Electronic Supplementary Information

The synthesis of HMF-based α-amino phosphonates *via* one-pot Kabachnik-Fields reaction

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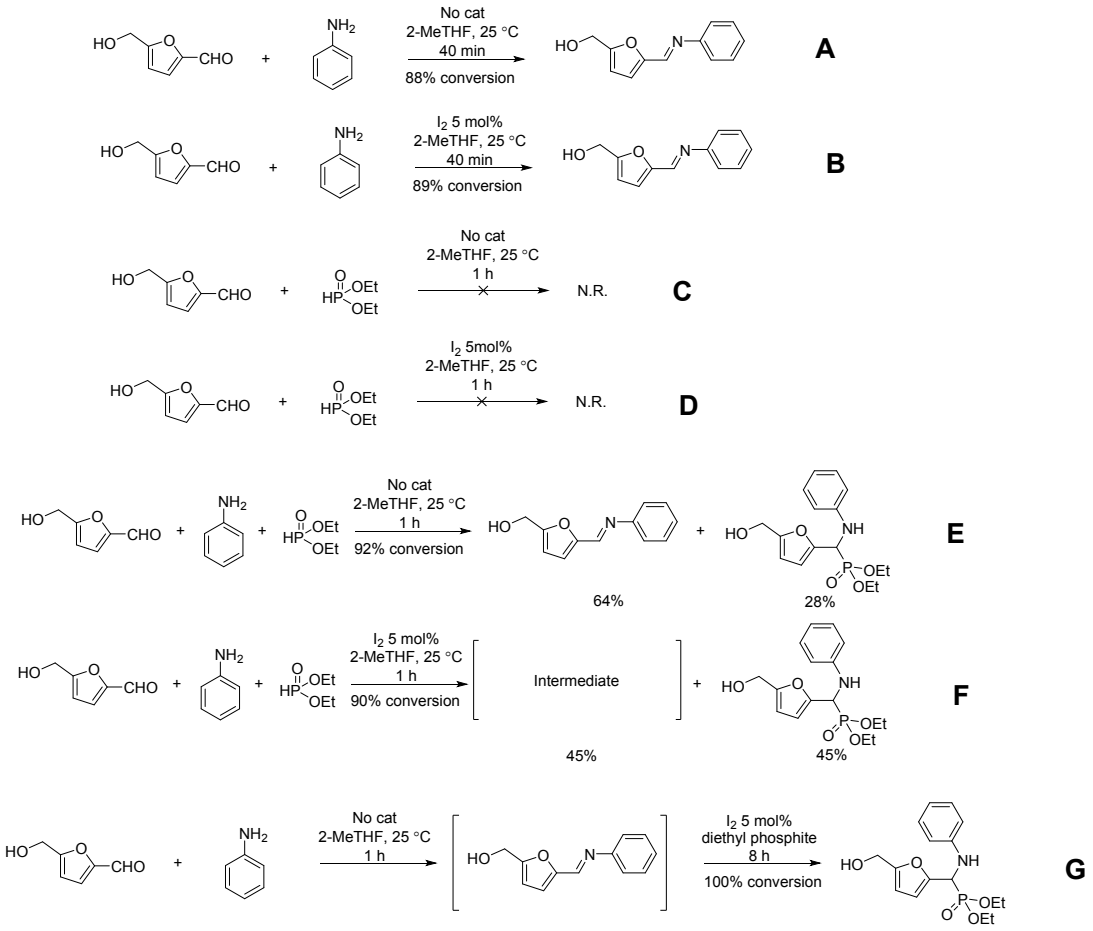
1. General information

Unless specified noted, all reagents and solvents were purchased from Sigma-Aldrich, TCI, Alfa Aesar, Fluka and Carbosynth, and were used without further purification. 5,5'-[Oxybis(methylene)]bis-2-furfural was prepared following Ananikov's method.[1] Thin layer chromatography (TLC) was carried out on 0.20 mm silica gel (ALUGRAM TLC sheet, Macherey-Nagel) and visualized using UV light or phosphomolybdic acid stain. Column chromatography was generally performed on silica gel (0.04-0.063 mm, Macherey-Nagel). The NMR spectra were recorded in $CDCl_3$ on Bruker spectrometers (300 MHz, 400 MHz or 500 MHz). Chemical shifts were reported in parts per million (δ) relative to TMS or residual solvent peak. The abbreviations are used: s = singlet, d = doublet, t = triplet, q = quartet, dd = doublet of doublets, td = triplet of doublets, m = multiplet, br = broad signal. HRMS spectra were measured on Bruker MicrOTOF-Q II XL spectrometer using ESI as ionization source.

2. General procedure for Kabachnik-Fields reaction

A solution of HMF (1 mmol) in 2-MeTHF (2 mL), amine (1 mmol), dialkyl phosphite (1.5 mmol) and iodine (5 mol%) was stirred at room temperature (25 °C) or 50 °C for indicated time. Then the mixture was concentrated under reduced pressure and purified by column chromatography on silica gel to provide pure α-amino phosphonate **4**.

3. Mechanistic study



Scheme 1. Control experiments

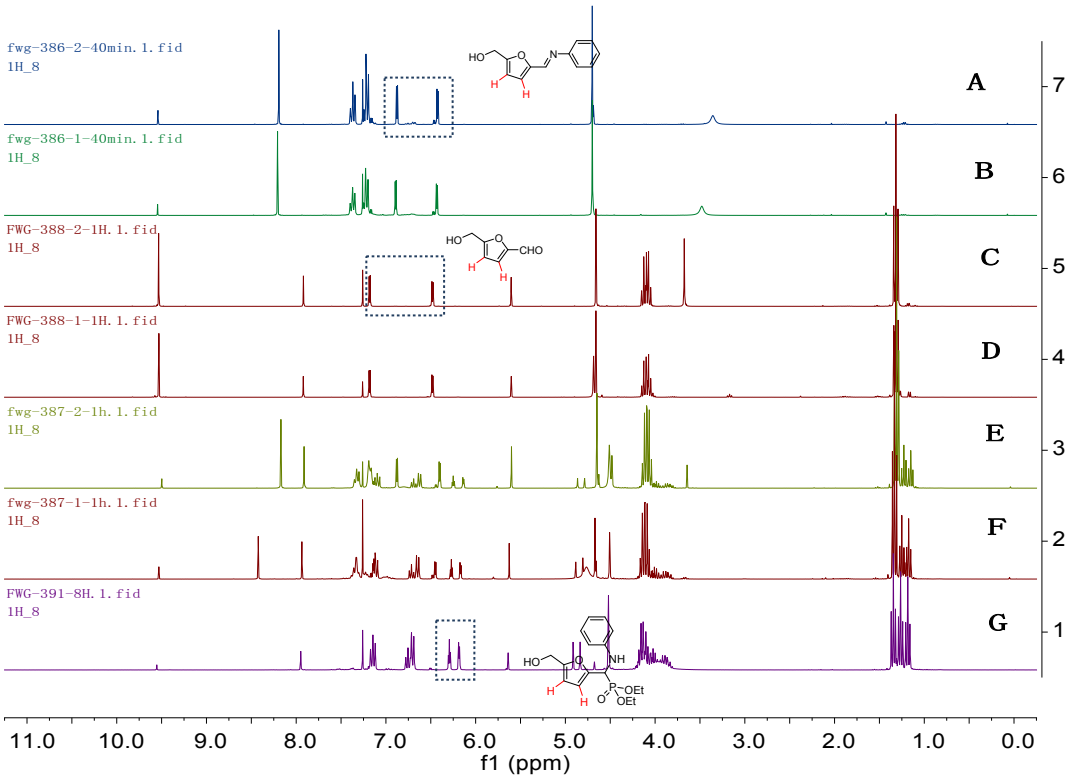


Figure 1. NMR spectra of control experiments

4. Characterization data of products

Diethyl ((5-(hydroxymethyl)furan-2-yl)(phenylamino)methyl)phosphonate (4a)

The title compound was obtained in 91% yield as a pale yellow sticky syrup after column chromatography (pentane: ethyl acetate = 1: 5 – 1: 10).

^{1}H NMR (500 MHz, $CDCl_3$) δ 7.15 – 7.09 (m, 2H, $H_{3''}$), 6.74 – 6.69 (m, 1H, $H_{4''}$), 6.68 – 6.63 (m, 2H, $H_{2''}$), 6.29 (dd, J = 3.2 Hz, 1H, $H_{3'}$), 6.17 (d, J = 3.2 Hz, 1H, $H_{4'}$), 4.86 (d, J = 23.5 Hz, 1H, H_1), 4.53 – 4.45 (AB, 2H, C$\underline{H}_2$OH), 4.19 – 4.08 (m, 2H, C$\underline{H}_2$CH$_3$), 4.06 – 3.97 (m, 1H, C$\underline{H}_2$CH$_3$), 3.89 – 3.82 (m, 1H, C$\underline{H}_2$CH$_3$), 1.25 (t, J = 7.0 Hz, 3H, CH$_2$C$\underline{H}_3$), 1.17 (t, J = 7.0 Hz, 3H, CH$_2$C$\underline{H}_3$). ^{13}C NMR (125 MHz, $CDCl_3$) δ 155.0 (d, ^4J = 3 Hz, $C_{5'}$), 148.6 (d, ^2J = 2 Hz, $C_{2'}$), 146.0 (d, ^3J = 13 Hz, $C_{1''}$), 129.2 (2$C_{3''}$), 118.8 ($C_{4''}$), 113.9 (2$C_{2''}$), 109.6 (d, ^3J = 8 Hz, $C_{3'}$), 108.4 (d, ^4J = 2 Hz, $C_{4'}$), 63.7 (d, ^2J = 7 Hz, $\underline{C}$H$_2$CH$_3$), 63.5 (d, ^2J = 7 Hz, $\underline{C}$H$_2$CH$_3$), 56.9 ($\underline{C}$H$_2$OH), 50.2 (d, ^1J = 160 Hz, C_1), 16.4 (d, ^3J = 6 Hz, CH$_2\underline{C}$H$_3$), 16.3 (d, ^3J = 6 Hz, CH$_2\underline{C}$H$_3$). ^{31}P NMR (202 MHz, $CDCl_3$) δ 20.3.

HRMS (ESI) m/z: Calcd for $[M+Na]^+$ $C_{16}H_{22}NNaO_5P$ 362.1128; Found 362.1118.

Diethyl ((5-(hydroxymethyl)furan-2-yl)((4-methoxyphenyl)amino)methyl)phosphonate (4b)

The title compound was obtained in 90% yield as a brown sticky syrup after column chromatography (pentane: ethyl acetate = 1: 5 – 1: 10).

^{1}H NMR (400 MHz, $CDCl_3$) δ 6.71 – 6.66 (m, 2H, H_{Ph}), 6.63 – 6.58 (m, 2H, H_{Ph}), 6.24 (dd, J = 3.2 Hz, 1H, $H_{3'}$), 6.15 (d, J = 3.2, 1H, $H_{4'}$), 4.74 (d, J = 23.6 Hz, 1H, H_1), 4.52 - 4.43 (AB, 2H, C$\underline{H}_2$OH), 4.19 – 4.07 (m, 2H, C$\underline{H}_2$CH$_3$), 4.06 - 3.94 (m, 1H, C$\underline{H}_2$CH$_3$), 3.90 – 3.78 (m, 1H, C$\underline{H}_2$CH$_3$), 3.66 (s, 3H, OC$\underline{H}_3$), 1.25 (t, J = 7.1, 3H, CH$_2$C$\underline{H}_3$), 1.16 (t, J = 7.1, 3H, CH$_2$C$\underline{H}_3$). ^{13}C NMR (100 MHz, $CDCl_3$) δ 154.9 (d, ^4J = 3 Hz, $C_{5'}$), 153.1 ($C_{4''}$), 148.8 (d, ^2J = 2 Hz, $C_{2'}$), 140.0 (d, ^3J = 14 Hz, $C_{1''}$), 115.7 (2CH_{Ph}), 114.7 (2CH_{Ph}), 109.6 (d, ^3J = 8 Hz, $C_{3'}$), 108.4 (d, ^4J = 3 Hz, $C_{4'}$), 63.7 (d, ^2J = 7 Hz, $\underline{C}$H$_2$CH$_3$), 63.4 (d, ^2J = 7 Hz, $\underline{C}$H$_2$CH$_3$), 56.9 ($\underline{C}$H$_2$OH), 55.6 (O$\underline{C}$H$_3$), 51.4 (d, ^1J = 160 Hz, C_1), 16.4 (d, ^3J = 6 Hz, CH$_2\underline{C}$H$_3$), 16.3 (d, ^3J = 6 Hz, CH$_2\underline{C}$H$_3$). ^{31}P NMR (162 MHz, $CDCl_3$) δ 20.5.

HRMS (ESI) m/z: Calcd for $[M+H]^+$ $C_{17}H_{25}NO_6P$ 370.1414; Found 370.1409.

Diethyl (((4-chlorophenyl)amino)(5-(hydroxymethyl)furan-2-yl)methyl)phosphonate (4c)

The title compound was obtained in 85% yield as a yellow sticky syrup after column chromatography (pentane: ethyl acetate = 1: 5 – 1: 10).

^{1}H NMR (300 MHz, $CDCl_3$) δ 7.14 – 7.06 (m, 2H, H_{Ph}), 6.64 – 6.55 (m, 2H, H_{Ph}), 6.31 (dd, J = 3.3 Hz, 1H, $H_{3'}$), 6.22 (d, J = 3.2 Hz, 1H, $H_{4'}$), 4.79 (d, J = 23.6 Hz, 1H, H_1), 4.55 (s, 2H, C$\underline{H}_2$OH), 4.25 – 3.80 (m, 4H, C$\underline{H}_2$CH$_3$), 1.29 (td, J = 7.1, 0.5 Hz, 3H, CH$_2$C$\underline{H}_3$), 1.20 (td, J = 7.1, 0.6 Hz, 3H, CH$_2$C$\underline{H}_3$). ^{13}C NMR (75 MHz, $CDCl_3$) δ 155.1 (d, ^4J = 3 Hz, $C_{5'}$), 148.1 (d, ^2J = 3 Hz, $C_{2'}$), 144.7 (d, ^3J = 13 Hz, $C_{1''}$), 128.9 (2CH_{Ph}), 123.3 ($C_{4''}$), 115.0 (2CH_{Ph}), 109.7 (d, ^3J = 8 Hz, $C_{3'}$), 108.3 (d, ^4J = 2 Hz, $C_{4'}$), 63.7 (d, ^2J = 7 Hz, $\underline{C}$H$_2$CH$_3$), 63.5 (d, ^2J = 7 Hz, $\underline{C}$H$_2$CH$_3$), 56.7 ($\underline{C}$H$_2$OH), 50.2 (d, ^1J = 160 Hz, C_1), 16.3 (d, ^3J = 6 Hz, CH$_2\underline{C}$H$_3$), 16.2 (d, ^3J = 6 Hz, CH$_2\underline{C}$H$_3$). ^{31}P NMR (122 MHz, $CDCl_3$) δ 20.0.

HRMS (ESI) m/z: Calcd for $[M+Na]^+$ $C_{16}H_{21}ClNNaO_5P$ 396.0738; Found 396.0719.

Diethyl (((4-bromophenyl)amino)(5-(hydroxymethyl)furan-2-yl)methyl)phosphonate (4d)

The title compound was obtained in 90% yield as a pale yellow sticky syrup after column chromatography (pentane: ethyl acetate = 1: 5 – 1: 10).

^{1}H NMR (300 MHz, $CDCl_3$) δ 7.18 – 7.12 (m, 2H, H_{Ph}), 6.54 – 6.47 (m, 2H, H_{Ph}), 6.26 (dd, *J* = 3.2 Hz, 1H, $H_{3'}$), 6.15 (d, *J* = 3.1 Hz, 1H, $H_{4'}$), 4.84 – 4.70 (m, 2H, H_1 and N<u>H</u>), 4.45 (s, 2H, C<u>H</u>$_2$OH), 4.20 – 3.75 (m, 4H, C<u>H</u>$_2$CH$_3$), 1.21 (td, *J* = 7.0, 0.6 Hz, 3H, CH$_2$C<u>H</u>$_3$), 1.13 (td, *J* = 7.0, 0.6 Hz, 3H, CH$_2$C<u>H</u>$_3$). ^{13}C NMR (75 MHz, $CDCl_3$) δ 155.0 (d, ^{4}J = 3 Hz, $C_{5'}$), 148.1 (d, ^{2}J = 2 Hz, $C_{2'}$), 145.1 (d, ^{3}J = 12 Hz, $C_{1''}$), 131.8 (2CH_{Ph}), 115.5 (2CH_{Ph}), 110.5 ($C_{4''}$), 109.7 (d, ^{3}J = 7 Hz, $C_{3'}$), 108.4 (d, ^{4}J = 2 Hz, $C_{4'}$), 63.7 (d, ^{2}J = 7 Hz, <u>C</u>H$_2$CH$_3$), 63.5 (d, ^{2}J = 7 Hz, <u>C</u>H$_2$CH$_3$), 56.8 (<u>C</u>H$_2$OH), 50.1 (d, ^{1}J = 160 Hz, C_1), 16.4 (d, ^{3}J =6 Hz, CH$_2$<u>C</u>H$_3$), 16.2 (d, ^{3}J = 6 Hz, CH$_2$<u>C</u>H$_3$). ^{31}P NMR (122 MHz, $CDCl_3$) δ 19.9.

HRMS (ESI) m/z: Calcd for $[M+Na]^+$ $C_{16}H_{21}BrNNaO_5P$ 440.0233; Found 440.0217.

Diethyl ((5-(hydroxymethyl)furan-2-yl)((4-iodophenyl)amino)methyl)phosphonate (4e)

The title compound was obtained in 77% yield as a yellow sticky syrup after column chromatography (pentane: ethyl acetate = 1: 5 – 1: 10).

^{1}H NMR (300 MHz, $CDCl_3$) δ 7.39 – 7.29 (m, 2H, H_{Ph}), 6.46 – 6.38 (m, 2H, H_{Ph}), 6.26 (dd, *J* = 3.2 Hz, 1H, $H_{3'}$), 6.15 (d, *J* = 3.2 Hz, 1H, $H_{4'}$), 4.84 – 4.70 (m, 2H, H_1 and N<u>H</u>), 4.46 (s, 2H, C<u>H</u>$_2$OH), 4.22 – 3.73 (m, 4H, C<u>H</u>$_2$CH$_3$), 1.22 (t, *J* = 7.1 Hz, 3H, CH$_2$C<u>H</u>$_3$), 1.14 (t, *J* = 7.1 Hz, 3H, CH$_2$C<u>H</u>$_3$). ^{13}C NMR (75 MHz, $CDCl_3$) δ 155.0 (d, ^{4}J = 3 Hz, $C_{5'}$), 148.1 (d, ^{2}J = 3 Hz, $C_{2'}$), 145.7 (d, ^{3}J = 12 Hz, $C_{1''}$), 137.7 (2CH_{Ph}), 116.1 (2CH_{Ph}), 109.7 (d, ^{3}J = 7 Hz, $C_{3'}$), 108.4 (d, ^{4}J = 2 Hz, $C_{4'}$), 79.9 ($C_{4''}$), 63.7 (d, ^{2}J = 7 Hz, <u>C</u>H$_2$CH$_3$), 63.5 (d, ^{2}J = 7 Hz, <u>C</u>H$_2$CH$_3$), 56.8 (<u>C</u>H$_2$OH), 49.9 (d, ^{1}J = 160 Hz, C_1), 16.4 (d, ^{3}J = 6 Hz, CH$_2$<u>C</u>H$_3$), 16.3 (d, ^{3}J = 6 Hz, CH$_2$<u>C</u>H$_3$). ^{31}P NMR (122 MHz, $CDCl_3$) δ 19.9.

HRMS (ESI) m/z: Calcd for $[M+Na]^+$ $C_{16}H_{21}INNaO_5P$ 488.0094; Found 488.0076.

Diethyl ((5-(hydroxymethyl)furan-2-yl)((4-nitrophenyl)amino)methyl)phosphonate (4f)

The title compound was obtained in 84% yield as a pale yellow sticky syrup after column chromatography (pentane: ethyl acetate = 1: 5 – 1: 10).

^{1}H NMR (300 MHz, $CDCl_3$) δ 8.04 – 7.97 (m, 2H, H_{Ph}), 6.72 – 6.65 (m, 2H, H_{Ph}), 6.40 (dd, *J* = 3.2 Hz, 1H, $H_{3'}$), 6.24 (d, *J* = 3.2 Hz, 1H, $H_{4'}$), 6.10 (dd, *J* = 9.0, 5.7 Hz, 1H, N<u>H</u>), 4.99 (dd, *J* = 22.8, 9.0 Hz, 1H, H_1), 4.53 (s, 2H, C<u>H</u>$_2$OH), 4.25 – 3.84 (m, 4H, C<u>H</u>$_2$CH$_3$), 1.27 (t, *J* = 7.1 Hz, 3H, CH$_2$C<u>H</u>$_3$), 1.21 (t, *J* = 7.1 Hz, 3H, CH$_2$C<u>H</u>$_3$). ^{13}C NMR (75 MHz, $CDCl_3$) δ 155.2 (d, ^{4}J = 3 Hz, $C_{5'}$), 151.8 (d, ^{3}J = 10 Hz, $C_{1''}$), 147.3 (d, ^{2}J = 2 Hz, $C_{2'}$), 138.8 ($C_{4''}$), 126.0 (2CH_{Ph}), 112.2 (2CH_{Ph}), 110.1 (d, ^{3}J = 7 Hz, $C_{3'}$), 108.6 (d, ^{4}J = 2 Hz, $C_{4'}$), 63.9 (d, ^{2}J = 7 Hz, <u>C</u>H$_2$CH$_3$), 63.7 (d, ^{2}J = 7 Hz, <u>C</u>H$_2$CH$_3$), 56.8 (<u>C</u>H$_2$OH), 49.3 (d, ^{1}J = 160 Hz, C_1), 16.4 (d, ^{3}J = 6 Hz, CH$_2$<u>C</u>H$_3$), 16.2 (d, ^{3}J = 6 Hz, CH$_2$<u>C</u>H$_3$). ^{31}P NMR (122 MHz, $CDCl_3$) δ 18.7.

HRMS (ESI) m/z: Calcd for $[M+Na]^+$ $C_{16}H_{21}N_2NaO_7P$ 407.0979; Found 407.0967.

Diethyl (((3-chlorophenyl)amino)(5-(hydroxymethyl)furan-2-yl)methyl)phosphonate (4g)

The title compound was obtained in 93% yield as a pale yellow sticky syrup after column chromatography (pentane: ethyl acetate = 1: 4 – 1: 8).

^{1}H NMR (400 MHz, $CDCl_3$) δ 7.01 (t, *J* = 8.0 Hz, 1H, $H_{5''}$), 6.71 – 6.64 (m, 2H, $H_{2''}$ and $H_{4''}$),

6.56 – 6.51 (m, 1H, $H_{6''}$), 6.32 (dd, J = 3.2 Hz, 1H, $H_{3'}$), 6.19 (d, J = 3.2 Hz, 1H, $H_{4'}$), 4.95 (dd, J = 9.5, 5.6 Hz, 1H, NH), 4.83 (dd, J = 23.0, 9.5 Hz, 1H, H_1), 4.50 (s, 2H, CH_2OH), 4.33 (br, 1H, OH), 4.23 – 3.79 (m, 4H, CH_2CH_3), 1.26 (t, J = 7.1 Hz, 3H, CH_2CH_3), 1.18 (t, J = 7.0 Hz, 3H, CH_2CH_3). ^{13}C NMR (100 MHz, $CDCl_3$) δ 155.1 (d, ^4J = 3 Hz, $C_{5'}$), 148.1 (d, ^2J = 2 Hz, $C_{2'}$), 147.3 (d, ^3J = 12 Hz, $C_{1''}$), 134.8 ($C_{3''}$), 130.1 ($C_{5''}$), 118.5 ($C_{2''}$ or $C_{4''}$), 113.7 ($C_{2''}$ or $C_{4''}$), 112.0 ($C_{6''}$), 109.8 (d, ^3J = 8 Hz, $C_{3'}$), 108.4 (d, ^4J = 2 Hz, $C_{4'}$), 63.7 (d, ^2J = 7 Hz, CH_2CH_3), 63.5 (d, ^2J = 7 Hz, CH_2CH_3), 56.8 (CH_2OH), 49.9 (d, ^1J = 161 Hz, C_1), 16.4 (d, ^3J = 6 Hz, CH_2CH_3), 16.2 (d, ^3J = 6 Hz, CH_2CH_3). ^{31}P NMR (162 MHz, $CDCl_3$) δ 19.8.
HRMS (ESI) m/z: Calcd for $[M+Na]^+$ $C_{16}H_{21}ClNNaO_5P$ 396.0738; Found 396.0723.

Diethyl ((5-(hydroxymethyl)furan-2-yl)((3-(trifluoromethyl)phenyl)amino)methyl)phosphonate (4h)

The title compound was obtained in 87% yield as a pale yellow sticky syrup after column chromatography (pentane: ethyl acetate = 1: 4 – 1: 8).
^{1}H NMR (400 MHz, $CDCl_3$) δ 7.23 – 7.17 (m, 1H, $H_{5''}$), 6.97 – 6.91 (m, 2H, $H_{2''}$ and $H_{4''}$), 6.83 – 6.77 (m, 1H, $H_{6''}$), 6.35 (dd, J = 3.2 Hz, 1H, $H_{3'}$), 6.20 (d, J = 3.2 Hz, 1H, $H_{4'}$), 5.14 (br, NH), 4.89 (d, J = 23.0 Hz, 1H, H_1), 4.51 (AB, 2H, CH_2OH), 4.23 – 3.82 (m, 4H, CH_2CH_3), 1.26 (t, J = 7.1 Hz, 3H, CH_2CH_3), 1.18 (t, J = 7.0 Hz, 3H, CH_2CH_3). ^{13}C NMR (100 MHz, $CDCl_3$) δ 155.2 (d, ^4J = 3 Hz, $C_{5'}$), 148.0 (d, ^2J = 2 Hz, $C_{2'}$), 146.5 (d, ^3J = 12 Hz, $C_{1''}$), 131.4 (q, ^2J = 32 Hz, $C_{3''}$), 129.7 ($C_{5''}$), 124.2 (q, ^1J = 272 Hz, CF_3), 116.7 ($C_{6''}$), 115.1 (q, ^3J = 4 Hz, $C_{2''}$ or $C_{4''}$), 110.4 (q, ^3J = 4 Hz, $C_{2''}$ or $C_{4''}$), 110.0 (d, ^3J = 8 Hz, $C_{3'}$), 108.5 (d, ^4J = 2 Hz, $C_{4'}$), 63.7 (d, ^2J = 7 Hz, CH_2CH_3), 63.7 (d, ^2J = 7 Hz, CH_2CH_3), 56.9 (CH_2OH), 49.9 (d, ^1J = 161 Hz, C_1), 16.4 (d, ^3J = 6 Hz, CH_2CH_3), 16.3 (d, ^3J = 6 Hz, CH_2CH_3). ^{31}P NMR (162 MHz, $CDCl_3$) δ 19.8.
HRMS (ESI) m/z: Calcd for $[M+Na]^+$ $C_{17}H_{21}F_3NNaO_5P$ 430.1002; Found 430.0998.

Diethyl (((2-chlorophenyl)amino)(5-(hydroxymethyl)furan-2-yl)methyl)phosphonate (4i)

The title compound was obtained in 82% yield as a pale yellow sticky syrup after column chromatography (pentane: ethyl acetate = 1: 4 – 1: 8).
^{1}H NMR (300 MHz, $CDCl_3$) δ 7.24 (dd, J = 8.2, 1.5 Hz, 1H, H_{Ph}), 7.06 (td, J = 7.8, 1.5 Hz, 1H, H_{Ph}), 6.70 – 6.63 (m, 2H, H_{Ph}), 6.31 (dd, J = 3.3 Hz, 1H, $H_{3'}$), 6.20 (d, J = 3.2 Hz, 1H, $H_{4'}$), 5.11 (dd, J = 9.0, 7.1 Hz, 1H, NH), 4.89 (dd, J = 23.4, 9.0 Hz, 1H, H_1), 4.52 (s, 2H, CH_2OH), 4.23 – 3.87 (m, 4H, CH_2CH_3), 1.28 (td, J = 7.1, 0.6 Hz, 3H, CH_2CH_3), 1.22 (td, J = 7.0, 0.6 Hz, 3H, CH_2CH_3). ^{13}C NMR (75 MHz, $CDCl_3$) δ 155.2 (d, ^4J = 3 Hz, $C_{5'}$), 148.2 (d, ^2J = 3 Hz, $C_{2'}$), 142.1 (d, ^3J = 12 Hz, $C_{1''}$), 129.3 (CH_{Ph}), 127.7 (CH_{Ph}), 120.3 ($C_{2''}$), 119.0 (CH_{Ph}), 112.6 (CH_{Ph}), 109.6 (d, ^3J = 7 Hz, $C_{3'}$), 108.5 (d, ^4J = 3 Hz, $C_{4'}$), 63.9 (d, ^2J = 7 Hz, CH_2CH_3), 63.6 (d, ^2J = 7 Hz, CH_2CH_3), 57.0 (CH_2OH), 50.1 (d, ^1J = 159 Hz, C_1), 16.4 (d, ^3J = 6 Hz, CH_2CH_3), 16.3 (d, ^3J = 6 Hz, CH_2CH_3). ^{31}P NMR (122 MHz, $CDCl_3$) δ 19.4.
HRMS (ESI) m/z: Calcd for $[M+Na]^+$ $C_{16}H_{21}ClNNaO_5P$ 396.0738; Found 396.0729.

Diethyl ((benzylamino)(5-(hydroxymethyl)furan-2-yl)methyl)phosphonate (4j)

The title compound was obtained in 71% yield as a yellow sticky syrup after column chromatography (pure ethyl acetate).
^{1}H NMR (300 MHz, $CDCl_3$) δ 7.37 – 7.19 (m, 5H, H_{Ph}), 6.30 – 6.22 (m, 2H, $H_{3'}$ and $H_{4'}$), 4.63 – 4.47 (AB, 2H, CH_2OH), 4.27 – 4.10 (m, 2H, CH_2CH_3), 4.08 – 3.95 (m, J = 22.4 Hz, 2H,

$C\underline{H}_2CH_3$ and H_1), 3.93 – 3.81 (m, 2H, $C\underline{H}_2CH_3$ and $C\underline{H}_2Ph$), 3.60 (d, J = 13.3 Hz, 1H, $C\underline{H}_2Ph$), 1.32 (t, J = 7.1 Hz, 3H, $CH_2C\underline{H}_3$), 1.17 (t, J = 7.1 Hz, 3H, $CH_2C\underline{H}_3$). ^{13}C NMR (100 MHz, $CDCl_3$) δ 155.2 (d, ^4J = 3 Hz, $C_{5'}$), 148.9 (d, ^2J = 4 Hz, $C_{2'}$), 139.0 ($C_{1''}$), 128.44 ($2CH_{Ph}$), 128.39 ($2CH_{Ph}$), 127.2 ($C_{4''}$), 110.3 (d, ^3J = 8 Hz, $C_{3'}$), 108.2 (d, ^4J = 2 Hz, $C_{4'}$), 63.5 (d, ^2J = 7 Hz, $\underline{C}H_2CH_3$), 63.0 (d, ^2J = 7 Hz, $\underline{C}H_2CH_3$), 57.0 ($\underline{C}H_2OH$), 53.0 (d, ^1J = 162 Hz, C_1), 51.3 (d, ^3J = 16 Hz, $\underline{C}H_2Ph$), 16.5 (d, ^3J = 6 Hz, $CH_2\underline{C}H_3$), 16.3 (d, ^3J = 6 Hz, $CH_2\underline{C}H_3$). ^{31}P NMR (162 MHz, $CDCl_3$) δ 21.2.
HRMS (ESI) m/z: Calcd for $[M+H]^+$ $C_{17}H_{25}NO_5P$ 354.1465; Found 354.1455.

Diethyl (((furan-2-ylmethyl)amino)(5-(hydroxymethyl)furan-2-yl)methyl)phosphonate (4k)

The title compound was obtained in 70% yield as a brown syrup after column chromatography (pentane: ethyl acetate = 1: 10 to pure ethyl acetate).
^{1}H NMR (400 MHz, $CDCl_3$) δ 7.34 (dd, J = 1.9, 0.9 Hz, 1H, $H_{5''}$), 6.34 – 6.26 (m, 2H, $H_{3'}$ and $H_{4''}$), 6.25 (d, J = 3.1 Hz, 1H, $H_{4'}$), 6.16 (dd, J = 3.2, 0.9 Hz, 1H, $H_{3''}$), 4.60 – 4.50 (AB, 2H, $C\underline{H}_2OH$), 4.24 – 3.86 (m, 5H, H_1 and $2C\underline{H}_2CH_3$), 3.74 (dd, J = 84.0, 14.5 Hz, 2H, $C\underline{H}_2Fur$), 1.30 (t, J = 7.1 Hz, 3H, $CH_2C\underline{H}_3$), 1.20 (t, J = 7.1 Hz, 3H, $CH_2C\underline{H}_3$). ^{13}C NMR (100 MHz, $CDCl_3$) δ 155.1 (d, ^4J = 3 Hz, $C_{5'}$), 152.6 ($C_{2''}$), 148.5 (d, ^2J = 4 Hz, $C_{2'}$), 142.1 ($C_{5''}$), 110.4 (d, ^3J = 8 Hz, $C_{3'}$), 110.2 ($C_{4''}$), 108.3 (d, ^4J = 2 Hz, $C_{4'}$), 107.9 ($C_{3''}$), 63.5 (d, ^2J = 7 Hz, $\underline{C}H_2CH_3$), 63.1 (d, ^2J = 7 Hz, $\underline{C}H_2CH_3$), 57.1 ($\underline{C}H_2OH$), 53.1 (d, ^1J = 162 Hz, C_1), 44.0 (d, ^3J = 16 Hz, $\underline{C}H_2Fur$), 16.5 (d, ^3J = 6 Hz, $CH_2\underline{C}H_3$), 16.3 (d, ^3J = 6 Hz, $CH_2\underline{C}H_3$). ^{31}P NMR (162 MHz, $CDCl_3$) δ 20.8.
HRMS (ESI) m/z: Calcd for $[M+Na]^+$ $C_{15}H_{22}NNaO_6P$ 366.1077; Found 366.1064.

Diethyl ((butylamino)(5-(hydroxymethyl)furan-2-yl)methyl)phosphonate (4l)

The title compound was obtained in 74% yield as a yellow sticky syrup after column chromatography (pure ethyl acetate).
^{1}H NMR (400 MHz, $CDCl_3$) δ 6.28 (dd, J = 3.2 Hz, 1H, $H_{3'}$), 6.24 (d, J = 3.2 Hz, 1H, $H_{4'}$), 4.59 – 4.48 (AB, 2H, $C\underline{H}_2OH$), 4.25 – 3.86 (m, 5H, $2C\underline{H}_2CH_3$ and H_1), 2.67 – 2.45 (m, 2H, $NHC\underline{H}_2CH_2CH_2CH_3$), 1.49 – 1.26 (m, 7H, $CH_2C\underline{H}_3$ and $NHCH_2C\underline{H}_2C\underline{H}_2CH_3$), 1.21 (t, J = 7.1 Hz, 3H, $CH_2C\underline{H}_3$), 0.87 (t, J = 7.2 Hz, 3H, $NHCH_2CH_2CH_2C\underline{H}_3$). ^{13}C NMR (100 MHz, $CDCl_3$) δ 154.9 (d, ^4J = 3 Hz, $C_{5'}$), 149.4 (d, ^2J = 3 Hz, $C_{2'}$), 109.7 (d, ^3J = 8 Hz, $C_{3'}$), 108.2 (d, ^4J = 2 Hz, $C_{4'}$), 63.4 (d, ^2J = 7 Hz, $\underline{C}H_2CH_3$), 63.0 (d, ^2J = 7 Hz, $\underline{C}H_2CH_3$), 57.0 ($\underline{C}H_2OH$), 54.7 (d, ^1J = 161 Hz, C_1), 47.9 (d, ^3J = 15 Hz, $NH\underline{C}H_2CH_2CH_2CH_3$), 31.8 ($NHCH_2\underline{C}H_2CH_2CH_3$), 20.2 ($NHCH_2CH_2\underline{C}H_2CH_3$), 16.5 (d, ^3J = 6 Hz, $CH_2\underline{C}H_3$), 16.3 (d, ^3J = 6 Hz, $CH_2\underline{C}H_3$), 13.9 ($NHCH_2CH_2CH_2\underline{C}H_3$). ^{31}P NMR (162 MHz, $CDCl_3$) δ 21.3.
HRMS (ESI) m/z: Calcd for $[M+Na]^+$ $C_{14}H_{26}NNaO_5P$ 342.1441; Found 342.1442.

