The effects of time, temperature and level of NH_3 application on the digestibility of sugar cane bagasse and cane tops

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Sankat, C. K., and Lauckner B. 1989. **The effects of time, temperature and level of NH_3 application on the digestibility of sugar cane bagasse and cane tops.** Can. Agric. Eng. **31**: 141–146. Sugar cane bagasse and cane tops are the principal crop residues of the sugar industry potentially available for use in ruminant livestock feeds. Through a series of laboratory experiments, the processing factors which influence the rate and extent of the improvements in the in vitro dry matter digestibilities (IVDMD) of bagasse and cane tops when treated with NH_3 were examined. A 6% level of NH_3 addition appears optimum, with a treatment time of 2-3 wk under ambient, tropical conditions. Treatment of bagasse and cane tops with NH_3 at 60 and 90°C improved both the rate and extent of the increase in IVDMD, compared to ambient treatment, with such processing being particularly beneficial to bagasse. At 90°C, a process time of 72 h is desirable.

INTRODUCTION

Sugar cane tops, representing 23% of the whole sugar cane plant, and bagasse, representing 25% of the sugar cane stalk, are the principal cellulosic residues of the sugar industry that are potentially available for use in ruminant rations. Trinidad and Tobago currently produces 90 000 t of sugar, with bagasse production being approximately 3.5 times this value. In their natural form and particularly for bagasse, such residues are characterized as feeding material of low digestibility and protein content with poor palatability. However, through appropriate processing methods of both a physical and/or chemical nature, the feeding value of these residues may be enhanced.

The treatment of cereal straws with NaOH to improve their digestibility has been reviewed by Jackson (1978), and is widely accepted as the most effective chemical treatment process, one which has been industrialized (Rexen 1979). The very positive response of sugar cane bagasse and cane tops to NaOH treatment was investigated by Sankat and Lauckner (1988), who reported that for up to 7% NaOH application, the in vitro dry matter digestibilities (IVDMD) of bagasse and cane tops may be given by the following empirical relationships:

$$IVDMD_{bagasse} = 6.19x + 18.38 \quad (1)$$

$$\text{and } IVDMD_{cane\ tops} = 5.07x + 35.54 \quad (2)$$

where x is the percentage level of NaOH application, on a dry matter basis.

In recent years, the treatment of staws with NH_3 has been reported, and Sundstol et al. (1978) have reviewed this process. Ammonia treatment of straws, though slower acting and less effective in terms of digestibility improvements compared to NaOH treatment, is attractive as NH_3 adds nitrogen to the straw thus enhancing its feeding value. Sundstol (1984) reported that ammonia-treated straw has been readily accepted by farmers in Norway and considerable amounts of straw are also used in Denmark and Eastern Europe. Perdok and Leng (1987) reported that cattle fed roughages treated with anhydrous ammonia developed a syndrome of hyper-excitability when ammoniated straw comprised at least 50% of the animal's ration. The ammoniated straw was processed at temperatures greater than 70°C and the feed contained a fair level of reducing sugars prior to ammoniation. It was noted that the nonreducing sugar sucrose, as found in sugar cane bagasse, did not appear to be involved in the formation of toxins in ammoniated straw.

The effect of the processing parameters on IVDMD improvements has been investigated, in part, by several authors (Waagepetersen and Thomsen 1977; Kernan et al. 1977; Westgaard 1981; Sankat and Bilanski 1982; Borhami and Sundstol 1982; Sankat and Lauckner 1987). For straws, an NH_3 application level of 3–4%, and a treatment time of 1 wk at 30°C have been recommended, with the duration of treatment increasing as process temperatures are reduced. At very low straw moisture contents (i.e., $<5\%$), anhydrous NH_3 treatment may have a negligible effect on straw IVDMD. Increasing the straw moisture content above normal levels (i.e., $> 12\%$) usually has a small positive effect on IVDMD. While the use of aqueous and anhydrous NH_3 have been reported in previous studies, it has been stated that aqueous NH_3 is as effective as anhydrous NH_3 in improving the straw digestibility when the same amount of NH_3 is used, though aqueous NH_3 is more effective when very dry straw is to be treated (Sundstol et al. 1979; Borhami and Sundstol 1982).

The objectives of this study were to evaluate the effects of NH_3 treatment on the digestibility (IVDMD) of sugar cane bagasse and cane tops, and the factors which may influence this reaction, as research work previously reported in the literature has dealt almost exclusively with the cereal straws. The study attempted to define the conditions for the NH_3 treatment of bagasse and cane tops through an examination of the effects on digestibiity of the level of NH_3 application, the process time, temperature and moisture content of the treated material.

