Synthesis of Unsymmetrical Ureas by Sulfur-Assisted Carbonylation with Carbon Monoxide and Oxidation with Molecular Oxygen under Mild Conditions

Takumi Mizuno,* Takeo Nakai, Masatoshi Mihara
Osaka Municipal Technical Research Institute, 1-6-50, Morinomiya, Joto-ku, Osaka 536-8553, Japan
Fax +81(6)69638049; E-mail: tmizuno@omtri.city.osaka.jp
Received 17 March 2009; revised 17 April 2009

Abstract: With ambient pressure of carbon monoxide and oxygen at room temperature, N,N-dialkyl-N'-arylureas were selectively accessible from secondary amines, aromatic amines, and sulfur in good to excellent yields. For example, N-butyl-N-methyl-N'-(3,4-dichlorophenyl)urea, which is used as a herbicide (neburon), was afforded successfully from butylmethylamine (2 equiv), 3,4-dichloroaniline (1 equiv) and sulfur (1 equiv) in 79% (21.8 g) yield using carbon monoxide (0.1 MPa) and oxygen (0.1 MPa) at 20 °C in DMF.

Key words: unsymmetrical ureas, carbon monoxide, oxygen, sulfur, herbicide

N,N-Dialkyl-N'-arylelas 1 were developed as effective herbicides that block photosynthesis of plants. These herbicides are safe for warm-blooded animals and are characterized by their high efficiency and low cost.1 For instance, N-butyl-N-methyl-N'-(3,4-dichlorophenyl)urea (1m; neburon) has been commercially exploited as an efficient herbicide for use on wheat, alfalfa, and strawberries.1–3

As part of a series of sulfur-assisted carbonylations of primary amines used to prepare urea derivatives from carbon monoxide,4–6 the synthetic methodology used for the synthesis of 1 was reported from secondary amines and aromatic amines.7 However, this reaction requires high temperature and pressurized carbon monoxide. The N,N-diethyl-N'-phenylurea (1b) was also produced by reductive carbonylation with nitrobenzene, diethylamine (2b) and carbon monoxide, using sulfur and a vanadium compound as promoter.8 Recently, piperidinecarboxanilide (1j) was obtained by reductive carbonylation using a catalytic amount of sulfur in ionic liquid.9 These reactions, however, need drastic conditions (high temperature and high pressure). A similar synthesis of 1 by selenium-catalyzed reductive carbonylation of nitrobenzene with carbon monoxide and sulfur also proceeded under high pressure and temperature,10 however, owing to the severe reaction conditions and toxicity of selenium, the use of this method is considerably limited.

Recently, solvent-assisted thiocarboxylation of amines with carbon monoxide and sulfur was reported to afford S-alkyl thiocarbamates in good yields.11 In this reaction system, the thiocarboxylation of amines with carbon monoxide and sulfur was powerfully assisted by dimethyl sulfoxide (DMSO) or N,N-dimethylformamide (DMF) as solvent under mild conditions (0.1 MPa, 20 °C).

In pursuit of a synthetic methodology for generating unsymmetrical ureas 1, a smooth synthetic method for producing symmetrical urea derivatives was recently explored through the carbonylation of amines with carbon monoxide and sulfur, followed by oxidation with molecular oxygen under mild conditions in DMF or DMSO. Using these reactions, symmetrical ureas were obtained from the corresponding primary amines in good to excellent yields under mild conditions (0.1 MPa, 20 °C).12

We have further extended this strategy in order to develop a user-friendly protocol for the synthesis of unsymmetrical urea derivatives 1. Herein, we report the full results for the selective synthesis of 1 from secondary amines 2, aromatic amines 3, and sulfur, in DMF with 0.1 MPa of carbon monoxide and oxygen at 20 °C (Scheme 1). The preparation of N,N-dipropyl-N'-phenylurea (1a) was used as a model system for screening the influence of base and solvent on the reaction (Table 1).