Diethyl ((cyclohexylamino)(5-(hydroxymethyl)furan-2-yl)methyl)phosphonate (4m)

The title compound was obtained in 63% yield as a pale yellow sticky syrup after column chromatography (pure ethyl acetate).
^{1}H NMR (400 MHz, $CDCl_3$) δ 6.27 – 6.22 (m, 2H, $H_{3'}$ and $H_{4'}$), 4.59 – 4.49 (AB, 2H, $C\underline{H}_2OH$), 4.28 – 4.12 (m, J = 23.3 Hz, 3H, $C\underline{H}_2CH_3$ and H_1), 4.08 – 3.97 (m, 1H, $C\underline{H}_2CH_3$), 3.95 – 3.83 (m, 1H, $C\underline{H}_2CH_3$), 2.48 – 2.38 (m, 1H, $H_{1''}$), 1.92 – 1.50 (m, 5H, H_{Cy}), 1.33 (t, J = 7.1 Hz, 3H,

$CH_2C\underline{H}_3$), 1.23 – 0.99 (m, 8H, $CH_2C\underline{H}_3$ and H_{Cy}). ^{13}C NMR (100 MHz, $CDCl_3$) δ 154.8 (d, ^4J = 3 Hz, $C_{5'}$), 150.0 (d, ^2J = 3 Hz, $C_{2'}$), 109.3 (d, ^3J = 8 Hz, $C_{3'}$), 108.2 (d, ^4J = 2 Hz, $C_{4'}$), 63.6 (d, ^2J = 7 Hz, $\underline{C}H_2CH_3$), 62.9 (d, ^2J = 7 Hz, $\underline{C}H_2CH_3$), 57.1 ($\underline{C}H_2OH$), 54.2 (d, ^3J = 15 Hz, $C_{1''}$), 51.6 (d, ^1J = 162 Hz, C_1), 34.0 (C_{Cy}), 32.2 (C_{Cy}), 26.0 (C_{Cy}), 24.8 (C_{Cy}), 24.4 (C_{Cy}), 16.5 (d, ^3J = 6 Hz, $CH_2\underline{C}H_3$), 16.3 (d, ^3J = 6 Hz, $CH_2\underline{C}H_3$). ^{31}P NMR (162 MHz, $CDCl_3$) δ 21.6.
HRMS (ESI) m/z: Calcd for $[M+H]^+$ $C_{16}H_{29}NO_5P$ 346.1778; Found 346.1767.

Diethyl ((allylamino)(5-(hydroxymethyl)furan-2-yl)methyl)phosphonate (4n)
The title compound was obtained in 53% yield as a yellow sticky syrup after column chromatography (pure ethyl acetate).
^1H NMR (400 MHz, $CDCl_3$) δ 6.28 (dd, J = 3.1 Hz, 1H, $H_{3'}$), 6.24 (d, J = 3.3 Hz, 1H, $H_{4'}$), 5.86 – 5.75 (m, 1H, $NHCH_2C\underline{H}=CH_2$), 5.19 – 5.08 (m, 2H, $NHCH_2CH=C\underline{H}_2$), 4.60 – 4.50 (AB, 2H, $C\underline{H}_2OH$), 4.26 – 3.87 (m, 5H, $C\underline{H}_2CH_3$ and H_1), 3.35 – 3.05 (m, 2H, $NHC\underline{H}_2CH=CH_2$), 1.33 (t, J = 7.1 Hz, 3H, $CH_2C\underline{H}_3$), 1.21 (t, J = 7.1 Hz, 3H, $CH_2C\underline{H}_3$). ^{13}C NMR (100 MHz, $CDCl_3$) δ 155.0 (d, ^4J = 3 Hz, $C_{5'}$), 149.0 (d, ^2J = 3 Hz, $C_{2'}$), 135.7 ($NHCH_2\underline{C}H=CH_2$), 117.2 ($NHCH_2CH=\underline{C}H_2$), 110.1 (d, ^3J = 8 Hz, $C_{3'}$), 108.2 (d, ^4J = 2 Hz, $C_{4'}$), 63.4 (d, ^2J = 7 Hz, $\underline{C}H_2CH_3$), 63.1 (d, ^2J = 7 Hz, $\underline{C}H_2CH_3$), 57.1 ($\underline{C}H_2OH$), 53.2 (d, ^1J = 162 Hz, C_1), 50.1 (d, ^3J = 16 Hz, $NH\underline{C}H_2CH=CH_2$), 16.5 (d, ^3J = 6 Hz, $CH_2\underline{C}H_3$), 16.4 (d, ^3J = 6 Hz, $CH_2\underline{C}H_3$). ^{31}P NMR (162 MHz, $CDCl_3$) δ 21.3.
HRMS (ESI) m/z: Calcd for $[M+Na]^+$ $C_{13}H_{22}NNaO_5P$ 326.1128; Found 326.1126.

Diethyl (((2-(1H-indol-3-yl)ethyl)amino)(5-(hydroxymethyl)furan-2-yl)methyl)phosphonate (4o)
The title compound was obtained in 57% yield as a yellow sticky syrup after column chromatography (ethyl acetate: methanol = 100: 1 to 50: 1).
^1H NMR (400 MHz, $CDCl_3$) δ 9.14 (d, J = 2.4 Hz, 1H, $H_{1''}$), 7.47 (dd, J = 7.9, 1.0 Hz, 1H, $H_{4''}$), 7.31 – 7.27 (m, 1H, $H_{7''}$), 7.11 (ddd, J = 8.1, 7.0, 1.2 Hz, 1H, $H_{6''}$), 7.02 (ddd, J = 8.0, 7.0, 1.1 Hz, 1H, $H_{5''}$), 6.85 (d, J = 2.4 Hz, 1H, $H_{2''}$), 6.18 (dd, J = 3.1 Hz, 1H, $H_{3'}$), 6.14 (d, J = 3.2 Hz, 1H, $H_{4'}$), 4.33 (s, 2H, $C\underline{H}_2OH$), 4.12 – 4.04 (m, 3H, $C\underline{H}_2CH_3$ and H_1), 3.99 – 3.91 (m, 1H, $C\underline{H}_2CH_3$), 3.85 – 3.74 (m, 1H, $C\underline{H}_2CH_3$), 2.98 – 2.81 (m, 4H, $C\underline{H}_2C\underline{H}_2$), 1.22 (t, J = 7.0 Hz, 3H, $CH_2C\underline{H}_3$), 1.11 (t, J = 7.1 Hz, 3H, $CH_2C\underline{H}_3$). ^{13}C NMR (100 MHz, $CDCl_3$) δ 155.0 (d, ^4J = 3 Hz, $C_{5'}$), 148.6 (d, ^2J = 4 Hz, $C_{2'}$), 136.5 ($C_{7''a}$), 127.3 ($C_{3''a}$), 122.6 ($C_{2''}$), 121.5 ($C_{6''}$), 118.7 ($C_{5''}$), 118.5 ($C_{4''}$), 112.4 ($C_{3''}$), 111.4 ($C_{7''}$), 110.2 (d, ^3J = 8 Hz, $C_{3'}$), 108.1 (d, ^4J = 2 Hz, $C_{4'}$), 63.5 (d, ^2J = 7 Hz, $\underline{C}H_2CH_3$), 63.2 (d, ^2J = 7 Hz, $\underline{C}H_2CH_3$), 56.6 ($\underline{C}H_2OH$), 54.5 (d, ^1J = 161 Hz, C_1), 47.9 (d, ^3J = 15 Hz, $NH\underline{C}H_2CH_2$), 25.3 ($NHCH_2\underline{C}H_2$), 16.3 (d, ^3J = 6 Hz, $CH_2\underline{C}H_3$), 16.2 (d, ^3J = 6 Hz, $CH_2\underline{C}H_3$). ^{31}P NMR (162 MHz, $CDCl_3$) δ 21.3.
HRMS (ESI) m/z: Calcd for $[M+H]^+$ $C_{20}H_{28}N_2O_5P$ 407.1730; Found 407.1716.

***tert*-Butyl ((diethoxyphosphoryl)(5-(hydroxymethyl)furan-2-yl)methyl)glycinate (4p)**
The title compound was obtained in 31% yield as a yellow syrup after column chromatography (pure ethyl acetate).
^1H NMR (400 MHz, $CDCl_3$) δ 6.33 (dd, J = 3.2 Hz, 1H, $H_{3'}$), 6.25 (d, J = 3.2 Hz, 1H, $H_{4'}$), 4.55 (AB, 2H, $C\underline{H}_2OH$), 4.24 (d, J = 20.3 Hz, 1H, H_1), 4.22 – 3.96 (m, 4H, $C\underline{H}_2CH_3$), 3.39 – 3.18 (m, 2H, $C\underline{H}_2COO$), 1.43 (s, 9H, $C(C\underline{H}_3)_3$), 1.33 (t, J = 7.1 Hz, 3H, $CH_2C\underline{H}_3$), 1.26 (t, J = 7.1

Hz, 3H, $CH_2C\underline{H}_3$). ^{13}C NMR (100 MHz, $CDCl_3$) δ 170.8 ($\underline{C}OO$), 155.2 (d, ^4J = 3 Hz, $C_{5'}$), 148.3 (d, ^2J = 5 Hz, $C_{2'}$), 110.7 (d, ^3J = 8 Hz, $C_{3'}$), 108.5 (d, ^4J = 3 Hz, $C_{4'}$), 81.5 ($\underline{C}(CH_3)_3$), 63.4 (d, ^2J = 7 Hz, $\underline{C}H_2CH_3$), 63.2 (d, ^2J = 7 Hz, $\underline{C}H_2CH_3$), 57.2 ($\underline{C}H_2OH$), 53.9 (d, ^1J = 161 Hz, C_1), 49.4 (d, ^3J = 15 Hz, $\underline{C}H_2COO$), 28.2 ($C(\underline{C}H_3)_3$), 16.5 (d, ^3J = 6 Hz, $CH_2\underline{C}H_3$), 16.4 (d, ^3J = 6 Hz, $CH_2\underline{C}H_3$). ^{31}P NMR (162 MHz, $CDCl_3$) δ 20.6.
HRMS (ESI) m/z: Calcd for $[M+H]^+$ $C_{16}H_{29}NO_7P$ 378.1676; Found 378.1660.

Diethyl ((5-(hydroxymethyl)furan-2-yl)(methyl(phenyl)amino)methyl)phosphonate (4q)
The title compound was obtained in 58% yield as a yellow sticky syrup after column chromatography (pentane: ethyl acetate = 1: 4 to 1: 6).
^1H NMR (400 MHz, $CDCl_3$) δ 7.27 – 7.21 (m, 2H, $H_{3''}$), 6.92 – 6.87 (m, 2H, $H_{2''}$), 6.82 – 6.77 (m, 1H, $H_{4''}$), 6.48 (dd, J = 3.4, 1.4 Hz, 1H, $H_{3'}$), 6.21 (d, J = 3.2 Hz, 1H, $H_{4'}$), 5.27 (d, J = 24.5 Hz, 1H, H_1), 4.49 (s, 2H, $C\underline{H}_2OH$), 4.21 – 3.95 (m, 4H, $C\underline{H}_2CH_3$), 2.92 (d, J = 1.3 Hz, 3H, $NC\underline{H}_3$), 1.20 (2t, J = 7.1 Hz, 6H, $2CH_2C\underline{H}_3$). ^{13}C NMR (100 MHz, $CDCl_3$) δ 155.1 (d, ^4J = 1 Hz, $C_{5'}$), 145.0 (d, ^3J = 6 Hz, $C_{1''}$), 147.4 (d, ^2J = 13 Hz, $C_{2'}$), 129.2 ($2C_{3''}$), 118.5 ($C_{4''}$), 114.3 ($2C_{2''}$), 111.6 (d, ^3J = 4 Hz, $C_{3'}$), 108.2 ($C_{4'}$), 63.4 (d, ^2J = 7 Hz, $\underline{C}H_2CH_3$), 62.8 (d, ^2J = 7 Hz, $\underline{C}H_2CH_3$), 57.1 ($\underline{C}H_2OH$), 56.3 (d, ^1J = 165 Hz, C_1), 34.5 ($N\underline{C}H_3$), 16.5 (d, ^3J = 6 Hz, $CH_2\underline{C}H_3$), 16.4 (d, ^3J = 6 Hz, $CH_2\underline{C}H_3$). ^{31}P NMR (162 MHz, $CDCl_3$) δ 19.8.
HRMS (ESI) m/z: Calcd for $[M+H]^+$ $C_{17}H_{25}NO_5P$ 354.1465; Found 354.1453.

Diethyl ((5-(hydroxymethyl)furan-2-yl)(((*R*)-1-phenylethyl)amino)methyl)phosphonate (4r)
The title compound was obtained in 72% yield in total after column chromatography (pentane: ethyl acetate = 1: 10 to pure ethyl acetate).
Diastereoisomer A: Major product, pale yellow sticky syrup. ^1H NMR (400 MHz, $CDCl_3$) δ 7.29 – 7.18 (m, 5H, H_{Ph}), 6.18 – 6.14 (m, 2H, $H_{3'}$ and $H_{4'}$), 4.54 – 4.43 (AB, 2H, $C\underline{H}_2OH$), 4.31 – 4.15 (m, 2H, $C\underline{H}_2CH_3$), 4.12 (d, J = 21.6 Hz, 1H, H_1), 4.08 – 3.97 (m, 1H, $C\underline{H}_2CH_3$), 3.94 – 3.81 (m, 2H, $C\underline{H}_2CH_3$ and $PhC\underline{H}CH_3$), 1.35 (t, J = 7.0 Hz, 3H, $CH_2C\underline{H}_3$), 1.33 (t, J = 6.7 Hz, 3H, $PhCHC\underline{H}_3$) 1.19 (t, J = 7.0 Hz, 3H, $CH_2C\underline{H}_3$). ^{13}C NMR (100 MHz, $CDCl_3$) δ 154.7 (d, ^4J = 3 Hz, $C_{5'}$), 149.6 (d, ^2J = 2 Hz, $C_{2'}$), 145.0 ($C_{1''}$), 128.4 ($2CH_{Ph}$), 127.2 ($C_{4''}$), 126.8 ($2CH_{Ph}$), 109.4 (d, ^3J = 8 Hz, $C_{3'}$), 108.2 (d, ^4J = 2 Hz, $C_{4'}$), 63.4 (d, ^2J = 7 Hz, $\underline{C}H_2CH_3$), 63.0 (d, ^2J = 7 Hz, $\underline{C}H_2CH_3$), 57.0 ($\underline{C}H_2OH$), 56.0 (d, ^3J = 12 Hz, $Ph\underline{C}HCH_3$), 52.2 (d, ^1J = 159 Hz, C_1), 22.8 ($PhCH\underline{C}H_3$), 16.6 (d, ^3J = 6 Hz, $CH_2\underline{C}H_3$), 16.4 (d, ^3J = 6 Hz, $CH_2\underline{C}H_3$). ^{31}P NMR (162 MHz, $CDCl_3$) δ 21.8.
HRMS (ESI) m/z: Calcd for $[M+H]^+$ $C_{18}H_{27}NO_5P$ 368.1621; Found 368.1604.
Diastereoisomer B: Minor product, pale yellow sticky syrup. ^1H NMR (400 MHz, $CDCl_3$) δ 7.35 – 7.23 (m, 5H, H_{Ph}), 6.25 (d, J = 2.9 Hz, 1H, $H_{4'}$), 6.16 (dd, J = 3.2 Hz, 1H, $H_{3'}$), 4.63 – 4.52 (AB, 2H, $C\underline{H}_2OH$), 4.29 – 4.11 (m, 2H, $C\underline{H}_2CH_3$), 4.03 – 3.92 (m, 1H, $C\underline{H}_2CH_3$), 3.86 – 3.75 (m, J = 24.1 Hz, 2H, $C\underline{H}_2CH_3$ and H_1), 3.72 – 3.65 (m, 1H, $PhC\underline{H}CH_3$), 1.35 (td, J = 7.0, 0.6 Hz, 3H, $CH_2C\underline{H}_3$), 1.33 (t, J = 6.5 Hz, 3H, $PhCHC\underline{H}_3$) 1.14 (td, J = 7.1, 0.6 Hz, 3H, $CH_2C\underline{H}_3$). ^{13}C NMR (100 MHz, $CDCl_3$) δ 154.9 (d, ^4J = 3 Hz, $C_{5'}$), 149.6 (d, ^2J = 3 Hz, $C_{2'}$), 144.1 ($C_{1''}$), 128.6 ($2CH_{Ph}$), 127.4 ($C_{4''}$), 127.3 ($2CH_{Ph}$), 110.3 (d, ^3J = 9 Hz, $C_{3'}$), 108.4 (d, ^4J = 2 Hz, $C_{4'}$), 63.5 (d, ^2J = 7 Hz, $\underline{C}H_2CH_3$), 62.9 (d, ^2J = 7 Hz, $\underline{C}H_2CH_3$), 57.4 ($\underline{C}H_2OH$), 55.7 (d, ^3J = 17 Hz, $Ph\underline{C}HCH_3$), 51.9 (d, ^1J = 163 Hz, C_1), 25.1 ($PhCH\underline{C}H_3$), 16.6 (d, ^3J = 6 Hz,

$CH_2\underline{C}H_3$), 16.4 (d, ^3J = 6 Hz, $CH_2\underline{C}H_3$). ^{31}P NMR (162 MHz, $CDCl_3$) δ 21.3.
HRMS (ESI) m/z: Calcd for $[M+H]^+$ $C_{18}H_{27}NO_5P$ 368.1621; Found 368.1610.

Diethyl ((5-(hydroxymethyl)furan-2-yl)(((*S*)-1-phenylethyl)amino)methyl)phosphonate (4s)

The title compound was obtained in 70% yield in total after column chromatography (pentane: ethyl acetate = 1: 10 to pure ethyl acetate).

Diastereoisomer A: Major product, pale yellow sticky syrup. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.30 – 7.18 (m, 5H, H_{Ph}), 6.19 – 6.15 (m, 2H, $H_{3'}$ and $H_{4'}$), 4.54 – 4.44 (AB, 2H, $C\underline{H}_2OH$), 4.31 – 4.16 (m, 2H, $C\underline{H}_2CH_3$), 4.12 (d, J = 21.7 Hz, 1H, H_1), 4.08 – 3.98 (m, 1H, $C\underline{H}_2CH_3$), 3.94 – 3.82 (m, 2H, $C\underline{H}_2CH_3$ and $PHC\underline{H}CH_3$), 1.35 (t, J = 7.1 Hz, 3H, $CH_2C\underline{H}_3$), 1.33 (t, J = 6.5 Hz, 3H, $PhCHC\underline{H}_3$) 1.19 (t, J = 7.0 Hz, 3H, $CH_2C\underline{H}_3$). ^{13}C NMR (100 MHz, $CDCl_3$) δ 154.6 (d, ^4J = 3 Hz, $C_{5'}$), 149.7 (d, ^2J = 2 Hz, $C_{2'}$), 145.0 ($C_{1''}$), 128.5 ($2CH_{Ph}$), 127.2 ($C_{4''}$), 126.8 ($2CH_{Ph}$), 109.5 (d, ^3J = 8 Hz, $C_{3'}$), 108.4 (d, ^4J = 2 Hz, $C_{4'}$), 63.5 (d, ^2J = 7 Hz, $\underline{C}H_2CH_3$), 63.1 (d, ^2J = 7 Hz, $\underline{C}H_2CH_3$), 57.2 ($\underline{C}H_2OH$), 56.1 (d, ^3J = 12 Hz, $Ph\underline{C}HCH_3$), 52.3 (d, ^1J = 159 Hz, C_1), 22.9 ($PhCH\underline{C}H_3$), 16.6 (d, ^3J = 6 Hz, $CH_2\underline{C}H_3$), 16.4 (d, ^3J = 6 Hz, $CH_2\underline{C}H_3$). ^{31}P NMR (162 MHz, $CDCl_3$) δ 21.8.
HRMS (ESI) m/z: Calcd for $[M+H]^+$ $C_{18}H_{27}NO_5P$ 368.1621; Found 368.1612.

Diastereoisomer B: Minor product, pale yellow sticky syrup. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.36 – 7.23 (m, 5H, H_{Ph}), 6.26 (d, J = 3.0 Hz, 1H, $H_{4'}$), 6.16 (dd, J = 3.2 Hz, 1H, $H_{3'}$), 4.64 – 4.52 (AB, 2H, $C\underline{H}_2OH$), 4.29 – 4.12 (m, 2H, $C\underline{H}_2CH_3$), 4.02 – 3.92 (m, 1H, $C\underline{H}_2CH_3$), 3.85 – 3.74 (m, J = 24.1 Hz, 2H, $C\underline{H}_2CH_3$ and H_1), 3.72 – 3.65 (m, 1H, $PhC\underline{H}CH_3$), 1.35 (td, J = 7.1, 0.6 Hz, 3H, $CH_2C\underline{H}_3$), 1.33 (t, J = 6.4 Hz, 3H, $PhCHC\underline{H}_3$) 1.14 (td, J = 7.1, 0.6 Hz, 3H, $CH_2C\underline{H}_3$). ^{13}C NMR (100 MHz, $CDCl_3$) δ 154.9 (d, ^4J = 3 Hz, $C_{5'}$), 149.5 (d, ^2J = 4 Hz, $C_{2'}$), 144.0 ($C_{1''}$), 128.6 ($2CH_{Ph}$), 127.4 ($C_{4''}$), 127.3 ($2CH_{Ph}$), 110.4 (d, ^3J = 9 Hz, $C_{3'}$), 108.4 (d, ^4J = 2 Hz, $C_{4'}$), 63.5 (d, ^2J = 7 Hz, $\underline{C}H_2CH_3$), 62.9 (d, ^2J = 7 Hz, $\underline{C}H_2CH_3$), 57.3 ($\underline{C}H_2OH$), 55.7 (d, ^3J = 17 Hz, $Ph\underline{C}HCH_3$), 51.9 (d, ^1J = 163 Hz, C_1), 25.1 ($PhCH\underline{C}H_3$), 16.6 (d, ^3J = 6 Hz, $CH_2\underline{C}H_3$), 16.4 (d, ^3J = 6 Hz, $CH_2\underline{C}H_3$). ^{31}P NMR (162 MHz, $CDCl_3$) δ 21.3.
HRMS (ESI) m/z: Calcd for $[M+H]^+$ $C_{18}H_{27}NO_5P$ 368.1621; Found 368.1611.

Dimethyl ((5-(hydroxymethyl)furan-2-yl)(phenylamino)methyl)phosphonate (4t)

The title compound was obtained in 89% yield as a pale yellow sticky syrup after column chromatography (pentane: ethyl acetate = 1: 4 to 1: 8).
^{1}H NMR (400 MHz, $CDCl_3$) δ 7.17 – 7.08 (m, 2H, $H_{3''}$), 6.78 – 6.69 (m, 1H, $H_{4''}$), 6.71 – 6.63 (m, 2H, $H_{2''}$), 6.30 (dd, J = 3.2 Hz, 1H, $H_{3'}$), 6.18 (d, J = 3.2 Hz, 1H, $H_{4'}$), 4.90 (d, J = 23.6 Hz, 1H, H_1), 4.49 (s, 2H, $C\underline{H}_2OH$), 3.75 (d, J = 10.6 Hz, 3H, $C\underline{H}_3$), 3.58 (d, J = 10.7 Hz, 3H, $C\underline{H}_3$). ^{13}C NMR (100 MHz, $CDCl_3$) δ 155.1 (d, ^4J = 3 Hz, $C_{5'}$), 148.2 (d, ^2J = 2 Hz, $C_{2'}$), 145.8 (d, ^3J = 12 Hz, $C_{1''}$), 129.2 ($2C_{3''}$), 119.0 ($C_{4''}$), 114.0 ($2C_{2''}$), 109.8 (d, ^3J = 8 Hz, $C_{3'}$), 108.5 (d, ^4J = 2 Hz, $C_{4'}$), 56.8 ($\underline{C}H_2OH$), 54.1 (d, ^2J = 7 Hz, $\underline{C}H_3$), 53.8 (d, ^2J = 7 Hz, $\underline{C}H_3$), 49.8 (d, ^1J = 161 Hz, C_1). ^{31}P NMR (162 MHz, $CDCl_3$) δ 22.8.
HRMS (ESI) m/z: Calcd for $[M+Na]^+$ $C_{14}H_{18}NNaO_5P$ 334.0815; Found 334.0808.

Diisopropyl ((5-(hydroxymethyl)furan-2-yl)(phenylamino)methyl)phosphonate (4u)

The title compound was obtained in 87% yield as a pale yellow sticky syrup after column

chromatography (pentane: ethyl acetate = 1: 4 to 1: 8).
^{1}H NMR (400 MHz, $CDCl_3$) δ 7.15 – 7.09 (m, 2H, $H_{3''}$), 6.74 – 6.68 (m, 1H, $H_{4''}$), 6.68 – 6.63 (m, 2H, $H_{2''}$), 6.28 (dd, J = 3.2 Hz, 1H, $H_{3'}$), 6.18 (d, J = 3.1 Hz, 1H, $H_{4'}$), 4.86 – 4.69 (m, 2H, H_1 and C<u>H</u>$(CH_3)_2$), 4.61 – 4.52 (m, 2H, C<u>H</u>$(CH_3)_2$ and N<u>H</u>), 4.50 (s, 2H, C<u>H</u>$_2$OH), 1.31 (d, J = 6.2 Hz, 3H, C<u>H</u>$_3$), 1.28 (d, J = 6.2 Hz, 3H, C<u>H</u>$_3$), 1.22 (d, J = 6.2 Hz, 3H, C<u>H</u>$_3$), 1.07 (d, J = 6.2 Hz, 3H, C<u>H</u>$_3$). ^{13}C NMR (100 MHz, $CDCl_3$) δ 154.8 (d, ^4J = 3 Hz, $C_{5'}$), 149.1 (d, ^2J = 2 Hz, $C_{2'}$), 146.3 (d, ^3J = 13 Hz, $C_{1''}$), 129.2 ($2C_{3''}$), 118.7 ($C_{4''}$), 114.0 ($2C_{2''}$), 109.4 (d, ^3J = 7 Hz, $C_{3'}$), 108.3 (d, ^4J = 2 Hz, $C_{4'}$), 72.45 (d, ^2J = 7 Hz, <u>C</u>H$(CH_3)_2$), 72.38 (d, ^2J = 7 Hz, <u>C</u>H$(CH_3)_2$), 57.1 (<u>C</u>H$_2$OH), 50.7 (d, ^1J = 161 Hz, C_1), 24.3 (d, ^3J = 3 Hz, <u>C</u>H$_3$), 24.2 (d, ^3J = 3 Hz, <u>C</u>H$_3$), 23.7 (d, ^3J = 5 Hz, <u>C</u>H$_3$), 23.5 (d, ^3J = 5 Hz, <u>C</u>H$_3$). ^{31}P NMR (162 MHz, $CDCl_3$) δ 18.2.
HRMS (ESI) m/z: Calcd for $[M+H]^+$ $C_{18}H_{27}NO_5P$ 368.1621; Found 368.1612.

Dibenzyl ((5-(hydroxymethyl)furan-2-yl)(phenylamino)methyl)phosphonate (4v)
The title compound was obtained in 86% yield as a pale yellow sticky syrup after column chromatography (pentane: ethyl acetate = 2: 3).
^{1}H NMR (400 MHz, $CDCl_3$) δ 7.31 – 7.15 (m, 10H, H_{Ph}), 7.12 – 7.05 (m, 2H, $H_{3''}$), 6.74 – 6.67 (m, 1H, $H_{4''}$), 6.63 – 6.57 (m, 2H, $H_{2''}$), 6.25 (dd, J = 3.2 Hz, 1H, $H_{3'}$), 6.14 (d, J = 3.1 Hz, 1H, $H_{4'}$), 5.08 – 4.98 (m, 2H, C<u>H</u>$_2$Ph), 4.97 – 4.87 (m, 2H, C<u>H</u>$_2$Ph and H_1), 4.84 – 4.76 (m, 1H C<u>H</u>$_2$Ph), 4.44 (s, 2H, C<u>H</u>$_2$OH). ^{13}C NMR (100 MHz, $CDCl_3$) δ 155.0 (d, ^4J = 3 Hz, $C_{5'}$), 148.4 (d, ^2J = 2 Hz, $C_{2'}$), 145.9 (d, ^3J = 12 Hz, $C_{1''}$), 135.9 (d, ^3J = 6 Hz, C_{Ph}), 135.8 (d, ^3J = 6 Hz, C_{Ph}), 129.2 ($2C_{3''}$), 128.54 ($2CH_{Ph}$), 128.52 ($2CH_{Ph}$), 128.48 (CH_{Ph}), 128.43 (CH_{Ph}), 128.1 ($2CH_{Ph}$), 127.9 ($2CH_{Ph}$), 119.0 ($C_{4''}$), 114.0 ($2C_{2''}$), 109.8 (d, ^3J = 8 Hz, $C_{3'}$), 108.5 (d, ^4J = 3 Hz, $C_{4'}$), 68.9 (d, ^2J = 7 Hz, <u>C</u>H$_2$Ph), 68.6 (d, ^2J = 7 Hz, <u>C</u>H$_2$Ph), 57.0 (<u>C</u>H$_2$OH), 50.5 (d, ^1J = 160 Hz, C_1). ^{31}P NMR (162 MHz, $CDCl_3$) δ 20.9.
HRMS (ESI) m/z: Calcd for $[M+H]^+$ $C_{26}H_{27}NO_5P$ 464.1621; Found 464.1617.

Bis(2,2,2-trifluoroethyl) ((5-(hydroxymethyl)furan-2-yl)(phenylamino)methyl)phosphonate (4w)
The title compound was obtained in 54% yield as a pale yellow sticky syrup after column chromatography (pentane: ethyl acetate = 2: 1 to 3:2).
^{1}H NMR (400 MHz, $CDCl_3$) δ 7.21 – 7.14 (m, 2H, $H_{3''}$), 6.84 – 6.78 (m, 1H, $H_{4''}$), 6.75 – 6.69 (m, 2H, $H_{2''}$), 6.35 (dd, J = 3.4 Hz, 1H, $H_{3'}$), 6.21 (d, J = 3.1 Hz, 1H, $H_{4'}$), 5.09 (d, J = 23.0 Hz, 1H, H_1), 4.49 (s, 2H, C<u>H</u>$_2$OH), 4.48 – 4.09 (m, 4H, C<u>H</u>$_2$$CF_3$). ^{13}C NMR (100 MHz, $CDCl_3$) δ 155.5 (d, ^4J = 3 Hz, $C_{5'}$), 146.7 ($C_{2'}$), 145.3 (d, ^3J = 12 Hz, $C_{1''}$), 129.5 ($2C_{3''}$), 127.4 – 117.5 ($2CF_3$), 120.0 ($C_{4''}$), 114.5 ($2C_{2''}$), 110.7 (d, ^3J = 9 Hz, $C_{3'}$), 108.8 (d, ^4J = 2 Hz, $C_{4'}$), 63.2 and 63.0 (qd, J = 38, 6 Hz, 2<u>C</u>H$_2$$CF_3$), 56.9 (<u>C</u>H$_2$OH), 50.7 (d, ^1J = 166 Hz, C_1). ^{31}P NMR (122 MHz, $CDCl_3$) δ 22.5.
HRMS (ESI) m/z: Calcd for $[M+Na]^+$ $C_{16}H_{16}F_6NNaO_5P$ 470.0562; Found 470.0542.

Diethyl ((5-(hydroxymethyl)furan-2-yl)(phenylamino)methyl)phosphonate dimer (4x)
The title compound was obtained in 86% yield as a pale yellow sticky syrup after column chromatography (pentane: ethyl acetate = 1: 5 to 1: 10).
^{1}H NMR (400 MHz, $CDCl_3$) δ 7.13 (t, J = 7.8 Hz, 4H, $H_{3''}$), 6.72 (t, J = 7.3 Hz, 2H, $H_{4''}$), 6.67 (d, J = 8.1 Hz, 4H, $H_{2''}$), 6.34 (t, J = 3.3 Hz, 2H, $H_{3'}$), 6.23 (d, J = 3.3 Hz, 2H, $H_{4'}$), 4.89 (dd, J

= 24.0, 7.7 Hz, 2H, H_1), 4.65 (q, *J* = 7.7 Hz, 2H, NH), 4.40 – 4.32 (m, 4H, $C\underline{H}_2OC\underline{H}_2$), 4.23 – 4.12 (m, 4H, $C\underline{H}_2CH_3$), 4.10 – 4.01 (m, 2H, $C\underline{H}_2CH_3$), 3.96 – 3.84 (m, 2H, $C\underline{H}_2CH_3$), 1.28 (t, *J* = 7.1 Hz, 6H, $CH_2C\underline{H}_3$), 1.19 (t, *J* = 7.1 Hz, 6H, $CH_2C\underline{H}_3$). ^{13}C NMR (100 MHz, $CDCl_3$) δ 151.2 (dd, *J* = 3, 2 Hz, $2C_{5'}$), 149.8 ($2C_{2'}$), 146.0 (dd, *J* = 13, 2 Hz, $2C_{1''}$), 129.1 ($4C_{3''}$), 118.8 (*J* = 2 Hz, $2C_{4''}$), 113.8 ($4C_{2''}$), 110.9 (d, ^4J = 3 Hz, $2C_{4'}$), 109.4 (dd, *J* = 7, 2 Hz, $2C_{3'}$), 63.5 (d, ^2J = 7 Hz, $2\underline{C}H_2CH_3$), 63.3 (d, ^2J = 7 Hz, $2\underline{C}H_2CH_3$), 63.1 and 63.0 ($\underline{C}H_2O\underline{C}H_2$), 50.1 (d, ^1J = 159 Hz, $2C_1$), 16.4 (d, ^3J = 6 Hz, $2CH_2\underline{C}H_3$), 16.2 (d, ^3J = 6 Hz, $2CH_2\underline{C}H_3$). ^{31}P NMR (162 MHz, $CDCl_3$) δ 20.0.
HRMS (ESI) m/z: Calcd for $[M+Na]^+$ $C_{32}H_{42}N_2NaO_9P_2$ 683.2258; Found 683.2223.