MATERIALS AND METHODS

Freshly harvested cane tops at 54% moisture content (MC) removed from burnt cane was sun dried to 7% MC, chopped to 25 mm in length by a forage chopper and ground in a hammer mill using a 3-mm screen. Samples held in glass jars, each of 64.5 g initial weight were treated with measured quantities of aqueous NH_3 having a specific gravity of 0.88 and containing 33% NH_3, such that 2, 4, 6 and 8% NH_3 (on a dry matter basis) were applied to the cane tops. Additional water was used so that the final resulting moisture content of the treated samples averaged 22%. Treated samples were stored at 30°C in an incubator and jars were opened after 1, 2, 3 and 4 wk, at each level of NH_3 application. All ammoniated samples were aerated for 2 h to eliminate excess NH_3 and oven-dried at 60°C for 72 h, prior to storage and subsequent analysis.

To determine the effects of the level of ammonia application and the treatment time on the IVDMD of sugar cane bagasse, anhydrous NH_3 was injected into a 17-kg sample of freshly milled bagasse averaging 67% moisture content. The sample was held in a sealed polyethelene bag. The sample bag, suspended from a balance, contained a probe connected to a plastic tube through which NH_3 was delivered to the bagasse from an NH_3 cylinder through a regulator. The quantity of NH_3 delivered to the bagasse was therefore measured by the increases in weight of the ammoniated bagasse sample, and 2, 4, 6 and 8% NH_3 treated samples (on a bagasse dry matter basis) were processed. The bags were held under ambient conditions (30°C) for up to 4 wk, with grab samples of the NH_3-treated bagasse quickly removed from each bag after 1 and 3 d, 1, 2, 3 and 4 wk.

To determine the effects of treatment temperatures and moisture contents on the IVDMD of NH_3-treated bagasse and cane tops, ground 60-g dry matter samples of each residue previously oven dried were treated with aqueous NH_3 and water as previously described to obtain a 6% NH_3 application level, and final moisture contents of 15, 30 and 50%. Treated samples held in glass jars at each moisture level were stored at 30°C, 60°C and 90°C using an incubator and two forced convection ovens. Bagasse samples at each moisture content were removed and jars opened after 3, 6, 12, 24 and 72 h for the 60 and 90°C treatments, and 3, 7, 14 and 21 d for the 30°C treatment. Cane top samples at each moisture content were removed after 6, 18, 72 and 168 h at each process temperature.

IVDMD of the anhydrous NH_3-treated bagasse samples were determined by the procedure of Tilley and Terry (1963). For all the other experiments, the digestibility (IVDMD) of bagasse and cane top samples were predicted from a pepsin-cellulase solubility (ES) assay described by Goto and Minson (1977). The relationship between ES and IVDMD was previously established (Sankat and Lauckner 1987) for a range of locally available cellulosic crop residues:

$$\text{IVDMD} = -6.025 + 1.770\ \text{ES} - 0.00894\ \text{ES}^2 \qquad (3)$$

RESULTS AND DISCUSSION

The effects of level of NH_3 application and ambient processing time on IVDMD

IVDMD results of aqueous NH_3-treated cane tops are shown in Table I, where each result is the mean of two observations. The average digestibility of untreated (control) cane tops was 42.8%. The NH_3 level means of Table I show a clear trend of increasing IVDMD of cane tops, with increasing level of NH_3 application. However, the differences in digestibility obtained between the two highest levels of NH_3 application (i.e., 6 and 8%) were small and not significant, while at the lowest level of NH_3 application (i.e., 2% NH_3) improvements were small, averaging only 3.9% IVDMD units above the value for untreated cane tops. At the 6% NH_3 application level, IVDMD improvements averaged 17.8% IVDMD units. There were small increases in the IVDMD of NH_3-treated cane tops over time, under ambient (30°C) conditions (Table I). At the lower levels of NH_3 application (i.e., < 4%) a treatment time of 2 wk appears adequate. To obtain the full benefits of ammoniation at the higher levels, a treatment time of 3-4 wk should be used.

