CERTIFICATE OF ANALYSIS

Order #	Order Status	Report #	Date of Report
1438	Order Fulfilled	1438-11264-ICPF	9th February 2021

Report for: Daniel Hayes, Celignis Limited, 111 Brookfield Hall, Castletroy, Limerick, Ireland

Sample Name - Grass Example

Biogas and Biomethane Potential (BMP) - Summary Data

Proximate Analysis

Total Solids (% Wet Basis)	Volatile Solids (% Dry Basis)	Volatile Solids (% Wet Basis)
39.00	95.33	37.18

Biogas and Biomethane Potential

Biogas Production			Biomethane Potential		
L/kg VS	L/kg Dry Mass	L/kg Wet Mass	L/kg VS	L/kg Dry Mass	L/kg Wet Mass
517.1	492.9	192.2	304.0	289.8	113.0

Weighted Biogas Composition

At Day	Methane (%)	CO_2 (%)	Oxygen (%)	H_2S (ppm)	Ammonia (ppm)
28	58.8	43.1	0.1	18	0
21	58.8	43.0	0.1	18	0
14	58.8	42.7	0.1	17	0
7	58.9	41.8	0.1	16	0
3	58.9	42.1	0.1	16	0

Biogas Composition During Periods

Between Days	Methane (%)	CO_2 (%)	Oxygen (%)	H_2S (ppm)	Ammonia (ppm)
1 and 3	58.9	42.1	0.1	16	0
4 and 7	58.9	41.7	0.1	16	0
8 and 14	58.3	48.7	0.2	25	0
15 and 21	58.0	51.1	0.2	29	0
22 and 28	57.9	52.2	0.2	30	0

- Results after 28 days of digestion (test complete).
- Gas yields and composition are inoculum-subtracted, unless otherwise stated.

Lab Manager Signature:

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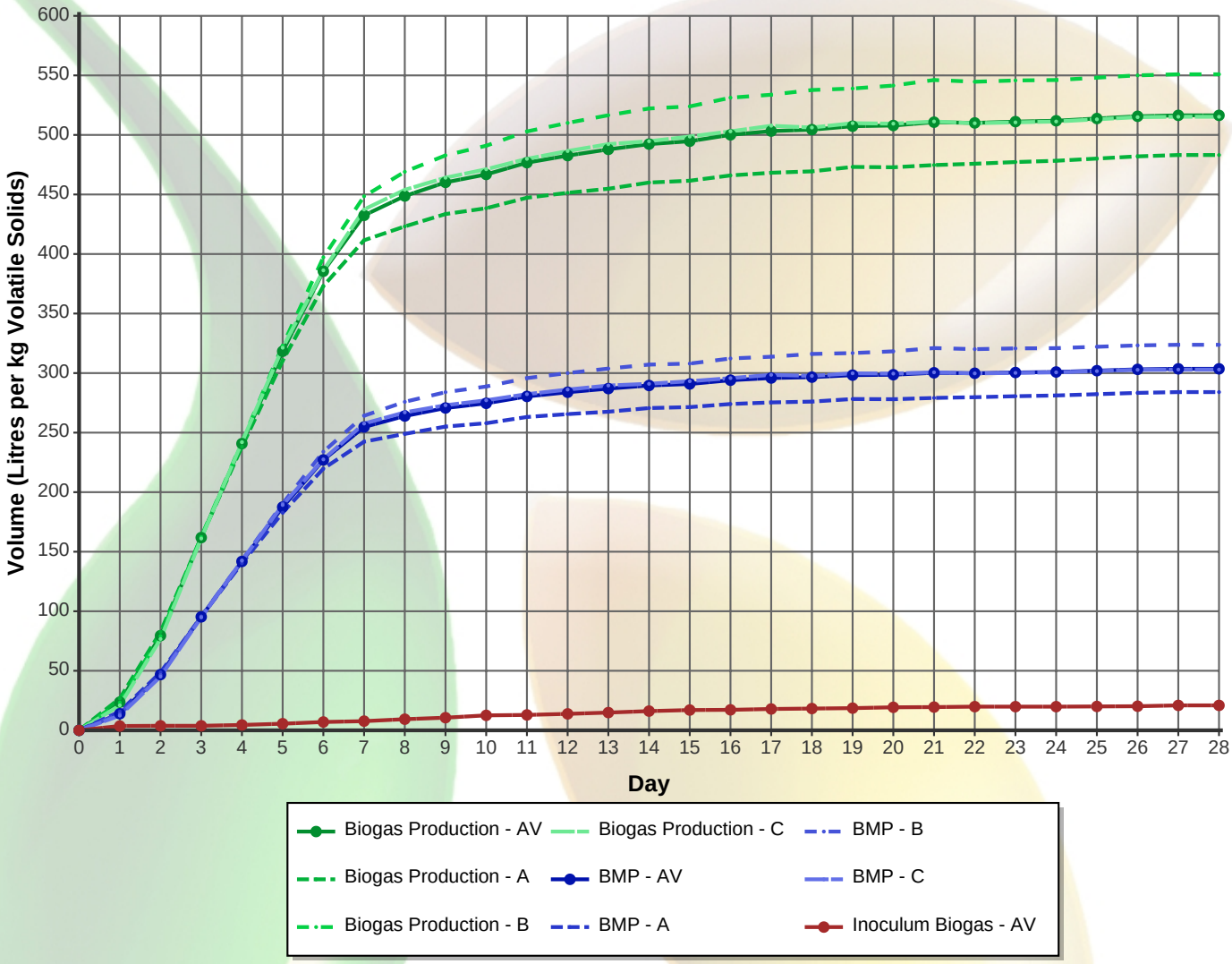
Report for: Daniel Hayes, Celignis Limited, 111 Brookfield Hall, Castletroy, Limerick, Ireland