Diethyl (((4-(((diethoxyphosphoryl)(5-(hydroxymethyl)furan-2-yl)methyl)amino)phenyl)amino)(5-(hydroxymethyl)furan-2-yl)methyl)phosphonate (4y)
The title compound was obtained in 72% yield as a brown sticky syrup after column chromatography (ethyl acetate: methanol = 40:1 to 20:1).
^{1}H NMR (400 MHz, $CDCl_3$) δ 6.52 (s, 4H, H_{Ph}), 6.23 (t, *J* = 3.2 Hz, 2H, $H_{3'}$), 6.14 (d, *J* = 3.2 Hz, 2H, $H_{4'}$), 4.71 (d, *J* = 23.6 Hz, 2H, H_1), 4.47 (s, 4H, $C\underline{H}_2OH$), 4.19 – 4.06 (m, 4H, $C\underline{H}_2CH_3$), 4.06 – 3.94 (m, 2H, $C\underline{H}_2CH_3$), 3.89 – 3.78 (m, 2H, $C\underline{H}_2CH_3$), 1.24 (t, *J* = 7.0 Hz, 6H, $CH_2C\underline{H}_3$), 1.16 (t, *J* = 7.1 Hz, 6H, $CH_2C\underline{H}_3$). ^{13}C NMR (100 MHz, $CDCl_3$) δ 154.7 (d, ^4J = 3 Hz, $2C_{5'}$), 148.8 (d, ^2J = 3 Hz, $2C_{2'}$), 139.2 (dd, *J* = 14, 4 Hz, $2C_{1''}$), 115.9 (d, *J* = 5 Hz, $4C_{2''}$), 109.7 (d, ^3J = 8 Hz, $2C_{3'}$), 108.4 (d, ^4J = 2 Hz, $2C_{4'}$), 63.8 (d, ^2J = 7 Hz, $2\underline{C}H_2CH_3$), 63.5 (d, ^2J = 7 Hz, $2\underline{C}H_2CH_3$), 56.8 ($2\underline{C}H_2OH$), 51.3 (dd, ^1J = 160, 8 Hz, $2C_1$), 16.4 (d, ^3J = 6 Hz, $2CH_2\underline{C}H_3$), 16.3 (d, ^3J = 6 Hz, $2CH_2\underline{C}H_3$). ^{31}P NMR (162 MHz, $CDCl_3$) δ 20.5.
HRMS (ESI) m/z: Calcd for $[M+Na]^+$ $C_{26}H_{38}N_2NaO_{10}P_2$ 623.1894; Found 623.1868.

Dimethyl ((5-formylfuran-2-yl)(phenylamino)methyl)phosphonate (4aa)
To the solution of K-F product **4t** (0.353 mmol, 110 mg) in DCM (3 mL), Dess–Martin periodinane (1.1 equiv., 0.388 mmol) was added. The suspension was stirred at room temperature for 2 h. Then 10 wt% $Na_2S_2O_3$ solution (10 mL) was added to quench the reaction. The mixture was extracted with DCM (20 mL). The organic layer was washed with saturated aqueous $NaHCO_3$ solution (10 mL) and brine (10 mL), dried over Na_2SO_4 and concentrated. The residue was purified by column chromatography (pentane: EA = 2:3 – 1:2) affording final product as a white solid (95 mg, 87% yield).
^{1}H NMR (300 MHz, $CDCl_3$) δ 9.55 (s, 1H, $C\underline{H}O$), 7.26 – 7.03 (m, 3H, $H_{4'}$ and $2H_{3''}$), 6.80 – 6.72 (m, 1H, $H_{4''}$), 6.68 – 6.56 (m, 2H, $H_{2''}$), 6.59 (dd, *J* = 3.4 Hz, 1H, $H_{3'}$), 5.01 (d, *J* = 24.9 Hz, 1H, H_1), 3.83 (d, *J* = 10.8 Hz, 3H, $C\underline{H}_3$), 3.69 (d, *J* = 10.8 Hz, 3H, $C\underline{H}_3$). ^{13}C NMR (100 MHz, $CDCl_3$) δ 177.4 ($\underline{C}HO$), 156.5 (d, ^2J = 2 Hz, $C_{2'}$), 152.7 (d, ^4J = 3 Hz, $C_{5'}$), 145.4 (d, ^3J = 13 Hz, $C_{1''}$), 129.4 ($2C_{3''}$), 122.5 ($C_{4'}$), 119.5 ($C_{4''}$), 113.9 ($2C_{2''}$), 111.6 (d, ^3J = 6 Hz, $C_{3'}$), 54.5 (d, ^2J = 7 Hz, $\underline{C}H_3$), 53.9 (d, ^2J = 7 Hz, $\underline{C}H_3$), 50.2 (d, ^1J = 157 Hz, C_1). ^{31}P NMR (162 MHz, $CDCl_3$) δ 21.0.
HRMS (ESI) m/z: Calcd for $[M+Na]^+$ $C_{14}H_{16}NNaO_5P$ 332.0658; Found 332.0663.

Dimethyl ((5-(azidomethyl)furan-2-yl)(phenylamino)methyl)phosphonate (4ab)
Under N_2 atmosphere, diphenylphosphoryl azide (1.5 equiv., 0.581 mmol) was added to a solution of K-F product **4t** (0.387 mmol, 120 mg) in toluene (3 mL). After stirring at room

temperature for 10 min, the reaction mixture was cooled to 0 °C and DBU (1.5 equiv., 0.581 mmol) was added dropwise. The mixture was stirred at 0 °C for 1.5 h, and then at room temperature for 18 h. Subsequently water (10 mL) was added and the mixture was extracted with ethyl acetate (2 × 15 mL). The combined organic layers were washed with brine (10 mL), dried over Na_2SO_4 and concentrated. The residue was purified by column chromatography (pentane: acetone = 5: 1 – 3: 1) affording the corresponding azide as a pale yellow solid. (55 mg, 42% yield).

^{1}H NMR (400 MHz, $CDCl_3$) δ 7.19 – 7.13 (m, 2H, $H_{3''}$), 6.79 – 6.73 (m, 1H, $H_{4''}$), 6.69 – 6.64 (m, 2H, $H_{2''}$), 6.37 (dd, *J* = 3.3 Hz, 1H, $H_{3'}$), 6.29 (d, *J* = 3.3 Hz, 1H, $H_{4'}$), 4.91 (d, *J* = 24.0 Hz, 1H, H_1), 4.25 (s, 2H, $C\underline{H}_2N_3$), 3.82 (d, *J* = 10.7 Hz, 3H, $C\underline{H}_3$), 3.67 (d, *J* = 10.7 Hz, 3H, $C\underline{H}_3$). ^{13}C NMR (100 MHz, $CDCl_3$) δ 150.2 (d, ^2J = 2 Hz, $C_{2'}$), 149.2 (d, ^4J = 3 Hz, $C_{5'}$), 145.8 (d, ^3J = 13 Hz, $C_{1''}$), 129.4 ($2C_{3''}$), 119.3 ($C_{4''}$), 114.1 ($2C_{2''}$), 110.9 (d, ^4J = 3 Hz, $C_{4'}$), 109.9 (d, ^3J = 7 Hz, $C_{3'}$), 54.1 (d, ^2J = 7 Hz, $\underline{C}H_3$), 53.9 (d, ^2J = 7 Hz, $\underline{C}H_3$), 50.0 (d, ^1J = 160 Hz, H_1), 47.0 ($\underline{C}H_2N_3$). ^{31}P NMR (162 MHz, $CDCl_3$) δ 22.3.

HRMS (ESI) m/z: Calcd for $[M+Na]^+$ $C_{14}H_{17}N_4NaO_4P$ 359.0880; Found 359.0877.

(5-((Dimethoxyphosphoryl)(phenylamino)methyl)furan-2-yl)methyl acrylate (4ac)

To the solution of K-F product **4t** (0.303 mmol, 94 mg) and triethylamine (1.25 equiv., 0.379 mmol) in THF (1.5 mL), acryloyl chloride (1 equiv., 0.303 mmol) was added dropwise at 0 °C. The mixture was stirred at 0 °C for 2 h, then at room temperature for 3 h. As conversion followed by TLC was not complete, additional triethylamine (0.6 equiv., 0.182 mmol) and acryloyl chloride (0.5 equiv., 0.152 mmol) were added. The mixture was stirred overnight. After the reaction completion, the mixture was diluted with DCM (5 mL) and water (10 mL), then extracted with DCM (3 × 10 mL). The combined organic layers were washed with brine (10 mL), concentrated and dried over Na_2SO_4. The residue was purified by column chromatography (pentane: ethyl acetate = 1: 2) affording the corresponding acrylate as a colorless solid (93 mg, 84% yield).

^{1}H NMR (300 MHz, $CDCl_3$) δ 7.18 – 7.10 (m, 2H, $H_{3'}$), 6.78 – 6.70 (m, 1H, $H_{4'}$), 6.69 – 6.63 (m, 2H, $H_{2'}$), 6.44 – 6.33 (m, 3H, $C\underline{H}_2$=CH, H_3 and H_4), 6.09 (dd, *J* = 17.3, 10.4 Hz, 1H, CH_2=C$\underline{H}$), 5.82 (dd, *J* = 10.4, 1.5 Hz, 1H, $C\underline{H}_2$=CH), 5.09 (s, 2H, $C\underline{H}_2O$), 4.91 (d, *J* = 24.0 Hz, 1H, C$\underline{H}$NH), 3.79 (d, *J* = 10.7 Hz, 3H, OC$\underline{H}_3$), 3.62 (d, *J* = 10.7 Hz, 3H, OC$\underline{H}_3$). ^{13}C NMR (75 MHz, $CDCl_3$) δ 165.6 (CO), 150.0 (d, ^2J = 2 Hz, C_5), 149.5 (d, ^4J = 3 Hz, C_2), 145.8 (d, ^3J = 13 Hz, $C_{1'}$), 131.4 ($\underline{C}H_2$=CH), 129.3 ($2C_{3'}$), 128.0 (CH_2=$\underline{C}$H), 119.1 ($C_{4'}$), 114.0 ($2C_{2'}$), 112.1 (d, ^4J = 3 Hz, C_3), 109.9 (d, ^3J = 7 Hz, C_4), 58.1 ($\underline{C}H_2O$), 54.0 (d, ^2J = 7 Hz, O$\underline{C}H_3$), 53.8 (d, ^2J = 7 Hz, O$\underline{C}H_3$), 49.9 (d, ^1J = 160 Hz, $\underline{C}$HNH). ^{31}P NMR (122 MHz, $CDCl_3$) δ 22.3.

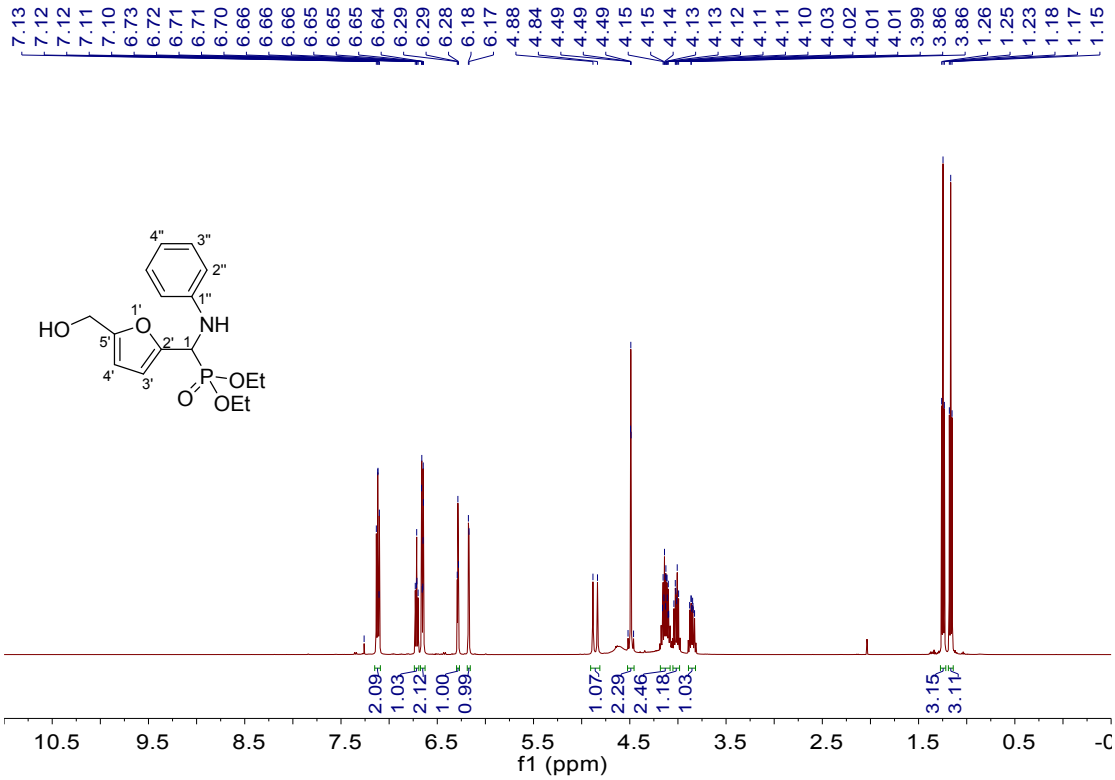
HRMS (ESI) m/z: Calcd for $[M+Na]^+$ $C_{17}H_{20}NNaO_6P$ 388.0920; Found 388.0914.

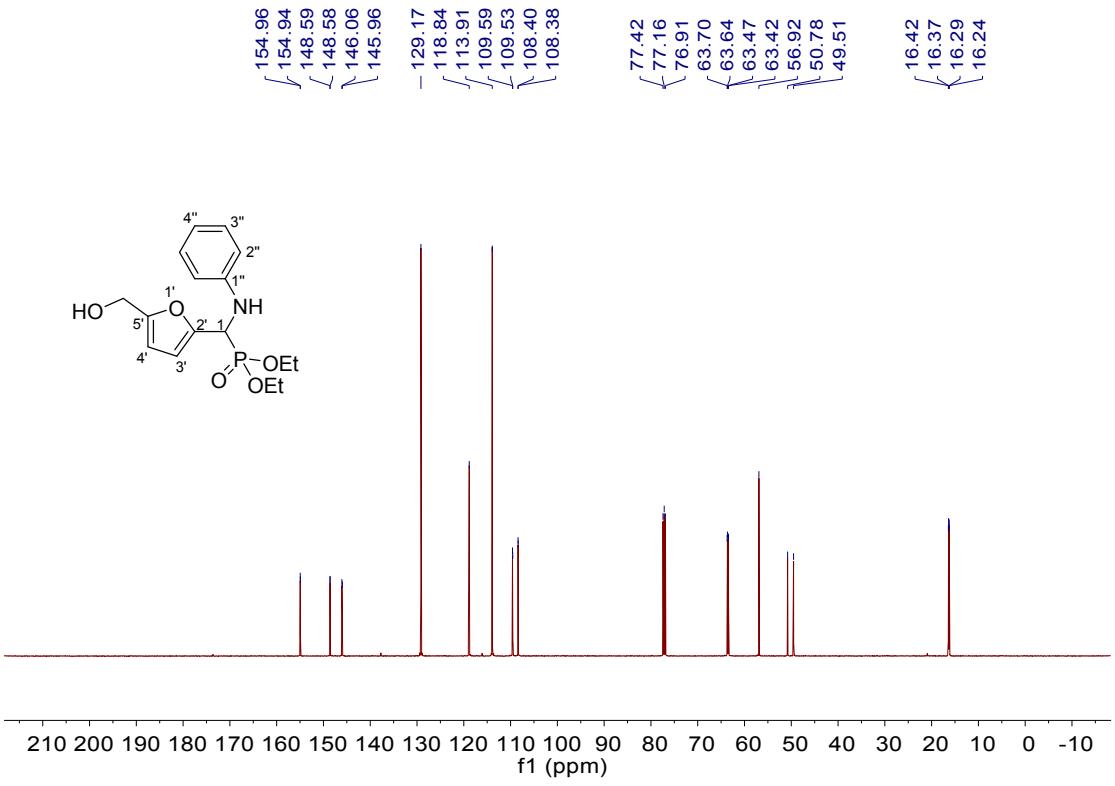
Reference

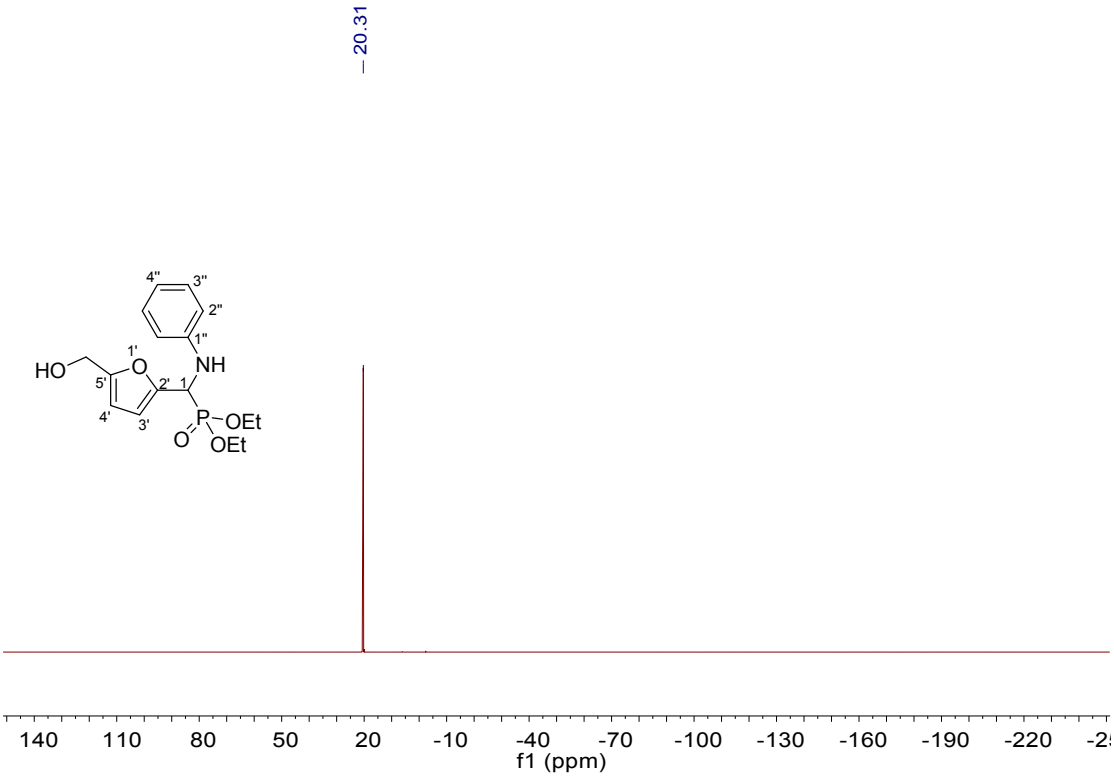
1. K. I. Galkin, E. A. Krivodaeva, L. V. Romashov, S. S. Zalesskiy, V. V. Kachala, J. V. Burykina and V. P. Ananikov, *Angew. Chem. Int. Ed.*, 2016, **55**, 8338.

5. ^{1}H, ^{13}C and ^{31}P NMR spectra of products

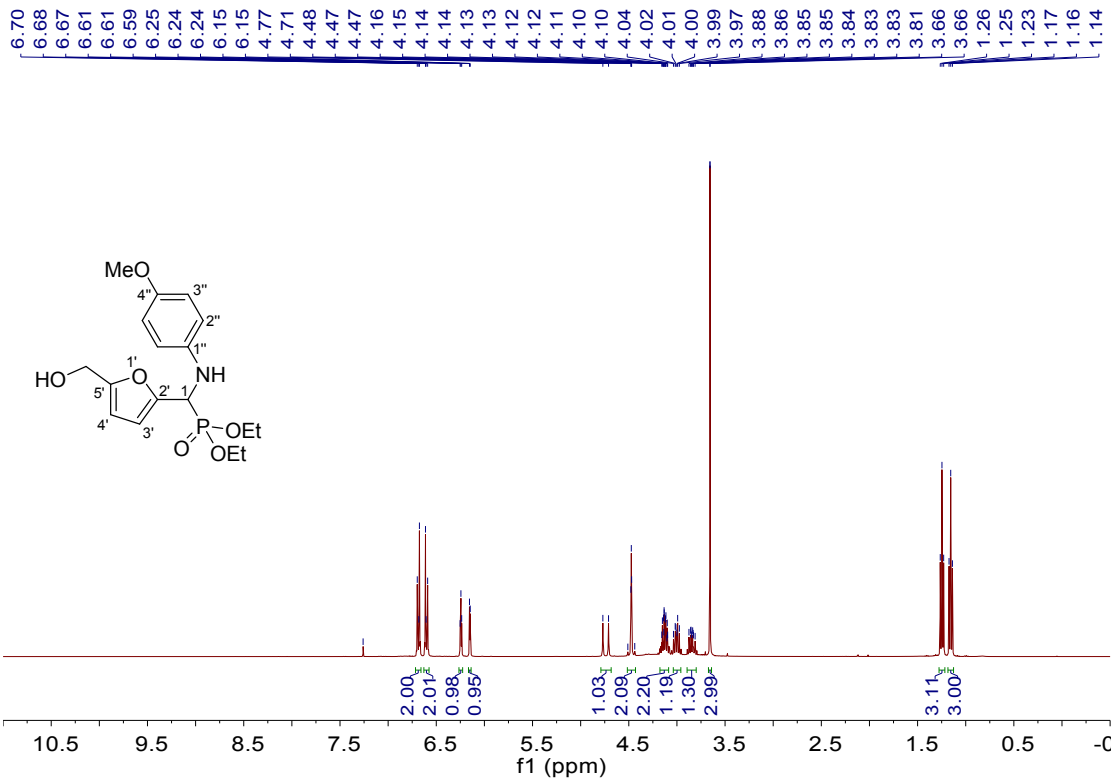
Diethyl ((5-(hydroxymethyl)furan-2-yl)(phenylamino)methyl)phosphonate (4a)

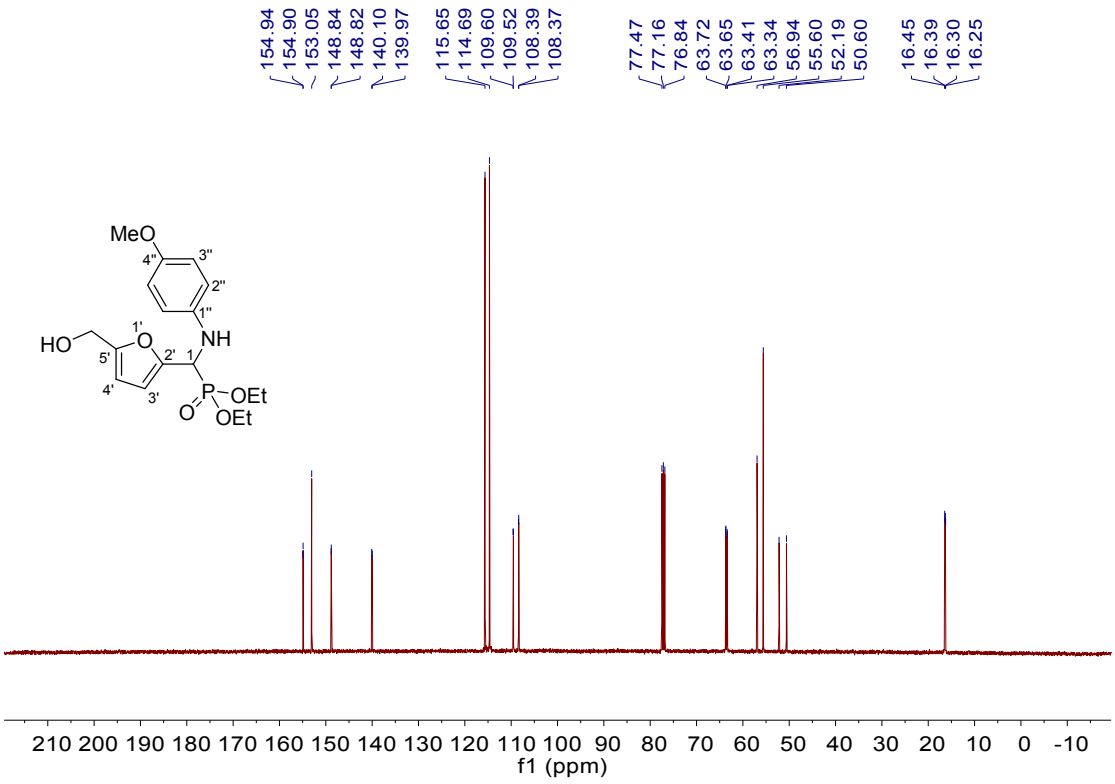






Diethyl ((5-(hydroxymethyl)furan-2-yl)((4-methoxyphenyl)amino)methyl)phosphonate (4b)

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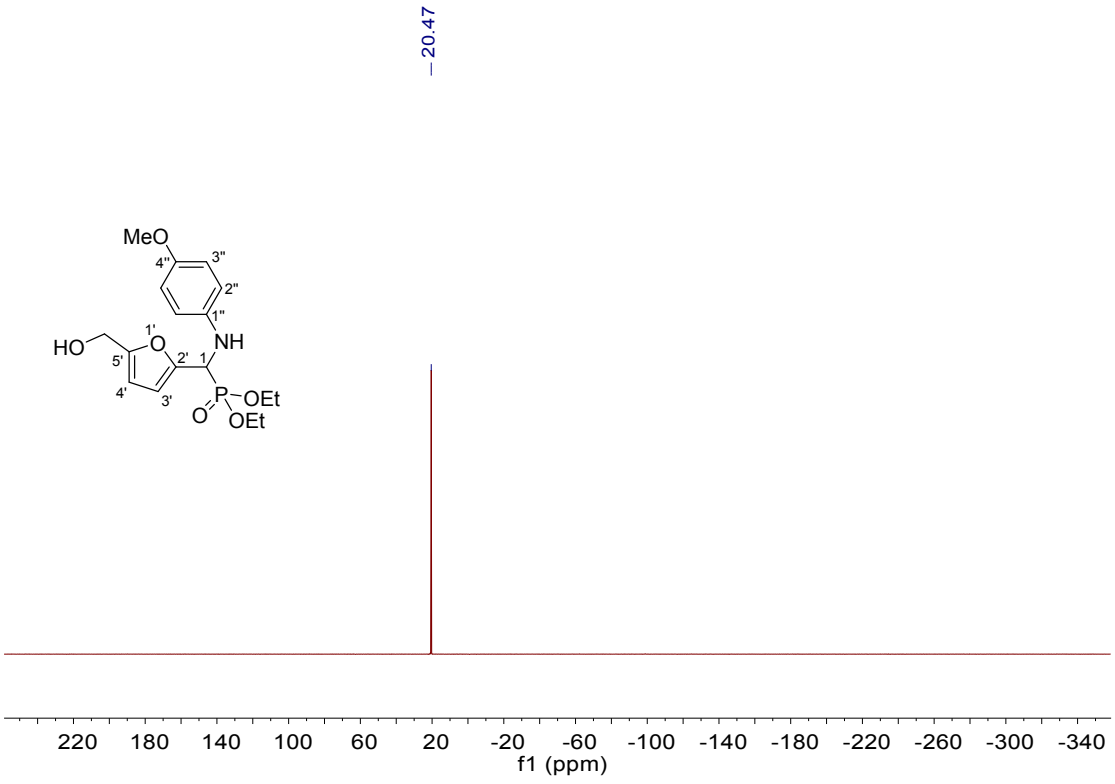
f1 (ppm)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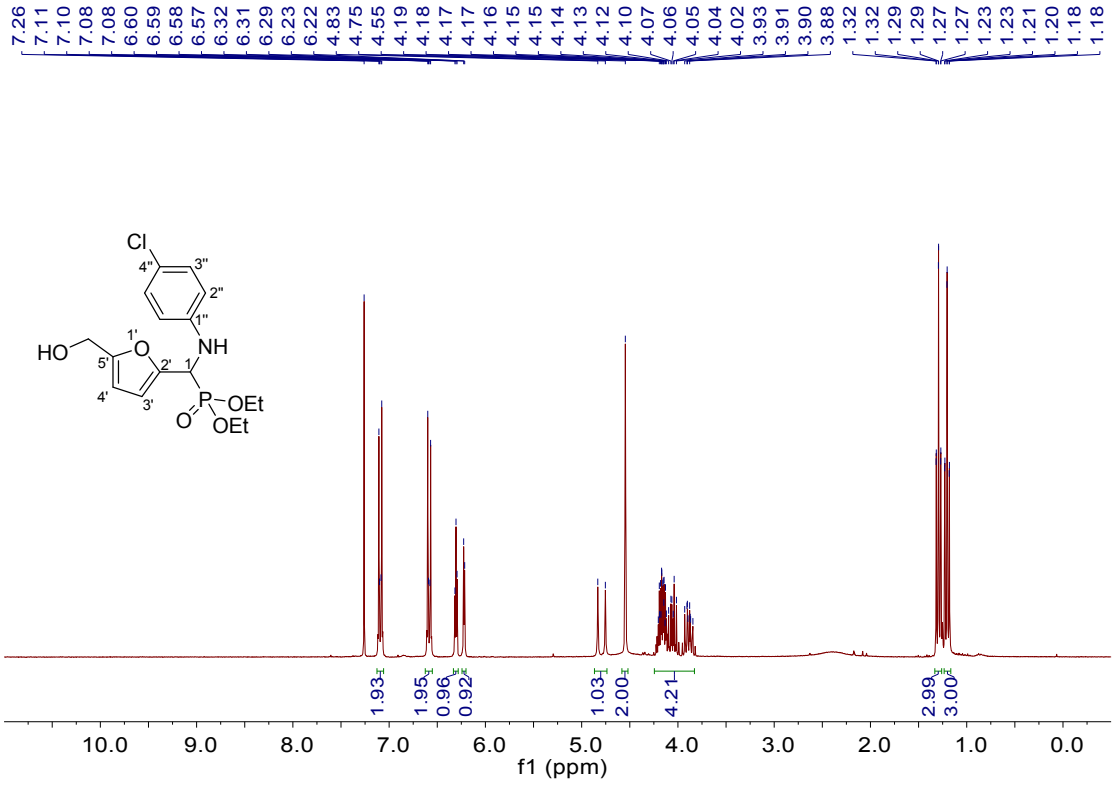
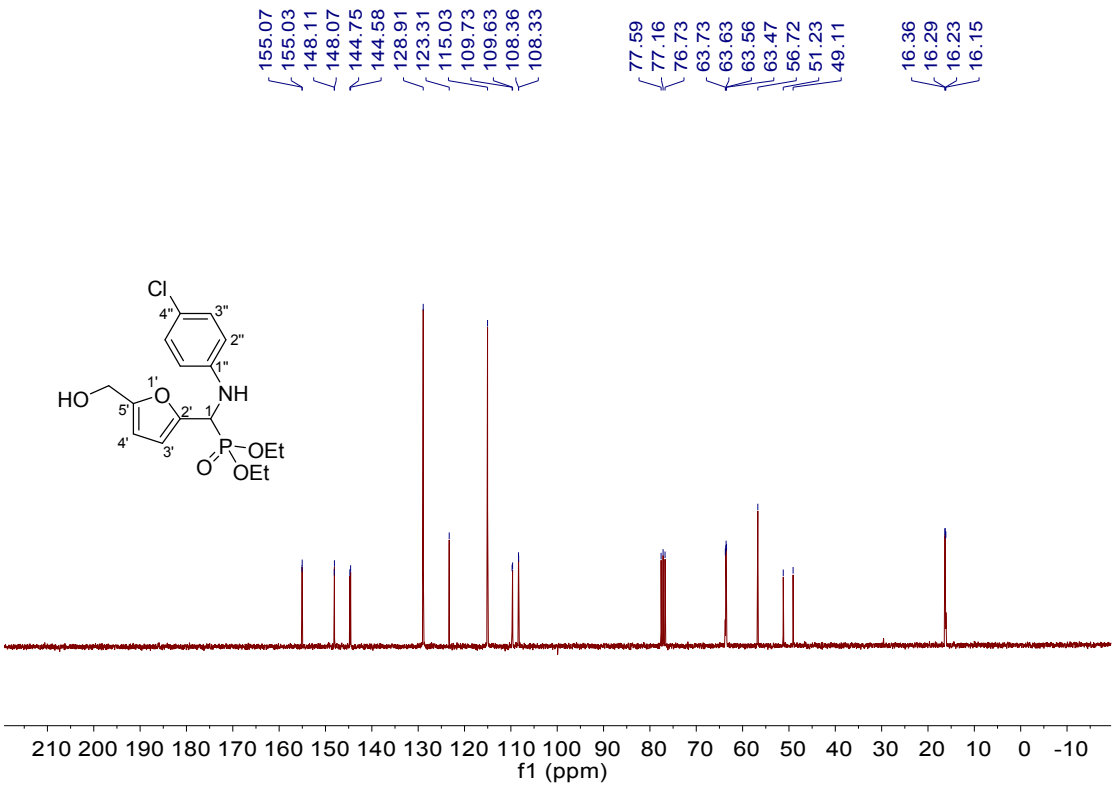
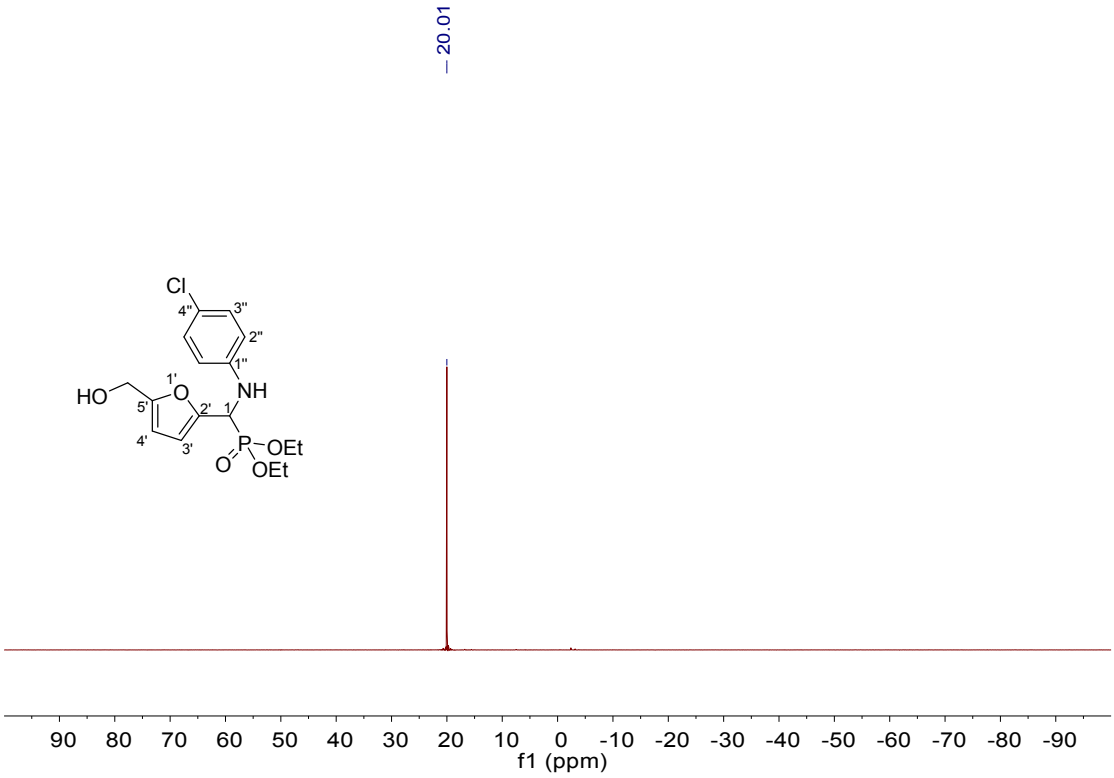
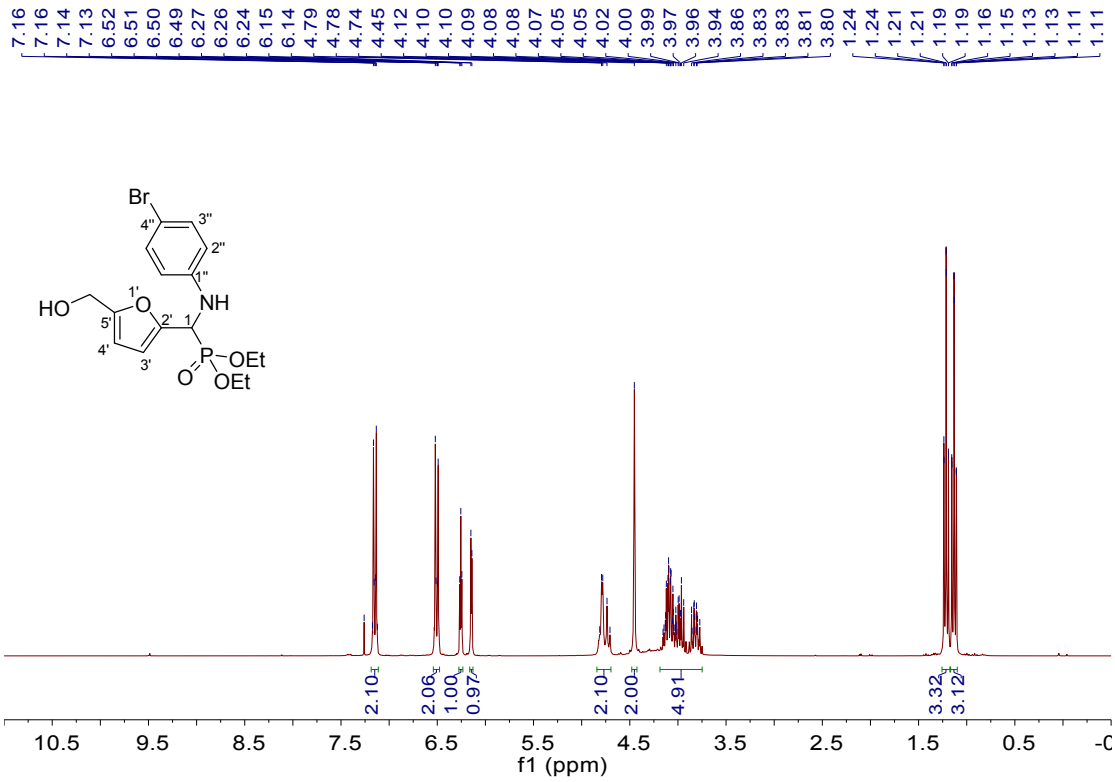
Diethyl (((4-chlorophenyl)amino)(5-(hydroxymethyl)furan-2-yl)methyl)phosphonate (4c)

