

1 Case report

2 HoMethan - Operation of 5 m³ biogas digesters with 3 manure and organic waste in Middle and South 4 America

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10 **Abstract:** Traditional small-scale biogas systems are struggling with several problems, e.g.
11 reliability, limitations in the variety of feedstock, and costs. To overcome these problems a bag-
12 reactor system, which includes stirring-units, was designed. The system has a capacity of 200 kg d⁻¹
13 input and 5.0 m³ d⁻¹ biogas output. Due to standardized components - available world-wide - the
14 system could be built-up within one day. Also, maintenance and repair are manageable due to the
15 standard components. The system could be operated with different feedstocks, does not need water
16 for dilution and no electricity. From 2015 to 2020 a total of 40 of these biogas plants were installed
17 in South/Middle America. The experiences from the plant operators were collected. Analyzes of gas
18 quality and quantity as well as the quality of the residues were done. It shows that the gas
19 production is stable, and the gas could be used for heating and electricity generation. The nutrition
20 value of the residues is 2.5-times higher compared to the input materials, the plant tolerance also
21 increases. It shows that small-scale biogas plants could be adapted to local requirements. It increases
22 the added value in rural areas, reduces the purchase of fertilizers and fuels and reduces emissions.

23 **Keywords:** biogas; small biogas plant; HoMethan; bag-reactor; stirred biodigester

25 1. Introduction

26 Biogas has a long history. Beginning from sewage treatment, it developed to a technology for
27 the treatment of residues from agricultural production. In both systems harmful substances are
28 reduced, an energy rich gas (biogas) is produced and an nutrient rich digestate for fertilizing is gained
29 [1]. From there it focused on the gas generation for electricity, heat, and fuel purposes over the last
30 20 years. Due to the immense investment costs, biogas plants are typically built in dimensions of
31 several thousand cubic meters of digester volume to achieve economies of scale.

32 Especially in development projects small scale biogas plants are still built in the form of
33 underground digesting vessels with a biogas holder [2]; most of them made from bricks. Even if this
34 is a mature technology, construction, maintenance, and repair are demanding [3]. Many small-scale
35 biogas plants fail because of inappropriate technical issues as well as missing knowledge of the
36 operator in relation to this complex technology [4]. Also, water for the dilution of the input materials
37 is needed, which is not always available in necessary amounts. If stirrers are used, electric power will
38 be necessary; if no stirrers are used sedimentation and floating layers will hinder the biogas process
39 in the digester. It has shown that many of these small-scale biogas plants are therefore operated below
40 their optimum, until they are abandoned due to technical reasons. Kebele states, that "... key factors
41 that limit the extension of the biogas technology to potential biogas adopters are the presence of failed
42 and damaged digesters, an inadequate plot of land for digester construction and the water
43 availability problem" [5].

44 It is the purpose of the HoMethan project to overcome these obstacles. In the HoMethan project
 45 a standardized biogas system was designed. The system is easy to build, operate and maintain.
 46 Repairs could be done with standard materials. It is possible to operate the system with a wide variety
 47 of input materials and with no need of water for dilution. It could be adapted to local requirements -
 48 e.g. low temperatures, which could harm the process stability- with little effort. With such a system,
 49 it would be possible to spread the biogas technology for small-scale applications. These would lead
 50 to a more hygienic waste treatment, a reduction of germs, less purchase of fuels due to the biogas,
 51 less climate gas emissions, a useful fertilizer from biogas residues and a higher income for in rural
 52 areas

