The effect of supplementing untreated, urea-supplemented and urea-ammoniated wheat-straw with maize-meal and/or fish-meal in sheep

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Supplementation of untreated, urea-supplemented or urea-ammoniated wheat-straw diets with sources of readily fermentable energy (maize-meal; 0 and 20% of the total diet) and rumen-undegradable protein (fish-meal; 0 and 5% of the total diet) was investigated in a 3 × 2 × 2 factorial experiment, involving an intake and in vivo digestibility trial with 80 adult S.A. Merino wethers. Straw dry matter (DM) intake on ammoniated wheat-straw diets was 27 and 22% higher (P < 0,01) than on untreated and urea-supplemented diets, respectively. No significant difference was found between the latter treatments. The inclusion of 5% fish-meal stimulated (P < 0,01) straw DM intake by 13% relative to the control diets without fish meal. Incorporation of the 20% maize-meal supplement alone, or in combination with 5% fish-meal, did not result in any further improvement in straw DM intake. The apparent digestibility of organic matter (OM), cell-wall constituents (CWC), acid detergent fibre (ADF) and hemicellulose was higher (P < 0,01) on the urea-ammoniated wheat-straw diets than on either the untreated wheat-straw diets or the urea-supplemented wheat-straw diets. No differences were obtained between the latter treatments. The apparent OM digestibility of the wheat-straw diets was improved by the inclusion of 5% fish-meal and/or 20% maize-meal. Apparent digestibility of CWC and ADF was not particularly affected by the inclusion of fish-meal or maize-meal. Combined supplementation of the straw diets with both 5% fish-meal and 20% maize-meal tended to suppress the apparent digestibility of CWC and ADF. Apparent hemicellulose digestibility of the wheat-straw diets was increased (P < 0,01) by 4,5% due to the inclusion of maize-meal. Apparent nitrogen (N) digestibility and N-balance was involved in significant (P < 0,01) three-factor interactions. Urea supplementation improved (P < 0,01) N-digestibility compared to untreated wheat-straw diets. Urea ammoniation similarly improved N-digestibility in relation to untreated wheat-straw with or without supplementary maize-meal. The apparent N-digestibility of urea-supplemented wheat-straw tended to be higher than on urea-ammoniated wheat-straw, but the only significant (P < 0,01) difference occurred between the diets without maize-meal and/or fish-meal. Nitrogen balance was generally improved in sheep receiving diets containing urea-ammoniated wheat-straw, and fish-meal alone or combined with maize-meal. No significant differences in N-balance were found between the untreated wheat-straw diets and corresponding urea-supplemented wheat-straw diets.

Aanvulling van onbehandelde, ureum-aangevulde en ureum-gaanmonisieerde koringstrooidiete met bronne van maklik fermenteerbare energie (meliemeel; 0 en 20% van die totale dieet) en rumen nie-degradeerbare proteïne (vismeel; 0 en 5% van die totale dieet) is ondersoek in 'n 3 × 2 × 2-faktoriaalsexperiment met 48 volwasse SA Vleismerinohamels. Strooi droë materiaal (DM)intake op die ureum-ammonisieerde koringstrooidiete was signifikant van 27 en 22% hoër (P < 0,01) as op onbehandelde en ureum-aangevulde diete. Geen betekenisvolle verskille is te ondersoek in 'n 3 × 2 × 2-factorfakotrissexperiment met 48 volwasse SA Vleismerinohamels. Strooi droë materiaal (DM)intake op die ureum-ammonisieerde koringstrooidiete met 5% vismeel of/en 20% meliemeel is van 4,5% hoër (P < 0,01) as op onbehandelde en ureum-aangevulde diete. Geen betekenisvolle verskille in N-balance is gevind tussen diete met meliemeel of vismeel of meliemeel en vismeel. Die N-balance was in algemene beter op diete met ureum-gaanmonisieerde koringstrooi en meliemeel of vismeel als aanvulling, terwyl die N-balance van diete met ureum-ammonisieerde koringstrooi, en meliemeel of vismeel, net die N-balance van diete met meliemeel en vismeel is. Die betekenisvolle verskille in N-balance is van die diete waarby meliemeel en vismeel as aanvulling is.

Keywords: Urea-ammoniation, supplementation, intake, digestibility, nitrogen balance.