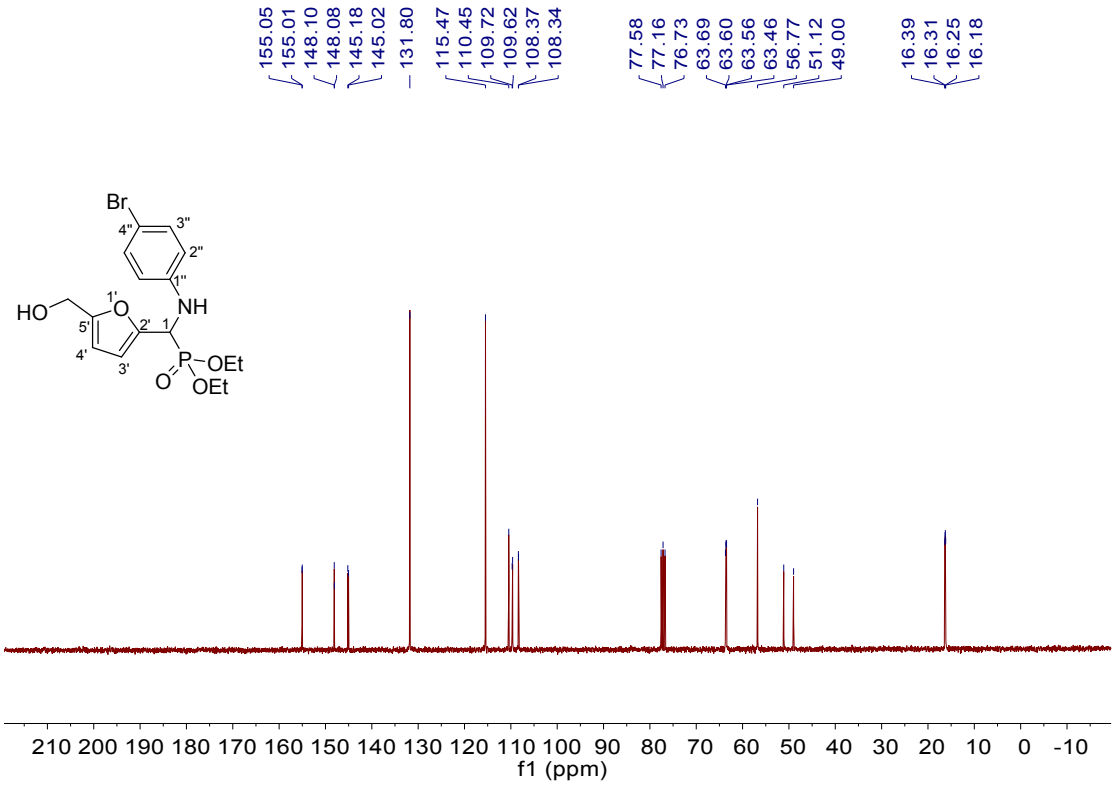


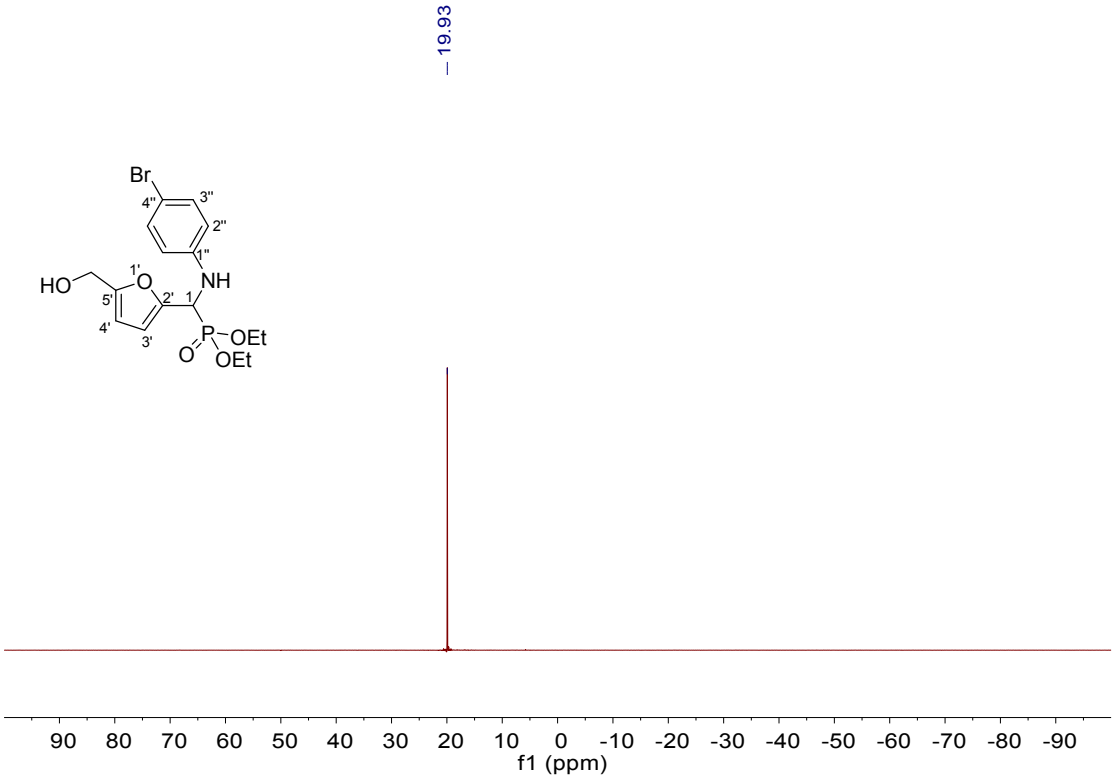




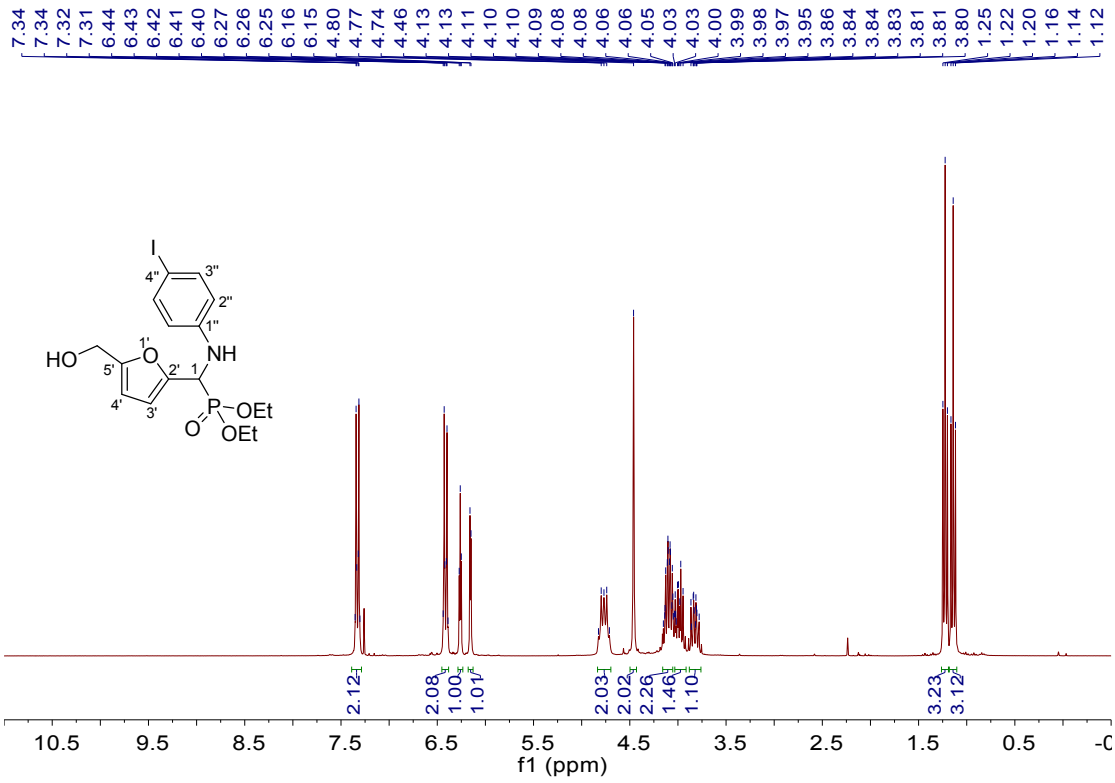
Diethyl (((4-bromophenyl)amino)(5-(hydroxymethyl)furan-2-yl)methyl)phosphonate (4d)

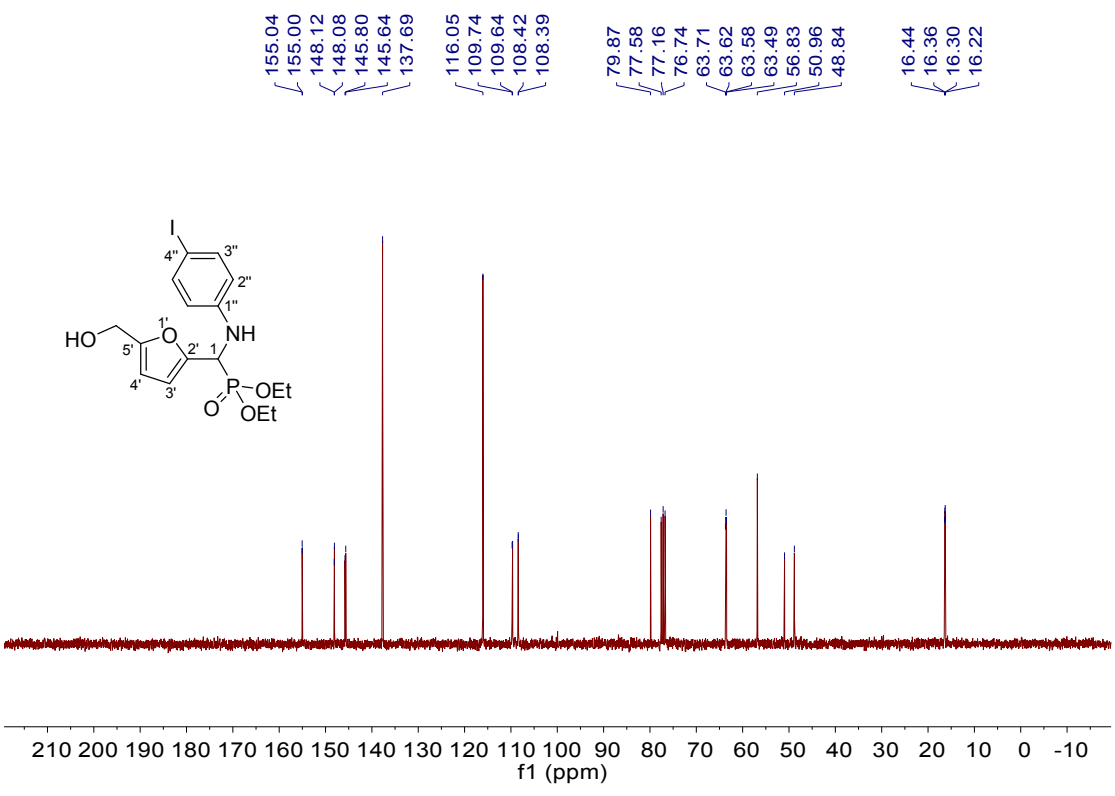


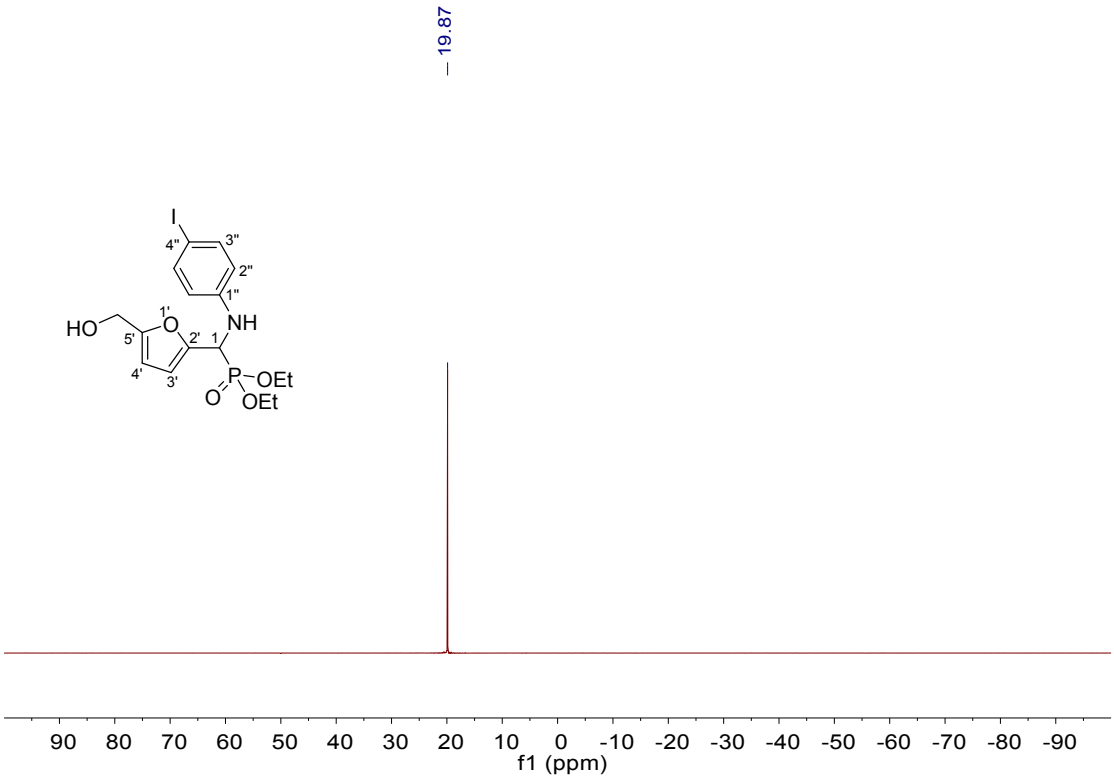

155.05
155.01
148.10
148.08
145.18
145.02
131.80
115.47
110.45
109.72
109.62
108.37
108.34
77.58
77.16
76.73
63.69
63.60
63.56
63.46
56.77
51.12
49.00
16.39
16.31
16.25
16.18
Br
4"
3"
2"
1"
NH
HO
1'
O
5'
2'
1
4'
3'
P
OEt
O
OEt
210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10
f1 (ppm)


19.93
Br
4"
3"
2"
1"
NH
HO
1'
O
5'
2'
1
4'
3'
P
OEt
O
OEt
90 80 70 60 50 40 30 20 10 0 -10 -20 -30 -40 -50 -60 -70 -80 -90
f1 (ppm)

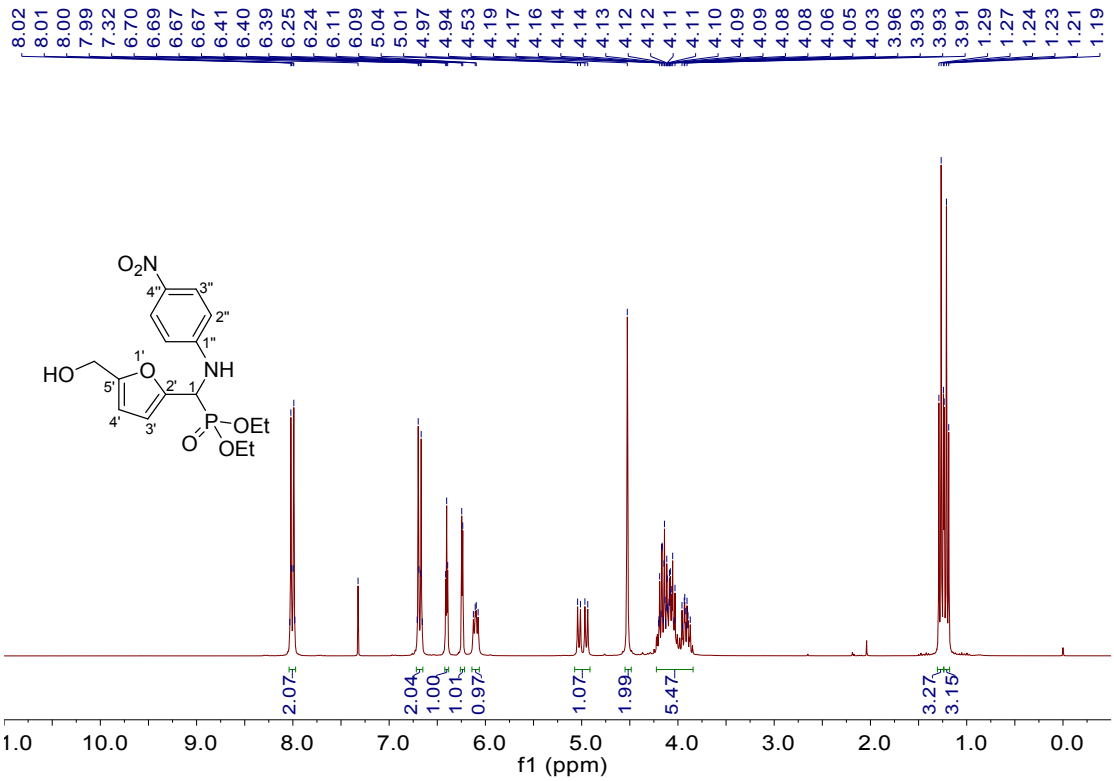
Diethyl ((5-(hydroxymethyl)furan-2-yl)((4-iodophenyl)amino)methyl)phosphonate (4e)

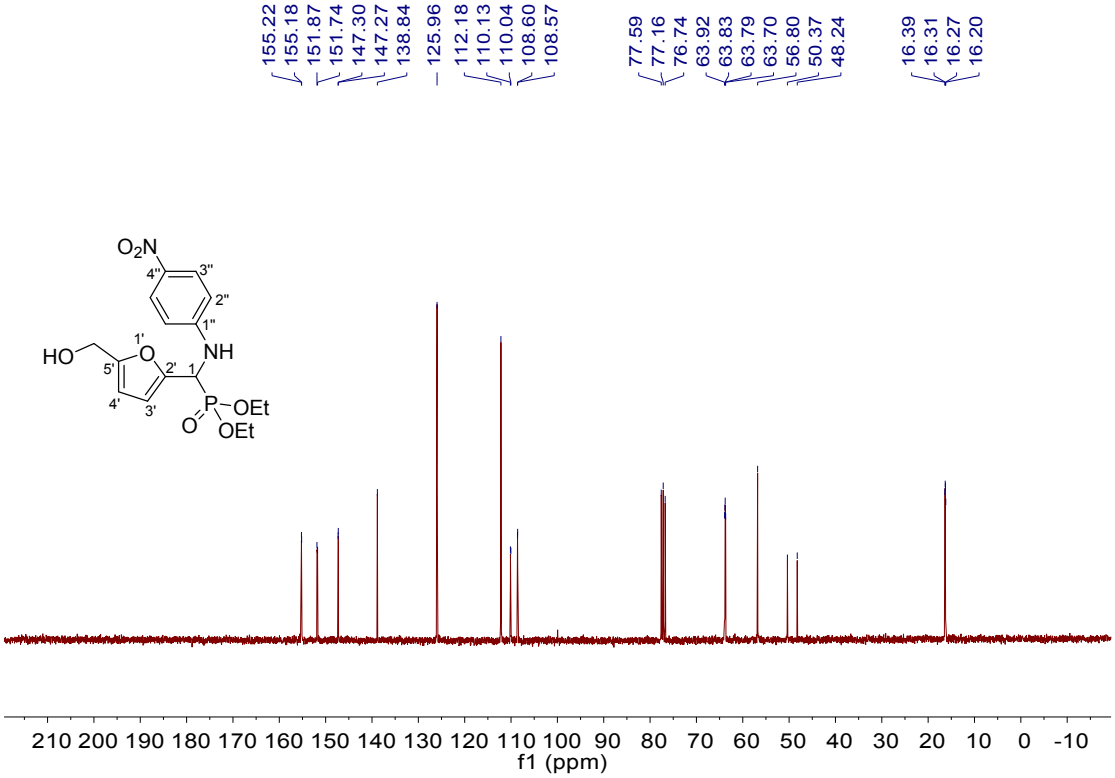


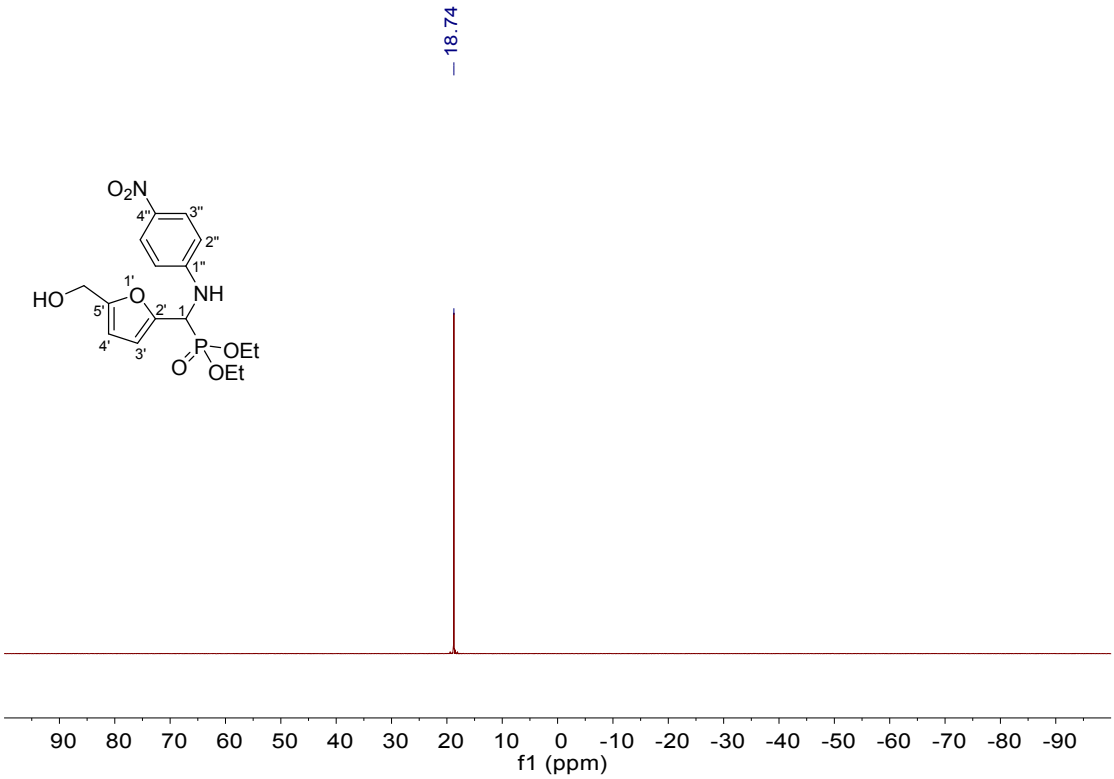




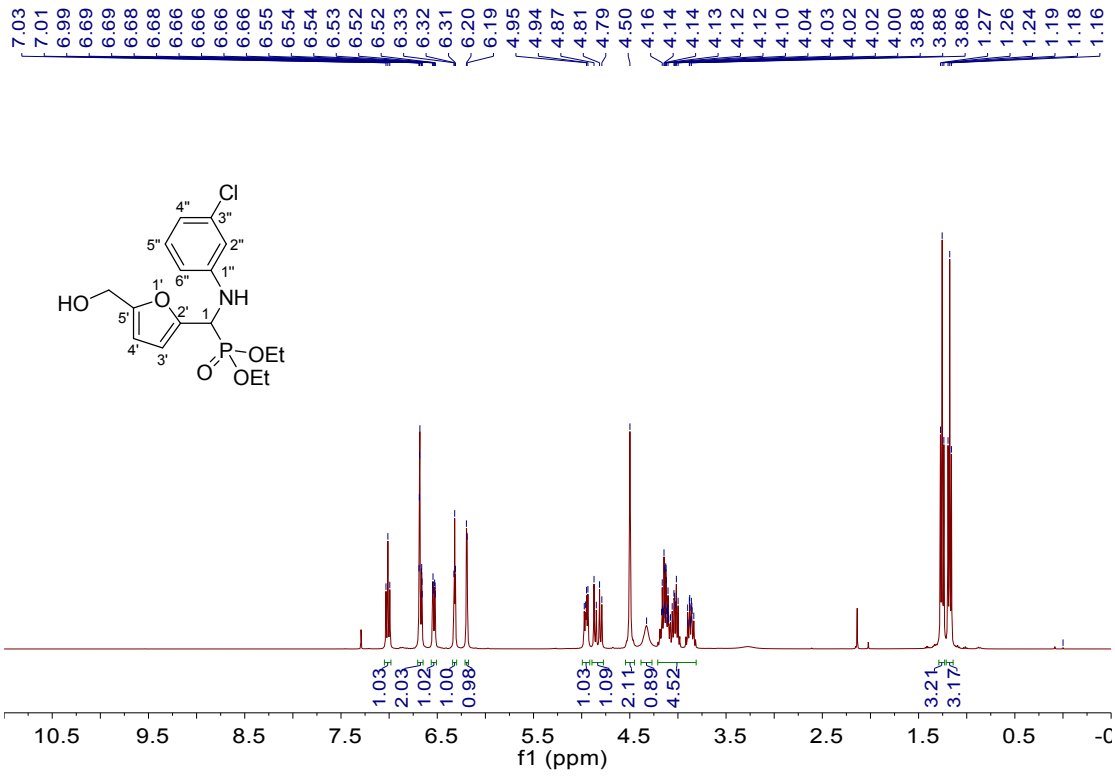
Diethyl ((5-(hydroxymethyl)furan-2-yl)((4-nitrophenyl)amino)methyl)phosphonate (4f)

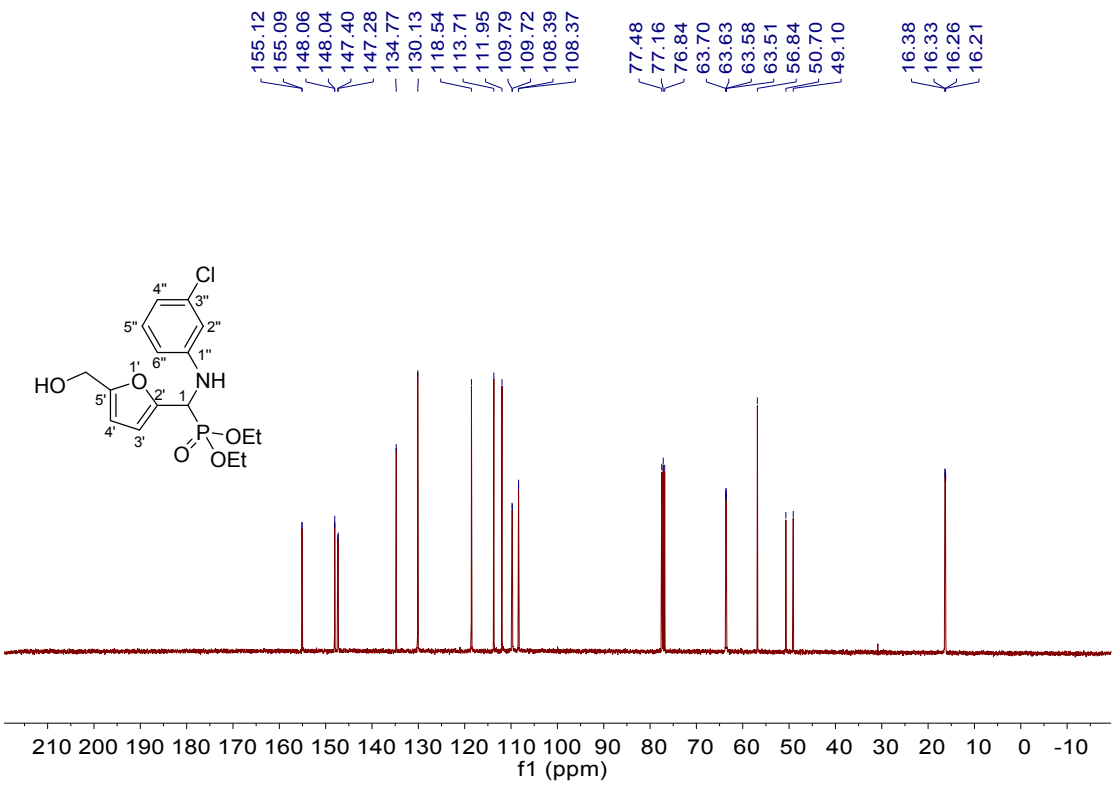


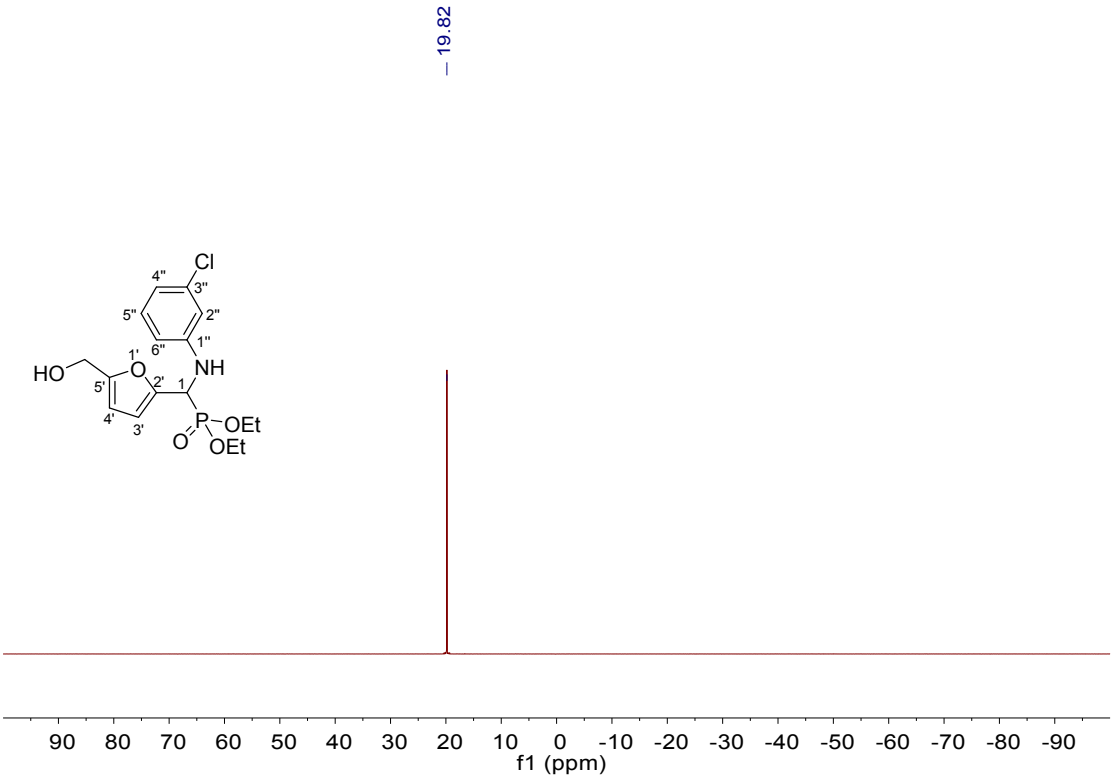

155.22
155.18
151.87
151.74
147.30
147.27
138.84
125.96
112.18
110.13
110.04
108.60
108.57
77.59
77.16
76.74
63.92
63.83
63.79
63.70
56.80
50.37
48.24
16.39
16.31
16.27
16.20
O2N
4"
3"
2"
1"
NH
HO
1'
O
5'
2'
1
4'
3'
P
OEt
O
OEt
210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10
f1 (ppm)


18.74
O2N
4"
3"
2"
1"
NH
HO
1'
O
5'
2'
1
4'
3'
P
OEt
O
OEt
90 80 70 60 50 40 30 20 10 0 -10 -20 -30 -40 -50 -60 -70 -80 -90
f1 (ppm)