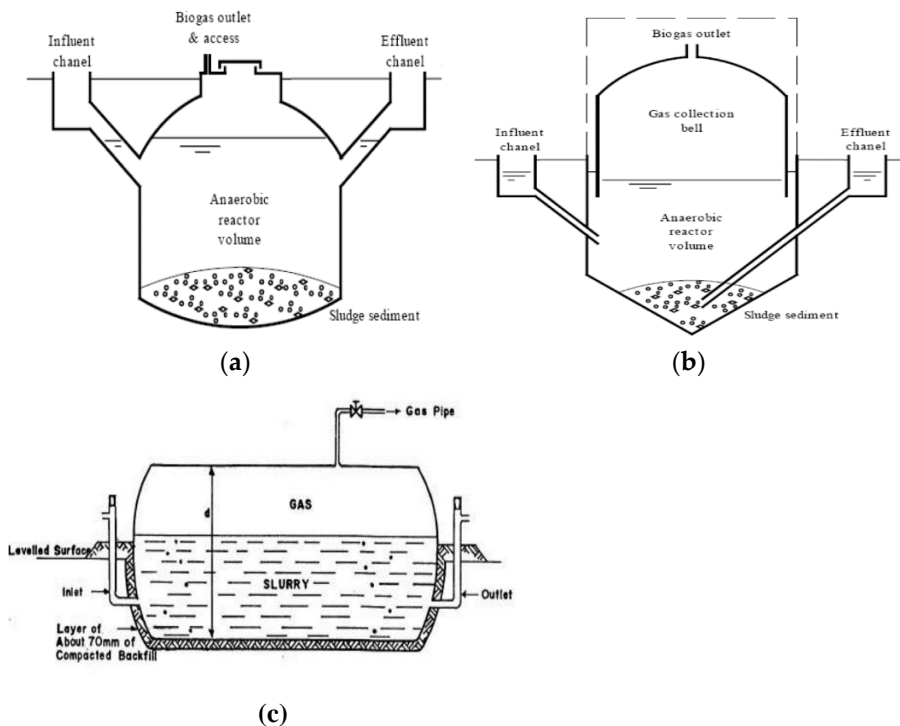
53 The thesis will present the HoMethan system, give information on the user experience, biogas
 54 quality and the quality of the fermentation residues as a fertilizer.

55 **2. Materials and Methods**

56 *2.1 State of the art – small-scale anaerobic digesters*

57 The first biogas plants were built in small-scale dimensions for wastewater treatment and for the
 58 treatment of manure and dung. Especially in developing countries some hundred thousand of small-
 59 scale biogas plants (SSAD) exist. Apart from this, there are millions of ultra-small-scale biogas plants
 60 in China [6]. Most of the systems are built in the form of (a) fixed-dome reactors, (b) floating-dome
 61 reactors or (c) bag reactors (see Figure 1).
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67 **Figure 1.** Popular constructions of small-scale biogas plants (a) fixed-dome reactor [7], (b) floating-
 68 dome reactor [7], (c) tubular or bag reactor. [8]

69 Each of these systems has its specific technical limitations as given in

70

71 Table 1. These technical obstacles are subject to different analyses of SSAD [9–14]. Especially the
 72 absence of stirring units causes dead zones in the reactor resulting in poor digester performance [15].

73 **Table 1:** Technical and design limitations of existing small-scale biogas reactors

fixed-dome reactor	floating-dome reactor	bag reactor
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Problems of gas-tightness of the brickwork gasholder can cause heavy losses of biogas Masonry structure become porous and prone to cracking resulting in gas leakages Gas pressure fluctuates substantially depending on the stored gas volume Lack of stirring systems Artisan skill levels required	Material costs of the steel parts are high and susceptible to corrosion. This can result in a short lifespan Regular maintenance costs due to drum painting Lack of stirring system	Life span can be relatively short as it is susceptible to damage Construction is easy Lack of stirring systems
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In the meta-study of Nevzorova&Kutcherov (2019) barriers for the wider implementation of biogas were analyzed. Beside technical problems, problems with financing and missing operator expertise were the main reasons for failed biogas projects [16]. A study about SSAD in Indonesia came to the result that 15 of 21 biogas systems were abandoned within three years due to technical problems [17].

80 *2.2 HoMethan biogas digester*

81 Considering the knowledge about the obstacles of existing SSAD, a bag reactor with stirring
82 units was designed, the HoMethan system. The bag reactor imposes low requirements in regard of
83 artisan skills when been built and maintained. The system is prefabricated, and quality controlled by
84 the manufacturer to reduce complications with the installation of the system. The installation time
85 for the whole system is one day and one-two days for preparing the trench. The reactor has a volume
86 of 5.0 m³ and is stirred with a transverse mixing system (see Figure 2, men in the middle; also
87 supplementary materials). The transverse mixing helps to avoid short circuit flows of the input
88 material. If stirring is done properly, most biogas process problems in small biogas
89 plants - stratification, instable temperature, bacteria distribution, limited organic load rate - could be
90 solved.



