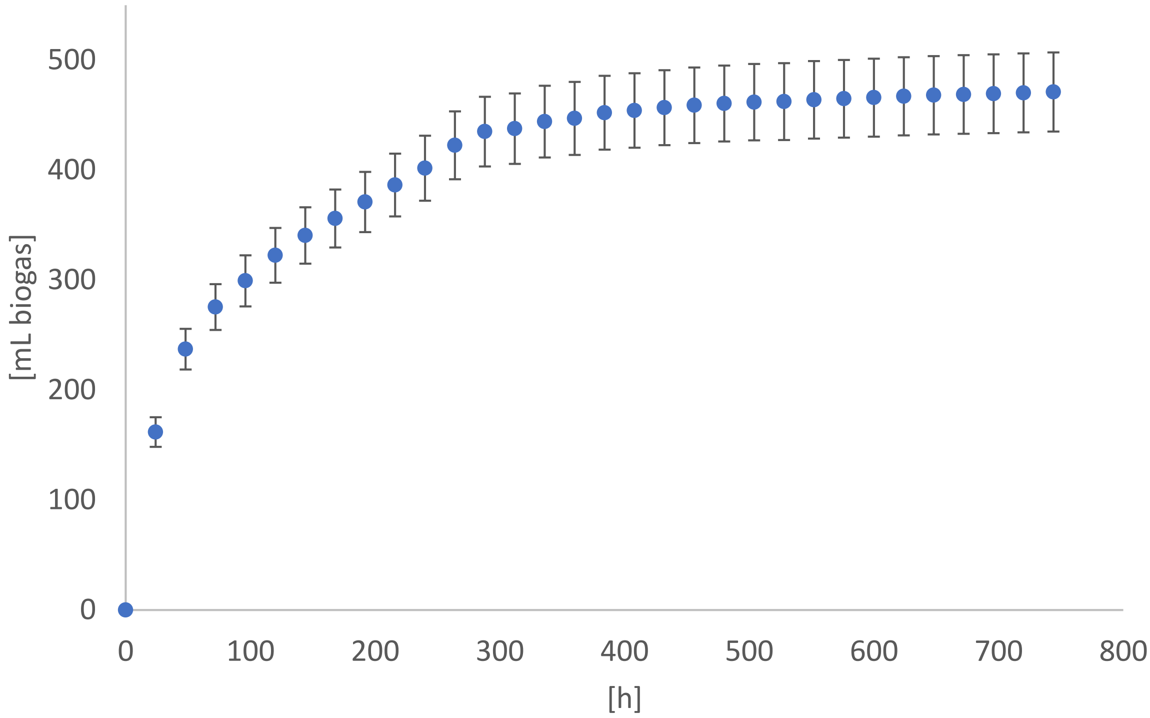

Figure 3: Methane production of mixed autumn leaves

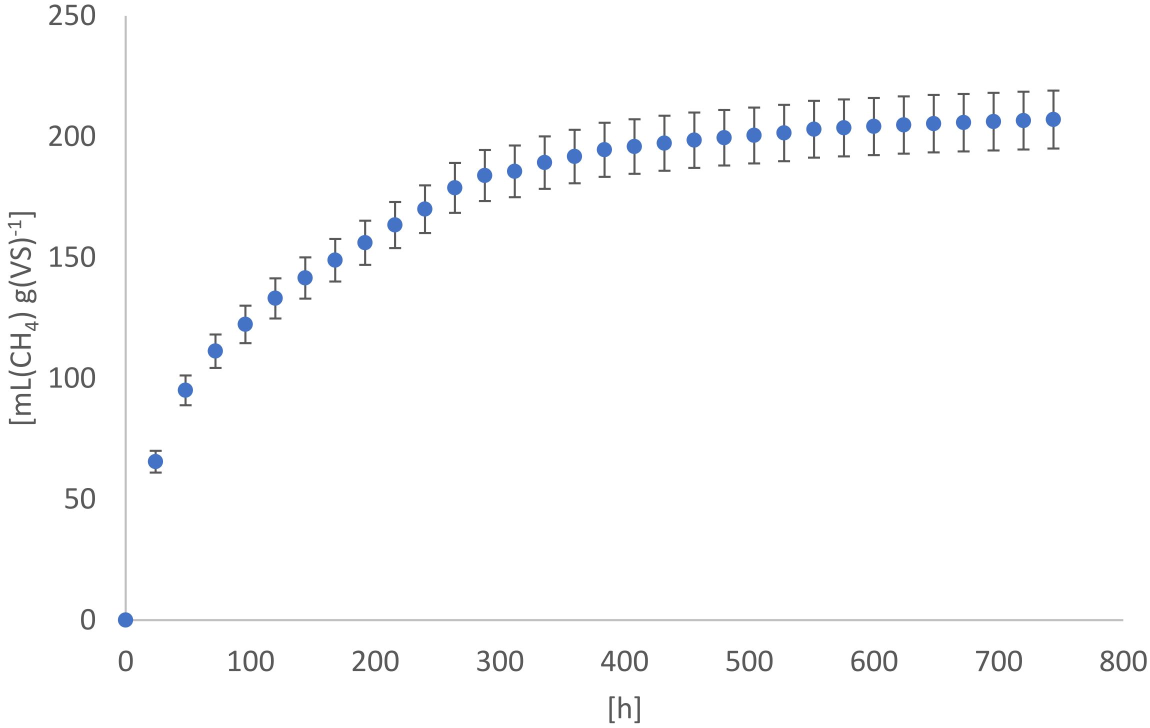

Figure 4: BMP of mixed autumn leaves

*This test was conducted with the AMPTS II system including a CO_2 trap and therefore values for CH_4 are obtained directly.

Table 9: Data of mixed autumn leaves BMP test

Time	Average methane production	Standard deviation	Average BMP	Standard deviation
h	mL	mL	mL(CH_4) g(VS)$^{-1}$	mL(CH_4) g(VS)$^{-1}$
0.00	0.00	0.00	0.00	0.00
24.00	161.77	13.49	65.54	4.50
48.00	237.15	18.55	95.08	6.18
72.00	275.47	20.78	111.27	6.93
96.00	299.30	23.22	122.33	7.74
120.00	322.47	24.92	133.14	8.31
144.00	340.62	25.62	141.56	8.54
168.00	356.02	26.39	148.90	8.80
192.00	370.98	27.41	156.12	9.14
216.00	386.42	28.59	163.44	9.53
240.00	401.75	29.60	170.03	9.87
264.00	422.54	30.92	178.81	10.31
288.00	435.06	31.68	183.93	10.56
312.00	437.67	32.00	185.66	10.67
336.00	444.07	32.64	189.27	10.88
360.00	447.00	33.14	191.80	11.05
384.00	452.17	33.62	194.57	11.21
408.00	454.18	33.87	195.90	11.29
432.00	456.76	34.10	197.27	11.37
456.00	458.97	34.33	198.52	11.44
480.00	460.50	34.52	199.56	11.51
504.00	461.76	34.70	200.49	11.57
528.00	462.30	34.94	201.54	11.65
552.00	463.89	35.25	203.05	11.75
576.00	464.88	35.35	203.62	11.78
600.00	465.93	35.45	204.20	11.82
624.00	467.08	35.56	204.82	11.85
648.00	468.06	35.66	205.37	11.89
672.00	468.77	35.73	205.79	11.91
696.00	469.48	35.81	206.21	11.94
720.00	470.24	35.88	206.64	11.96
744.00	471.05	35.96	207.09	11.99