Table I. The effect of level of NH_3 application on the in vitro dry matter digestibility (IVDMD) of cane tops processed under ambient conditions

Time (d)	IVDMD (%) — Level of NH_3 application (%) 2	4	6	8	Means (±1.4)
7	46.4	51.0	54.7	56.5	52.2
14	49.2	55.2	59.9	58.6	55.7
21	42.1	57.0	63.9	65.4	57.1
28	48.8	55.1	63.8	67.7	58.9
Means† (±1.4)	46.7	54.5	60.6	62.1	

†Standard errors of means are indicated by ± and are based on 25 degrees of freedom.

Table II. The effect of level of NH_3 application on the in vitro dry matter digestibility (IVDMD) of bagasse processed under ambient conditions

Time (d)	IVDMD (%) — Level of NH_3 application (%) 2	4	6	8	Means (±1.2)
1	36.0	41.8	42.9	44.4	41.3
3	40.6	41.7	47.3	44.6	43.6
7	38.2	41.7	45.6	45.5	42.8
14	41.5	45.9	50.9	50.3	47.2
21	39.6	44.2	46.4	49.7	45.0
28	40.5	45.7	49.7	51.3	46.8
Means† (±1.0)	39.4	44.1	47.1	47.6	

†Standard errors of means are indicated by ± and are based on 24 degrees of freedom.

IVDMD values of freshly milled bagasse treated with anhydrous NH_3 are shown in Table II, where the results given are the means of two observations. The average IVDMD of untreated (control) bagasse was 37.7%, a value much higher than expected and probably due to the maturity of the cane stalk at harvest, as well as the negligible duration of its storage after cane milling. The effect of the level of NH_3 application on the digestibility of the bagasse was highly significant ($P < 0.001$). It is noted, however, that there is little difference between IVDMD obtained at the 6 and 8% NH_3 application levels. The effect of treatment time was not significant ($P > 0.05$). While no overall trend with respect to time was detected, an examination of the time means shows that the IVDMD values of NH_3-treated bagasse obtained after 14 d treatment and above were higher than those obtained after 7 d treatment or less.

At the 2% NH_3 application level, digestibility improvements for bagasse and cane tops, above the untreated, control values averaged 1.7 and 3.9% IVDMD units, respectively, while at the 6% NH_3 application level, the corresponding values were 9.4 and 17.8% IVDMD units, respectively. Bagasse, in particular, does not appear very responsive to NH_3 treatment. As stated in Eq. 1, with NaOH treatment, digestibility improvements of 6.19 and 5.07% IVDMD units for bagasse and cane tops, respectively, can be obtained for each percentage level of NaOH addition. While NH_3 application levels of 3–4% have been recommended for straws (Kernan et al. 1977; Sundstol et al. 1978), the findings here indicate that on the basis of IVDMD improvements only, a 6% level of NH_3 application to both bagasse and cane tops appears desirable. The results confirm the slow rate of the reaction at ambient conditions between NH_3 and low-quality roughages as compared to NaOH treatment, and show that for cane tops longer processing times are desirable, compared to those reported for straw (Kernan et al. 1977; Sundstol et al. 1978; Sankat and Lauckner 1987).

Process time/temperature/moisture content relationships

The IVDMD of NH_3-treated cane tops, having varying moisture contents, process temperatures and process times, are shown in Table III, where the values shown are the means of two observations. Analyses of variance of these data indicate very highly significant effects of process temperature and time ($P < 0.001$), and significant effects of moisture content ($P < 0.05$), interactions of temperature and time ($P < 0.05$), and interactions of temperature and moisture content ($P < 0.05$). The highly significant effects of process time and temperature are clearly illustrated by the appropriate means in Table III, as well as the asymptotic values given in Table IV, for the curves shown in Fig. 1. These curves were obtained by regression analyses, using an asymptotic model of the form:

$$y = a - be^{-Kt} \qquad (3)$$

where y is the IVDMD. The parameter a represents the asymptote or maximum value of IVDMD reached with time (t), for a particular level of NH_3 application. The other parameters represent the shape of the curve, where the value of b is the difference in the fitted, maximum IVDMD attainable on treatment with NH_3 from the fitted, untreated value (at time t = 0), and the value of K is an indication of the steepness of the IVDMD approach to the asymptote. The IVDMD of untreated cane tops, averaging 43.9% at $t = 0$, was used in the regression analysis. Increasing the process temperature increased both the rate and extent of IVDMD improvements as described by the K and b values of Table IV. Cane tops processed at 60 and 90°C, and for 72 h and longer, had an IVDMD average of 69.2% compared to 58% at 30°C. The results show that for treatment at 90°C, the ammoniation process is complete within 72 h, while for the lower treatment temperatures longer process times are required, as expected. Generally, increasing the level of moisture in the cane tops had a small deleterious effect on digestibility as shown by the means (moisture content) of Table III. This was observed very clearly at 30°C, less evident at 60°C and not apparent at 90°C (Fig. 1). This observation for cane tops is at variance with previously reported information on straws (Sundstol et al. 1979; Borhami and Sundstol 1982; Sankat and Lauckner 1987) where increasing moisture contents have generally contributed to small improvements in digestibilities.