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Figure 1. HoMethan system, fill-in unit (left side), two stirrers in the middle.

93 The system is an “all-eater”; a wide variety of substances can be used. The reactor manages up
94 to 20% dry matter content in the input materials without need for dilution. As no water is used for
95 dilution the reactor temperature is more stable, compared to standard systems. This results in a more
96 stable biogas production. The digester has a footprint of 8.5 m², a total space of 6 m x 10 m is needed.

97 Compared with existing bag reactors (rubber-balloon) and their high wear of the bag foil, a
98 durable and approved membrane is used. The membrane is custom-built for this system. The
99 membrane is resistant to UV radiation and aggressive biogas components. It is also resistant to
100 mechanical damages. The manufacturer expects a lifespan of 20 years for the membrane and the
101 whole system. Additionally, the reactor is equipped with a manhole for maintenance purposes; this
102 makes the inspection of the process possible. The system is autarkic, no additional water or electric
103 energy is needed.

104 The system is designed for an input of 200 kg d⁻¹ manure. Also, organic wastes or a mixture of
105 manure and organic waste can be used. From this input an amount of 5.0 m³ d⁻¹ should perform. This
106 input could be mixture of e.g. 150 l cow manure (9 cows) and 30 l organic waste [18,19]. The output
107 of 5.0 m³ d⁻¹ biogas is equivalent to 75 kg LPG or 90 kg Diesel per month. For buffering the biogas, a
108 2.0 m³ gasholder is installed. The hydraulic residence time (HRT) in warm climate is 25 days.
109 Operating experience and modelling might expect longer HRT in cold climate [20].

110 As mission operator knowledge is a main reason for failed systems (see chapter 2.2), a training
111 for plant operators was added. In each region, where the system is implemented, a train-the-trainer
112 workshop is held. These trainers -typically biogas plant operators on their own- afterwards, train
113 new biogas plant operators on the HoMethan system.

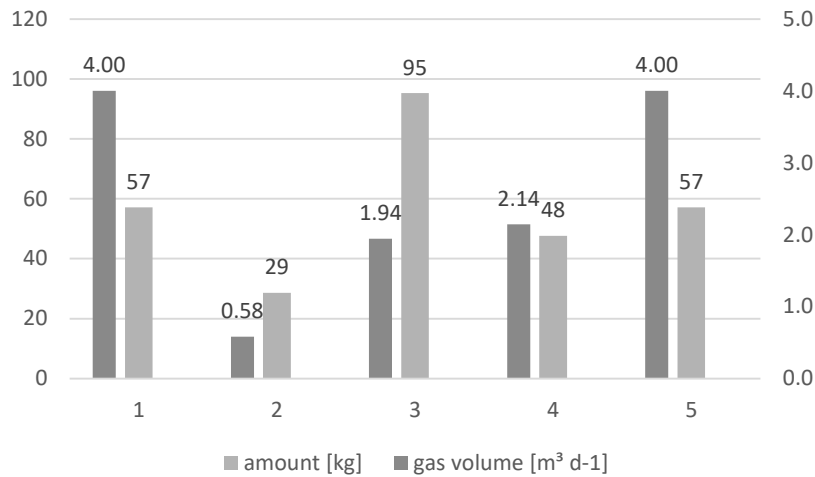
114 2.3 Economy

115 The economic advantages of the system are depending on the special situation of each
116 installation. Therefore, a calculation with average values was done by [21], corresponding to the
117 situation of most of the installed systems in Colombia. The calculation is done with dynamic capital
118 budgeting. The input values are:

- 119 • 2000/3000/6000 kg manure month⁻¹
- 120 • Biogas replaces 90 l diesel or 75 kg LPG month⁻¹
- 121 • Digestate replaces 90 kg triple-fertilizer month⁻¹
- 122 • Prices: diesel 1900 COP l⁻¹, triple-fertilizer 2500 COP kg⁻¹
- 123 • Investment: 7.45 million COP
- 124 • Interest rate: 15%
- 125 • Price increase fertilizer and diesel 3% a⁻¹