Sample Name - Grass Example

Plot of Biogas and Biomethane Potential (BMP) - Inoculum Subtracted



Days of Digestion	28 (Digestion Complete)
Max. biogas production reached at day	28
70% of total biogas reached at day	6
80% of total biogas reached at day	7
90% of total biogas reached at day	10
1% gas production reached at day	10

Lab Manager Signature:

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1438	Order Fulfilled	1438-11264-ICPF	9th February 2021

Report for: Daniel Hayes, Celignis Limited, 111 Brookfield Hall, Castletroy, Limerick, Ireland

Sample Name - Grass Example

Feedstock Analysis - Summary Data

Test	Method Reference	Units	As-Received	Dry Mass Basis	Dry Ash-Free Basis
Moisture	EN 14774-1:2009	%	61.00	-	-
Total Solids	Calculated	%	39.00	-	-
Ash	EN 14775:2009	%	1.82	4.67	-
Volatile Solids	Calculated	%	37.18	95.33	-
Carbon	EN 15104:2011	%	18.65	47.81	50.15
Hydrogen	EN 15104:2011	%	2.23	5.73	6.01
Nitrogen	EN 15104:2011	%	1.07	2.74	2.87
Sulphur	EN 15289:2011	%	0.09	0.22	0.23
Oxygen	By Difference	%	15.15	38.84	40.74
Aluminium	EN ISO 16967:2015	ppm	87	224	-
Calcium	EN ISO 16967:2015	ppm	1,659	4,254	-
Iron	EN ISO 16967:2015	ppm	161	413	-
Magnesium	EN ISO 16967:2015	ppm	429	1,100	-
Sodium	EN ISO 16967:2015	ppm	928	2,379	-
Phosphorus	EN ISO 16967:2015	ppm	764	1,960	-
Potassium	EN ISO 16967:2015	ppm	5,912	15,159	-
Silicon	EN ISO 16967:2015	ppm	949	2,434	-
Titanium	EN ISO 16967:2015	ppm	5	12	-
COD	In-House	g/kg	445.9	1,143.3	-
BOD	In-House	g/kg	360.3	923.8	-
Ammonia	In-House	g/kg	1.54	-	-

- Data at www.celignis.com/output/analytical_customer_view.php?editid1=28198
- Data converted to different bases according to EN 15296:2011.
- COD = Chemical Oxygen Demand; BOD = Biological Oxygen Demand.