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suggested that the digestible nutrient intake of ammoniated wheat, oat and barley-straw and oat-hay was inadequate for production functions like growth, pregnancy and lactation (Brand et al., 1989). Strategies for supplementing such roughages so as to improve nutrient intake would therefore appear to be necessary.

The effects of supplementing untreated urea-supplemented and urea-ammoniated wheat-straw with sources of readily fermentable energy (maize-meal) and rumen-undegradable protein (fish-meal) on the voluntary intake, digestibility and nitrogen balance of these diets were therefore investigated.

Material and methods

Two-hundred-and-fifty bales of wheat-straw were ammoniated (55 g urea/kg and 400 ml water/kg wheat-straw) in a stack, as described by Cloete & Kritzinger (1984). The stack was subsequently sealed under a plastic canvas, and treated for a period of 8 weeks. After treatment, the ammoniated wheat-straw was spread on a cement floor to dry to <85% dry matter, before being hammermilled through an 18-mm screen prior to utilization. Untreated wheat-straw of the same batch was similarly milled.

These roughages were used in a 3×2×2 factorial experiment, in order to investigate the effects of straw treatment (untreated, supplemented with 2% urea or urea-ammoniated), a source of readily fermentable energy (unsupplemented or 20% maize-meal) and a source providing rumen-undegradable protein (unsupplemented or 5% fish-meal; Erasmus et al., 1988).

For this purpose 48 adult SA Mutton Merino wethers, with an average initial mass (± SD) of 72.1 ±0.8 kg, were stratified on the basis of live mass, and randomly allotted to 12 experimental diets according to the design described above. After an adaptation period of 14 days, voluntary intake on the respective diets was determined over another 10 day period. This was followed by a 10 day collection period, during which animals were fed at a fixed level of 85% of the voluntary dry matter (DM) intake of the diet ingested at the lowest level. Representative samples (± 100 g) of the diets and orts were taken daily for dry matter determinations. Total faeces and urine output were measured daily. Representative urine samples (10% of the daily urine output) were taken and pooled for nitrogen analyses. After thorough mixing of the wet faeces, representative samples were taken and dried at 55°C for 48 h, together with representative feed and orts samples. These samples were milled through a 1-mm screen prior to chemical analyses for DM, organic matter (OM) and nitrogen (N) according to the methods of Van Soest (1963) and Van Soest & Wine (1967). Dry-matter intake and output were determined by the drying of representative feed, orts and faeces samples at 105°C to a constant mass. Standard procedures for the calculation of apparent digestibility coefficients and nitrogen balance were then followed.

Standard statistical procedures for the analysis in a 3×2×2 factorial design were followed (Snedecor & Cochran, 1967). The effects of independent variables and interactions were tested for significance by using the mean square for remainder as error term. Significant (P<0.05) two- and three-factor interactions were discussed where they occurred. Significant differences between means were determined by the Bonferroni method (Van Ark, 1981).

Results and discussion

Chemical composition

The chemical composition of the untreated, urea-supplemented and urea-ammoniated wheat-straw used in the study are given in Table 1. Ammoniation and urea-supplementation resulted in marked increases in nitrogen content, as was reported previously (Cloete & Kritzinger, 1984). Ammoniation generally causes a reduction in the NDF and hemicellulose contents of crop residues (Kiangi et al., 1981; Cloete & Kritzinger, 1984; Brand et al., 1989) due to the solubilization of hemicellulose (Solaiman et al., 1979). No conclusive evidence of such a reduction could be obtained from the present investigation.

Voluntary intake

The effect of straw treatment was not involved in interactions with other main effects as far as voluntary DM intake of the total diet and the straw portion of the diet were concerned. Ammoniation improved (P<0.01) the voluntary DM intake of the total diet by 27% and 21%, respectively, in comparison with the untreated diets and the diets containing urea (Table 2). Straw DM intake was similarly improved by 27% and 22%, respectively. The improvement in straw DM intake over the untreated control is smaller than improvements of 47% for urea-ammoniated barley-straw and 47.6% for urea-ammoniated wheat-straw reported by Hadjipanayiotou (1982) and Cloete & Kritzinger (1984), respectively. The higher intake of ammoniated wheat-straw in comparison with supplemented wheat-straw accords with corresponding improvements in the literature, ranging from 16.4 to 27.3% (Streeter & Horn, 1982; Cloete et al., 1983; Dryden & Kempton, 1983/84; Dias-Da-Silva & Sundstøl, 1986). Other researchers found no difference in voluntary intake between urea-supplemented wheat-straw and anhydrous-ammoniated wheat-straw (Wanapat et al., 1985) or urea-ammoniated wheat-straw (Cloete & Kritzinger, 1984).