126 2.4 Feeding

127 The feeding data of the HoMethan systems in this report are from five farms in Grenada. Input
128 data and the calculate gas output for these system are given in Figure 3. Plants 1 and 5 are fed with
129 seasonal fruits and vegetable waste, plants 2 and 3 are fed with pig manure, and plant 4 is fed with
130 pig manure and vegetable waste. The gas output is calculated with 20 m³ biogas kg⁻¹ manure and 70
131 m³ biogas kg⁻¹ vegetable waste. Plants 1 and 5 are fed from Monday-Friday, while plants 2-4 are fed
132 daily.



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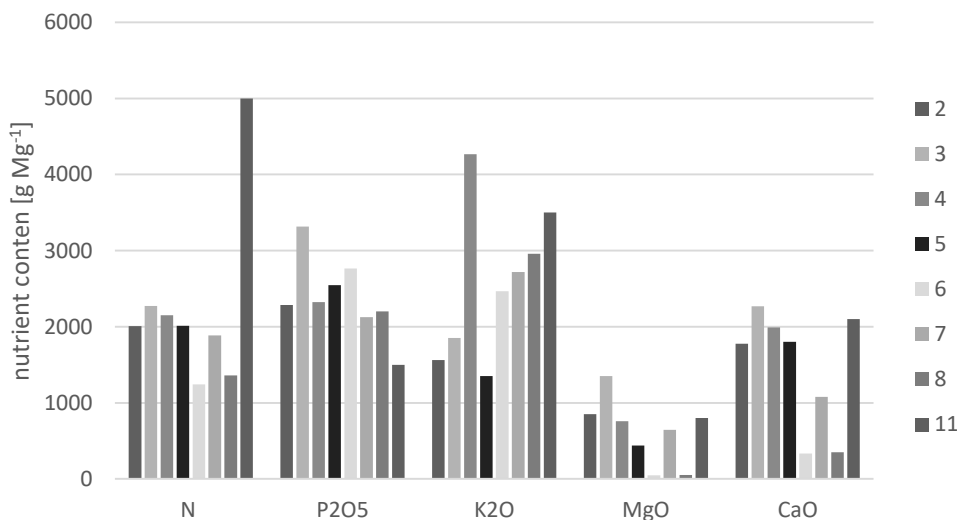
134 **Figure 2.** Feeding amounts [kg d⁻¹] and calculated gas volume [m³ d⁻¹] for five HoMethan systems in
135 Grenada.

136 *2.5 Gas quality*

137 The gas measurements were done with a Severin Multitec 540 gas instrument. There are no gas
138 measure devices on the plants installed. So, measuring can only be done when a gas instrument is
139 brought to the plants.

140 *2.6 Digestate*

141 The digestate of the anaerobic process is a valuable organic fertilizer. The exact nutrient value
142 varies due to the input of each biogas plant, and must be analyzed. The nutrient values of the
143 digestate from the HoMethan systems are given in Figure 1. The biogas plants with the numbers 2-5
144 are the same as in Figure 4, but for the digestate more and some additional plants were tested. The
145 given dates for plants 5-7 are average values from two dates, all others were tested once. Plant
146 number 11 is a average value from several German biogas plants, which process manure.



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148 **Figure 1:** Digestate nutrient content of tested HoMethan systems (2-8) and average of German manure
149 digesters (11). Samples 2-4 were done by PFI, samples 5,6,8 by University Valle, 5 additional by
150 University Nariño

151 The liquid residues from the biogas process are used as fertilizer. The digestate could be applied
152 directly, or liquid and solid phase could be separated, e.g. via sieve. This separation is sometimes

153 done to improve the handling of the fertilizer. Fertilizer tests were performed using the following
154 fertilizers:

- 155 • Digested diluted
- 156 • Chemical fertilizer (15-15-15)
- 157 • organic fertilizer (caldo súper cuatro) [22,23]
- 158 • Control (no fertilizer)

159

160 The fertilizers were applied to maize plants and grassland. Maize was placed in planters, the
161 grassland slots were 5 m x 12 m. All tests were done with three repetitions. The tests were done on
162 the farm Imacal (Nariño, 3013m above sea level, Colombia) in 2016. Dosage and fertilizing periods
163 for each fertilizer were done following guidelines from Agroscience (agricultural lab, Germany). In
164 Figure 5 the maize plant test is given.