3.2.3 Biogas production and BMP of different summer leaves

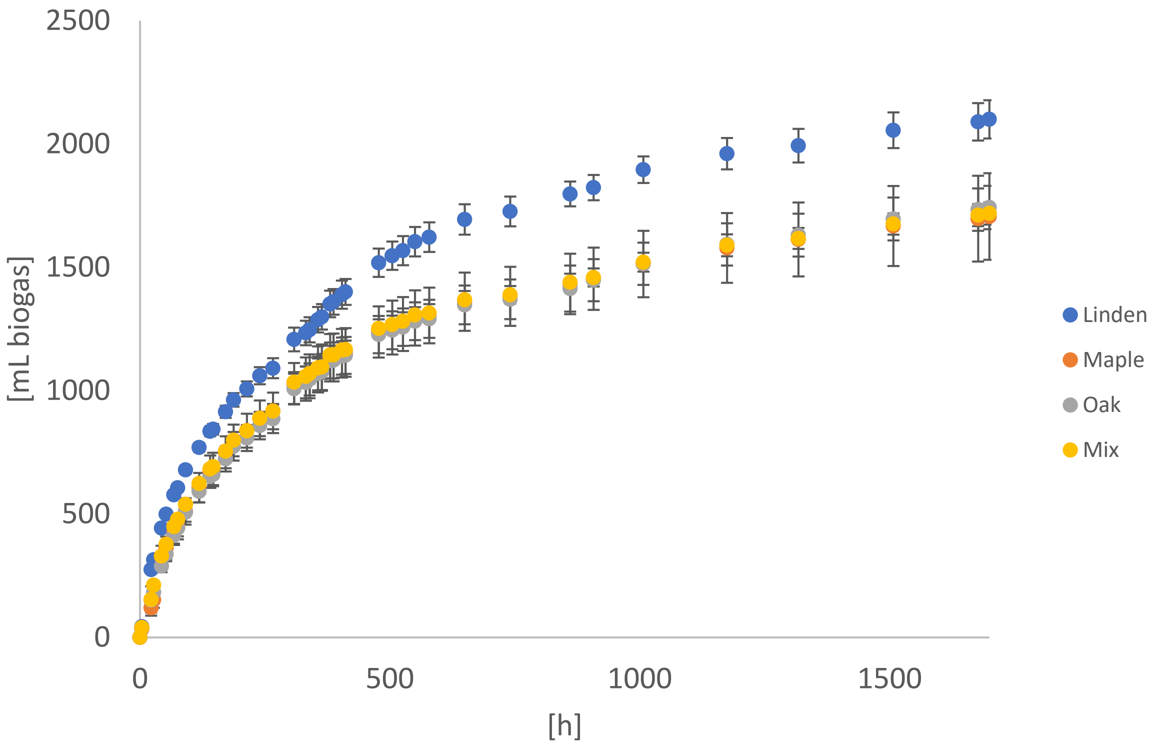

Figure 5: Biogas production of different summer leaves

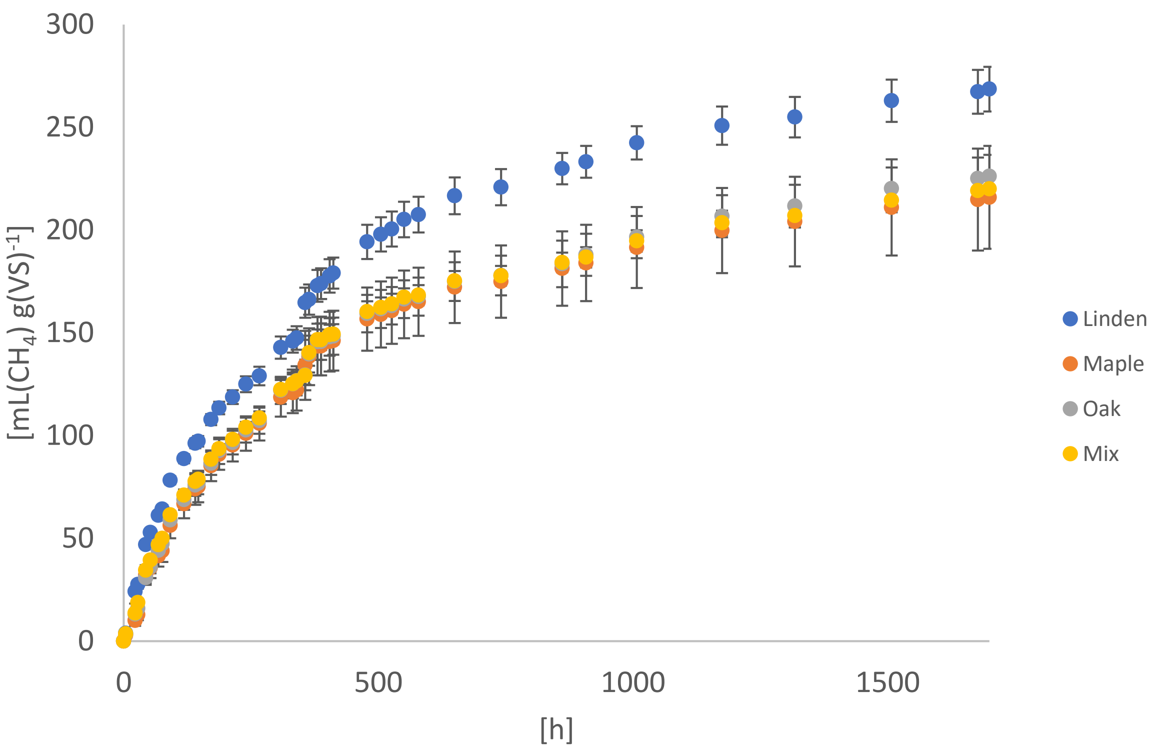

Figure 6: BMP of different summer leaves

Table 10: Data of mixed summer leaves BMP test

Mixed summer leaves				
Time	Average biogas production	Standard deviation	Average BMP	Standard deviation
h	mL	mL	mL(CH_4) g(VS)$^{-1}$	mL(CH_4) g(VS)$^{-1}$
0.00	0.00	0.00	0.00	0.00
4.00	40.21	1.49	3.57	0.14
22.50	153.55	53.17	13.61	4.66
27.75	211.74	13.89	18.80	1.10
43.25	330.31	15.39	34.49	1.61
52.50	377.37	15.06	39.40	1.58
68.00	449.14	14.72	46.89	1.55
75.75	478.78	14.85	49.99	1.56
91.25	539.68	15.53	61.40	1.98
118.50	624.16	16.07	71.01	2.06
140.50	683.22	16.32	77.73	2.10
146.33	691.91	16.29	78.72	2.10
171.50	755.10	18.10	88.47	2.15
187.33	798.92	18.68	93.61	2.22
214.00	837.29	19.34	98.10	2.30
240.00	887.91	22.03	104.03	2.61
266.33	917.25	29.31	108.50	3.30
308.50	1034.41	41.21	122.36	4.68
332.00	1058.02	40.82	125.15	4.63
339.50	1069.53	40.38	126.52	4.57
356.33	1092.31	38.50	129.21	4.35
364.00	1095.96	47.43	140.29	6.29
380.50	1145.04	37.73	146.57	5.06
387.50	1145.52	37.10	146.63	4.98
404.25	1164.89	35.81	149.11	4.81
411.50	1166.70	36.52	149.34	4.91
478.00	1252.59	37.17	160.33	5.02
505.00	1267.91	36.62	162.29	4.94
526.50	1281.52	36.76	164.03	4.96
550.50	1307.26	31.92	167.33	4.35
579.00	1315.15	36.14	168.34	4.90
650.00	1368.85	35.82	175.21	4.84
741.00	1388.88	35.48	177.78	4.80
861.00	1439.37	35.42	184.24	4.79
908.00	1459.04	36.68	186.76	4.96
1007.50	1521.18	38.56	194.71	5.21
1175.00	1589.84	44.36	203.50	5.89
1318.00	1617.40	42.62	207.03	5.75