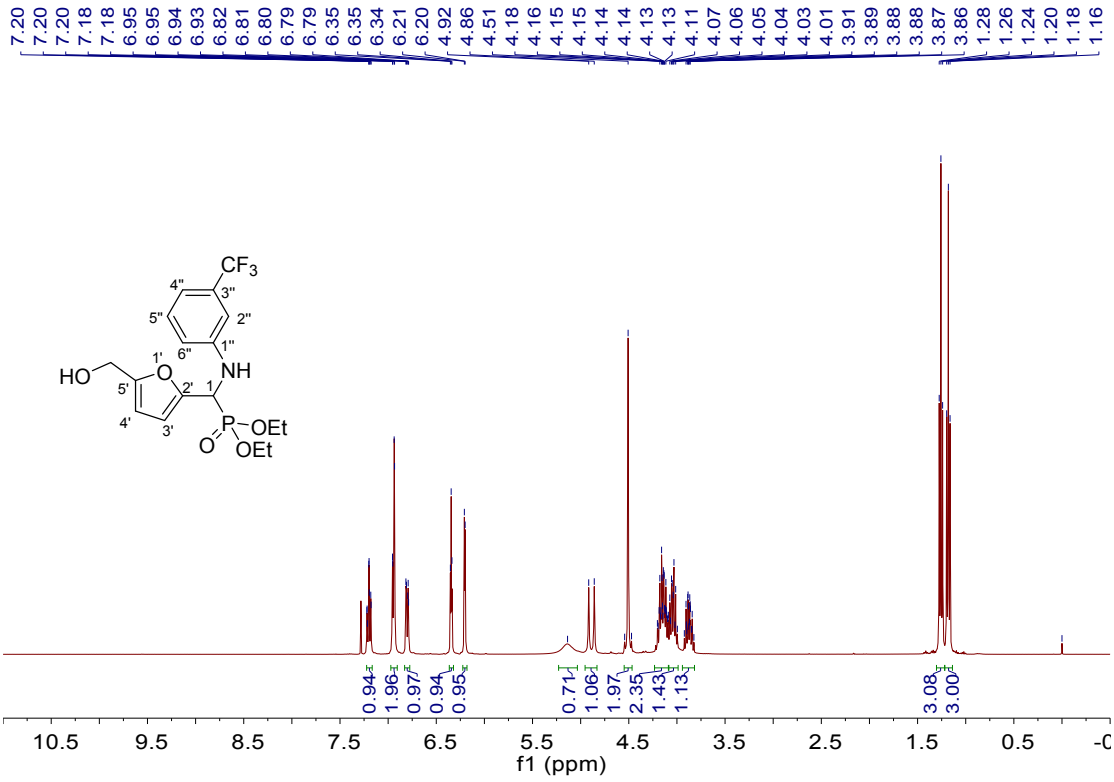
Diethyl (((3-chlorophenyl)amino)(5-(hydroxymethyl)furan-2-yl)methyl)phosphonate (4g)

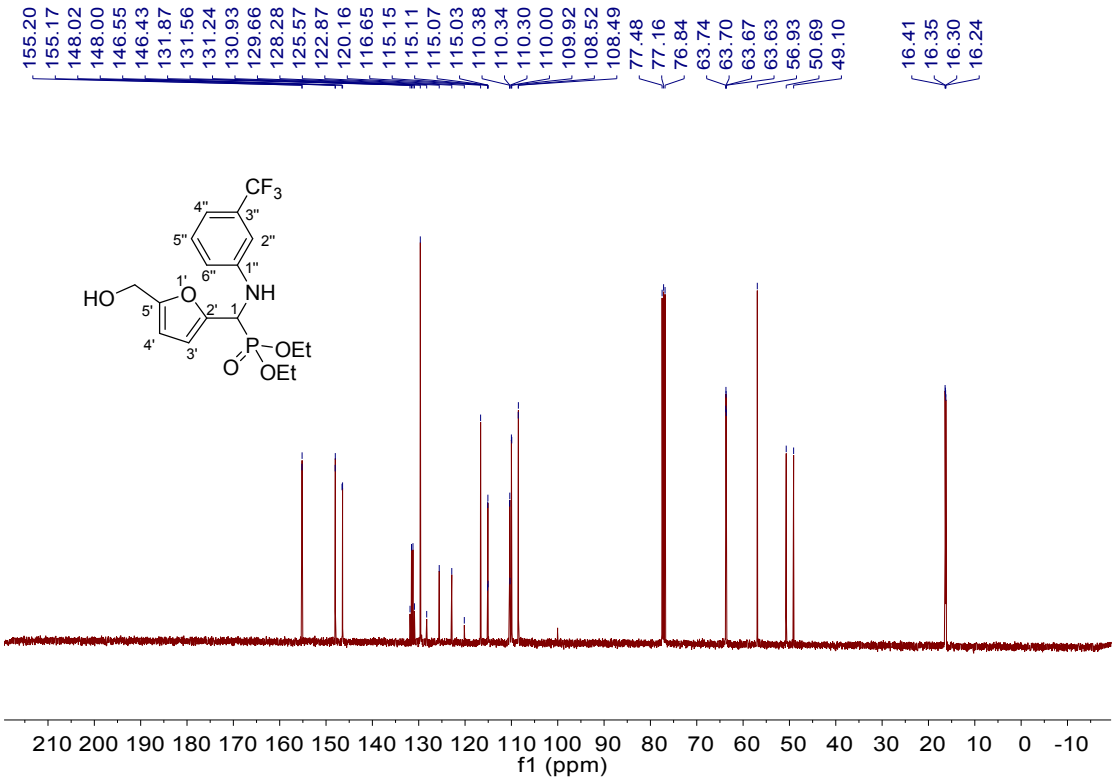


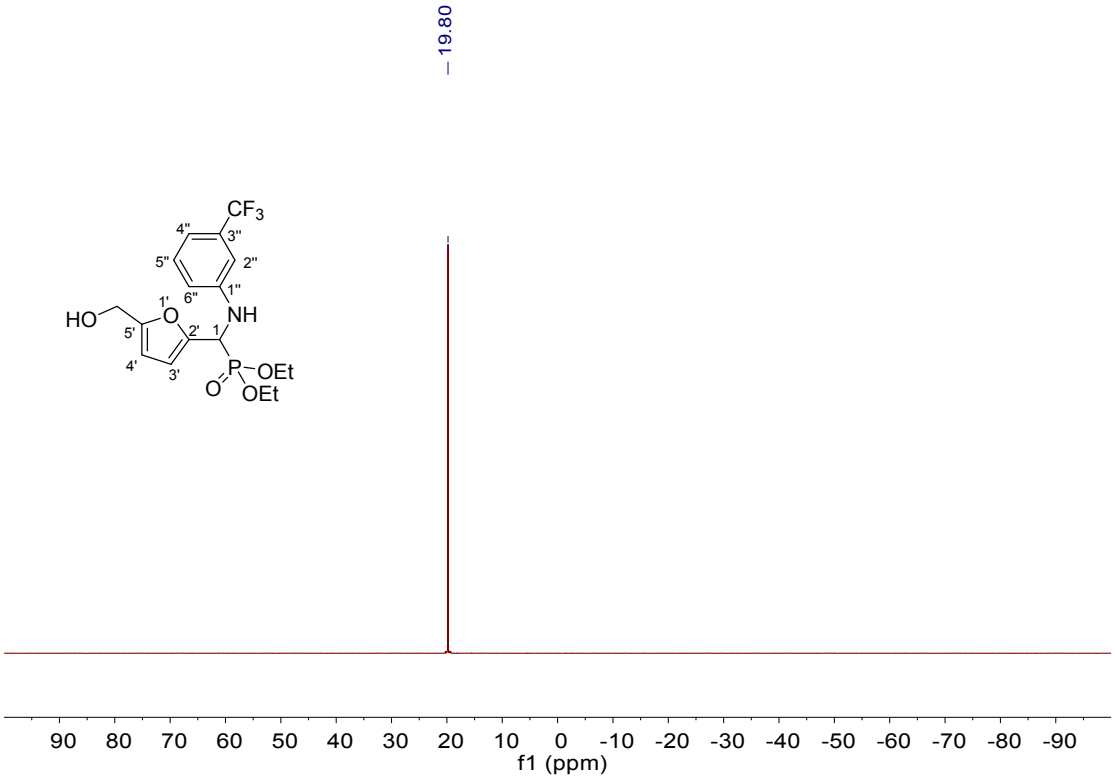




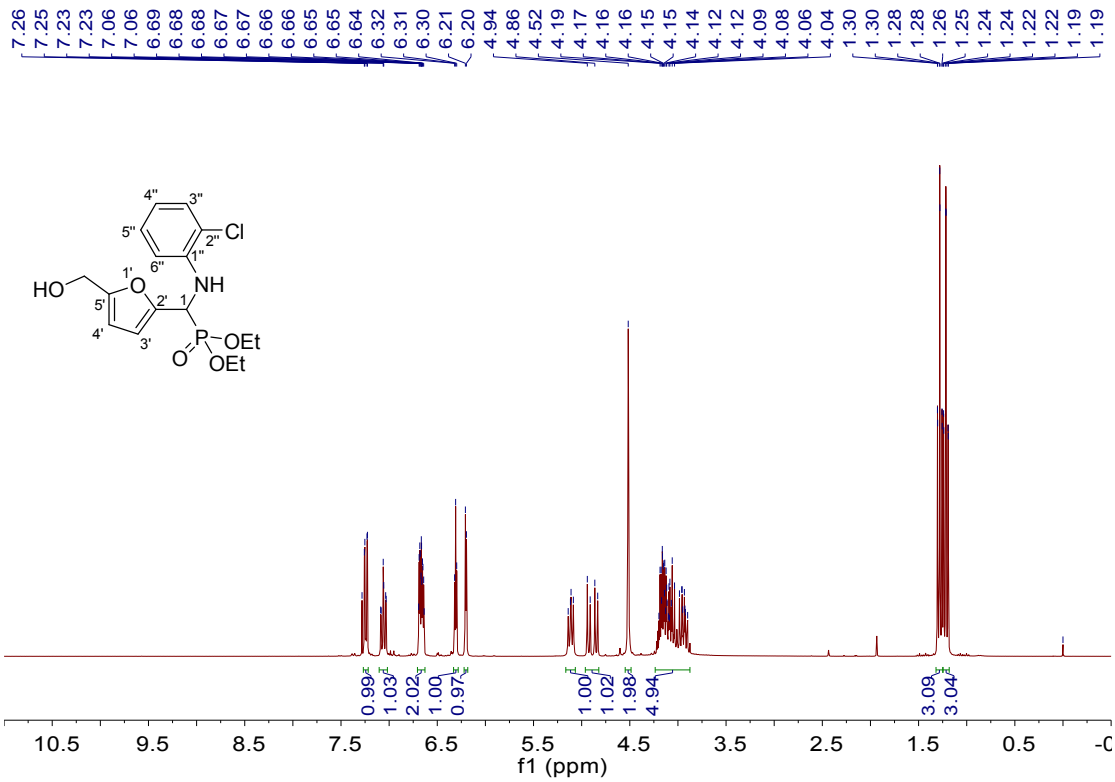
Diethyl ((5-(hydroxymethyl)furan-2-yl)((3-(trifluoromethyl)phenyl)amino)methyl)phosphonate (4h)

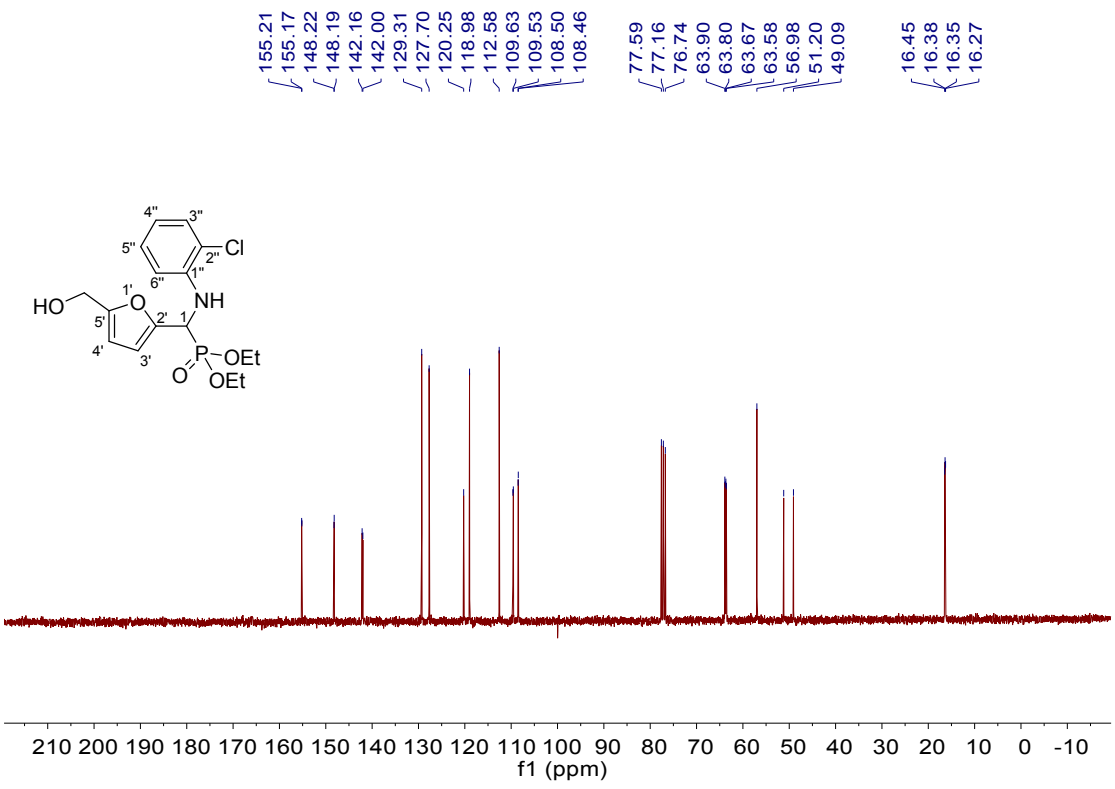


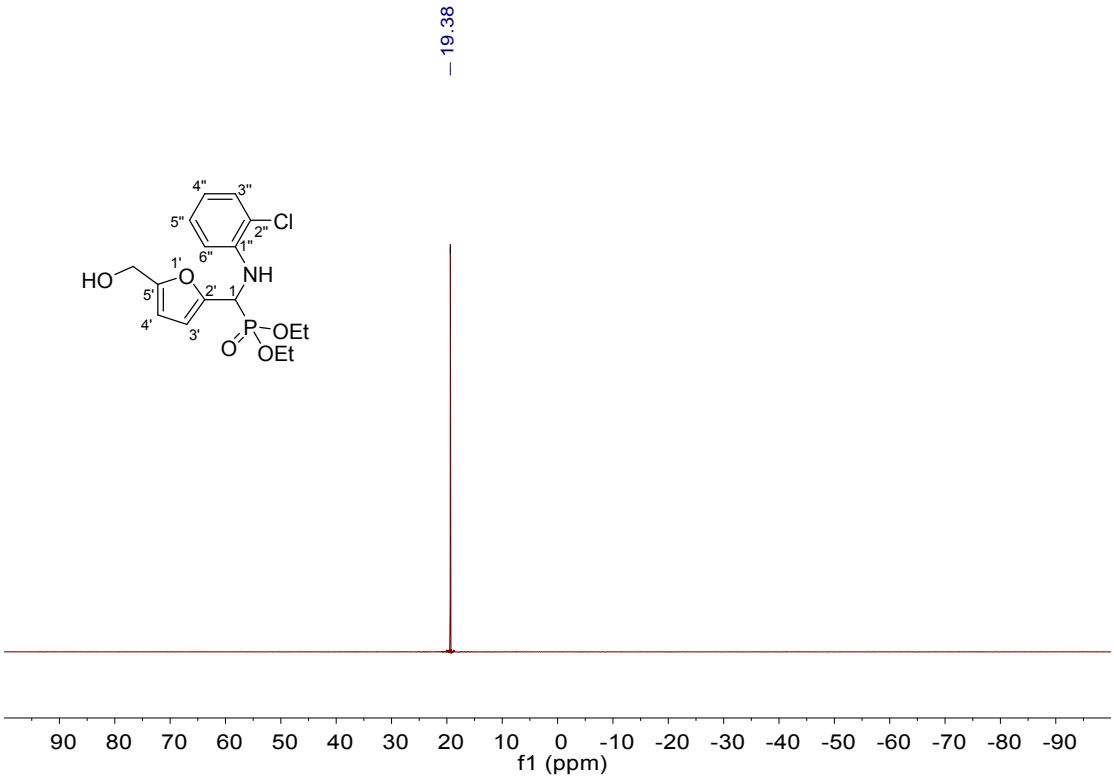




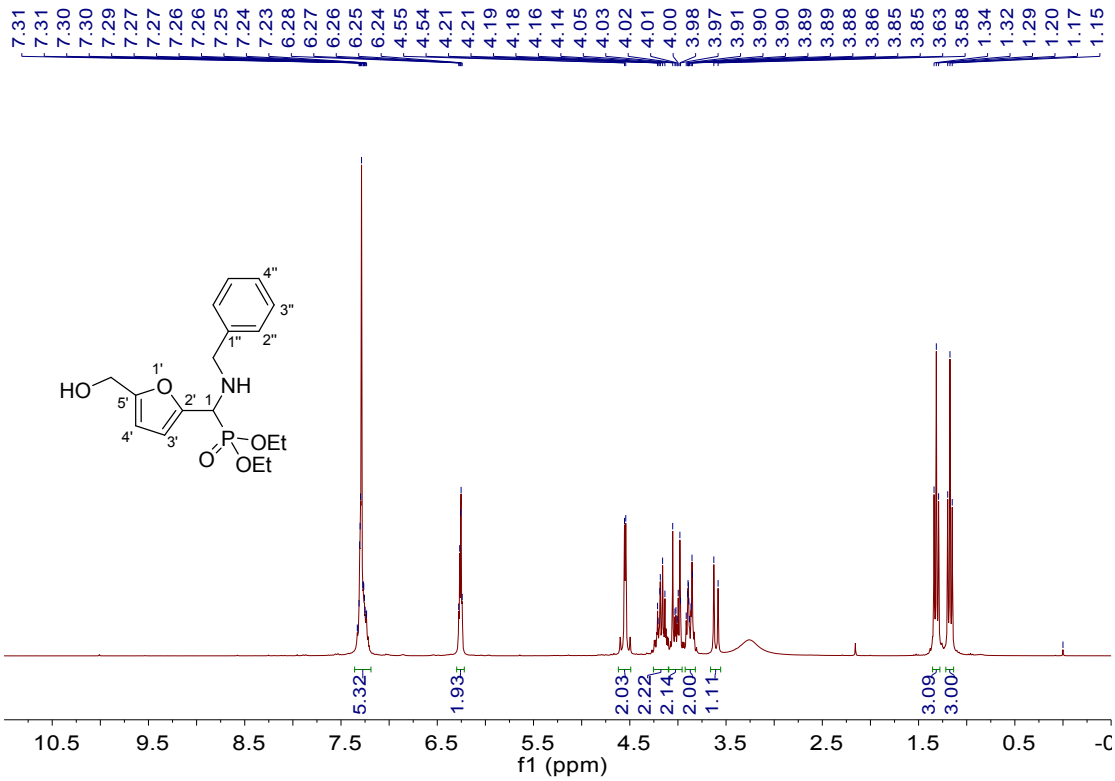
Diethyl (((2-chlorophenyl)amino)(5-(hydroxymethyl)furan-2-yl)methyl)phosphonate (4i)

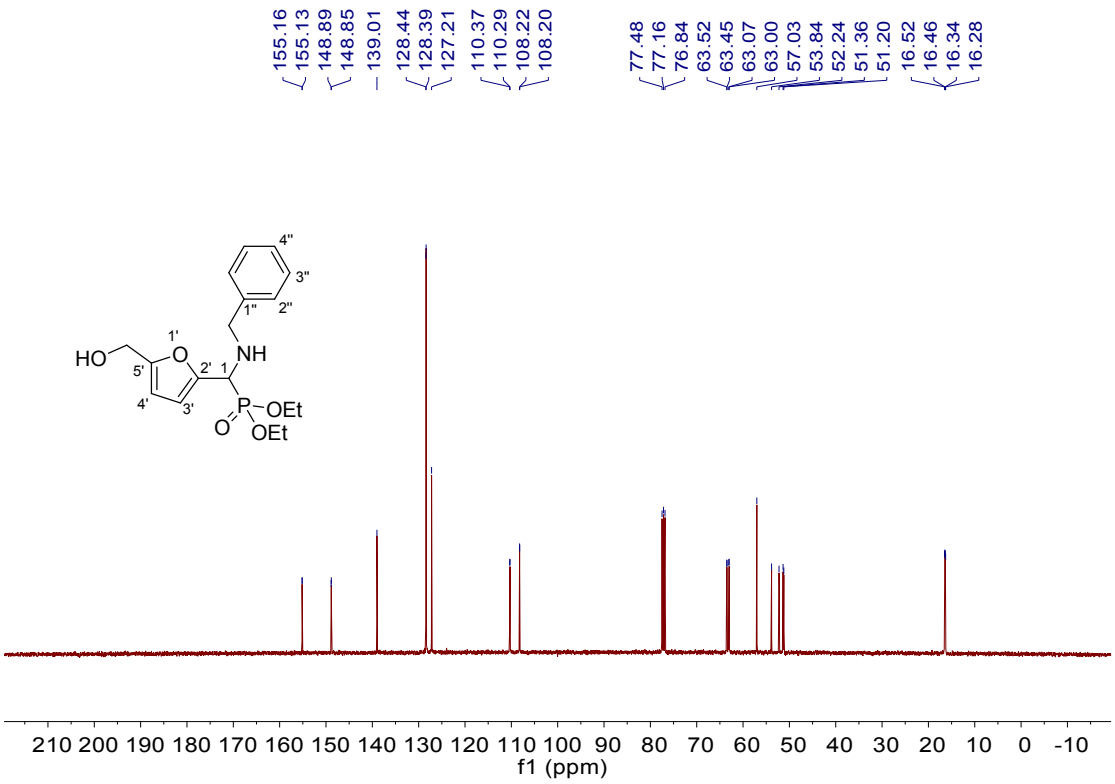

7.26 7.25 7.23 7.23 7.06 7.06 6.69 6.68 6.68 6.67 6.67 6.66 6.66 6.65 6.65 6.64 6.32 6.31 6.30 6.21 6.20 4.94 4.86 4.52 4.19 4.17 4.16 4.16 4.15 4.15 4.14 4.12 4.12 4.09 4.08 4.06 4.04 1.30 1.30 1.28 1.28 1.26 1.25 1.24 1.24 1.22 1.22 1.19 1.19
HO
NH
Cl
OEt
OEt
0.99 1.03 2.02 1.00 0.97 1.00 1.02 1.98 4.94 3.09 3.04
10.5 9.5 8.5 7.5 6.5 5.5 4.5 3.5 2.5 1.5 0.5
f1 (ppm)

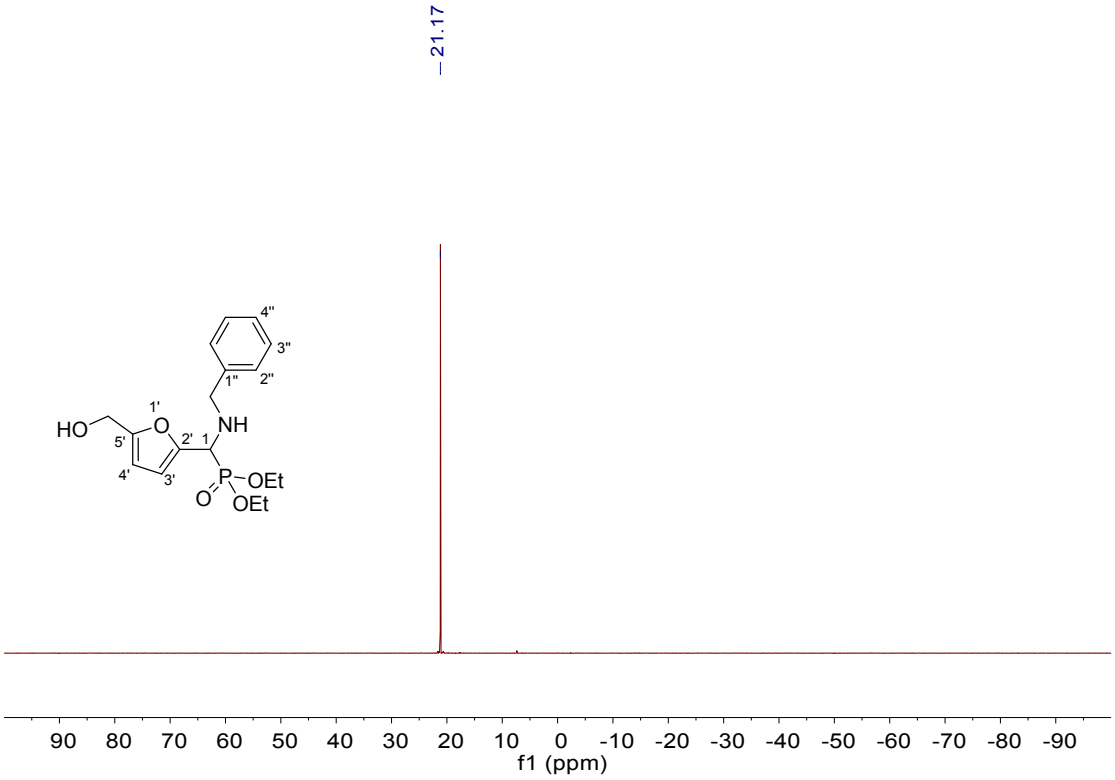

155.21 155.17 148.22 148.19 142.16 142.00 129.31 127.70 120.25 118.98 112.58 109.63 109.53 108.50 108.46 77.59 77.16 76.74 63.90 63.80 63.67 63.58 56.98 51.20 49.09 16.45 16.38 16.35 16.27
HO
NH
Cl
OEt
OEt
210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10
f1 (ppm)



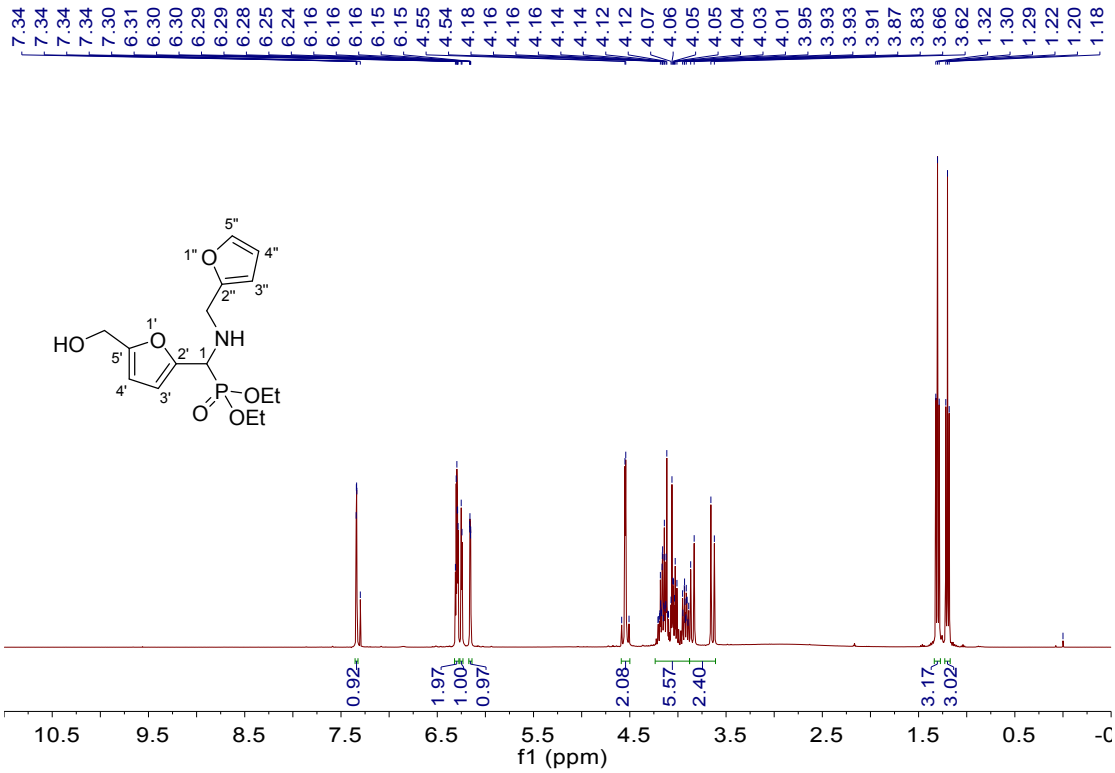
Diethyl ((benzylamino)(5-(hydroxymethyl)furan-2-yl)methyl)phosphonate (4j)

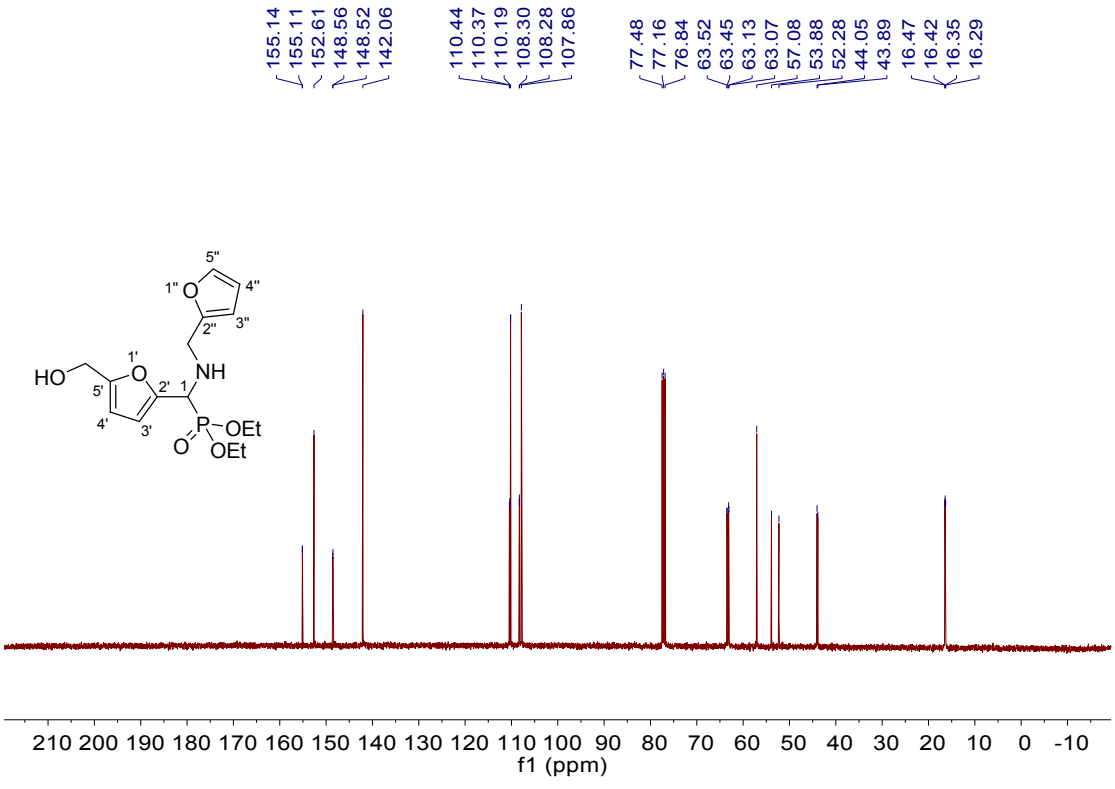


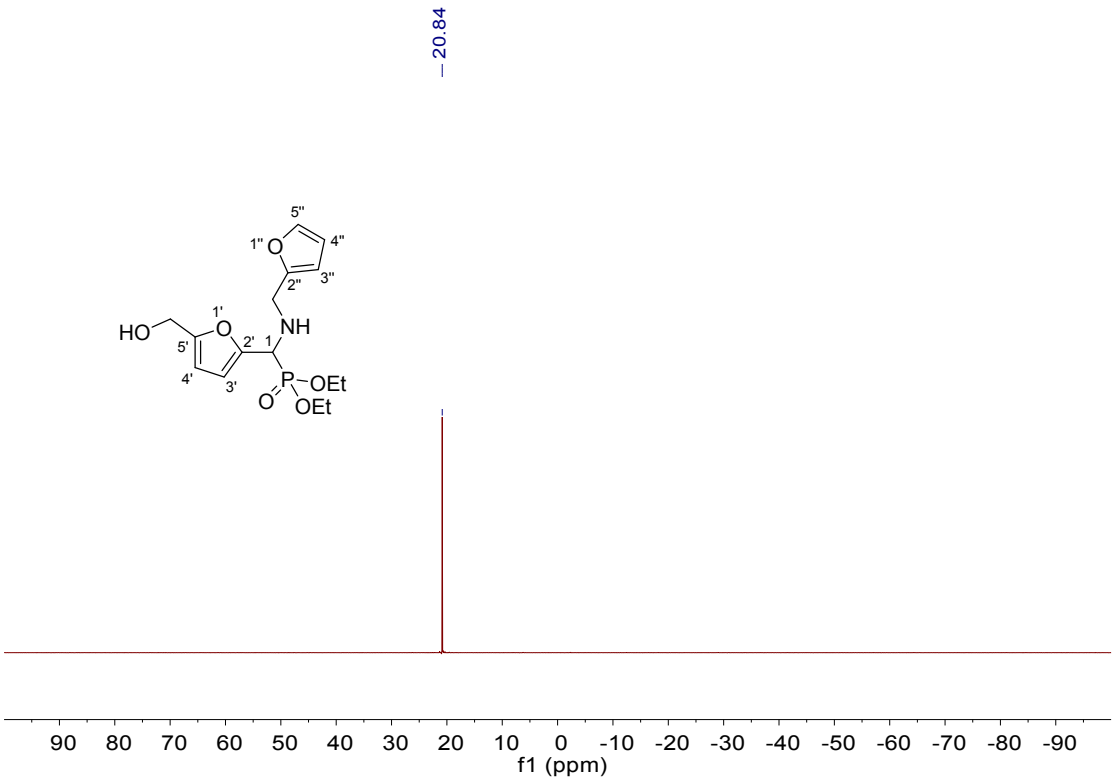

155.16
155.13
148.89
148.85
139.01
128.44
128.39
127.21
110.37
110.29
108.22
108.20
77.48
77.16
76.84
63.52
63.45
63.07
63.00
57.03
53.84
52.24
51.36
51.20
16.52
16.46
16.34
16.28
HO
NH
OEt
OEt
210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10
f1 (ppm)


21.17
HO
NH
OEt
OEt
90 80 70 60 50 40 30 20 10 0 -10 -20 -30 -40 -50 -60 -70 -80 -90
f1 (ppm)

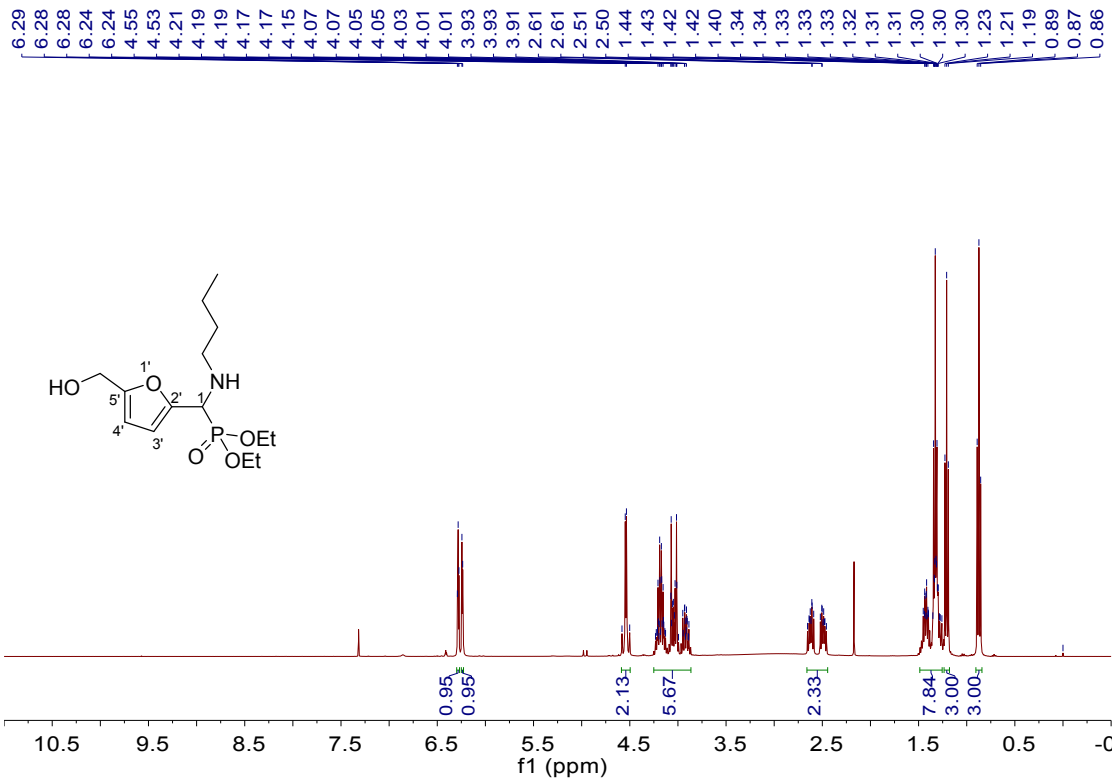
Diethyl (((furan-2'-ylmethyl)amino)(5-(hydroxymethyl)furan-2-yl)methyl)phosphonate (4k)