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Report for: Daniel Hayes, Celignis Limited, 111 Brookfield Hall, Castletroy, Limerick, Ireland

Sample Name - Grass Example

Major Elements - Dry Matter Basis (mg/kg Dry Mass)

Element	Method Reference	Units	Average	Rep 1	Rep 2	Std Dev
Al - Aluminium	EN ISO 16967:2015	ppm	**224**	223	224	1
Ca - Calcium	EN ISO 16967:2015	ppm	**4,254**	4,281	4,227	38
Fe - Iron	EN ISO 16967:2015	ppm	**413**	418	408	7
Mg - Magnesium	EN ISO 16967:2015	ppm	**1,100**	1,100	1,100	0
Na - Sodium	EN ISO 16967:2015	ppm	**2,379**	2,382	2,376	4
P - Phosphorus	EN ISO 16967:2015	ppm	**1,960**	1,953	1,967	10
K - Potassium	EN ISO 16967:2015	ppm	**15,159**	15,198	15,120	55
Si - Silicon	EN ISO 16967:2015	ppm	**2,434**	2,430	2,437	5
Ti - Titanium	EN ISO 16967:2015	ppm	**12**	11	12	1

- Data at www.celignis.com/output/analytical_customer_view.php?editid1=28198

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Report for: Daniel Hayes, Celignis Limited, 111 Brookfield Hall, Castletroy, Limerick, Ireland

Sample Name - Grass Example

Minor Elements - Dry Matter Basis (mg/kg Dry Mass)

Element	Method Reference	Units	Average	Rep 1	Rep 2	Std Dev
As - Arsenic	EN ISO 16968:2015	ppm	**<1**	<1	<1	<1
Cd - Cadmium	EN ISO 16968:2015	ppm	**<1**	<1	<1	<1
Co - Cobalt	EN ISO 16968:2015	ppm	**2**	2	1	1
Cr - Chromium	EN ISO 16968:2015	ppm	**41**	42	39	2
Cu - Copper	EN ISO 16968:2015	ppm	**10**	10	9	1
Hg - Mercury	EN ISO 16968:2015	ppm	**18**	18	17	1
Mn - Manganese	EN ISO 16968:2015	ppm	**35**	35	35	0
Mo - Molybdenum	EN ISO 16968:2015	ppm	**2**	2	2	0
Ni - Nickel	EN ISO 16968:2015	ppm	**54**	57	51	4
Pb - Lead	EN ISO 16968:2015	ppm	**<1**	<1	<1	<1
Sb - Antimony	EN ISO 16968:2015	ppm	**<1**	9	<1	<1
V - Vanadium	EN ISO 16968:2015	ppm	**<1**	<1	<1	<1
Zn - Zinc	EN ISO 16968:2015	ppm	**47**	46	48	1

- Data at www.celignis.com/output/analytical_customer_view.php?editid1=28198

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Report for: Daniel Hayes, Celignis Limited, 111 Brookfield Hall, Castletroy, Limerick, Ireland

Sample Name - Grass Example

Proximate Analysis for BMP Test - Replicate Data

Dry Matter Basis (% Dry Mass)

Test	Method Reference	Average	Replicate 1	Replicate 2	Standard Deviation
Volatile Solids	Calculated from Ash	95.33	95.31	95.36	0.04
Ash	EN14775:2009	4.67	4.69	4.64	0.04

Fresh Matter Basis (% Wet Mass)

Test	Method Reference	Average	Replicate 1	Replicate 2	Standard Deviation
Total Solids	Calculated from Moisture	39.00	39.50	38.50	0.71
Moisture Content	14774-1:2009	61.00	60.50	61.50	0.71
Volatile Solids	Calculated	37.18	37.17	37.19	0.01
Ash	Calculated	1.82	1.83	1.81	0.01

Additional Sample and Digestion Details

Sample Type (Solid/Liquid/Slurry)	
Sample Consistency	
Sample pH	
Inoculum to Substrate Ratio (VS-basis)	4:1
Digester Volume to Headspace Ratio	7:3
Temperature of Digestion	37 ^{o}C
Additional Comments:	None

Lab Manager Signature:

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Report for: Daniel Hayes, Celignis Limited, 111 Brookfield Hall, Castletroy, Limerick, Ireland

Sample Name - Grass Example

Biogas and Biomethane Potential (BMP) - Replicate Data

Biogas Production

Basis	Average	Replicate A	Replicate B	Replicate C	Standard Deviation
Volatile Solids (L/kg-VS)	517.1	482.4	552.5	516.3	35.1
Dry Matter (L/kg-DM)	492.9	459.9	526.7	492.2	33.4
Fresh Matter (L/kg-FM)	192.2	179.4	205.4	192.0	13.0