\[
\begin{align*}
R_2NH + ArNH_2 + S & \xrightarrow{\text{CO, DMF, O}_{2}} \text{R}_2NC(O)NHAr \\
2 & 3 & 0.1 \text{ MPa, } 20 \degree \text{C} & 1
\end{align*}
\]

Scheme 1 Synthesis of N,N-dialkyl-N'-arylelas 1

Initially, the synthesis of N,N-dipropyl-N'-phenylurea (1a) was carried out by the carbonylation of dipropylamine (2a; 10 mmol), aniline (3a), and powdered sulfur in DMF with carbon monoxide, and oxidation by molecular oxygen. The reactions proceeded smoothly under 0.1 MPa pressure, at 20 °C, to give 1a selectively in moderate yield (66%; entry 1). Furthermore, using two equivalents of 2a, the unsymmetrical urea 1a was successfully obtained in a superior yield (90%; entry 2). However, shorter reaction times (4 h for carbonylation and 2 h for oxidation) led to a lower yield of 1a (entry 3).

The effect of the base (10 mmol) on the synthesis of 1a was then examined. By addition of 1,8-diazabicyclo[5.4.0]undec-7-ene (DBU), 1,5-diazabicyclo[4.3.0]non-5-ene (DBN), triethylamine, 1-methylpyrrolidine, or triethylamine in DMF, the yields of 1a were improved (en-
tries 4–7). It was found that one equivalent of DBU gave almost the same effect as two equivalents of 2a, whereas, the use of 1,4-diazabicyclo[2.2.2]octane (DABCO) did not have any additional effect on the preparation (entry 8). Potassium carbonate (K₂CO₃) lowered the yield of 1a (entry 9). The solvent used had a great impact on the reaction. 1a was obtained in good yields using dimethyl sulfoxide (DMSO) as solvent with two equivalents of DBU (entry 10). However, tetrahydrofuran (THF) and toluene were found to be unsuitable for the preparation of 1a (entries 11 and 12).

In order to demonstrate the efficiency and scope of the synthetic methodology for the preparation of N,N-dialkyl-N'-arylamines 1, a variety of urea derivatives 1a–m were prepared under the optimized reaction conditions [dialkylamines 2a–h (2.0 equiv), arylamines 3a–f (1.0 equiv), DMF, 0.1 MPa CO, 20 °C, 16 h, then 0.1 MPa O₂, 20 °C, 6 h]. The results are summarized in Table 2.

Generally, unsymmetrical urea derivatives 1a–m were selectively obtained in good to excellent yields under ambient pressure at room temperature. However, diisopropylamine (2c) gave the corresponding unsymmetrical urea 1g in only moderate yield, presumably because of the bulkiness of 2c. This unsymmetrical urea synthesis displayed good tolerance for several substituents on 3. Even weakly basic 4-chloroaniline (3d) and 3,4-dichloroaniline (3f), having electron-withdrawing groups, afforded 1e and 1m, respectively, in good yields (entries 5 and 13). Additionally, the use of 2a–c (1 equiv) and DBU (1 equiv) gave slightly lower yields of 1a, 1b and 1g, respectively (entries 1, 2 and 7).

Furthermore, the unsymmetrical urea herbicide neburon (1m) was also prepared in reasonable yield (79%) on a larger scale (21.8 g; Scheme 2).