The IVDMD of NH_3-treated bagasse at three temperature levels and three moisture levels are shown in Table V, where each result is the mean of two observations. Previous trials had indicated that the ammoniation process on bagasse was much slower at 30°C (ambient) than at 60 and 90°C, and whereas IVDMD observations were confined to 3 d at the two higher temperatures, they were continued for 21 d at 30°C. This choice of process times is supported by the results of Table V. Regression curves, previously described for cane tops and using the asymptotic model of Eq. 4, were obtained for the bagasse samples. The regression curves for the digestibility effects at 30°C are shown in Fig. 2, and those at 60 and 90°C are

Table III. The effects of process time, temperature and moisture content on the in vitro dry matter digestibility (IVDMD) of 6% NH_3 treated cane tops

	IVDMD (%)									
	15% moisture content			30% moisture content			50% moisture content			
	Temperature (°C)			Temperature (°C)			Temperature (°C)			
Process time (d)	30	60	90	30	60	90	30	60	90	Means† (time) (±0.4)
0.25	46.2	51.7	61.0	45.9	51.9	57.7	43.5	53.2	59.3	52.3
0.75	48.8	56.8	64.7	50.1	60.7	65.4	49.4	55.8	66.9	57.6
3.00	58.4	68.0	71.1	57.6	67.0	70.5	53.0	63.4	70.0	64.3
7.00	62.2	70.3	70.7	60.0	68.6	70.2	56.2	68.1	72.5	66.6
Means (moisture content) (±0.4)		60.8			60.5			59.3		
Means (temperature) (±0.4)		30°C:52.6			60°C:61.3			90°C:66.7		

†Standard error of means are indicated by ± and are based on 36 d.f.

Table IV. Parameters of the regression equation, $y = a - b \exp(-Kt)$, for the in vitro dry matter digestibility y (%) of NH_3-treated bagasse and cane tops as a function of time t (d)

Process temperature (°C)	Moisture content (%)	*a*	*b*	*K*	Coefficient of correlation
Cane tops					
30	15	63.4	19.3	0.432	0.98
60	15	70.0	24.9	0.912	0.98
90	15	69.9	25.2	3.456	0.98
30	30	60.3	16.2	0.600	0.99
60	30	68.0	23.7	1.560	0.99
90	30	70.1	25.4	2.592	0.98
30	50	55.8	12.9	0.648	0.95
60	50	66.3	21.2	1.080	0.95
90	50	70.9	27.3	3.144	0.99
Bagasse					
30	15	52.0	24.4	0.026	0.93
30	30	42.7	12.7	0.076	0.99
30	50	40.6	12.9	0.140	0.99
60	15	40.9	13.3	1.855	0.98
60	30	44.5	12.8	1.139	0.96
60	50	42.2	15.0	2.642	0.95
90	15	43.0	128.0	17.757	0.99
90	30	54.3	25.5	1.445	0.99
90	50	54.5	24.4	2.180	0.99