Table 1 The chemical composition of the untreated, urea-supplemented and urea-ammoniated wheat-straw used in the experiment (DM basis)

<table>
<thead>
<tr>
<th>Composition (%)</th>
<th>Untreated</th>
<th>Urea-supplemented</th>
<th>Urea-ammoniated</th>
</tr>
</thead>
<tbody>
<tr>
<td>Organic matter</td>
<td>95.2</td>
<td>93.3</td>
<td>94.2</td>
</tr>
<tr>
<td>Nitrogen</td>
<td>0.55</td>
<td>1.40</td>
<td>1.42</td>
</tr>
<tr>
<td>Neutral detergent fibre</td>
<td>78.4</td>
<td>76.8</td>
<td>77.8</td>
</tr>
<tr>
<td>Acid detergent fibre</td>
<td>50.9</td>
<td>49.8</td>
<td>50.4</td>
</tr>
<tr>
<td>Hemicellulose</td>
<td>27.5</td>
<td>27.0</td>
<td>27.4</td>
</tr>
</tbody>
</table>
Table 2 Voluntary intake (g DM/kg W0.75/day) and apparent digestibility coefficients for untreated, urea-supplemented and urea-ammoniated wheat-straw

<table>
<thead>
<tr>
<th>Straw treatment</th>
<th>Untreated</th>
<th>Supplemented</th>
<th>Ammoniated</th>
<th>SE mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voluntary Intake (g DM/kg W0.75/day)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total diet</td>
<td>56.81</td>
<td>59.51</td>
<td>72.22</td>
<td>1.83</td>
</tr>
<tr>
<td>Straw intake</td>
<td>49.51</td>
<td>51.51</td>
<td>62.72</td>
<td>1.63</td>
</tr>
<tr>
<td>Digestibility coefficients (%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Organic matter</td>
<td>57.31</td>
<td>56.71</td>
<td>61.83</td>
<td>0.48</td>
</tr>
<tr>
<td>Cell wall constituents</td>
<td>55.61</td>
<td>55.21</td>
<td>66.13</td>
<td>0.66</td>
</tr>
<tr>
<td>Acid detergent fibre</td>
<td>51.21</td>
<td>51.31</td>
<td>58.23</td>
<td>0.83</td>
</tr>
<tr>
<td>Hemicellulose</td>
<td>60.01</td>
<td>64.31</td>
<td>81.92</td>
<td>1.01</td>
</tr>
</tbody>
</table>

1, 2 denote significant differences (P ≤ 0.01)

The lack of an improvement in voluntary DM intake due to the inclusion of urea (Table 2) is in disagreement with most results in the literature (Kempton & Leng, 1979; Kompton, 1982; Stephenson et al, 1983; Cloete & Kritzinger 1984). No response in voluntary intake due to urea supplementation was also reported by Barry & Johnstone (1976) and Sudana & Leng (1986) for barley-straw diets including 0.6% urea and wheat-straw diets including 2.5% urea, respectively. The lack of an intake response in the present study could possibly be ascribed to a rather low urea-supplementation level (2%) relative to the optimum level of 2.8% for maximal microbial protein synthesis (Kellaway & Leibholz, 1983). Straw intake on control diets without urea could also be affected by the inclusion of maize-meal and/or fish-meal, as the means depicted in Table 2 are over treatments.

The inclusion of maize-meal as readily fermentable energy with the wheat-straw diets interacted (P ≤ 0.05) with the inclusion of rumen-undegradable protein (provided by fish-meal) as far as voluntary DM intake was concerned. Both the inclusion of 5% fish-meal and 20% maize-meal stimulated (P ≤ 0.01) the voluntary intake of the total diet when compared to the control diets including no fish-meal or maize-meal (Table 3). No further improvements were, however, obtained when both fish-meal and maize-meal were included in the wheat-straw diets. The inclusion of fish-meal in the wheat-straw diets stimulated (P ≤ 0.01) straw DM intake by 13% relative to the control. Abidin & Kempton (1981) similarly found increased voluntary DM intakes of straw, when fed together with supplements of 240 and 360 g heat-treated protein meal/kg straw. Corresponding improvements in roughage DM intake were reported by researchers providing supplements containing protein from oilmeal products to cattle (Redman et al, 1980; McCollum & Galyean, 1983; Stokes et al, 1988) or sheep (Krysl et al, 1987). Possible reasons for the enhancement of roughage DM intake are an increased rate of passage of particulates (McCollum & Galyean, 1983), or an expansion of gastrointestinal fill (Krysl et al, 1987). The response in straw intake due to the inclusion of undegradable protein in the present study can also be related to an improvement of 72.7% in the intake of the total barley-straw diet following supplementation with 15% cottonseed-meal that was reported by Sudana & Leng (1986). Straw DM intake was unaffected by the inclusion of maize-meal alone, or in combination with fish-meal (Table 3). This result is consistent with reports of a lower roughage DM intake in low-quality fibrous diets containing increasing energy levels.