1508.00	1675.99	43.27	214.53	5.84
1677.50	1711.93	44.86	219.12	6.02
1700.00	1718.95	45.03	220.02	6.04

Table 11: Data of linden summer leaves BMP test

Linden summer leaves				
Time	Average biogas production	Standard deviation	Average BMP	Standard deviation
h	mL	mL	mL(CH_4) g(VS)$^{-1}$	mL(CH_4) g(VS)$^{-1}$
0.00	0.00	0.00	0.00	0.00
4.00	43.30	6.22	3.80	0.63
22.50	275.06	15.31	24.10	1.86
27.75	314.58	16.47	27.57	2.04
43.25	443.22	11.81	46.95	1.55
52.50	499.42	12.09	52.91	1.58
68.00	577.61	13.72	61.19	1.82
75.75	606.66	14.40	64.27	1.90
91.25	679.04	16.11	78.26	1.98
118.50	770.09	17.83	88.75	2.16
140.50	835.35	20.05	96.27	2.40
146.33	843.78	21.68	97.24	2.57
171.50	914.80	24.56	107.80	2.67
187.33	962.79	27.77	113.45	3.05
214.00	1007.42	30.32	118.71	3.33
240.00	1060.88	34.86	125.01	3.85
266.33	1091.16	40.61	129.02	4.52
308.50	1207.95	48.15	142.83	5.39
332.00	1234.14	49.64	145.92	5.56
339.50	1247.20	51.00	147.47	5.72
356.33	1287.85	51.38	164.70	7.32
364.00	1299.56	51.69	166.20	7.37
380.50	1351.80	54.06	172.88	7.73
387.50	1360.16	52.07	173.95	7.48
404.25	1389.50	56.83	177.70	8.12
411.50	1400.21	52.56	179.07	7.58
478.00	1518.90	57.52	194.25	8.32
505.00	1547.33	57.58	197.89	8.34
526.50	1567.71	58.97	200.49	8.54
550.50	1604.18	59.42	205.16	8.62
579.00	1622.64	59.92	207.52	8.66
650.00	1694.27	61.45	216.68	8.93
741.00	1727.04	60.31	220.87	8.82
861.00	1797.64	50.35	229.89	7.61
908.00	1823.50	51.15	233.20	7.74
1007.50	1895.93	53.87	242.46	8.10
1175.00	1961.10	63.84	250.79	9.33
1318.00	1993.52	68.22	254.94	9.82
1508.00	2056.01	72.21	262.93	10.28
1677.50	2090.00	75.94	267.27	10.69
1700.00	2100.23	77.24	268.58	10.85