### Table 1 Influence of Base and Solvent on the Synthesis of 1a[^a^]

<table>
<thead>
<tr>
<th>Entry</th>
<th>Base</th>
<th>Solvent</th>
<th>Yield (%)[^b^]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>none</td>
<td>DMF</td>
<td>66</td>
</tr>
<tr>
<td>2</td>
<td>none</td>
<td>DMF</td>
<td>90[^c^]</td>
</tr>
<tr>
<td>3</td>
<td>DBU[^d^]</td>
<td>DMF</td>
<td>61[^c,d^]</td>
</tr>
<tr>
<td>4</td>
<td>DBN[^e^]</td>
<td>DMF</td>
<td>77</td>
</tr>
<tr>
<td>5</td>
<td>Et₃N</td>
<td>DMF</td>
<td>75</td>
</tr>
<tr>
<td>6</td>
<td>1-methylpyrrolidine</td>
<td>DMF</td>
<td>75</td>
</tr>
<tr>
<td>7</td>
<td>DABCO[^f^]</td>
<td>DMF</td>
<td>66</td>
</tr>
<tr>
<td>8</td>
<td>K₂CO₃</td>
<td>DMF</td>
<td>50</td>
</tr>
<tr>
<td>9</td>
<td>none</td>
<td>DMSO</td>
<td>81[^c]</td>
</tr>
<tr>
<td>10</td>
<td>none</td>
<td>THF</td>
<td>40[^c]</td>
</tr>
<tr>
<td>11</td>
<td>none</td>
<td>toluene</td>
<td>0[^c]</td>
</tr>
</tbody>
</table>

[^a^]: Reagents and conditions: Pr₂NH (1.37 mL, 10 mmol), PhNH₂ (0.911 mL, 10 mmol), sulfur (321 mg, 10 mmol), base (10 mmol), solvent (20 mL), CO (0.1 MPa), 20 °C, 16 h; then 6 h O₂ (0.1 MPa), 20 °C, 6 mL, 10 mmol), sulfur (321 mg, 10 mmol), base (10 mmol), solvent.

[^b^]: Isolated yields.

[^c^]: Pr₂NH (2a: 2.73 mL, 20 mmol) was used.

[^d^]: Reaction times were 4 h for carbonylation and 2 h for oxidation.

[^e^]: 1,8-Diazabicyclo[5.4.0]undec-7-ene.

[^f^]: 1,5-Diazabicyclo[4.3.0]non-5-ene.

[^g^]: 1,4-Diazabicyclo[2.2.2]octane.

### Table 2 Synthesis of Unsymmetrical Ureas 1a–m[^a^]

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Pr</td>
<td>Pr</td>
<td>H</td>
<td>H</td>
<td>H</td>
<td>3a 1a 90 (85)[^c^]</td>
</tr>
<tr>
<td>2</td>
<td>Et</td>
<td>Et</td>
<td>2b</td>
<td>H</td>
<td>H</td>
<td>3a 1b 82 (75)[^c]</td>
</tr>
<tr>
<td>3</td>
<td>Et</td>
<td>Et</td>
<td>2b</td>
<td>Me</td>
<td>H</td>
<td>3b 1c 85</td>
</tr>
<tr>
<td>4</td>
<td>Et</td>
<td>Et</td>
<td>2b</td>
<td>H</td>
<td>H</td>
<td>3e 1d 92</td>
</tr>
<tr>
<td>5</td>
<td>Et</td>
<td>Et</td>
<td>2b</td>
<td>H</td>
<td>H</td>
<td>3d 1e 90</td>
</tr>
<tr>
<td>6</td>
<td>Et</td>
<td>Et</td>
<td>2b</td>
<td>H</td>
<td>H</td>
<td>3e 1f 83</td>
</tr>
<tr>
<td>7</td>
<td>i-Pr</td>
<td>i-Pr</td>
<td>2c</td>
<td>H</td>
<td>H</td>
<td>3a 1g 51 (41)[^c]</td>
</tr>
<tr>
<td>8</td>
<td>Bu</td>
<td>Bu</td>
<td>2d</td>
<td>H</td>
<td>H</td>
<td>3a 1h 68</td>
</tr>
<tr>
<td>9</td>
<td>–(CH₂)₃–</td>
<td>2e</td>
<td>H</td>
<td>H</td>
<td>3a 1i 64</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>–(CH₂)₃–</td>
<td>2f</td>
<td>H</td>
<td>H</td>
<td>3a 1j 62</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>–(CH₂)₃–</td>
<td>2f</td>
<td>H</td>
<td>H</td>
<td>3e 1k 82</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>–(CH₂)₃O(CH₂)₃–</td>
<td>2g</td>
<td>H</td>
<td>H</td>
<td>3a 1l 65</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>Bu</td>
<td>Me</td>
<td>2h</td>
<td>H</td>
<td>Cl</td>
<td>3f 1m 73[^d]</td>
</tr>
</tbody>
</table>