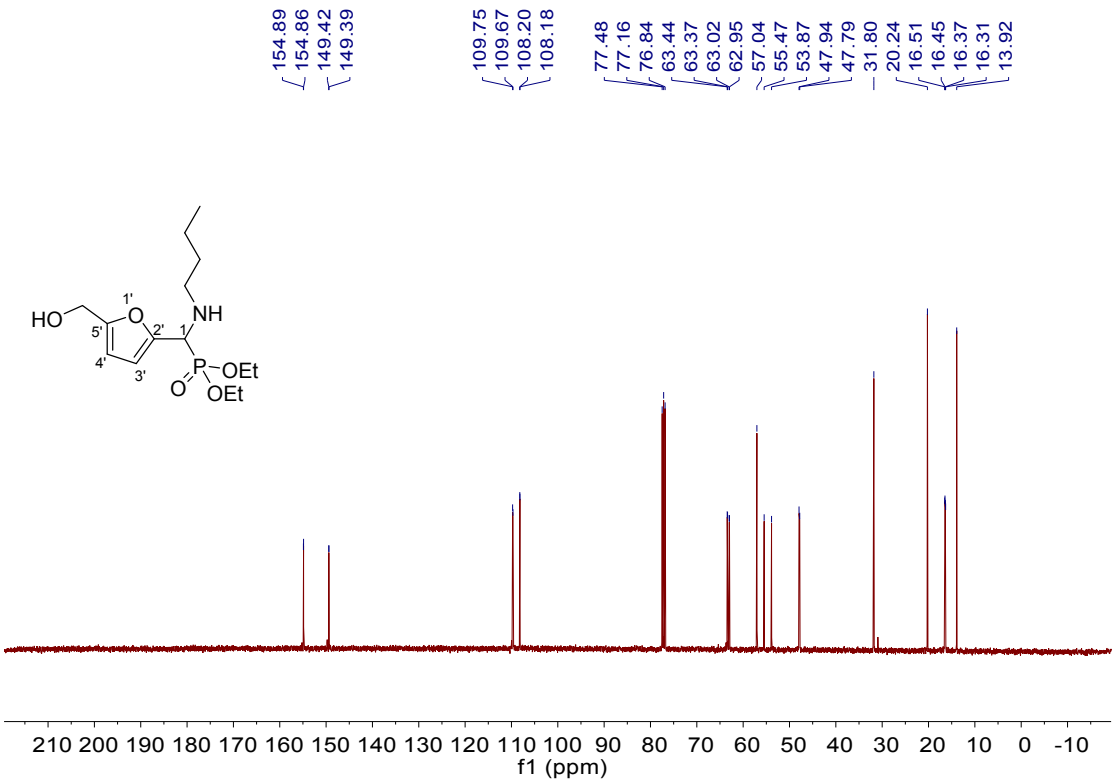


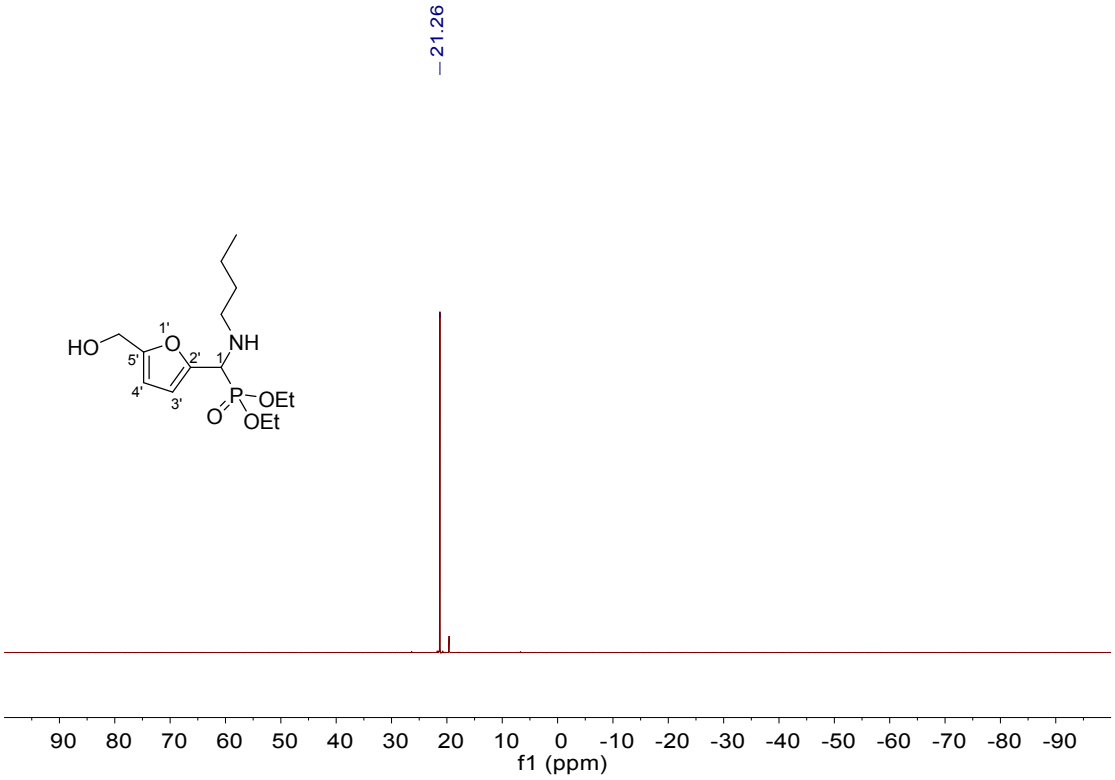




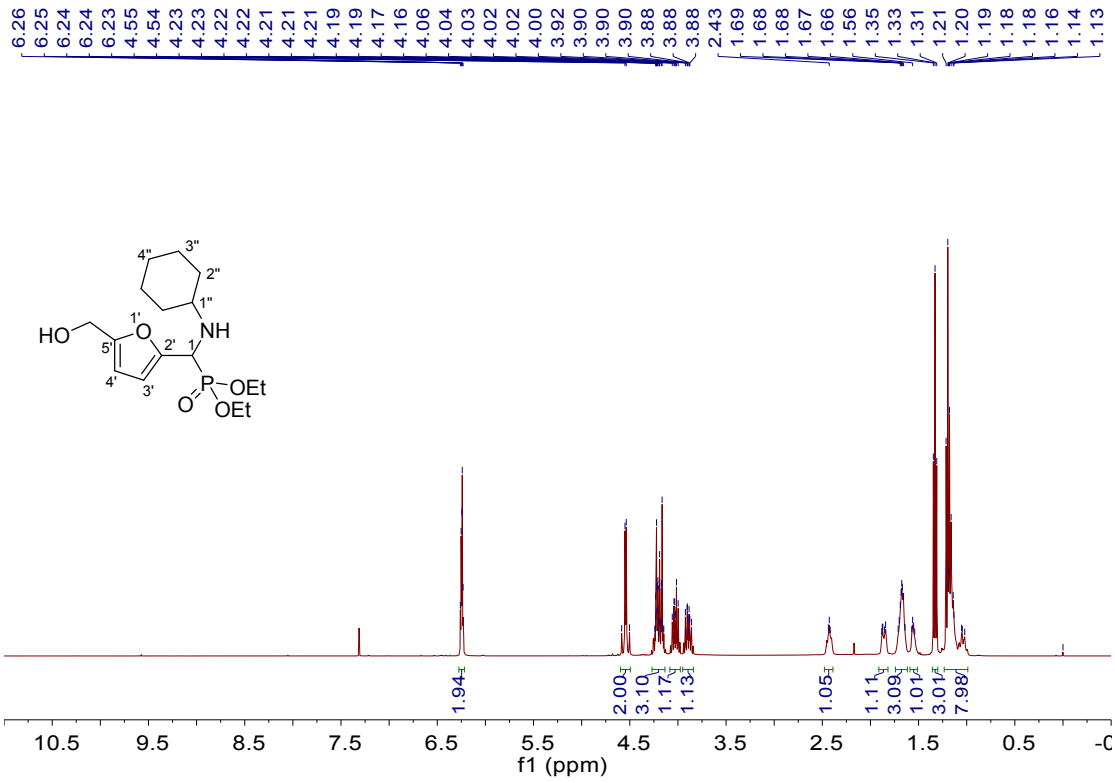
Diethyl ((butylamino)(5-(hydroxymethyl)furan-2-yl)methyl)phosphonate (4l)

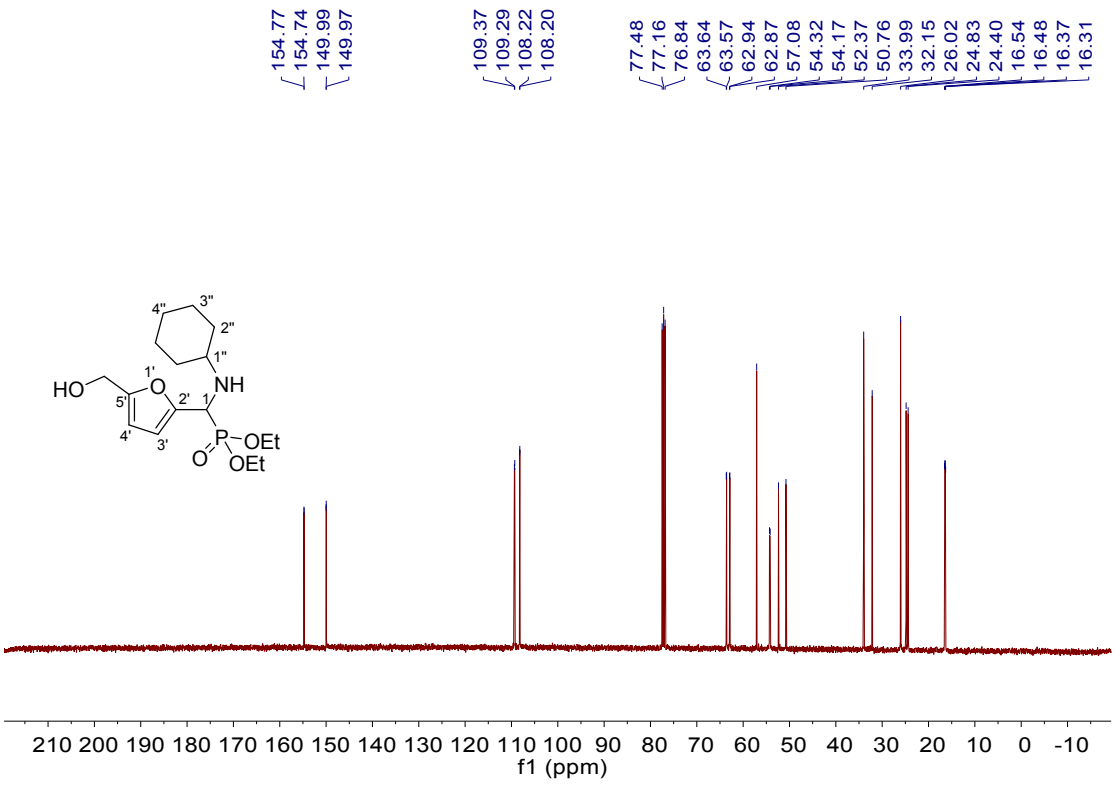


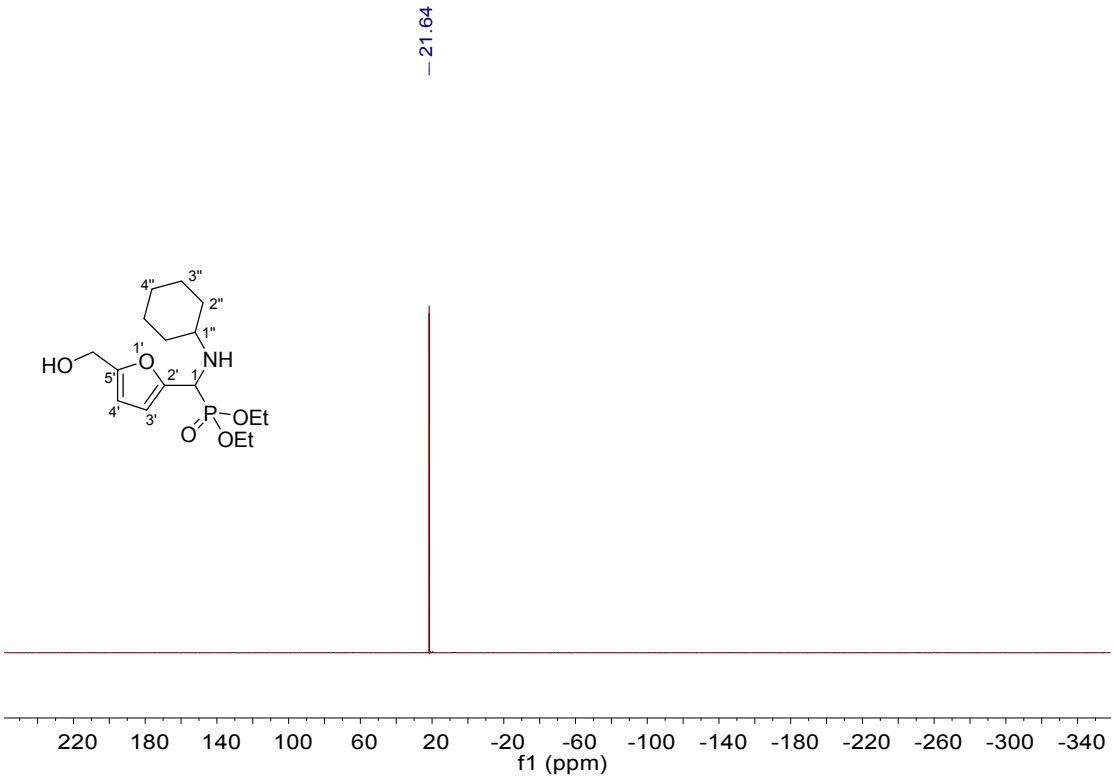

154.89
154.86
149.42
149.39
109.75
109.67
108.20
108.18
77.48
77.16
76.84
63.44
63.37
63.02
62.95
57.04
55.47
53.87
47.94
47.79
31.80
20.24
16.51
16.45
16.37
16.31
13.92
HO
1'
O
2'
1
NH
5'
4'
3'
P
OEt
O
OEt
210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10
f1 (ppm)


21.26
HO
1'
O
2'
1
NH
5'
4'
3'
P
OEt
O
OEt
90 80 70 60 50 40 30 20 10 0 -10 -20 -30 -40 -50 -60 -70 -80 -90
f1 (ppm)

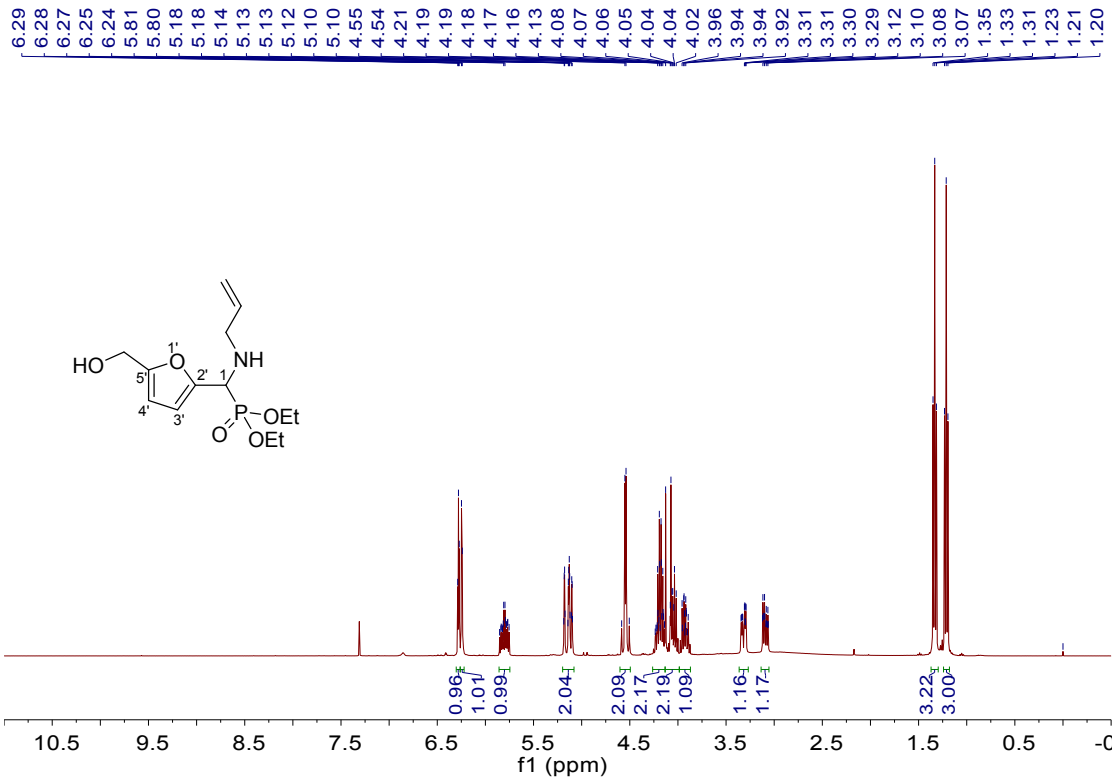
Diethyl ((cyclohexylamino)(5-(hydroxymethyl)furan-2-yl)methyl)phosphonate (4m)

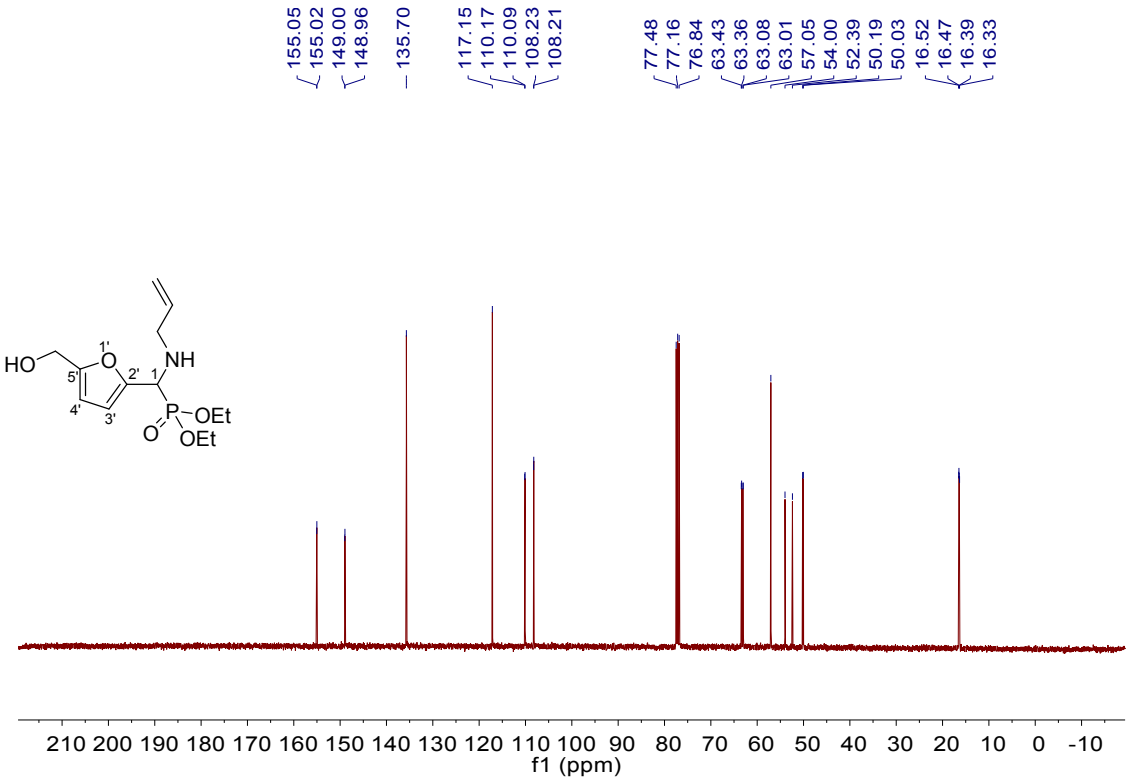


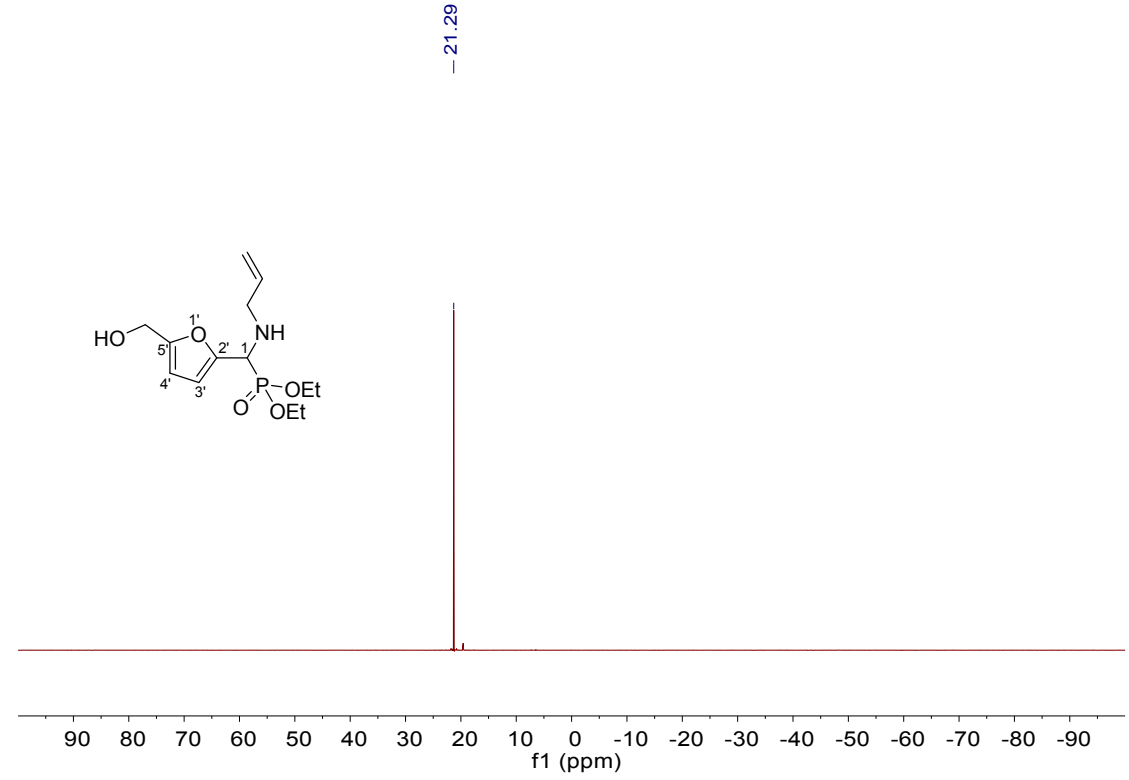




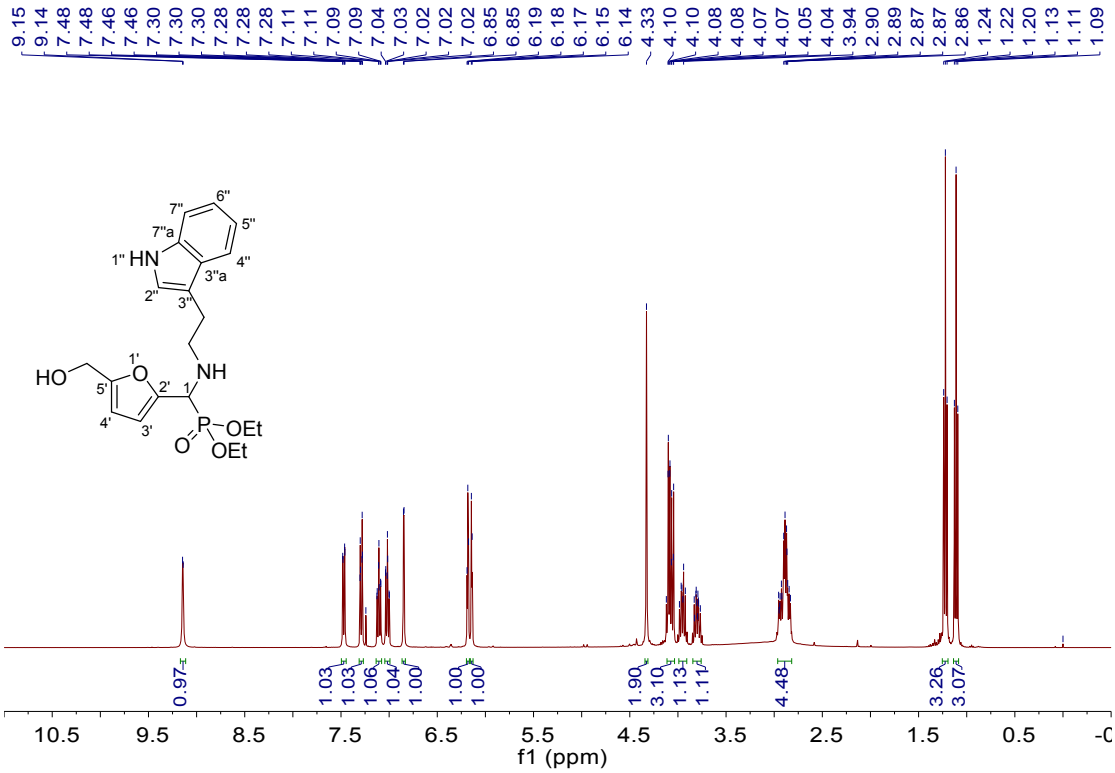
Diethyl ((allylamino)(5-(hydroxymethyl)furan-2-yl)methyl)phosphonate (4n)

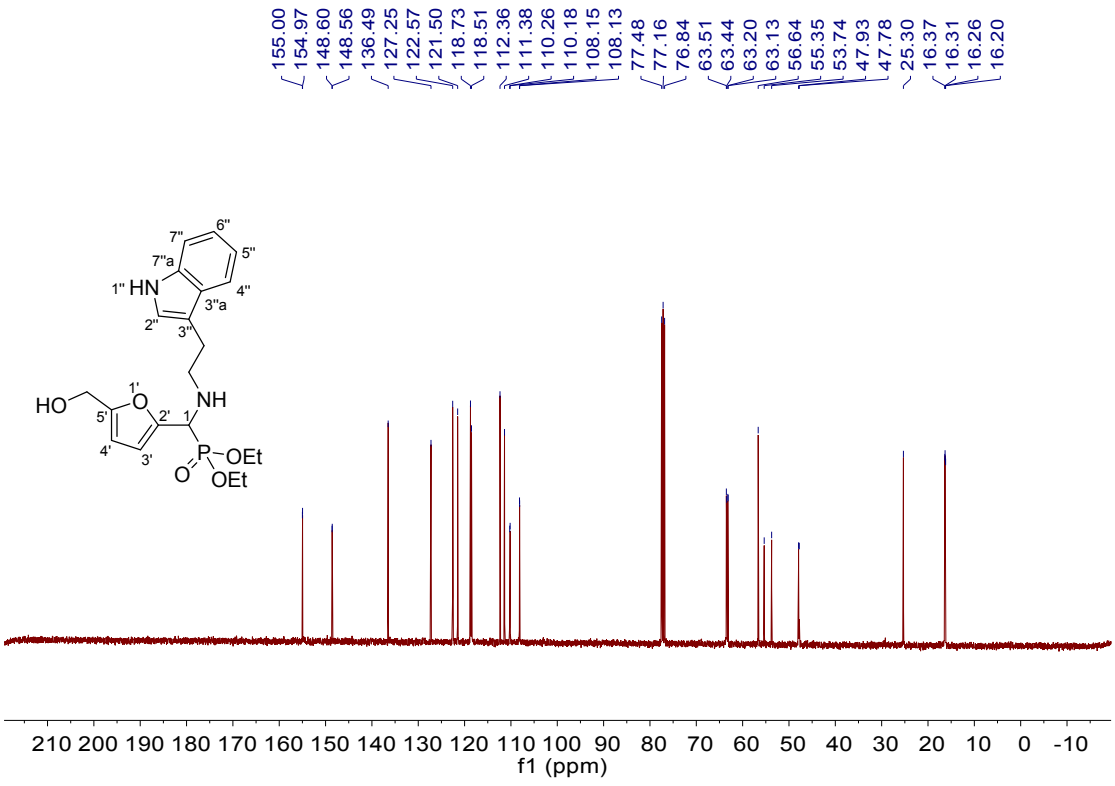


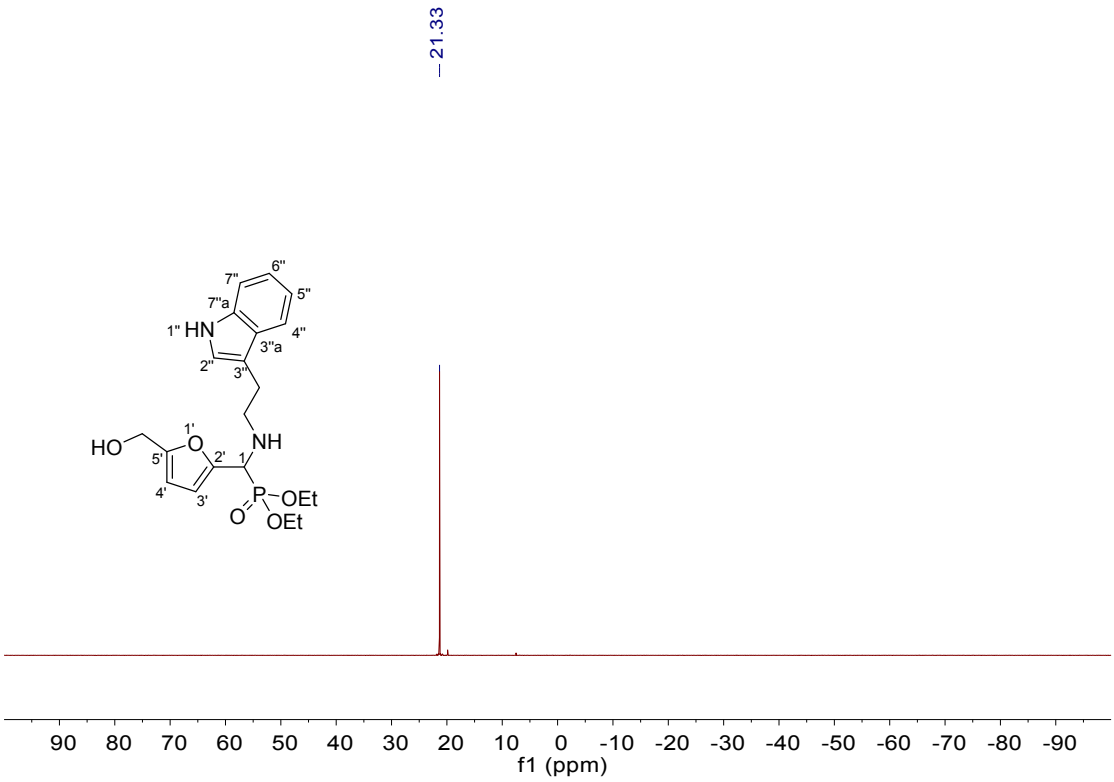

155.05
155.02
149.00
148.96
135.70
117.15
110.17
110.09
108.23
108.21
77.48
77.16
76.84
63.43
63.36
63.08
63.01
57.05
54.00
52.39
50.19
50.03
16.52
16.47
16.39
16.33
HO
1'
O
5'
2'
1
NH
4'
3'
P
OEt
O
OEt
210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10
f1 (ppm)


21.29
HO
1'
O
5'
2'
1
NH
4'
3'
P
OEt
O
OEt
90 80 70 60 50 40 30 20 10 0 -10 -20 -30 -40 -50 -60 -70 -80 -90
f1 (ppm)

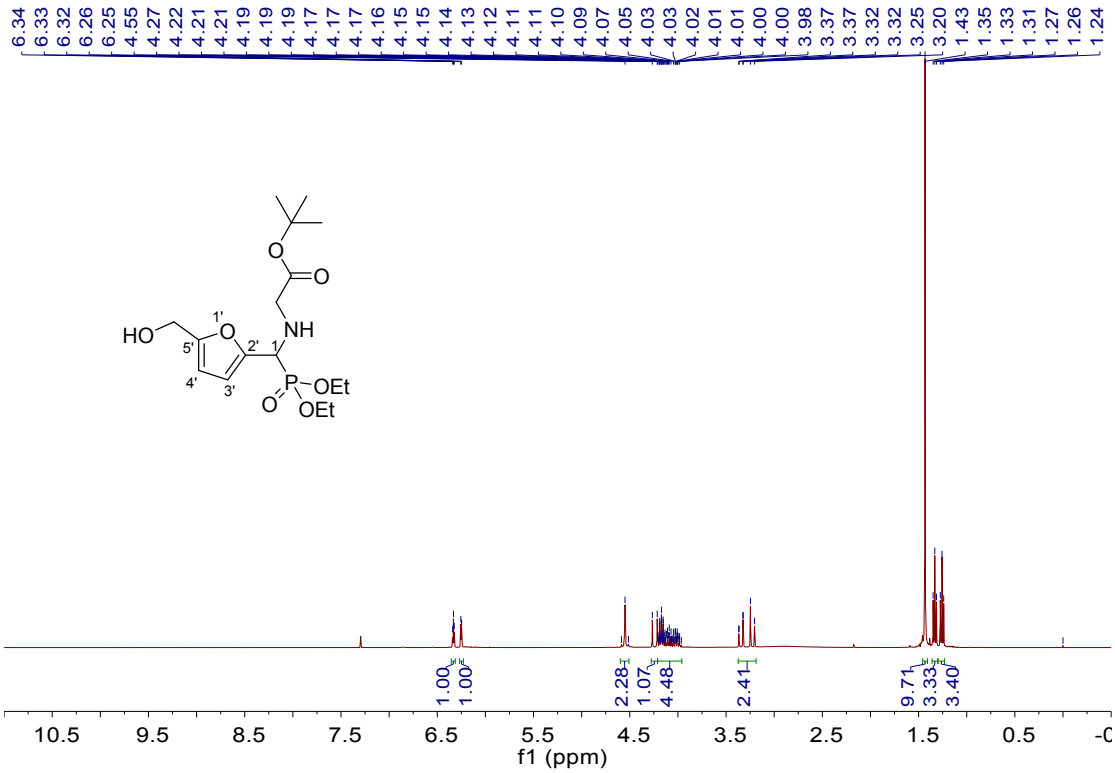
Diethyl (((2-(1H-indol-3-yl)ethyl)amino)(5-(hydroxymethyl)furan-2-yl)methyl)phosphonate (4o)