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Figure 5. Fertilizer test with maize plants in planters.

167 3. Results

168 3.1 User experience and economy

169 More than 40 of the HoMethan systems have been built in Colombia, Grenada, Brazil, and
170 Zimbabwe in the past five years. According to the manufacturer all these systems are still operated
171 except for two or three systems. The systems are fed with a wide variety of feedstock and operated
172 with the planned efforts for maintenance and repair. The transversal stirring system in the digester
173 effectively prevents swimming and sinking layers. As a result, the biological process is stable and
174 technical disturbances are avoided. Also, the special designed fermenter bag (membrane) is operated
175 without damages; a weakness of conventional bag- or rubber-balloon digesters. The training of the
176 plant operators helps to avoid biological and technical disturbances. In comparison to similar SSAD
177 systems (see chapter 2.1) far fewer biogas plants were abandoned; so, the technical and educational
178 measures seem to be successful.

179 The successful operation of the biogas plant is the prerequisite for economic benefit. The
180 economic analyses for Colombia in the full capacity scenario (6000 kg manure month⁻¹) shows average
181 savings of 395x10³ COP month⁻¹. These savings break down into 170x10³ COP for diesel and 225x10³
182 for artificial fertilizer. The total return over a period of 20 years will be around 200 million COP. The
183 return-on-investment (ROI) will be reached within 1.5 years. If the input will be reduced to 3000 kg
184 manure month⁻¹ (medium capacity scenario), the savings will be reduced to 197.5x10³ COP month⁻¹
185 and the ROI will be reached after 2.5 years. Even in a low capacity scenario, the installation will be
186 economically. When the input is minimized to 2000 kg month⁻¹, the savings will be 132x10³ COP
187 month⁻¹. This will lead to total savings of 23 million COP withing 20 years and a ROI will be reached
188 after 8.5 years.

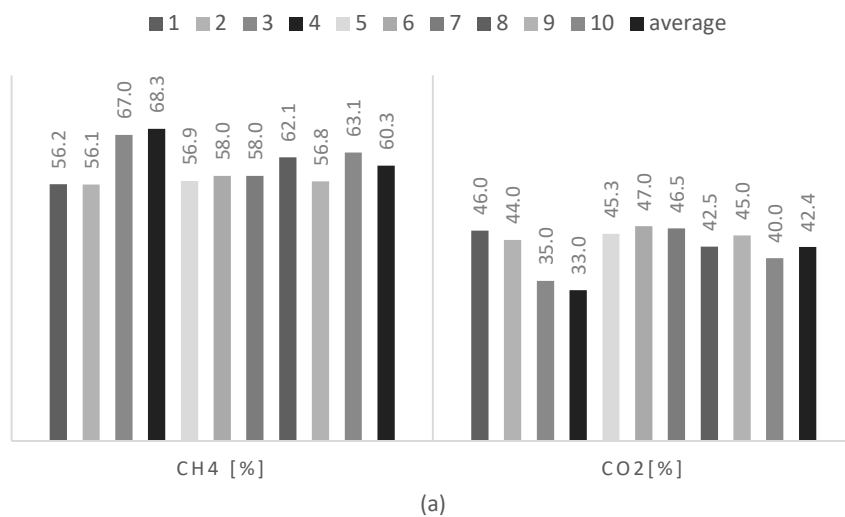
189 It has also shown, that in Colombia the LPG price is a key for determining savings and payback
 190 periods. Even if the LPG price is regulated in Colombia, it can fluctuate $\pm 100\%$ even in areas with no
 191 subsidies.

192 The support of the users over the past 5 years has shown that a key factor for the success of a
 193 SSAD project is the offering of a wide range of applications to use biogas, e.g. generators, stoves,
 194 heaters, etc. Therefore, the system was offered with several devices, which were adapted to the
 195 HoMethan system (see testimonials in the supplementary materials). With these different systems
 196 biogas surpluses could be used more flexible and makes it therefore more useful.