Biomethane Potential (BMP)

Basis	Average	Replicate A	Replicate B	Replicate C	Standard Deviation
Volatile Solids (L/kg-VS)	304.0	283.6	324.7	303.5	20.5
Dry Matter (L/kg-DM)	289.8	270.4	309.5	289.4	19.6
Fresh Matter (L/kg-FM)	113.0	105.4	120.7	112.9	7.6

Inoculum Biogas Production

Basis	Average	Replicate A	Replicate B	Replicate C	Standard Deviation
Volatile Solids (L/kg-VS)	21.5	13.3	18.4	32.8	10.1

- Results after 28 days of digestion (test complete).
- Gas yields and composition are inoculum-subtracted, unless otherwise stated.

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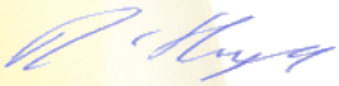

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Report for: Daniel Hayes, Celignis Limited, 111 Brookfield Hall, Castletroy, Limerick, Ireland

Sample Name - Grass Example

Biogas Composition - Period Data

	% of Final Net Biogas Volume	Methane (%)	Carbon Dioxide (%)	Oxygen (%)	Hydrogen Sulphide (ppm)	Ammonia (ppm)
Between Days 1 and 3						
Biogas	31.3	59.0	41.0	0.1	15	0
Inoculum		60.0	30.0	0.0	0	0
Inoculum-Subtracted		58.9	42.1	0.1	16	0
Weighted (Days 1 to 3)		58.9	42.1	0.1	16	0
Between Days 4 and 7						
Biogas	52.3	59.0	41.0	0.1	15	0
Inoculum		60.0	30.0	0.0	0	0
Inoculum-Subtracted		58.9	41.7	0.1	16	0
Weighted (Days 1 to 7)		58.9	41.8	0.1	16	0
Between Days 8 and 14						
Biogas	11.6	59.0	41.0	0.1	15	0
Inoculum		60.0	30.0	0.0	0	0
Inoculum-Subtracted		58.3	48.7	0.2	25	0
Weighted (Days 1 to 14)		58.8	42.7	0.1	17	0
Between Days 15 and 21						
Biogas	3.6	59.0	41.0	0.1	15	0
Inoculum		60.0	30.0	0.0	0	0
Inoculum-Subtracted		58.0	51.1	0.2	29	0
Weighted (Days 1 to 21)		58.8	43.0	0.1	18	0
Between Days 22 and 28						
Biogas	1.2	59.0	41.0	0.1	15	0
Inoculum		60.0	30.0	0.0	0	0
Inoculum-Subtracted		57.9	52.2	0.2	30	0
Weighted (Days 1 to 28)		58.8	43.1	0.1	18	0

- Results after 28 days of digestion (test complete).
- Gas yields and composition are inoculum-subtracted, unless otherwise stated.

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Sample Name - Grass Example

Ultimate Analysis - Replicate Data

Test	Method Reference	Average	Replicate 1	Replicate 2	Standard Deviation
Dry Matter Basis (% Dry Mass)					
Carbon	EN 15104:2011	47.81	47.78	47.84	0.04
Hydrogen	EN 15104:2011	5.73	5.80	5.65	0.10
Nitrogen	EN 15104:2011	2.74	2.76	2.71	0.04
Sulphur	EN 15289:2011	0.22	0.24	0.20	0.03
Oxygen	Calculated	38.84	38.75	38.93	0.12
As-Received Basis (% Wet Mass)					
Carbon	Calculated	18.65	18.63	18.66	0.02
Hydrogen	Calculated	2.23	2.26	2.21	0.04
Nitrogen	Calculated	1.07	1.08	1.06	0.01
Sulphur	Calculated	0.09	0.09	0.08	0.01
Oxygen	Calculated	15.15	15.11	15.18	0.05
Dry Ash-Free Basis (% DAF)					
Carbon	Calculated	50.15	50.12	50.18	0.04
Hydrogen	Calculated	6.01	6.09	5.93	0.11
Nitrogen	Calculated	2.87	2.90	2.84	0.04
Sulphur	Calculated	0.23	0.25	0.21	0.03
Oxygen	Calculated	40.74	40.65	40.83	0.13

- Data at www.celignis.com/output/analytical_customer_view.php?editid1=28198
- Data corrected to different bases according to EN 15296:2011.