[^a^]: Reagents and conditions: dialkylamine (20 mmol), arylamine (10 mmol), sulfur (321 mg, 10 mmol), DMF (20 mL), CO (0.1 MPa), 20 °C, 16 h; then O₂ (0.1 MPa), 20 °C, 6 h.

[^b^]: Isolated yields.

[^c^]: Dialkylamine (10 mmol) and DBU (10 mmol) were used.

[^d^]: Neburon (herbicide).

### Scheme 2 Herbicide neburon (1m) synthesis on a large scale
In order to understand the selective formation of unsymmetrical urea derivatives of type 1, the following reactions with 2a or 3a were performed (Scheme 3). When dipropylamine (2a; 20 mmol) was carbonylated in the presence of sulfur (10 mmol) in DMF under 0.1 MPa of carbon monoxide at 20 °C for 16 hours then oxidized with 0.1 MPa of oxygen (10 mmol) in DMF under 0.1 MPa of carbon monoxide at 20 °C for six hours, bis(N,N-dipropylcarbamoyl)disulfide (4a) was formed.\(^{13}\) On the other hand, a similar reaction with aniline (3a) did not give urea derivatives (Scheme 3). In this case, the corresponding N,N'-diphenylurea was given in moderate yield under mild conditions only in the presence of a strong base (DBU).\(^{12}\)

\[
\begin{align*}
4 \text{Pr}_2\text{NH} + 2 \text{S} & \quad \text{CO, DMF} \quad 0.1 \text{MPa}, 20 ^\circ\text{C}, 16 \text{h} \quad \text{O}_2 \quad 6 \text{h} \\
\text{Pr}_2\text{N(CO)(S)}_2 & \quad \text{Pr}_2\text{NH}_2^+ \\
2 \text{PhNH}_2 + \text{S} & \quad \text{CO, DMF} \quad 0.1 \text{MPa}, 20 ^\circ\text{C}, 16 \text{h} \quad \text{O}_2 \quad 6 \text{h} \\
\text{PhNH(CO)S}^- \text{PhNH}_3^+ & \quad 0 \%
\end{align*}
\]

Scheme 3 Reaction of 2a and 3a

From these experimental clues, a possible pathway for the synthesis of 1a was envisaged as indicated in Scheme 4. First, an N,N'-dipropylthiocarbamate salt could be generated via ready reaction of the thiolate salts with carbon monoxide (Scheme 5).\(^{14}\) The formed thiocarbamate salt could then be oxidized by molecular oxygen, giving bis(N,N-dipropylcarbamoyl)disulfide (4a). Due to the steric bulk of 4a and 2a, it is difficult to form the tetrapro pylurea through aminolysis. In contrast, the ammonium salt of N,N'-diphenylthiocarbamate is not formed, because of the low nucleophilicity of aniline (4a). Therefore, the aminolysis of 4a with 3a leads to the selective preparation of N,N'-dipropyl-N'-phenylurea (1a).