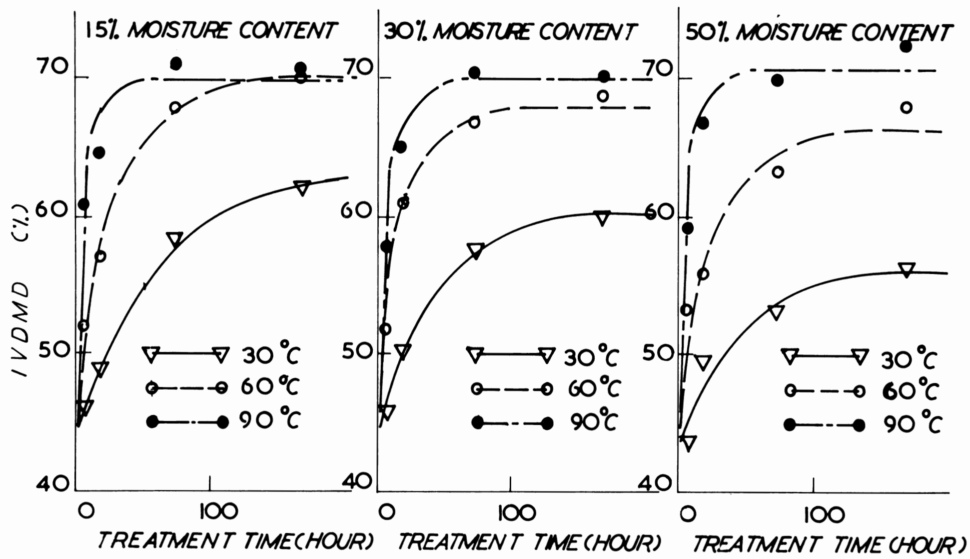

Figure 1. In vitro dry matter digestibility (IVDMD) of 6% NH_3-treated cane tops processed at 30, 60 and 90°C and at three moisture levels.

shown in Fig. 3. Values for the parameters a, b and K of Eq. 4 for each curve are given in Table IV. At 60 and 90°C, the main effects of time, temperature and moisture content were all very highly significant ($P < 0.001$), indicating an overall trend of higher digestibility with increasing treatment time, temperature and moisture content as shown in Fig. 3. Interactions of time and temperature and of moisture content and temperature were significant at levels of 0.01 and 0.05, respectively. At 30°C, IVDMD values for bagasse were lower than at the two higher temperatures. There was a very highly significant effect due to treatment time ($P < 0.001$) as illustrated in Fig. 2 but no statistical significance was found for the effect of moisture content or the interaction of moisture content and time. The results at 30°C confirm previous observations on the NH_3 treatment of bagasse, that is the process is not very effective in improving digestibility unless a treatment time of 14 d or longer is used. From a practical viewpoint, the results show that reducing the MC of bagasse by drying before ammoniation under ambient (30°C) conditions will have no effect on the IVDMD. However for high temperature ammoniation, particularly at 90°C, higher moisture contents are desirable. As with cane tops, NH_3 treatment of bagasse at 90°C is complete within 72 h, with digestibility improvements of up to 26% IVDMD units being possible, using 6% NH_3 treatment.

Table V. The effects of process time, temperature and moisture content on the in vitro dry matter digestibility (IVDMD) of 6% NH_3-treated bagasse

	IVDMD (%)								
	15% moisture content			30% moisture content			50% moisture content		
	Temperature (°C)			Temperature (°C)			Temperature (°C)		
Process time (d)	30	60	90	30	60	90	30	60	90
0.000 (untreated)	28.8	–	–	29.7	–	–	27.6	–	–
0.125	–	30.0	29.1	–	33.2	32.3	–	30.3	35.6
0.250	–	33.4	41.5	–	34.2	37.7	–	36.6	40.2
0.500	–	34.7	42.9	–	39.1	41.6	–	37.6	47.3
1.000	–	39.3	41.7	–	39.1	48.1	–	40.0	50.4
3.000	28.3	40.7	44.4	32.9	44.3	54.1	32.5	43.1	55.0
7.000	30.5	–	–	35.7	–	–	35.4	–	–
14.000	37.4	–	–	37.3	–	–	39.0	–	–
21.000	37.1	–	–	40.6	–	–	39.9	–	–
Means	32.4	35.6	40.0	35.2	38.0	42.8	34.9	37.5	45.7
(SE)	(±0.8)	(±0.7)	(±0.7)	(±0.8)	(±0.7)	(±0.7)	(±0.8)	(±0.7)	(±0.7)
Degrees of freedom	15	30	30	15	30	30	15	30	30

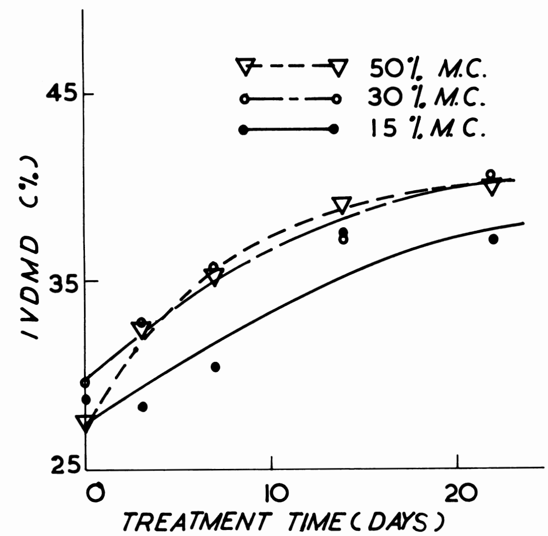

Figure 2. In vitro dry matter digestibility (IVDMD) of bagasse treated with 6% NH_3 at 30°C and at three moisture levels.