Table 12: Data of maple summer leaves BMP test

Maple summer leaves				
Time	Average biogas production	Standard deviation	Average BMP	Standard deviation
h	mL	mL	mL(CH_4) g(VS)$^{-1}$	mL(CH_4) g(VS)$^{-1}$
0.00	0.00	0.00	0.00	0.00
4.00	33.80	2.23	2.85	0.16
22.50	119.61	31.58	10.05	2.56
27.75	152.58	32.58	12.83	2.61
43.25	327.05	44.59	32.18	4.80
52.50	362.72	46.02	35.69	4.99
68.00	421.98	47.27	41.51	5.19
75.75	446.08	48.40	43.88	5.34
91.25	510.65	53.45	56.26	6.23
118.50	606.60	59.86	66.83	7.01
140.50	672.13	65.56	74.05	7.69
146.33	682.94	65.46	75.24	7.68
171.50	750.26	64.86	85.35	7.48
187.33	798.34	64.23	90.82	7.42
214.00	838.17	68.81	95.35	7.94
240.00	888.05	72.38	101.03	8.36
266.33	918.08	74.27	105.93	8.31
308.50	1028.44	84.05	118.66	9.41
332.00	1047.26	88.10	120.83	9.88
339.50	1058.75	88.82	122.16	9.96
356.33	1086.35	93.34	134.21	16.78
364.00	1093.76	93.95	138.39	13.82
380.50	1133.87	96.21	143.46	14.18
387.50	1134.77	97.10	143.58	14.29
404.25	1151.80	98.59	145.73	14.52
411.50	1155.57	98.58	146.21	14.52
478.00	1238.38	104.04	156.68	15.36
505.00	1256.12	109.56	158.94	16.11
526.50	1270.45	109.43	160.75	16.11
550.50	1294.93	111.88	163.84	16.47
579.00	1305.21	112.67	165.15	16.59
650.00	1360.81	118.06	172.18	17.38
741.00	1382.50	119.64	174.93	17.62
861.00	1432.87	122.80	181.30	18.10
908.00	1454.17	126.24	184.00	18.58
1007.50	1513.73	134.46	191.54	19.70
1175.00	1578.90	141.55	199.78	20.69
1318.00	1613.30	150.11	204.14	21.79
1508.00	1667.61	162.32	211.02	23.36
1677.50	1697.59	173.70	214.82	24.78
1700.00	1706.30	175.41	215.92	25.01

Table 13: Data of oak summer leaves BMP test

Oak summer leaves				
Time	Average biogas production	Standard deviation	Average BMP	Standard deviation
h	mL	mL	mL(CH_4) g(VS)$^{-1}$	mL(CH_4) g(VS)$^{-1}$
0.00	0.00	0.00	0.00	0.00
4.00	36.54	1.82	3.18	0.12
22.50	151.09	11.25	13.13	0.81
27.75	182.98	14.93	15.91	1.10
43.25	288.96	24.49	30.85	2.58
52.50	337.80	29.04	36.07	3.06
68.00	413.25	33.08	44.12	3.48
75.75	443.12	33.50	47.31	3.52
91.25	507.09	38.18	58.97	4.27
118.50	592.00	43.79	68.84	4.90
140.50	652.69	46.59	75.90	5.20
146.33	660.37	47.55	76.80	5.31
171.50	723.62	50.97	86.52	5.60
187.33	774.70	58.00	92.62	6.41
214.00	808.30	52.66	96.65	5.75
240.00	858.88	55.80	102.69	6.09
266.33	886.06	58.07	107.27	6.35
308.50	1007.69	61.13	122.00	6.63
332.00	1033.25	64.48	125.09	7.01
339.50	1046.02	65.20	126.64	7.09
356.33	1069.64	68.34	129.50	7.45
364.00	1076.10	73.60	139.65	8.93
380.50	1122.45	72.81	145.67	8.81
387.50	1123.17	73.23	145.76	8.86
404.25	1140.38	75.10	148.00	9.09
411.50	1143.41	74.91	148.39	9.07
478.00	1227.88	75.60	159.35	9.11
505.00	1245.18	76.81	161.60	9.25
526.50	1257.48	75.89	163.20	9.13
550.50	1281.86	76.43	166.36	9.18
579.00	1291.54	76.99	167.62	9.25
650.00	1347.96	78.65	174.94	9.43
741.00	1370.58	80.33	177.88	9.64
861.00	1414.39	93.48	183.56	11.32
908.00	1448.21	85.30	187.95	10.24
1007.50	1514.69	85.70	196.58	10.25
1175.00	1592.94	85.69	206.74	10.21
1318.00	1631.05	86.93	211.69	10.34
1508.00	1696.26	86.99	220.15	10.32
1677.50	1734.40	86.07	225.10	10.17
1700.00	1742.81	87.70	226.19	10.38

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