\[
\begin{align*}
2 \text{Pr}_2\text{NH} + \text{CO} + \text{S} & \quad \text{Pr}_2\text{N(CO)(S)}_2\text{Pr}_2\text{NH}_2^+ \\
2 \text{Pr}_2\text{N(CO)(S)}^-\text{Pr}_2\text{NH}_3^+ & \quad \text{O}_2 \quad (\text{Pr}_2\text{N(CO)(S)}_2)_{2a} \quad 4a, 23\% \\
2 \text{PhNH}_2 + \text{CO} + \text{S} & \quad \text{PhNH(CO)S}^-\text{PhNH}_3^+ \\
(\text{Pr}_2\text{N(CO)(S)}_2)_2 + 2 \text{PhNH}_2 & \quad 2 \text{Pr}_2\text{N(CO)(S)}\text{PhNH}_2^+
\end{align*}
\]

Scheme 4 Reaction path for the formation of 1a

\[
\begin{align*}
2 \text{R'NH} + \text{S}_x & \quad \text{R'N-S}_x\text{S}^-\text{R'NH}_2^+ \\
\text{R'N-S}_x\text{S}^-\text{R'NH}_3^+ & \quad \text{CO} - \text{S}_x \quad \text{R'N(CO)(S)}^-\text{R'NH}_2^+
\end{align*}
\]

Scheme 5 Reaction of thiolate anions with carbon monoxide

In conclusion, a useful protocol for the synthesis of unsymmetrical urea derivatives 1 in good to excellent yields has been developed. The method works under mild conditions (0.1 MPa, 20 °C) in DMF, and involves sulfur-assisted carbonylation with carbon monoxide and sulfur, and oxidation with molecular oxygen. From the viewpoint of developing an application for the practical production of 1, including herbicide 1m, the present method is very significant in terms of the use of easily available and cheap carbon monoxide, oxygen, sulfur and DMF, and because of the mild reaction conditions that are needed (0.1 MPa, 20 °C).

Melting points were determined on a Mettler FP 5 instrument and are uncorrected. FT-IR spectra were recorded on a JASCO FT/IR-4100 instrument.\(^1\) and \(^{13}\)NMR spectra were obtained on a JEOL JNM-AL300 (300 MHz, 75 MHz) instrument. Chemical shifts (\(\delta\)) are reported in ppm relative to TMS. Both low and high-resolution mass spectra were measured on a JEOL JMS-600 spectrometer. Di-alkylamines 2a-h, arylamines 3a-f, base (DBU, DBN, DABCO, Et,N, 1-methylpyrrolidine and K2CO3), powdered sulfur (99.5%), and solvents (DMF, DMSO, THF, toluene) were used as purchased. CO (99.9%) and O2 (99.9%) were also used as received.

Synthesis of N,N-Dipropyl-N'-phenylurea (1a): Typical Procedure

Into a 100 mL flask, Pr2NH (2a; 2.73 mL, 20 mmol), aniline (3a; 0.911 mL, 10 mmol) and powdered sulfur (321 mg, 10 mmol) were added in DMF (20 mL) under an argon atmosphere. Ambient pressure of CO was charged and the mixture was vigorously stirred under a CO balloon (0.1 MPa) at 20 °C for 16 h (the color of the solution changed from reddish-black to pale-orange). CO was purged and O2 (0.1 MPa) was charged at 20 °C (slightly exothermic reaction). The reaction mixture was stirred under an O2 balloon (0.1 MPa) for an additional 6 h at 20 °C. The resulting orange emulsion was then poured into 1 M HCl (100 mL) and extracted with t-BuOMe (2 × 50 mL). Evaporation of solvents and purification by short-column chromatography (silica gel; EtOAc), gave N,N-dipropyl-N'-phenylurea (1a).

Yield: 1.98 g (90%); mp 68.1 °C (Lit.10 68–70 °C).