Table 3 Voluntary intake (g DM/kg W0.75/day) and apparent digestibility coefficients of straw diets, as affected by supplementation with 20% maize-meal and/or 5% fish-meal

<table>
<thead>
<tr>
<th>Fish-meal level (%)</th>
<th>0</th>
<th>20</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maize-meal level (%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Voluntary Intake (g DM/kg W0.75/day)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total diet</td>
<td>52.51</td>
<td>62.72</td>
</tr>
<tr>
<td>Straw intake</td>
<td>52.51</td>
<td>59.25</td>
</tr>
<tr>
<td>Digestibility coefficients (%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Organic matter</td>
<td>54.01</td>
<td>57.82</td>
</tr>
<tr>
<td>Cell wall constituents</td>
<td>58.31</td>
<td>60.03</td>
</tr>
<tr>
<td>Acid detergent fibre</td>
<td>52.71</td>
<td>55.95</td>
</tr>
<tr>
<td>Hemicellulose</td>
<td>69.11</td>
<td>70.21a</td>
</tr>
</tbody>
</table>

1, 2 denote significance (P ≤ 0.05)

1, 2, 3 denote significance (P ≤ 0.01)
(Crabtree & Williams, 1971; Lamb & Eadle, 1979; Streeter et al., 1983; Sanson et al., 1990), and could probably be related to the substitution effect. There is also evidence in the literature that straw intake may be improved by the inclusion of a small percentage of starch (Crabtree & Williams, 1971) or molasses (Mbata et al., 1983). The level of energy supplied in our study (20%) was probably too high to stimulate straw intake to an extent worth mentioning.

Apparent digestibility of organic matter and fibre

The effect of straw treatment was not involved in interactions with other main effects as far as apparent digestibility coefficients for OM, CWC, ADF, and hemicellulose were concerned. The apparent OM digestibility of urea-ammoniated wheat-straw was higher \((P \leq 0.01)\) than that of the untreated straw diets \((7.9\%)\) or the urea-supplemented wheat-straw diets \((9.0\%\); Table 2\). These results correspond with previous reports of Cloete & Kritzinger (1984), Dryden & Kempton (1983/84), Zorrilla-Rios et al., (1984) and Djajanegara & Doyle (1989). Dias-Da-Silva & Sundstøl (1986) reported comparable improvements in the apparent digestibility of wheat-straw after ammoniation. The apparent OM digestibility of wheat-straw was unaffected by the inclusion of urea, as also found by Cloete & Kritzinger (1984).

Apparent digestibility coefficients for CWC, ADF and hemicellulose were improved \((P \leq 0.01)\) by urea-ammoniation by respectively 18.9, 13.7, and 36.5\% compared to the untreated wheat-straw diets (Table 2). Similar improvements of 19.7, 13.5 and 27.4\%, respectively, were obtained in comparison with the diets containing urea. These results are in general agreement with those previously obtained and cited from the literature by Cloete & Kritzinger (1984), and subsequently reported by Djajanegara & Doyle (1989).

The inclusion of fish-meal and maize-meal in the wheat-straw diets resulted in respective improvements of 7.0\% and 12.8\% in apparent OM digestibility \((P \leq 0.01\); Table 3\). The inclusion of fish-meal and maize-meal in combination resulted in no further improvement in apparent OM digestibility of the wheat-straw diets, thus causing a significant \((P = 0.01)\) interaction between the provision of readily fermentable energy and rumen-undegradable protein.