CONCLUSION

From these trials the following conclusions can be drawn:

(i) The in vitro dry matter digestibilities (IVDMD) of both bagasse and cane tops can be improved with NH_3 treatment. However, under ambient process conditions bagasse is less responsive to NH_3 treatment compared to cane tops.

(ii) On the basis of IVDMD improvements only, a 6% level of NH_3 addition to both bagasse and cane tops appears to be the optimum level of application.

(iii) For the treatment of both bagasse and cane tops under ambient, tropical conditions (30°C) with 6% NH_3, and using the stack method of ammoniation, minimum treatment times of 2 and 3 wk are recommended for bagasse and cane tops respectively to achieve the potential benefits of ammoniation.

(iv) Treatment of bagasse and cane tops with NH_3 at 60 and 90°C improved both the rate and extent of the improvements in digestibility compared to ambient treatment. High-temperature treatment is very beneficial to the ammoniation of bagasse in particular due to the relatively small improvements in IVDMD achieved under ambient conditions.

(v) At 90°C, a treatment time of 72 h appear necessary to complete the ammoniation process for bagasse and cane tops.

(vi) There were no differences in the IVDMD of cane tops at 15, 30 and 50% MC when treated with NH_3 at 90°C. However, for bagasse processed under similar conditions the higher moisture contents proved desirable, as higher IVDMD values were achieved.

(vii) Drying of both bagasse and cane tops from more than 50% to 15% MC, followed by NH_3 treatment under ambient conditions (30°C) will have no deleterious effect on the improvements in IVDMD. Drying of the residues may be necessary for prolonged storage.

(viii) Results to date show that the crude protein content of bagasse and cane tops may be increased by 2–3 times, with NH_3 treatment.

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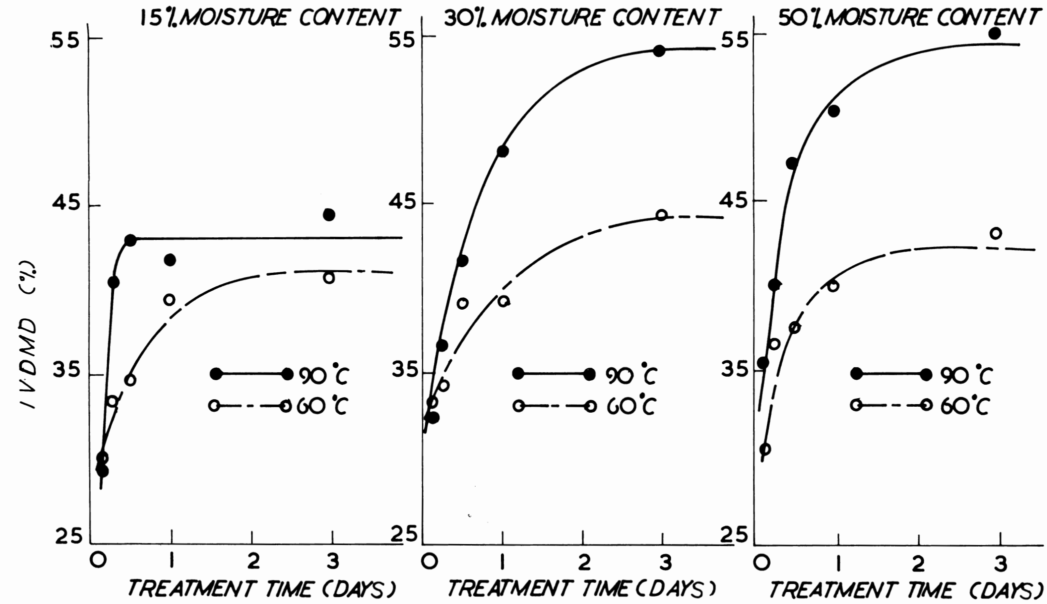

Figure 3. In vitro dry matter digestibility (IVDMD) of 6% NH_3–treated bagasse processed at 60°C and 90°C and at three moisture levels.

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