IR (KBr): 3320, 2962, 1639, 1541, 1447, 1239, 755 cm–1.

\[^{1}H\text{ NMR (300 MHz, CDCl}_{3}\]: \(\delta = 0.94 \text{ (t, } J = 7.4 \text{ Hz, } 6 \text{ H, } 2 \times \text{CH}_3\), 1.64 (sex, \(J = 7.4 \text{ Hz, } 4 \text{ H, } 2 \times \text{CH}_2\)), 3.26 (t, \(J = 7.4 \text{ Hz, } 4 \text{ H, } 2 \times \text{CH}_2\)), 6.32 (br s, \(1 \text{ H, NH}\)), 7.00 (t, \(J = 7.5 \text{ Hz, } 1 \text{ H, CH}\)), 7.26 (t, \(J = 7.5 \text{ Hz, } 2 \text{ H, } 2 \times \text{CH}\)), 7.37 (d, \(J = 7.5 \text{ Hz, } 2 \text{ H, } 2 \times \text{CH}\)).

\[^{13}C\text{ NMR (75 MHz, CDCl}_{3}\]: \(\delta = 11.3, 21.8, 49.4, 119.7, 122.7, 128.7, 139.3, 155.0\).

MS (EI, 70 eV): \(m/z\) (%): 220 (100) [M+], 191 (11), 128 (41), 86 (10), 72 (18).

HRMS (EI, 70 eV): \(m/z\) calcd for C13H20ON2: 220.1593; found: 220.1593.

N,N-Diethyl-N'-phenylurea (1b)

Compound 1b was purified by recrystallization (hexane–toluene).

Yield: 1.58 g (82%); mp 86.8 °C (Lit.10 85–87 °C).

IR (KBr): 3307, 2973, 1638, 1536, 1445, 1303, 1244, 753 cm–1.

\[^{1}H\text{ NMR (300 MHz, CDCl}_{3}\]: \(\delta = 1.21 \text{ (t, } J = 7.1 \text{ Hz, } 6 \text{ H, } 2 \times \text{CH}_3\), 3.36 (q, \(J = 7.1 \text{ Hz, } 4 \text{ H, } 2 \times \text{CH}_2\)), 6.34 (br s, \(1 \text{ H, NH}\)), 7.00 (t, \(J = 7.7 \text{ Hz, } 1 \text{ H, CH}\)), 7.26 (d, \(J = 7.7 \text{ Hz, } 2 \text{ H, } 2 \times \text{CH}\)), 7.38 (d, \(J = 7.7 \text{ Hz, } 2 \text{ H, } 2 \times \text{CH}\)).

\[^{13}C\text{ NMR (75 MHz, CDCl}_{3}\]: \(\delta = 13.9, 41.6, 119.8, 122.7, 128.7, 139.3, 154.6\).

MS (EI, 70 eV): \(m/z\) (%): 192 (81) [M+], 100 (100), 72 (52), 58 (11).
N,N-Diethyl-N-(2-methylphenyl)urea (1c)  
Compound 1c was purified by recrystallization (hexane–toluene).  
Yield: 1.74 g (85%); mp 80.7 °C (Lit.15 78–79 °C).  
IR (KBr): 3283, 2970, 2932, 1633, 1514, 1296, 1235, 1168, 820 cm⁻¹.

N,N-Diethyl-N-(4-methylphenyl)urea (1d)  
Compound 1d was purified by short-column chromatography (silica gel; EtOAc).  
Yield: 1.90 g (92%); mp 69.0 °C (Lit.15 67.5–68 °C).  
IR (KBr): 3336, 2979, 2930, 1636, 1518, 1418, 1244, 813, 509 cm⁻¹.

N,N-Diethyl-N-(4-chlorophenyl)urea (1e)  
Compound 1e was purified by recrystallization (hexane–toluene).  
Yield: 2.03 g (90%); mp 116.5 °C (Lit.15 116–118.5 °C).  
IR (KBr): 3328, 2984, 1633, 1494, 1304, 1243, 819, 506 cm⁻¹.

N,N-Diethyl-N-(4-methoxyphenyl)urea (1f)  
Compound 1f was purified by recrystallization (hexane–toluene).  
Yield: 1.84 g (83%); mp 62.0 °C (Lit.15 61.5–62 °C).  
IR (KBr): 3283, 2970, 2932, 1633, 1514, 1296, 1235, 1168, 820 cm⁻¹.