Fibre digestibility of the wheat-straw diets was not markedly affected by the inclusion of fish-meal and/or maize-meal (Table 3). With regard to apparent CWC and ADF digestibility, there was a tendency for diets including fish-meal to have a higher digestibility than the control. When maize-meal was provided together with fish-meal, CWC and ADF digestibility tended to decrease, resulting in a significant \((P \leq 0.05)\) two-factor interaction between the inclusion of maize-meal and fish-meal. Hemicellulose digestibility was improved \((P \leq 0.01)\) by 4.5\% due to the inclusion of maize-meal. Evidence from the literature suggests that the inclusion of protein and energy at low levels may improve fibre digestibility (Williams, 1983/84). High levels of soy bean meal and maize gluten meal were, however, found to suppress the cellulose and hemicellulose digestibility of wheat-straw diets (Streeter et al., 1983). The apparent ADF digestibility of low quality roughages was also adversely affected by high levels of barley (Lamb & Eadie, 1979) and molasses (Williams, 1983/84). These findings may possibly be related to rumen pH levels lower than 6.2, thus suppressing the activity of cellulotic microbes (Ørskov, 1982; Williams, 1983/84). Rumen pH levels of 6.31 and 6.26, respectively, were observed 8 h after feeding on the diets including maize-meal only, and maize-meal together with fish-meal, indicating that the level of readily fermentable energy supplied was possibly high enough to influence fibre digestibility.

**Figure 1** The effect of supplementation with 20% maize-meal (MM) and/or 5% fish-meal (FM) on the apparent digestibility of nitrogen (N) in untreated, urea-supplemented, and urea-ammoniated wheat-straw.
hindgut fermentation and bonding of nitrogen via the Maillard reaction (Cloete, et al., 1983). Unidentified aromatic amines in treated straw may also be involved (Dryden & Kempton, 1983/84).

Nitrogen balance results were also influenced by the three-factor interaction ($P < 0.01$) between straw treatment, the inclusion of maize-meal as a source of readily fermentable energy and fish-meal as a source of rumen-undegradable protein. Urinary N-losses largely cancelled the higher apparent N-digestibility coefficients consistently obtained for the urea-supplemented wheat-straw diets in comparison with untreated wheat-straw diets and ammoniated wheat-straw diets (Figure 2), as also found previously (Cloete & Kritzinger 1984). The provision of maize-meal only did not influence the N-balance of untreated and urea-supplemented wheat-straw, but it improved ($P < 0.01$) the N-balance of urea-ammoniated wheat-straw from 0.17g/day to 2.78g/day. The latter result is consistent with results published by Zorrilla-Rios et al. (1984). When compared to the respective diets containing neither fish-meal nor maize-meal, the inclusion of fish-meal led to improvements ($P < 0.01$) in the N-balance of untreated and urea-ammoniated wheat-straw but not in urea-supplemented wheat-straw. The poor N-balance figures on the latter diets, despite the observed high apparent N-digestibility coefficients (Figure 1), seem to imply protein utilization for energy or a lack of protein synthesis both probably owing to limited energy intake. As no response in N-utilization was observed on the urea-supplemented diet containing maize-meal alone, protein intake also appeared to be a limiting factor. The improved N-utilization on urea-supplemented wheat-straw including fish-meal and maize-meal in combination, supports the contention that both energy and protein were limited (Clanton & Zimmerman, 1970). The provision of fish-meal and maize-meal in combination also resulted in marked improvements ($P < 0.01$) in N-balance on untreated and urea-ammoniated wheat straw. Sheep on urea-ammoniated wheat-straw generally had higher ($P < 0.05$) N-balance figures than those on untreated or urea-supplemented wheat-straw receiving similar supplements. The only exceptions were relative to urea-supplemented wheat-straw, when fed either diets containing no fish-meal or maize-meal, or when fish-meal and maize-meal were both supplied. The higher N-balance on unsupplemented urea-ammoniated wheat-straw in comparison with the untreated control diet is consistent with previous results (Cloete & Kritzinger 1984; Djianjenga & Doyle, 1989). Nitrogen utilization on urea-ammoniated wheat-straw appears to be more efficient than on untreated wheat-straw or urea-supplemented wheat-straw (Figure 2). This observation could possibly be related to the higher energy content of the diets containing urea-ammoniated wheat-straw as reflected by higher apparent OM digestibility coefficients (Table 2).

**Conclusions**

Voluntary DM intake of straw was markedly improved by urea-ammoniation. There is, however, evidence indicating that voluntary intake levels on diets containing 50 to 60% urea-ammoniated wheat-straw were not sufficient to sustain optimal levels of production in pregnant and lactating ewes.