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Sample Name - Grass Example

Stoichiometric Methane Potential (SMP)

Volatile Solids Basis (L per kg VS)

	Biogas	Methane	Carbon Dioxide	% Methane
Calculated from Buswell Equation	935	474	461	50.7
Actual Values at Day 28	517	304	223	58.8
Biodegradability Index (%)	55.3	64.1		

Dry Mass Basis (L per kg Dry Matter)

	Biogas	Methane	Carbon Dioxide	% Volatile Solids
Calculated from Buswell Equation	892	452	439	
Actual Values at Day 28	493	290	212	95.33

As-Received Basis (L per kg Fresh Matter)

	Biogas	Methane	Carbon Dioxide	% Total Solids
Calculated from Buswell Equation	348	176	171	
Actual Values at Day 28	192	113	83	39.00

- Results after 28 days of digestion (test complete).
- Data at www.celignis.com/output/biogas_view.php?editid1=276
- For Buswell Equation see www.celignis.com/anaerobic-digestion.php#buswell

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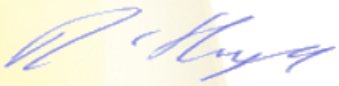

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Sample Name - Grass Example

COD and BOD Analysis - Replicate Data

Dry Matter Basis (g/kg)

Test	Sample	Units	Average	Replicate 1	Replicate 2	Standard Deviation
COD	Feedstock	g/kg	1,143.3	1,200.1	1,086.4	80.4
BOD	Feedstock	g/kg	923.8	914.6	932.9	12.9

As-Received Basis (g/kg-fresh-mass)

Test	Sample	Units	Average	Replicate 1	Replicate 2	Standard Deviation
COD	Feedstock	g/kg	445.9	468.0	423.7	31.3
BOD	Feedstock	g/kg	360.3	356.7	363.8	5.0

- Data at www.celignis.com/output/biogas_view.php?editid1=276
- Data corrected to different bases according to EN 15296:2011 and EN 14918:2009.
- COD = Chemical Oxygen Demand; BOD = Biological Oxygen Demand.

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Sample Name - Grass Example

Fertiliser Properties Analysis - Replicate Data

Test	Sample	Units	Average	Replicate 1	Replicate 2	Standard Deviation
Dry Matter Basis (% Dry Mass)						
Nitrogen	Feedstock	% dm	2.74	2.76	2.71	0.04
Phosphorus	Feedstock	% dm	0.20	0.20	0.20	0.00
Potassium	Feedstock	% dm	1.52	1.52	1.51	0.01
As-Received Basis (% Wet Mass)						
Nitrogen	Feedstock	% wb	1.07	1.08	1.06	0.01
Phosphorus	Feedstock	% wb	0.08	0.08	0.08	0.00
Potassium	Feedstock	% wb	0.59	0.59	0.59	0.00
Ammonia	Feedstock	g/kg	1.54	1.54	1.53	0.01
Ash Basis (% Total Ash)						
Phosphorus Pentoxide	Feedstock	% Ash	9.62	9.58	9.65	0.05
Potassium Oxide	Feedstock	% Ash	38.97	39.07	38.87	0.14

- Data at www.celignis.com/output/biogas_view.php?editid1=276
- Data corrected to different bases according to EN 15296:2011 and EN 14918:2009.

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Report for: Daniel Hayes, Celignis Limited, 111 Brookfield Hall, Castletroy, Limerick, Ireland

Sample Name - Grass Example

Digestion of Sample - Discussion of Results

Feedstock Characteristics
The moisture of the sample is 61.00% with total solids of 39.00% and the percentage of ash in the sample on wet basis and dry basis is 1.82% and 4.67%. Volatile solids percentage is 37.18% and 95.33% on wet and dry basis respectively.

Biogas Potential
The biogas potential of the sample is 189.9 L/Kg in Fresh Matter basis which on dry matter basis is 486.9 L/Kg. On Volatile solids basis the biogas potential is 510.7 L/Kg.