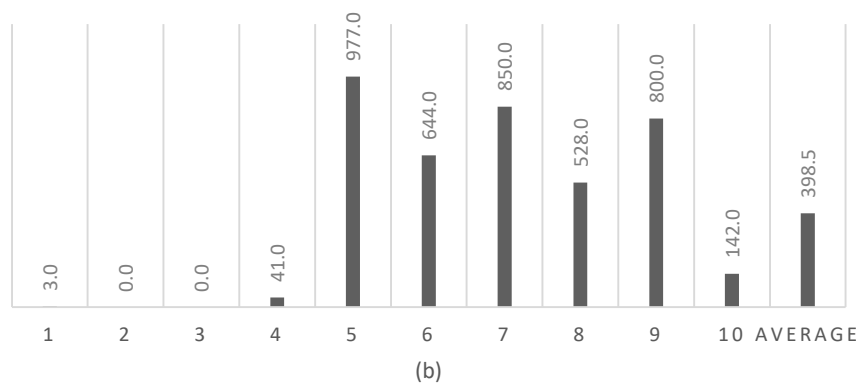
197 The lesson learned from all implemented systems is, that financing, economy of scales and local
 198 manufacturing are key factors for the success of the SSAD systems. If these factors are given, the
 199 farmers will have access to an affordable technology

200 3.2. Gas quality

201 The gas quality was analyzed 1 - 3 times on each biogas plant after the process was biological stable.
 202 The results are given in Figure 2 (a). It could be seen that the CH₄-share in all plants is around 60%
 203 with low variance; the CO₂-share corresponds with the CH₄-value. The H₂S-value is given in Figure 2
 204 (b). There is a difference in the values 1-4 compared to 5-10. The reason for this difference will be
 205 explained in the discussion.



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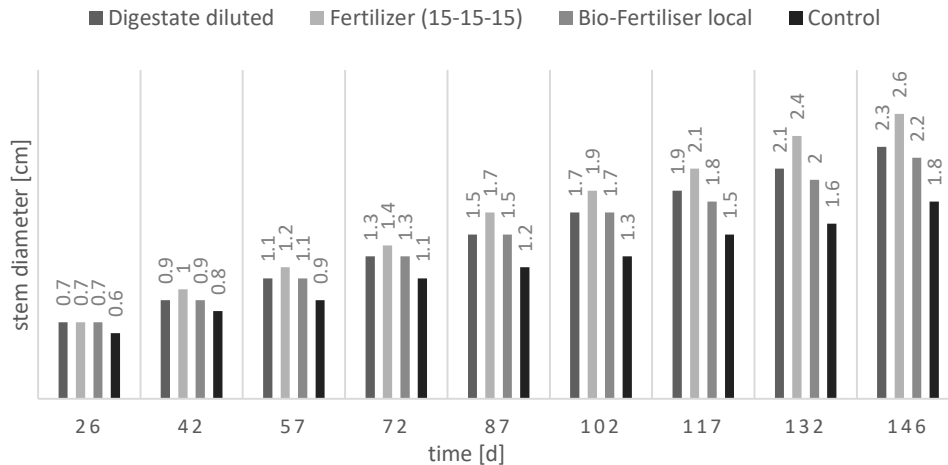
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208 **Figure 2:** (a) CH₄- and CO₂-share [%], (b) H₂S-share [ppm] in the biogas from several HoMethan plants in
 209 Grenada (1-4) and Colombia (5-10) and average value

210 3.3. Fertilizer quality

211 In Figure 7 the results of the maize growth test with the different fertilizers are given. The artificial
 212 fertilizer shows the highest growth rate in comparison of all variants. Compared to the diluted
 213 digestate the growth difference is +10% in average.

214 Comparable results were gained with the with the application of the different fertilizers in grassland.
 215 The yields in the variant with the artificial fertilizer were highest with 2.3 kg m⁻². The súper cuatro
 216 variant had a yield of 2.2 kg m⁻² and the diluted digestate gained 2.0 kg m⁻². The control had a yield
 217 of 0.4 kg m⁻².



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219 **Figure 7.** Results from maize growth test, average diameter of maize stem [cm].

