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Biomethanation of rice and wheat straw

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When rice or wheat straw was added to cattle dung slurry and digested anaerobically, daily gas production increased from 176 to 331 l/kg total solids with 100% rice straw and to 194 l/kg total solids with 40% wheat straw. Not only was methane production enhanced by adding chopped crop residues but a greater biodegradability of organic matter in the straws was achieved.

Key words: Biogas, biomethanation, non-conventional energy, rice straw, wheat straw.

As animal dung is relatively scarce, agricultural and forest residues represent the most important energy sources readily available in rural areas. Plant residues normally have a high content of cellulose, which has a combustion energy of 15 kJ/g or, if converted to methane, 50 kJ/g (Khan *et al.* 1983). Studies with various materials, such as crude straw, manure mixtures, delignified straw, cellulose and other agricultural by-products such as green leaves, grasses, apple wastes, animal wastes and oil cakes, have shown the potential for biogas production from these substrates (Oi *et al.* 1982; Gunnarson *et al.* 1985; Zubr 1986; Dar & Tandon 1987; Sharma *et al.* 1987; Kalia *et al.* 1992). The majority of these studies have used batch fermenters and not continuously-fed digesters. Hill & Roberts (1981), using semi-continuous digesters, showed that methane production could be increased by adding chopped field crop residues, barley straw, rice hulls or rice straw to fresh dairy manure. Maximum gas production was with barley straw, followed by rice straw and methane generation was maximal when the ratio of non-lignin carbon to nitrogen ratio of these feedstocks was around 30 : 1.

The present study is on the utilization of rice and wheat straw for biomethanation in semi-continuous digesters at various levels of substitution and at various hydraulic retention times (HRT).

Materials and Methods

Wide-mouthed 2-l Winchester bottles were used as mini-digesters. A sample (1.8 l) of a slurry prepared with cattle dung (10% w/v) and 180 ml of an inoculum capable of producing methane were placed in each digester. Cattle dung was replaced sequentially with either powdered rice straw (RS) or powdered wheat straw (WS) over a 40-day period to attain proportions of rice or wheat straw ranging from 20 to 100% of the total solids in 20% increments. The digesters were each connected for gas measurement to an inverted measuring cylinder held in acidic saline, were fed daily on a 30-, 40- or 50-day HRT and were acclimated on 10% solids for at least two retention times before withdrawing samples for analysis.

Constituent Analysis

Well mixed slurry (20 g) taken before and after 30, 40 or 50 days' anaerobic digestion, according to the HRT, was used for the determination of volatile fatty acids (VFA) by the method of Banerjee (1978). The sample was then oven-dried to determine moisture content (Association of Official Analytical Chemists, 1975) and further analyses made as follows: cellulose by the method of Updegraff (1969); hemicellulose according to Deschatelets & Yu (1986); organic matter by a calorimetric procedure described by Graham (1948); lignin by the method of Iiyama & Wallis (1990); carbohydrates by the anthrone method; and nitrogen by the micro-Kjeldahl method.

Gas Analysis

The biogas produced was analysed for methane content using a dual channel GC (Sigma 2000; Perkin Elmer) equipped with a thermal conductivity detector and a 2-m Porapak Q (80 to 100 mesh) column. Carrier gas was H_2 at a flow rate of 20 ml/min.

Results and Discussion

The initial cattle dung slurry (CD) was sequentially replaced by either powdered rice (RS) or wheat straw (WS) over a period of 40 days. Consequently, during the transition phase, the biogas came from CD and either RS or WS. Methane production per day in the steady-state periods is shown in Table 1 and Table 2 for RS and WS, respectively.

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Table 1. Biomethanation and the decrease (%) in the various constituents of the digester fluid supplemented with rice straw at a 40-day hydraulic retention time.