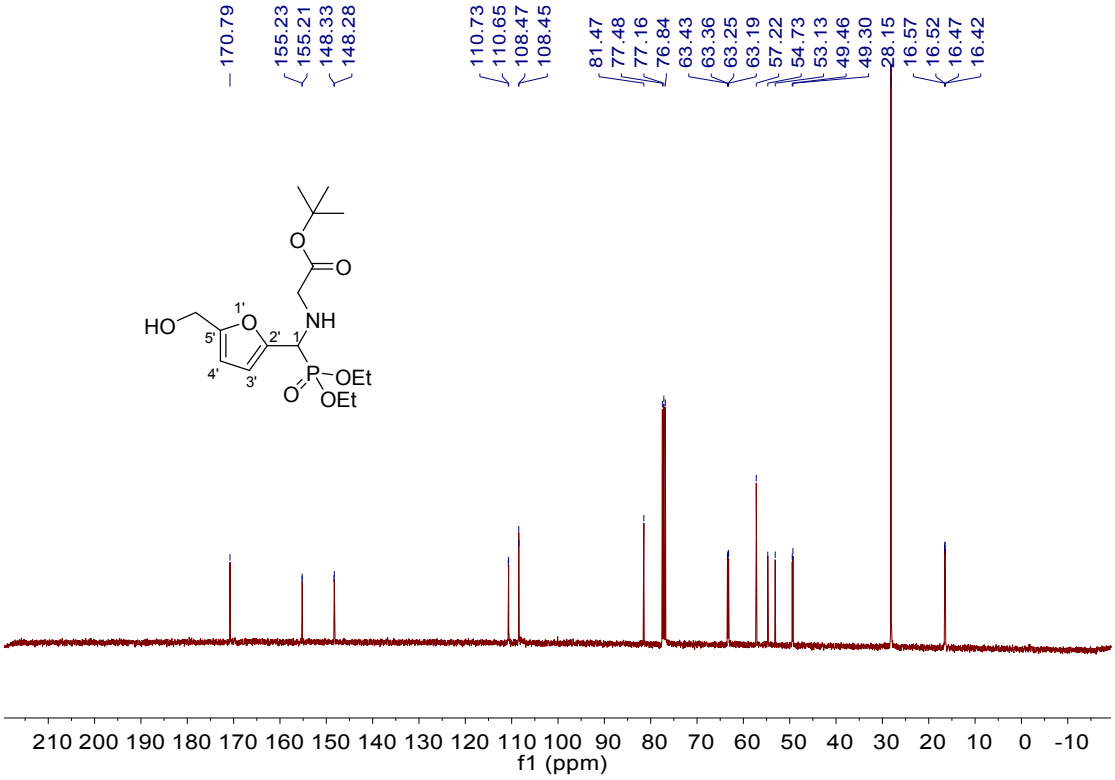


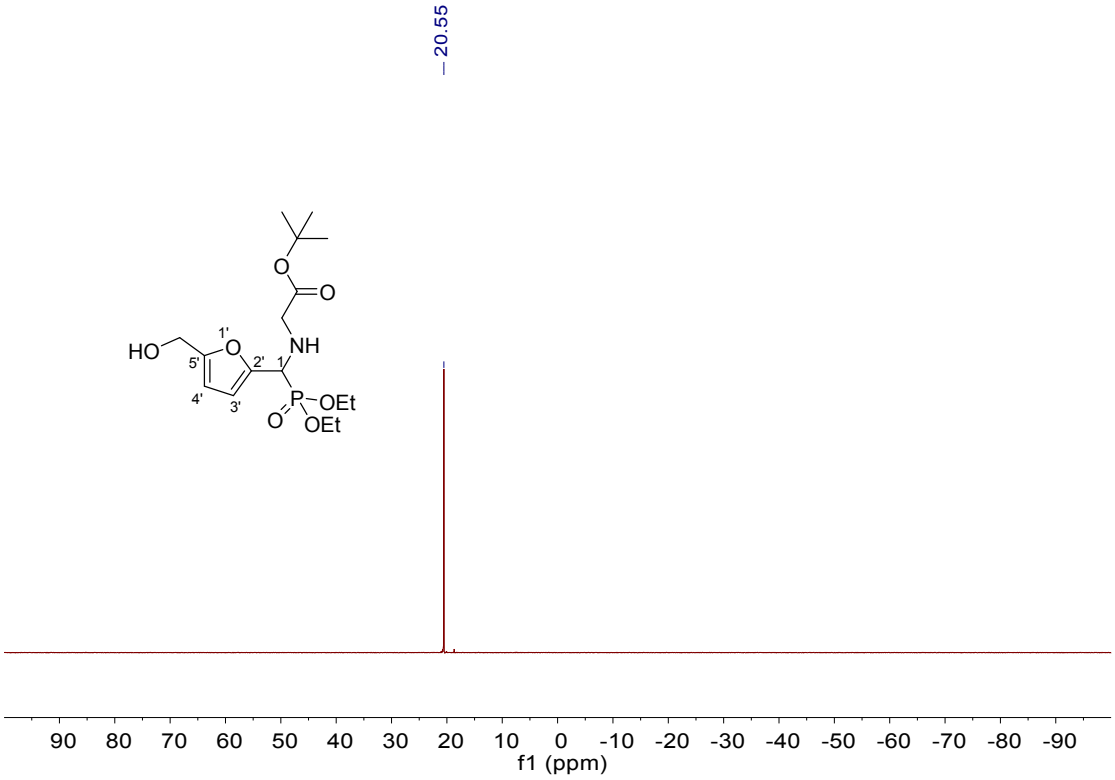




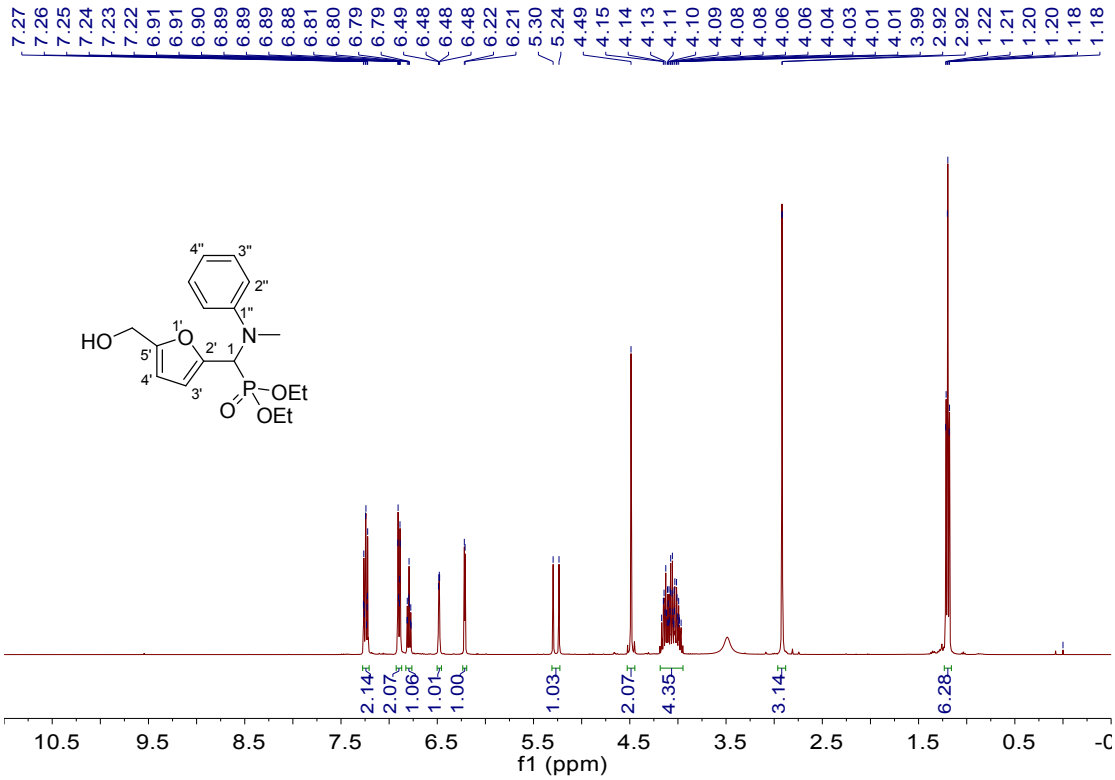
***tert*-Butyl ((diethoxyphosphoryl)(5-(hydroxymethyl)furan-2-yl)methyl)glycinate (4p)**

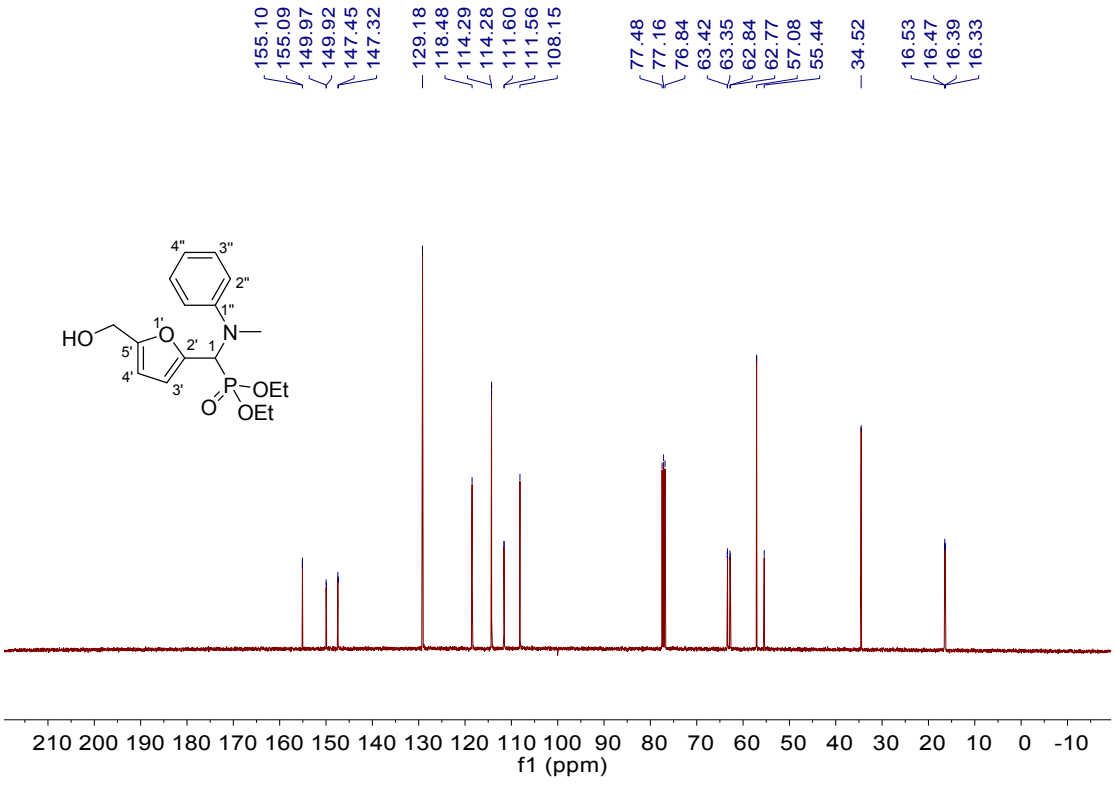


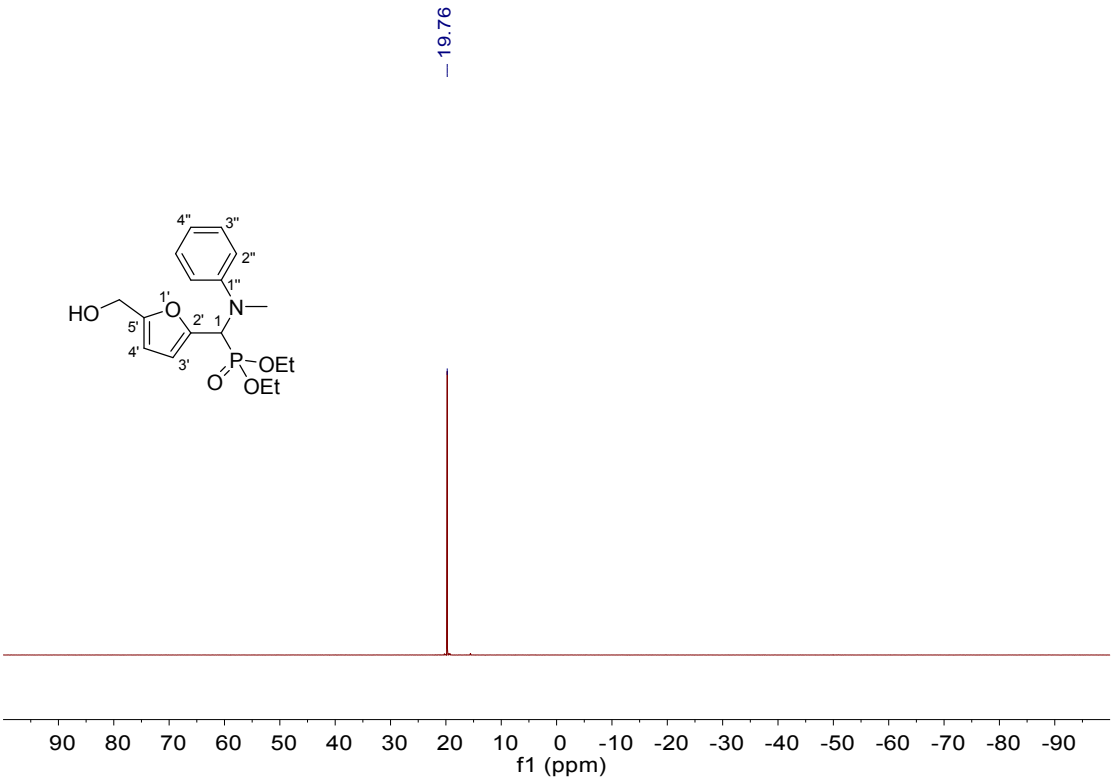

170.79
155.23
155.21
148.33
148.28
110.73
110.65
108.47
108.45
81.47
77.48
77.16
76.84
63.43
63.36
63.25
63.19
57.22
54.73
53.13
49.46
49.30
28.15
16.57
16.52
16.47
16.42
HO
O
NH
P
OEt
OEt
210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10
f1 (ppm)


20.55
HO
O
NH
P
OEt
OEt
90 80 70 60 50 40 30 20 10 0 -10 -20 -30 -40 -50 -60 -70 -80 -90
f1 (ppm)

Diethyl ((5-(hydroxymethyl)furan-2-yl)(methyl(phenyl)amino)methyl)phosphonate (4q)

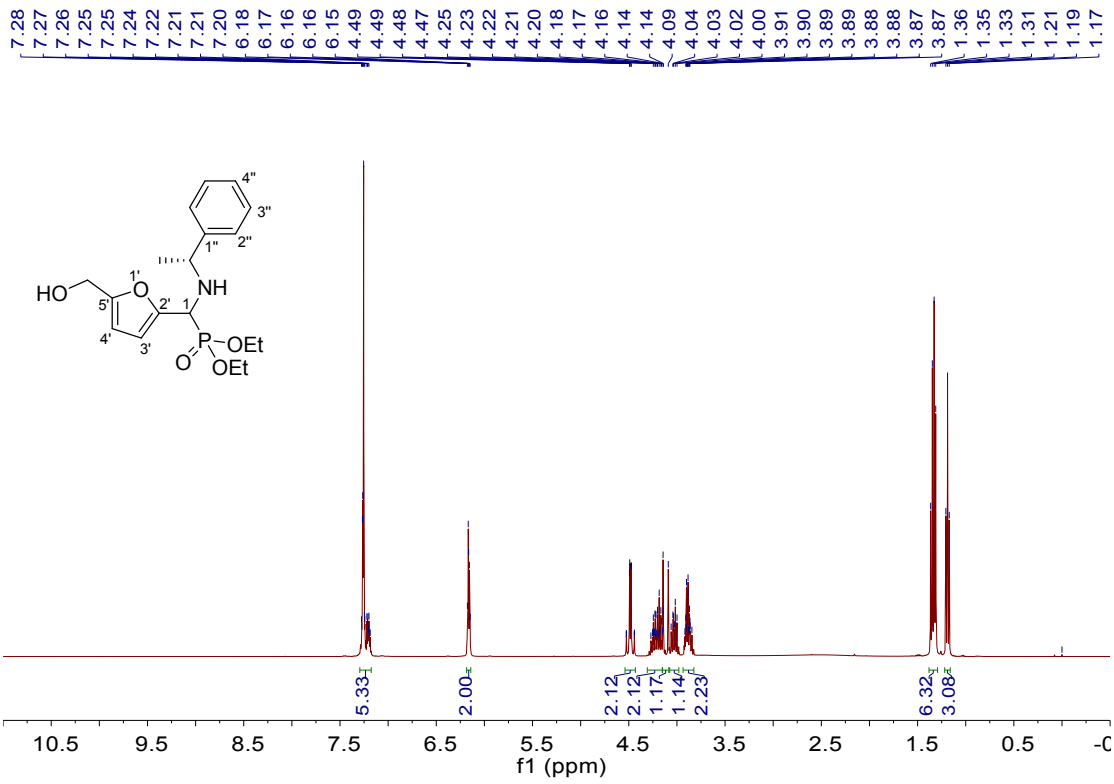


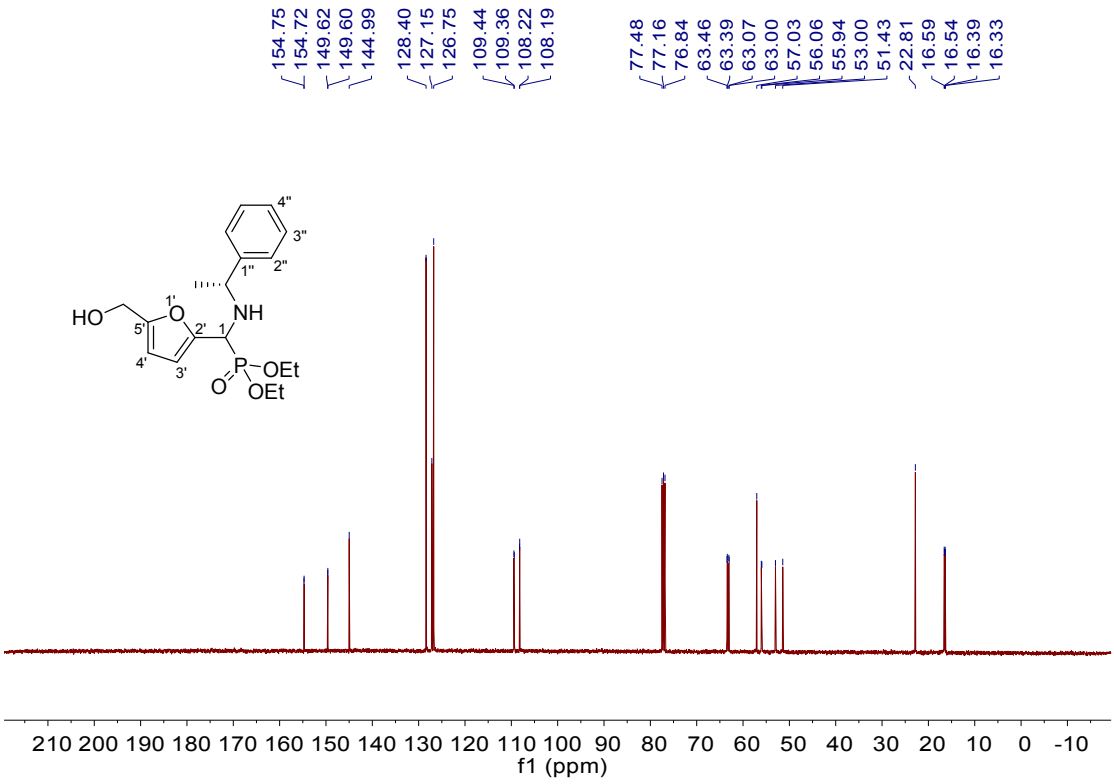


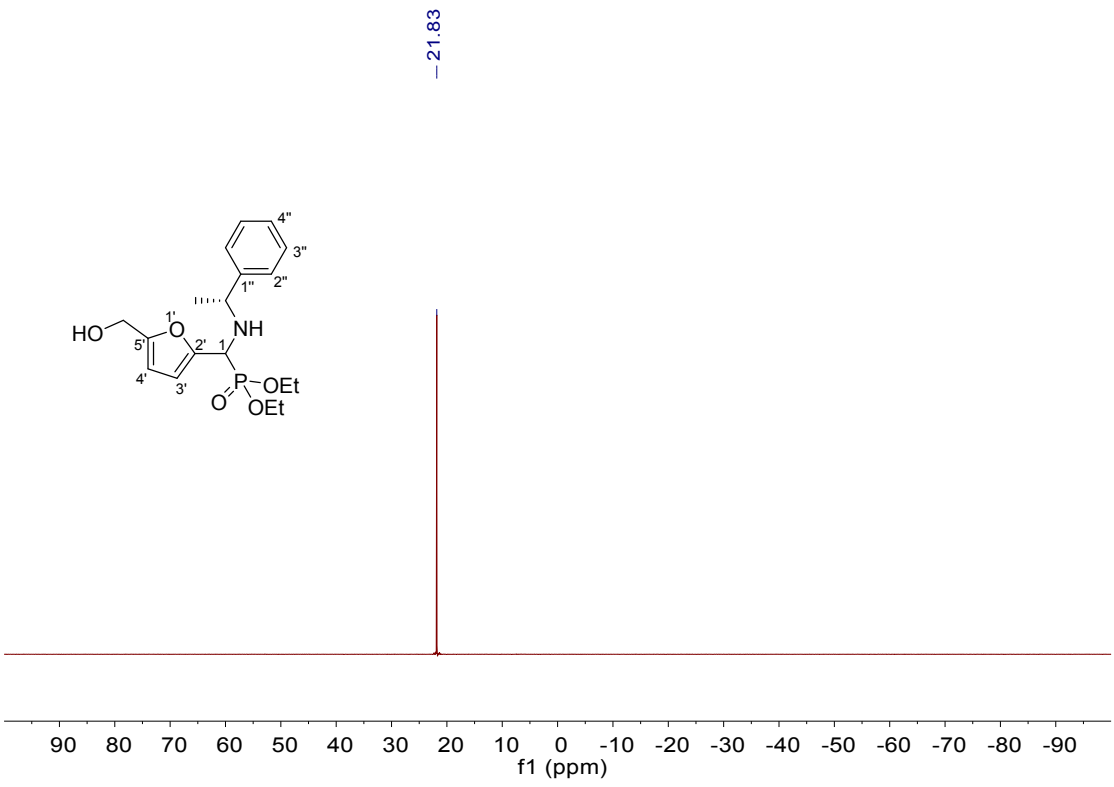


Diethyl ((5-(hydroxymethyl)furan-2-yl)(((R)-1-phenylethyl)amino)methyl)phosphonate (4r)

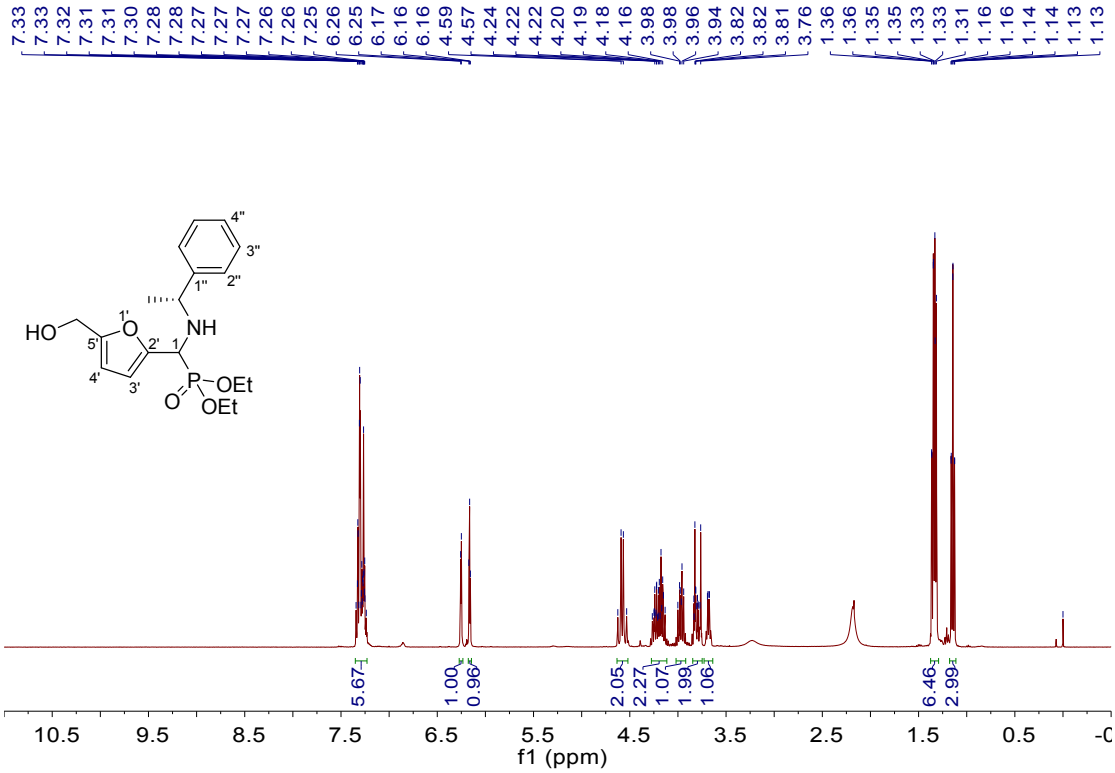
Diastereoisomer A:

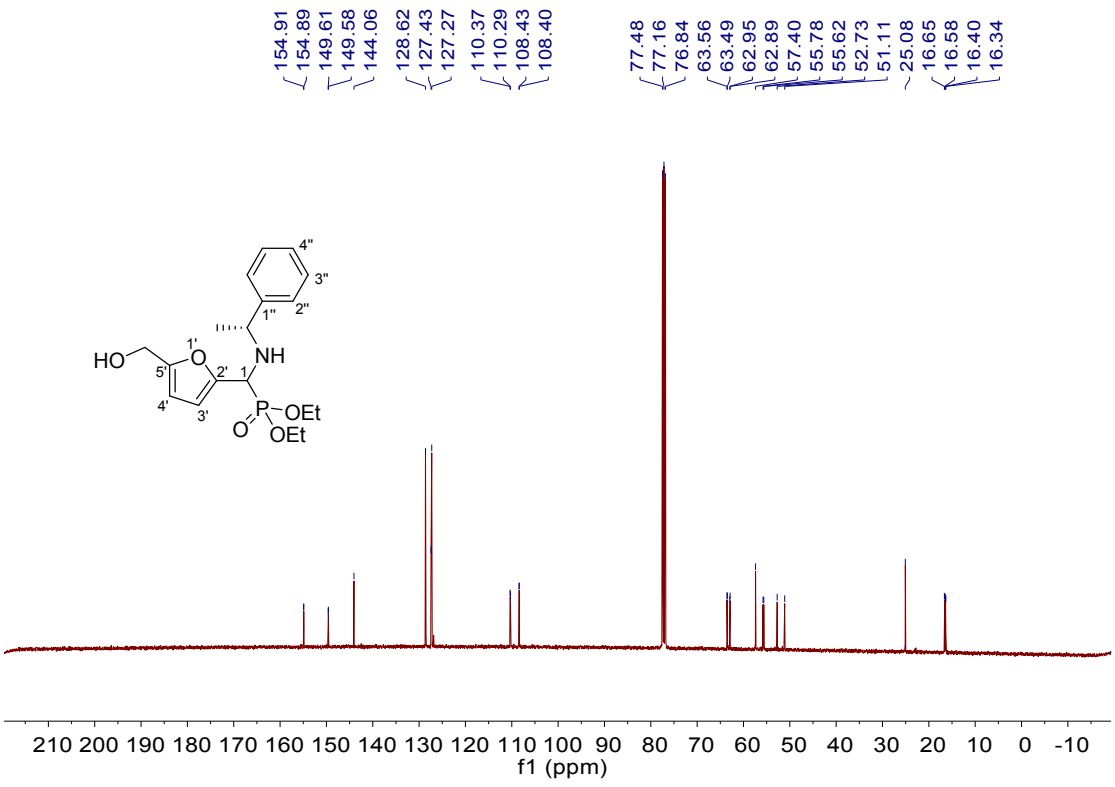


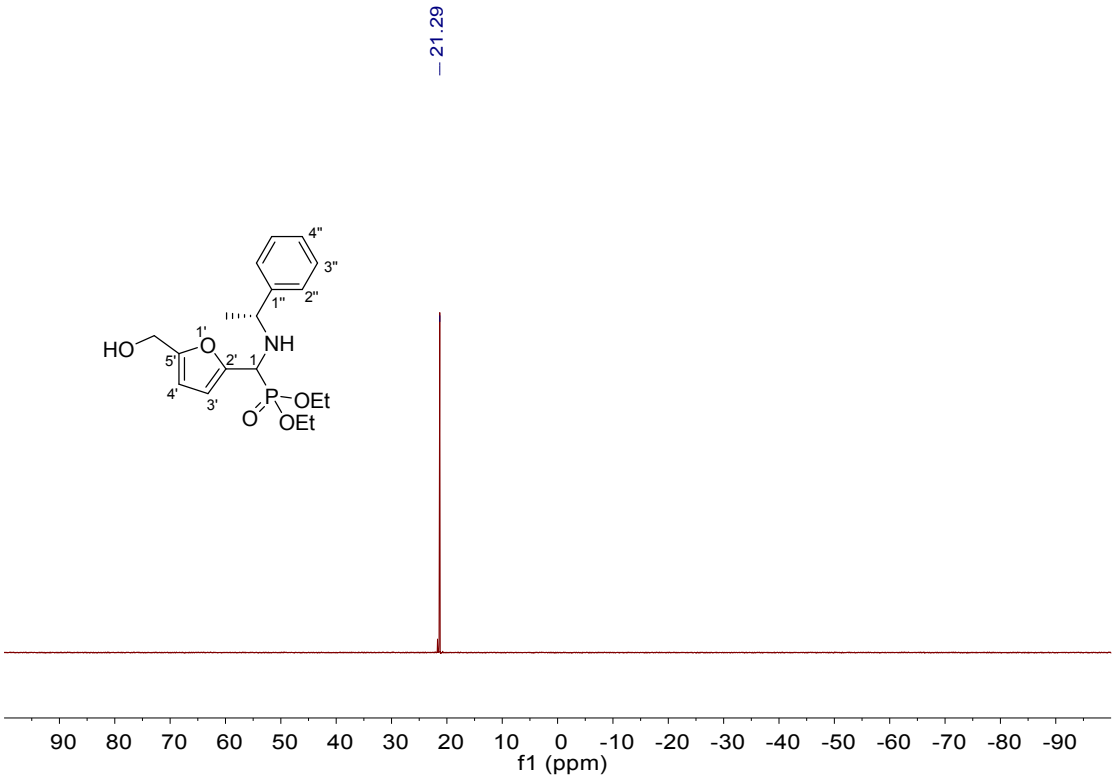

154.75
154.72
149.62
149.60
144.99
128.40
127.15
126.75
109.44
109.36
108.22
108.19
77.48
77.16
76.84
63.46
63.39
63.07
63.00
57.03
56.06
55.94
53.00
51.43
22.81
16.59
16.54
16.39
16.33
HO
O
NH
P
OEt
OEt
f1 (ppm)


21.83
HO
O
NH
P
OEt
OEt
f1 (ppm)

Diastereoisomer B:

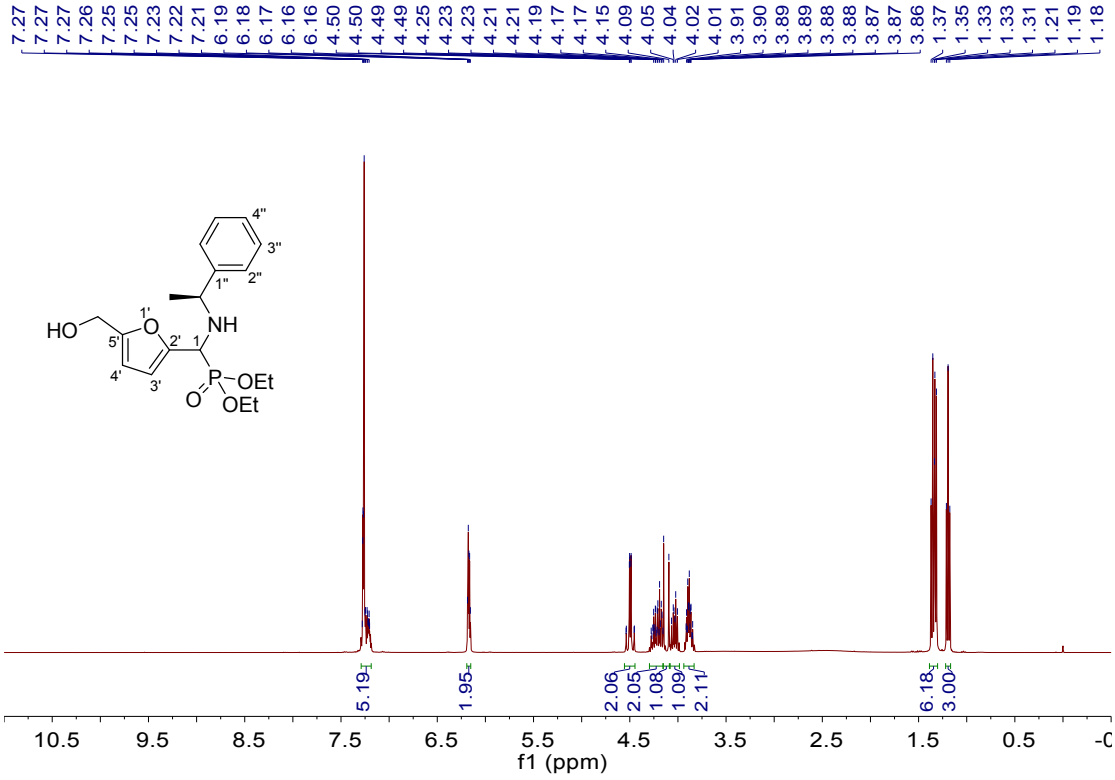


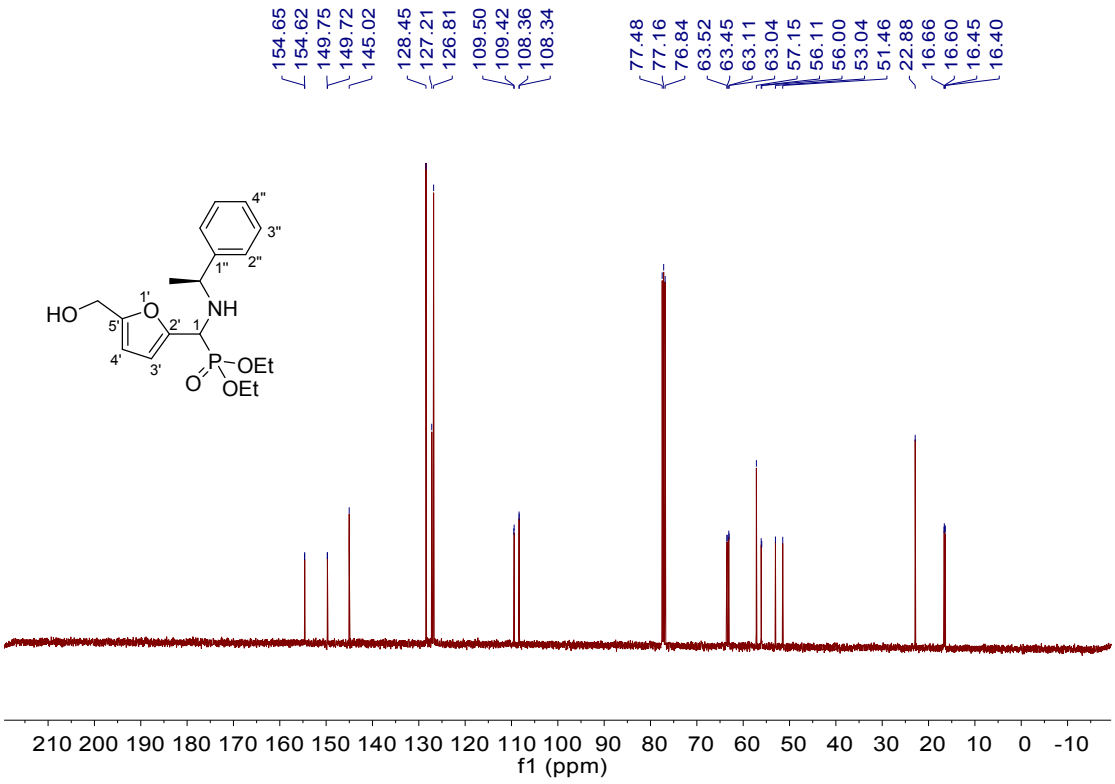


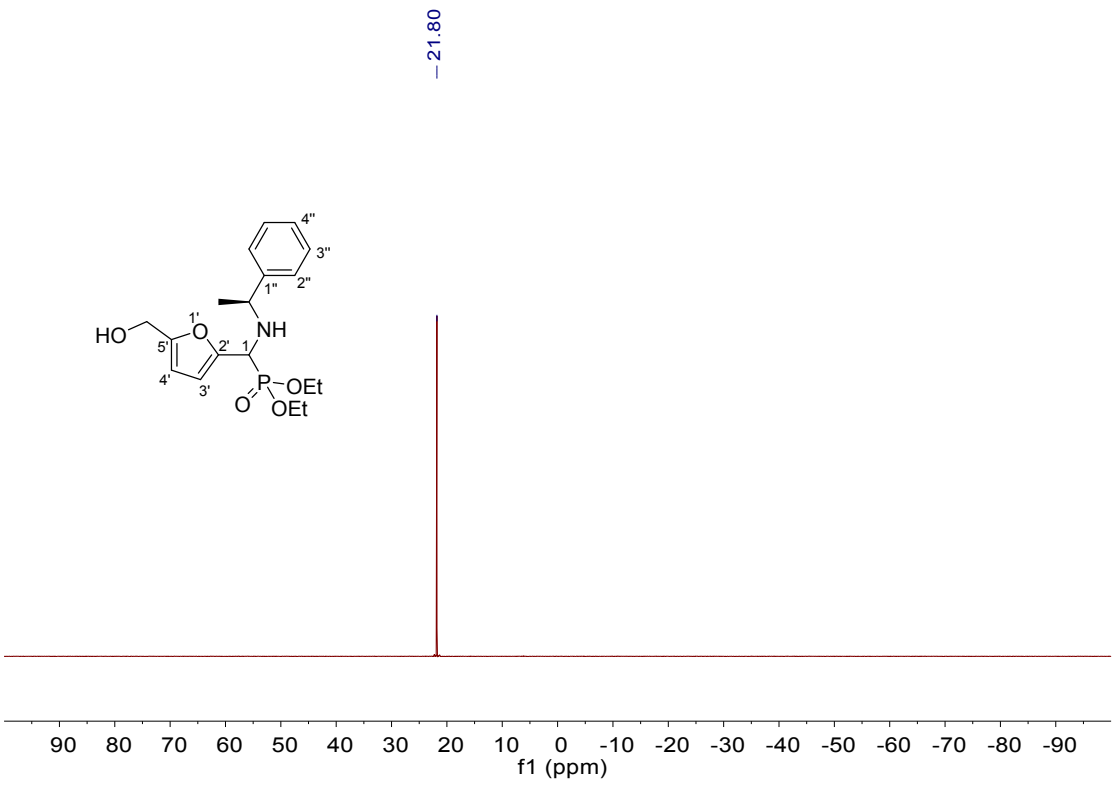


Diethyl ((5-(hydroxymethyl)furan-2-yl)(((S)-1-phenylethyl)amino)methyl)phosphonate (4s)