220 4. Discussion

221 The biogas system presented in this study should overcome the technical problems of existing
 222 small-scale anaerobic digesters. Therefore, prefabricated systems and human powered stirring units
 223 are elements of this approach. The user experience from more than 40 plants built over the last five
 224 years shows stable operation without considerable technical problems. In future it will be shown if
 225 stability of operation could be kept on this level. A primary focus will be on the membrane and the
 226 avoidance of layer formation.

227 This study focuses on the technology of the HoMethan system. Also, data from feeding, gas
 228 quality and nutrients in the digestate are presented to give the reader as much information as possible
 229 regarding the whole system. The data quality is on a typical level for field studies. Data collection
 230 and analysis are not consistent. The quality of measurements is not always transparent. In the case of
 231 gas quality measurement this means that it is not known when the gas measurement was calibrated.
 232 Also, the gas measurement was done before (system 2+4) and after (all others) the gas scrubbing.
 233 Therefore, the CH₄ values of systems 2+3 are higher compared to the other systems. The presented
 234 H₂S values are also not realistic for systems 1-4, they are expected to be around some 100 ppm. This
 235 could be a result from improper measuring. For this report, the quality of measured data is
 236 acceptable, because the study focusses on the new technical approach for SSAD and the therefore
 237 resulting process stability and user satisfaction. If this system should be analyzed more detailed in
 238 the future, data acquisition must be planned mor carefully.

239 The systems, from which data are collected, are operated far below the maximum capacity level
 240 (15-50% of 200 kg d⁻¹). If the system will be stable, especially thermal stable, with higher feedstock
 241 capacities must be checked. The low capacity level does not result in low gas output for those plants
 242 using vegetable wastes. These plants are operated on the magnitude of the planned 5.0 m³ biogas d⁻¹.

243 Data of the economic analyses are based on theoretical values and tested with three variants.
 244 This is done because no detailed data from the plant operators could be get, which is typical for such
 245 studies. For an individual case, detailed data from a single installation must be used. If a SSAD is
 246 operated or not is mostly depending on the economic advantages due to fuel and fertilizer savings,

247 which are gained by biogas and the digestate. So, the prices for LPG, diesel, and artificial fertilizers
248 affect the long-time operation of the system. If the operator gains economic advantages from the
249 operation of the biogas plant, he has an incentive to operate the system. Low prices for fossil fuels,
250 e.g. due to subsidies, could bring an SSAD system to an economic tipping point, so the operator will
251 quit the operation.

252 The differences in maize growth -related to the different fertilizers- are also influenced by the
253 fact that most of the $\text{NH}_4^+\text{-N}$ is in the liquid phase, while the organic nitrogen is in the solid phase.
254 When the digestate is diluted and only the solid phase is used less direct available -this means in
255 directly an in the year of application- nutrients are available for the plant. If the application was only
256 based on equivalent amounts of the $\text{NH}_4^+\text{-N}$ fraction in the digestate, comparable apparent $\text{NH}_4^+\text{-N}$
257 recoveries of digestates and mineral fertilizers were reported [24]. Based on the average nutrient
258 content (NPK) of the digestate an amount of 50-130 kg would be needed to substitute 1 kg of standard
259 triple fertilizer (15% NPK). If the biogas plant is operated on its rated output (190 kg d⁻¹), it would
260 replace around 760 kg of triple fertilizer annually in Colombia. [25]

261 **Supplementary Materials:** An educational video is available online at <http://bit.ly/39Ua324>. Testimonials of the
262 plant operators are given at <https://bit.ly/2kSApO0>. A report in the Biogas Journal (Geman Biogas Association)
263 is given at <https://www.oekobit-biogas.com/wp-content/uploads/theartofdownsizing.pdf>. More descriptions of
264 the fertilizing tests could be given by the authors.

265 **Author Contributions:** For research articles with several authors, a short paragraph specifying their individual
266 contributions must be provided. The following statements should be used “Conceptualization, Hartmann,
267 Kilian; methodology, Hartmann, Kilian; investigation, Lluch, Montserrat; resources, Lluch, Montserrat;
268 writing—original draft preparation, Hartmann, Kilian; writing—review and editing, Hartmann, Kilian; All
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