N,N-Diethyl-N-(4-chlorophenyl)urea (1g)  
Compound 1g was purified by short-column chromatography (silica gel; EtOAc).  
Yield: 1.27 g (62%); mp 168.3 °C (Lit.10 168–170 °C).  
IR (KBr): 3297, 2973, 2873, 1642, 1537, 1442, 1380, 1241, 761 cm⁻¹.

N,N-Diethyl-N-(4-methoxyphenyl)urea (1h)  
Compound 1h was purified by recrystallization (hexane).  
Yield: 1.68 g (68%); mp 83.4 °C (Lit.10 83–84 °C).  
IR (KBr): 3297, 2957, 1637, 1533, 1446, 1408, 1223, 754 cm⁻¹.

N,N-Dibutyl-N'-phenylurea (1i)  
Compound 1i was purified by recrystallization (silica gel; EtOAc).  
Yield: 1.12 g (51%); mp 116.1 °C (Lit.16 113–115 °C).  
IR (KBr): 3287, 2968, 1633, 1527, 1447, 1336, 1248, 1148, 758 cm⁻¹.

N,N-Di-i-propyl-N'-phenylurea (1j)  
Compound 1j was purified by washing with hexane.  
Yield: 1.27 g (62%); mp 168.3 °C (Lit.10 168–170 °C).  
IR (KBr): 3289, 2925, 2855, 1630, 1536, 1449, 1243, 754 cm⁻¹.
7.61 (d, J = 8.8 Hz, 1 H, CH), 7.29 (d, J = 8.8 Hz, 1 H, CH), 7.61 (d, J = 2.3 Hz, 1 H, CH).

13C NMR (75 MHz, CDCl3): δ = 13.8, 20.0, 30.1, 34.6, 48.9, 119.0, 121.4, 125.8, 130.1, 132.4, 138.9, 154.8.

MS (EL, 70 eV): m/z (%) = 276 (42) [M+ + 2], 274 (65) [M+], 187 (10), 161 (11), 114 (100), 58 (16), 57 (88).

HRMS (EL, 70 eV): m/z calc for C11H10ON2Cl: 274.0664; found: 274.0635.

Bis(N,N-dipropylcarbamoyl)disulfide (4a)

Pr2NH (2a, 2.73 mL, 20 mmol), powdered sulfur (321 mg, 10 mmol), and DMF (20 mL) were placed in a 100 mL flask under an argon atmosphere. The flask was charged with CO (0.1 MPa), and the mixture was vigorously stirred under a balloon of CO (0.1 MPa) at 20 °C for 16 h. The flask was purged of CO, and charged with O2 (0.1 MPa) at 20 °C, then the solution was stirred under a balloon of O2 (0.1 MPa) for an additional 6 h at 20 °C. The resulting orange solution was poured into 1 M HCl (100 mL), and extracted with t-BuOH (2 × 50 mL). Bis(N,N-dipropylcarbamoyl)disulfide (4a) was purified as an oil, by short-column chromatography (silica gel; EtOAc).

Yield: 374 mg (23%); oil.13

IR (NaCl): 2964, 2933, 2874, 1681, 1404, 1218, 1119, 708 cm−1.

1H NMR (300 MHz, CDCl3): δ = 0.90–0.92 (m, 12 H, 4 CH2). 13C NMR (75 MHz, CDCl3): δ = 11.2, 20.9, 22.1, 50.5, 163.4.

MS (EL, 70 eV): m/z (%) = 320 (29) [M+], 129 (27), 128 (100), 86 (77).

HRMS (EL, 70 eV): m/z calc for C12H16O2N2S2: 230.1592; found: 230.1576.

References

(1) Bioorganic Chemistry of Pesticides; Eio, M., Ed.; Soft Science Publications: Tokyo, 1985, 73.