Biomethane Potential
The weighted average methane percentage is 58.8% which is good, but considering the type of inoculum used for the test which can produce biogas over 85% methane with the optimum feedstock, the methane percentage seems low.

The biomethane potential is 111.6 L/Kg, 286.2 L/Kg and 300.3 L/Kg on fresh matter, dry mass and volatile solids respectively.

Feedstock Chemical Properties and Fertiliser Properties

Ultimate Analysis
Elemental analysis is performed to determine the carbon, hydrogen, nitrogen and sulphur. The C/N ratio and C/S ratio are amongst the key indicators to identify the suitability of the feedstock for mono-digestion or identifying the suitable co-digestion feedstock.

The ratio of C/N for the sample is 19:1 indicating that the feedstock is highly suitable for monodigestion, if other necessary trace elements are added. The C:S ratio is 240:1 indicating that the risk of H2S accumulation is low.

Major and Minor Elements Analysis for Suitability of Digestion and Fertiliser Properties
The potassium concentrations are in the desirable range 5912 ppm as received basis. Potassium concentration should be in excess to sodium to neutralise the cell membrane potential and in this case, it is 6 times higher, but is not at inhibitory levels if the dilution effect in the digester is considered. However, the sodium levels (928m ppm as received basis) seem low when dilution effect is considered and hence should be monitored to avoid any deficiency as it might affect the quality of the biogas produced.
The phosphorous concentration which is another key nutrient, but is known to cause eutrophication problems when it is present in high concentrations in the digestate. Also, it is proven to inhibit anaerobic digestion at high concentrations over 500 ppm. The phosphorous concentration in the feedstock is only 764 ppm and hence the digestate produced will not be a problem of eutrophication. However, care

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should be taken and should meet all the national and European guidelines before disposing or land spreading the digestate.
The trace elements analysis indicates that there could be deficiency of iron, cobalt and molybdenum in the digester and might need supplementation. The other trace nutrients should be monitored and should be supplied if the deficiency occurs in the long run.
The nitrogen, phosphorous and potassium levels indicates that the sample is not a good source of fertiliser, as the ratios on dry basis are 14:1:7.5 which is very different from the recommended concentrations 3:1:1.

Stoichiometric Potential and Biodegradability Index
From the Buswell equation calculations, the stoichiometric potential of the feedstock is 935 m3/ton biomass which is 1.8 times higher than the actual yield. This could be due to the low biodegradability index of the feedstock which from the predicted and actual results is only 54.6%.

Based on the COD analysis, the predicted value for total methane production is 400 L/Kg Dry mass, but the actual yield is 286 L/kg dry mass which is 1.4 times lower than the maximum achievable yield. And the efficiency is only 71%. But, considering that all the feedstock is not biologically degradable, Biological Oxygen Demand (BOD) tests are performed. If the conversion is based on the BOD analysis and its ratio to COD, the predicted methane production is 314 L/Kg Dry mass and the efficiency in terms of actual yield is 91% which is considerably good. The biodegrability index in terms of BOD5 to COD ratio is 0.8 which indicates that the majority of the sample is easily biodegradable.

Digestate Chemical Properties and Fertiliser Properties

Ultimate Analysis
The ratio of C:N for the digestate obtained from the sample is 8.5:1 indicating that nitrogen is concentrated in the digestate. This ratio is similar to carbon and nitrogen ratio of the soil organic matter. Higher carbon to nitrogen will cause depletion of nitrogen in the soil, as microorganisms strip the nitrogen from soil to breakdown and assimilate carbon. This indicates that the digestate from the grass sample is suitable as fertiliser in terms of carbon to nitrogen ratio.

The COD and BOD of the digestate is lower than the feedstock and the biodegradability index is 0.87 indicating that the digestate is easily biodegradable under aerobic conditions in the presence of suitable consortium bacteria such as activated sludge.

Fertiliser Properties Analysis
The ratio of Nitrogen: Phosphorous: Potassium has changed significantly with the anaerobic digestion (2:1.6:1) and is closer to the recommended fertiliser concentration when compared to the undigested sample.

Lab Manager Signature:

- For further discussion of the results for this sample contact lalitha@celignis.com.