Parameter	Supplementation with rice straw (%)					
	0	20	40	60	80	100
Daily biogas yield (l/kg total solids)	176	209	234	253	293	331
Daily methane yield (l/kg total solids)	107	121	136	149	167	195
Methane (% of biogas)	61	58	58	59	58	59
Gas specific yield*	0.44	0.52	0.59	0.63	0.71	0.83
Decrease (%) in:†						
Total solids	24	35	40	44	47	51
Organic matter	27	36	48	51	54	64
Carbohydrates	26	29	39	42	54	62
Crude protein	25	24	22	17	9	4
Cellulose	67	78	81	82	83	85
Hemicellulose	28	38	47	55	63	70
Lignin	1.0	1.2	1.1	1.0	1.2	1.1

* Volume of gas produced per working volume of the digester per day (vol/vol/day).

† The initial total solids content of the slurry was 10% (w/v). 100% values for organic matter, crude protein, cellulose, hemicellulose and lignin, were respectively, 80, 10, 29, 13 and 25% (w/w) of initial total solids for cowdung and 85, 4.5, 27, 28, 26% (w/w) for rice straw.

Table 2. Biomethanation and the decrease (%) in the various constituents of the digester fluid supplemented with wheat straw at a 40-day hydraulic retention time.

Parameter	Supplementation with wheat straw (%)					
	0	20	40	60	80	100
Daily biogas yield (l/kg total solids)	178	187	194	174	167	148
Daily methane yield (l/kg total solids)	107	109	113	103	97	87
Methane (% of biogas)	60	58	59	59	58	59
Gas specific yield*	0.44	0.46	0.48	0.43	0.44	0.37
Decrease (%) in:†						
Total solids	23	22	30	27	22	15
Organic matter	27	37	32	34	32	33
Carbohydrates	26	51	72	49	41	51
Crude protein	25	27	12	−2	−15	−17
Cellulose	67	70	73	70	61	18
Hemicellulose	28	37	65	60	53	47
Lignin	1.1	1.2	1.0	1.1	1.2	1.0

* Volume of gas produced per working volume of the digester per day (vol/vol/day).

† 100% values for organic matter, crude protein, cellulose, hemicellulose and lignin, of wheat straw were 80, 4, 27, 30, 25% (w/w) of initial total solids. Other values as for Table 1.

Table 1 clearly indicates that as the level of RS was increased there was an increase in gas production, with 87% higher production at 100% substitution compared with that at 0% substitution.

Gas production was maximum with a 40-day HRT and was lower at 30- and 50-day HRT at all levels of substitution with RS (data not shown).

Gas production with various levels of WS and a 40-day HRT is shown in Table 2. Maximum production was at 40% substitution; this was unlike gas production with RS which continuously increased as the percentage substitution was increased. The decline in production at high concentrations of WS may have been because nitrogen became a limiting factor. A 40-day HRT was again the best among the three HRT studied (data not shown).

Chemical analysis of the RS- and WS-supplemented slurries (Tables 1 and 2) showed that the organic matter, carbohydrate, cellulose and hemicellulose contents of the slurries decreased with increasing RS whereas all these contents were lower with 40% WS than with less or more WS. Dar & Tandon (1987) reported 50 to 54% organic matter degradation of cattle dung supplemented with pretreated lantana residues and apple and peach leaf litter. In the present study organic matter degradation was from 35 to 51% with RS compared with 27% in CD alone. The degradation of hemicellulose was always greater than that of cellulose in all the supplemented slurries, as Hill & Roberts (1981) also observed. The enhanced degradation of hemicellulose and cellulose resulting from RS supplementation was probably the result of the increased availability of carbon for methane formation. The decreases observed in the major constituents of the slurry during anaerobic digestion correlate well with the increased biogas production. Although Badger *et al.* (1979) also reported increased gas production after supplementation with various crop residues they used batch digesters and so no direct comparison can be made. Zauner & Kuntzel (1985), using fresh and ensiled plant materials, achieved a daily gas production of 135 to 247 l/kg total solids while Hill and Roberts (1981) produced 360 l methane/kg Chemical Oxygen Demand destroyed/day with RS when the non-lignin carbon to Kjeldahl nitrogen ratio was around 30:1. Zubr (1986) showed a conversion efficiency of 54% to 69% using various fresh and ensiled plant materials.

The present experiments with semi-continuous feeding clearly establish the potential of two agricultural by-products, particularly rice straw, for biogas production. This offers new scope for the development of alternate feed materials for biogas generation when the supply of cattle dung is limited.

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