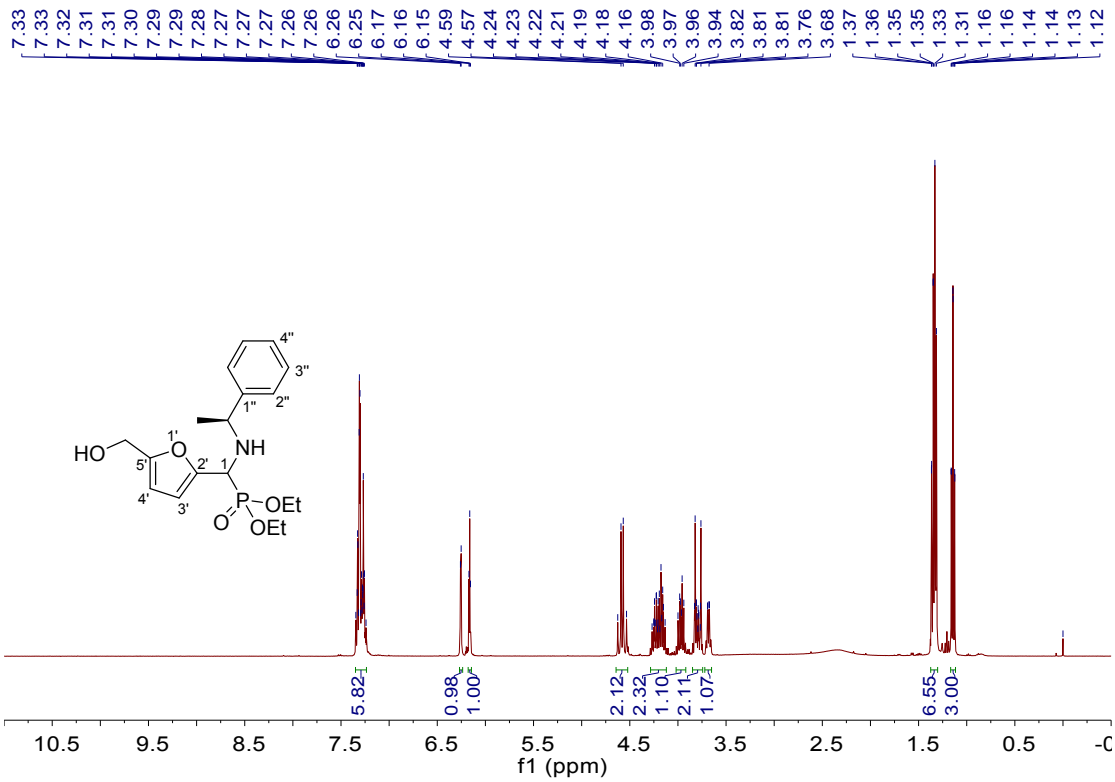
Diastereoisomer A:

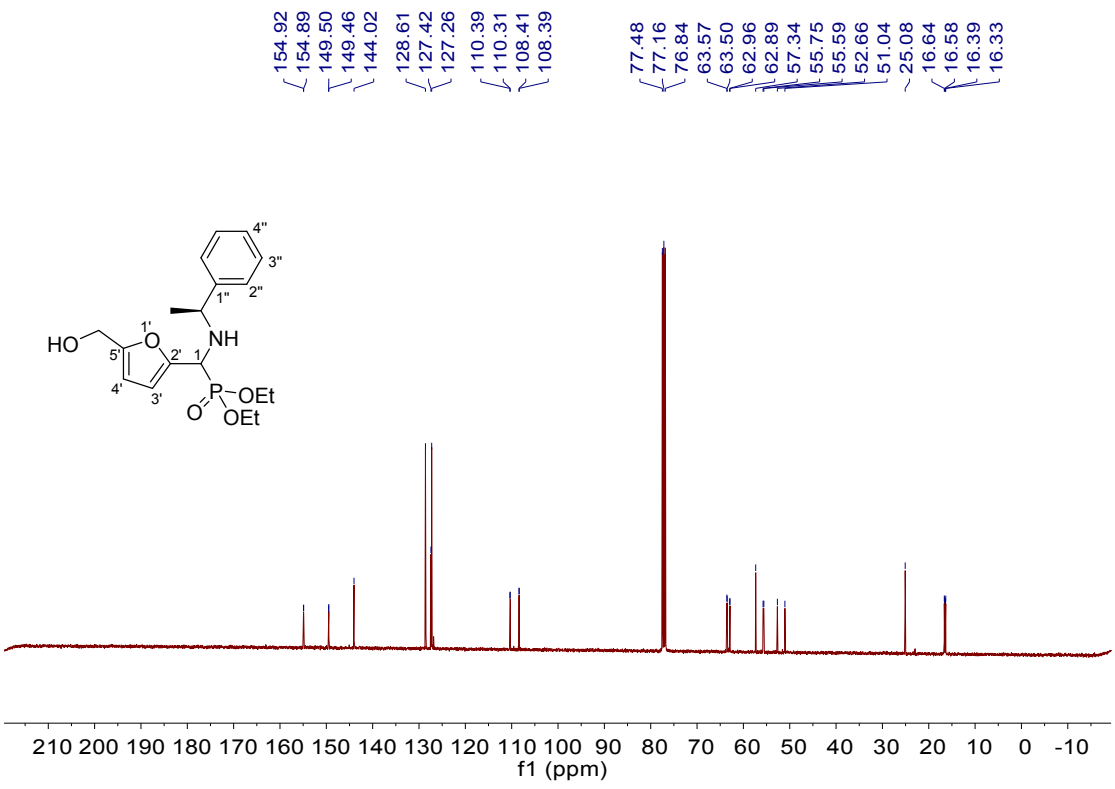


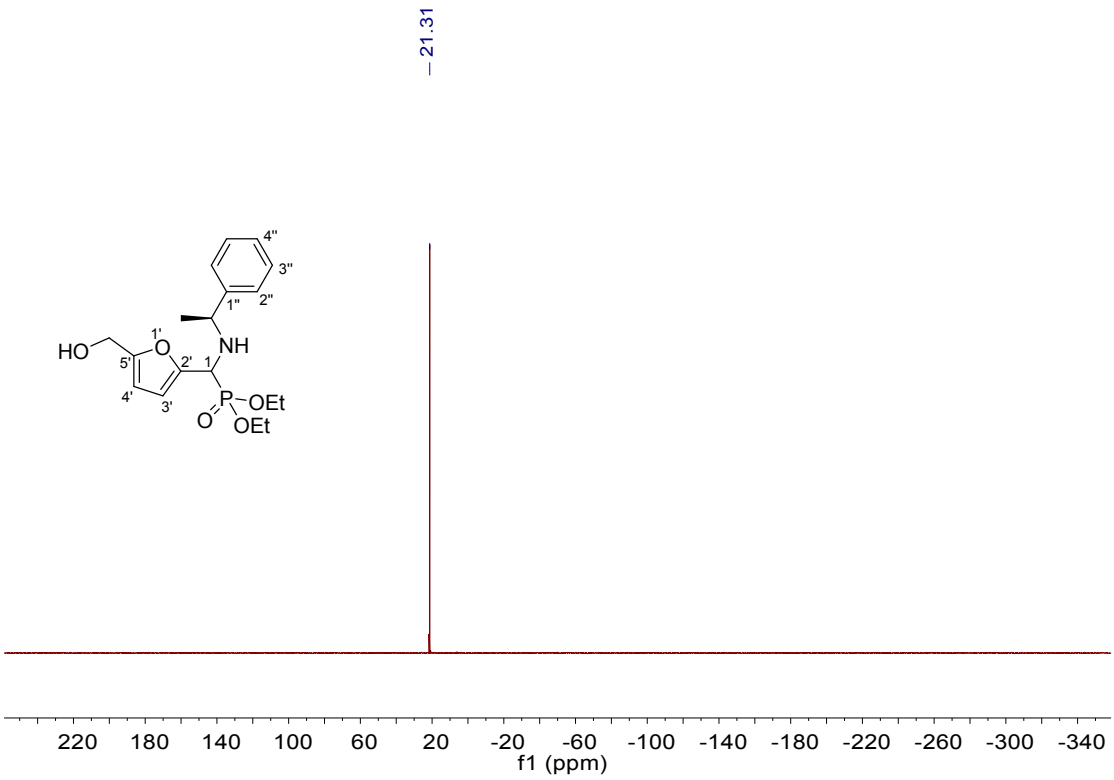

154.65
154.62
149.75
149.72
145.02
128.45
127.21
126.81
109.50
109.42
108.36
108.34
77.48
77.16
76.84
63.52
63.45
63.11
63.04
57.15
56.11
56.00
53.04
51.46
22.88
16.66
16.60
16.45
16.40
HO
NH
OEt
OEt
210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10
f1 (ppm)


21.80
HO
NH
OEt
OEt
90 80 70 60 50 40 30 20 10 0 -10 -20 -30 -40 -50 -60 -70 -80 -90
f1 (ppm)

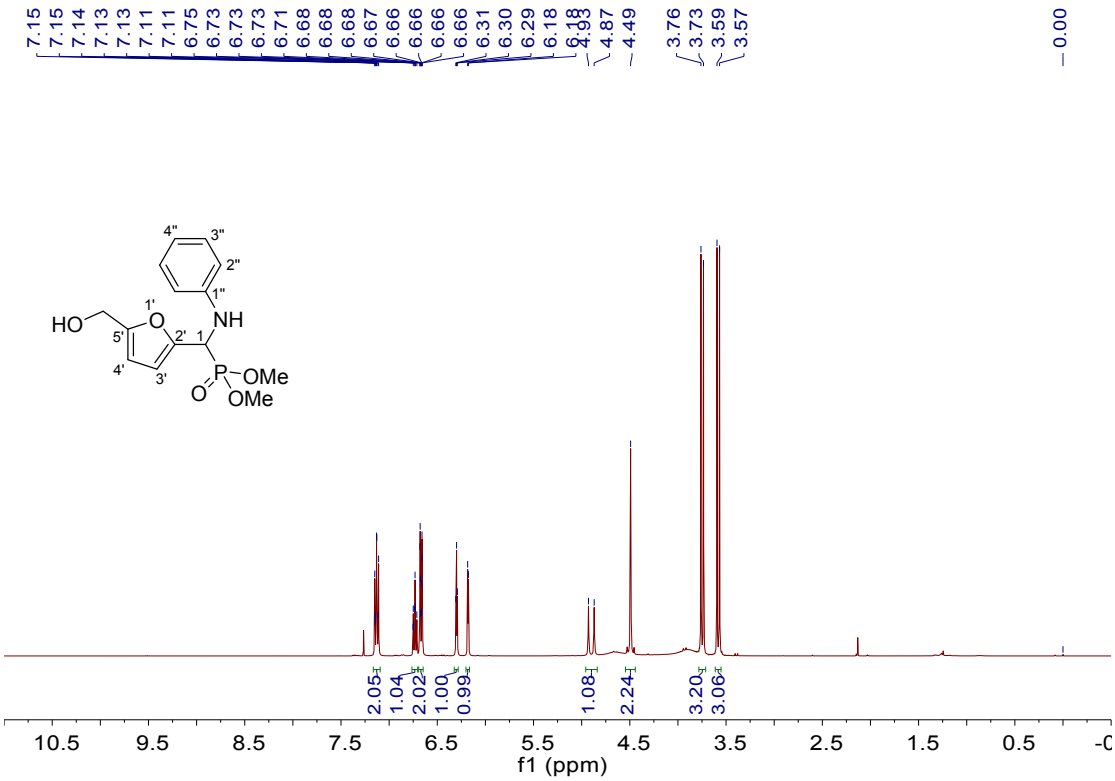
Diastereoisomer B:

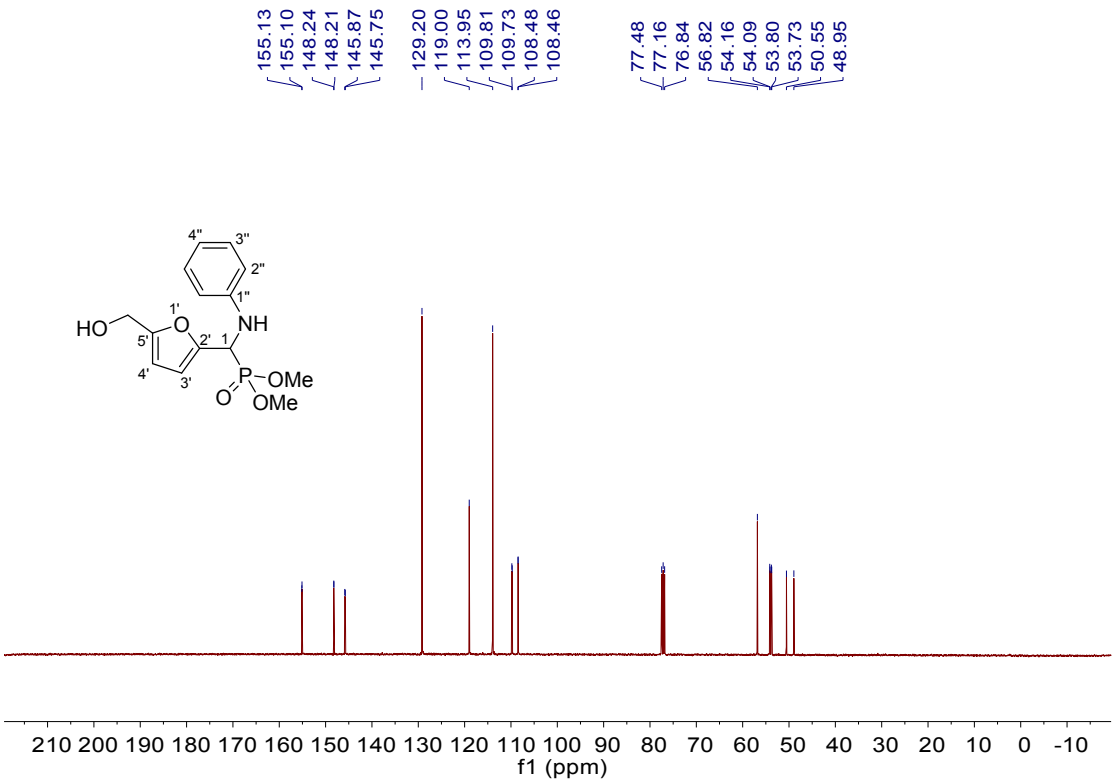


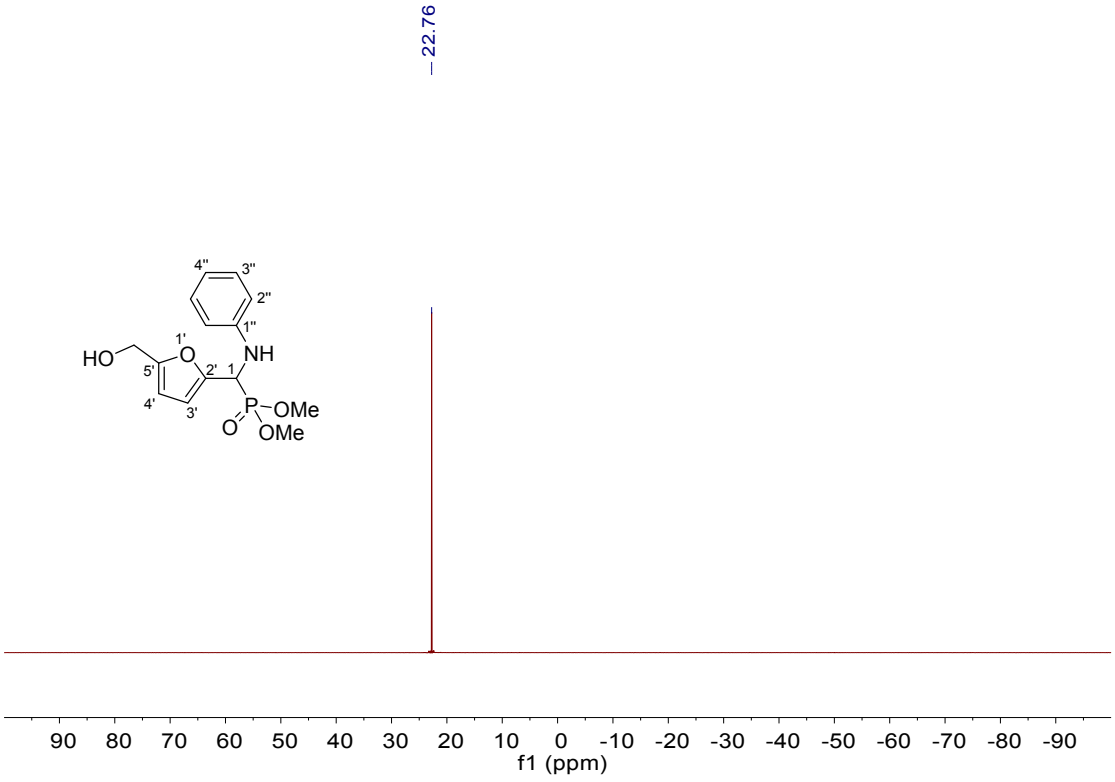




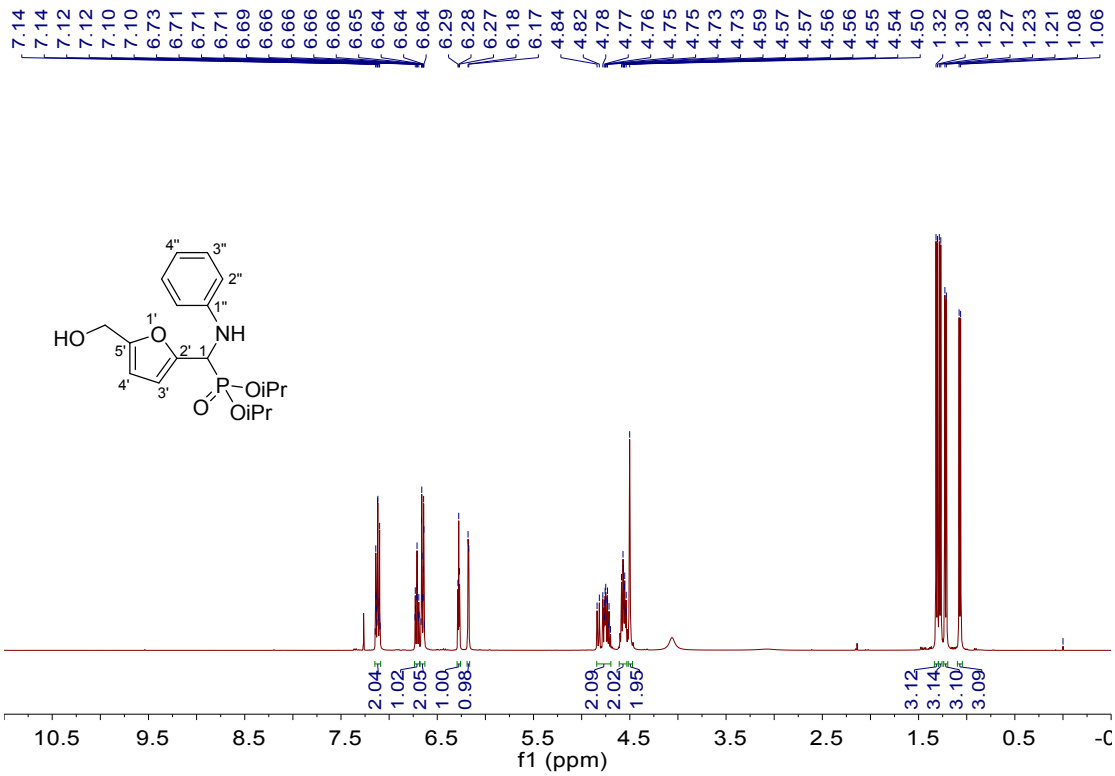
Dimethyl ((5-(hydroxymethyl)furan-2-yl)(phenylamino)methyl)phosphonate (4t)

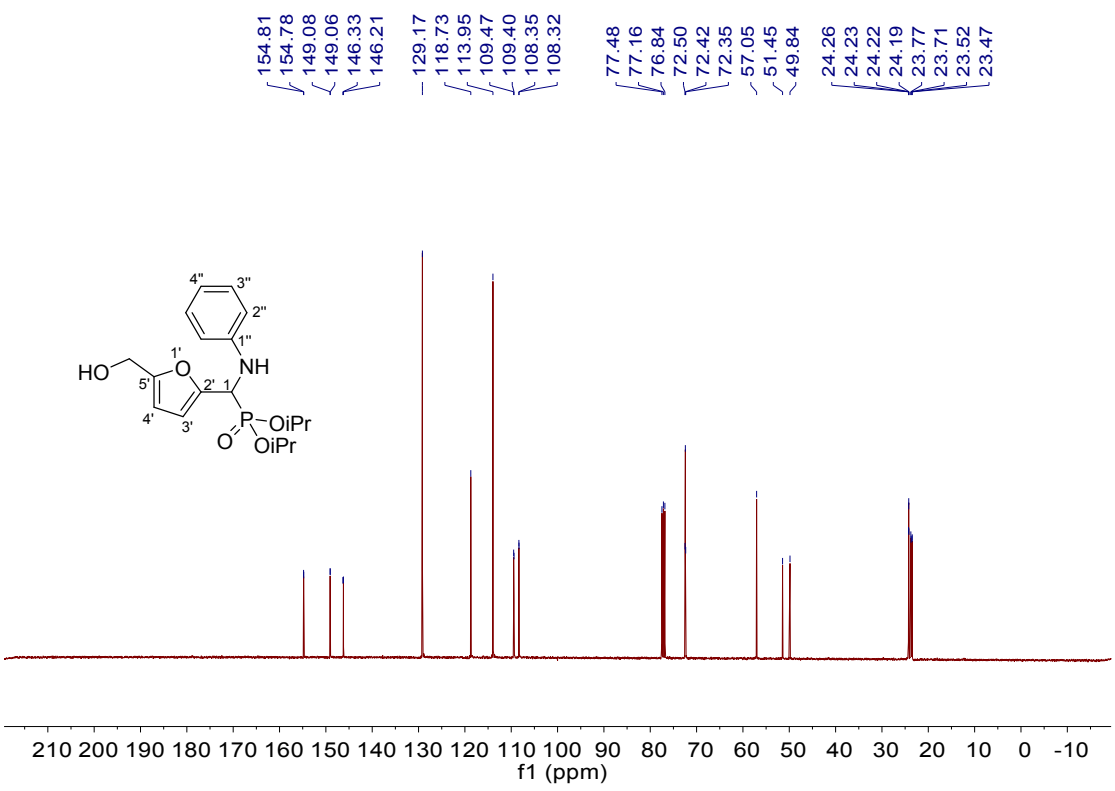


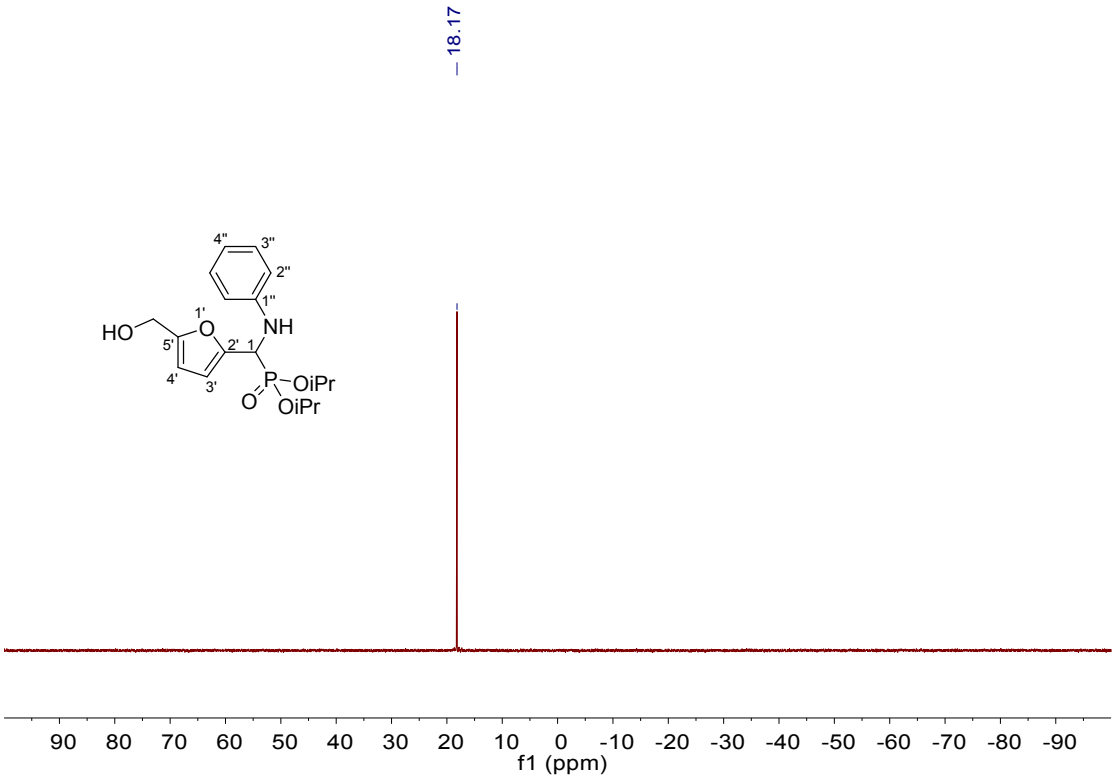




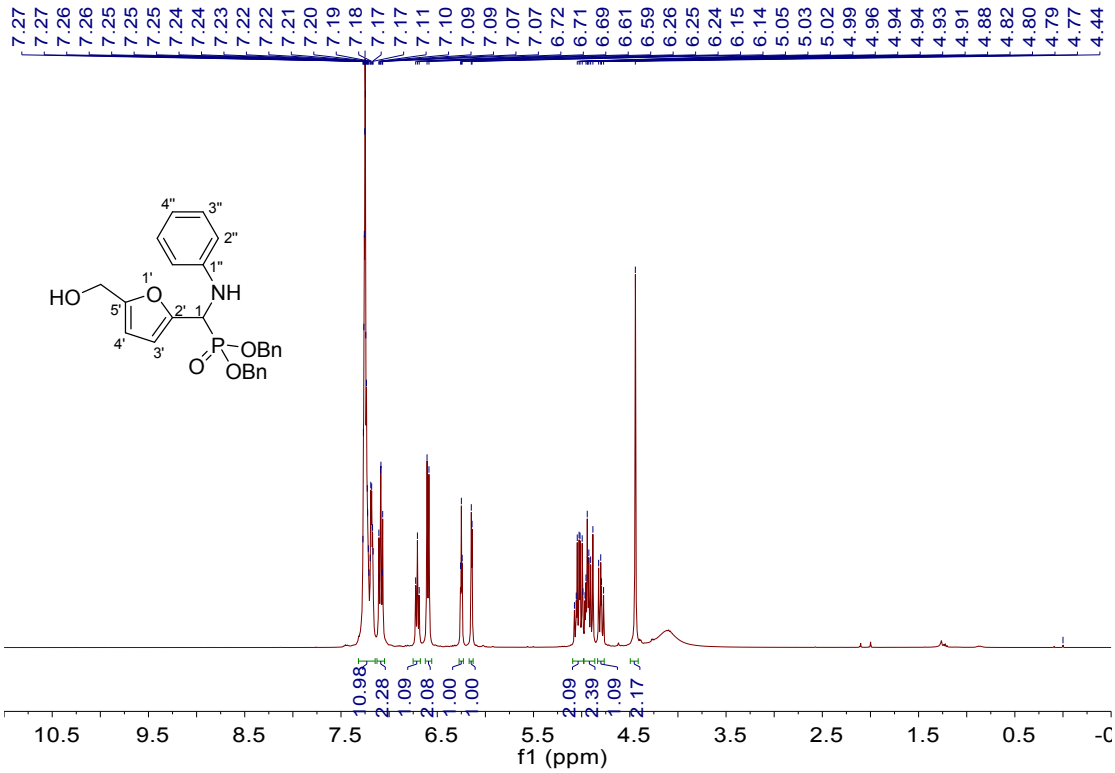
Diisopropyl ((5-(hydroxymethyl)furan-2-yl)(phenylamino)methyl)phosphonate (4u)

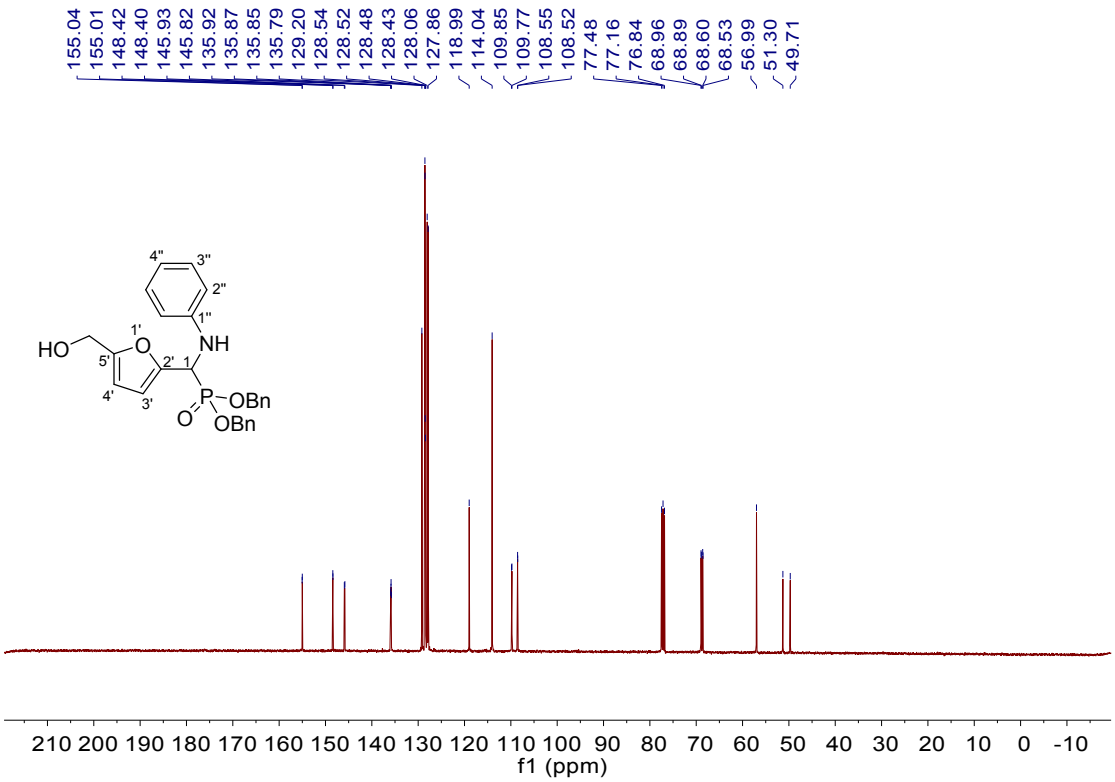

7.14 7.14 7.12 7.12 7.10 7.10 6.73 6.71 6.71 6.71 6.69 6.66 6.66 6.66 6.66 6.65 6.64 6.64 6.64 6.29 6.28 6.27 6.18 6.17 4.84 4.82 4.78 4.77 4.76 4.75 4.75 4.73 4.73 4.59 4.57 4.57 4.56 4.56 4.55 4.54 4.50 1.32 1.30 1.28 1.27 1.23 1.21 1.08 1.06
HO
NH
OiPr
OiPr
2.04 1.02 2.05 1.00 0.98 2.09 2.02 1.95 3.12 3.14 3.10 3.09
10.5 9.5 8.5 7.5 6.5 5.5 4.5 3.5 2.5 1.5 0.5
f1 (ppm)

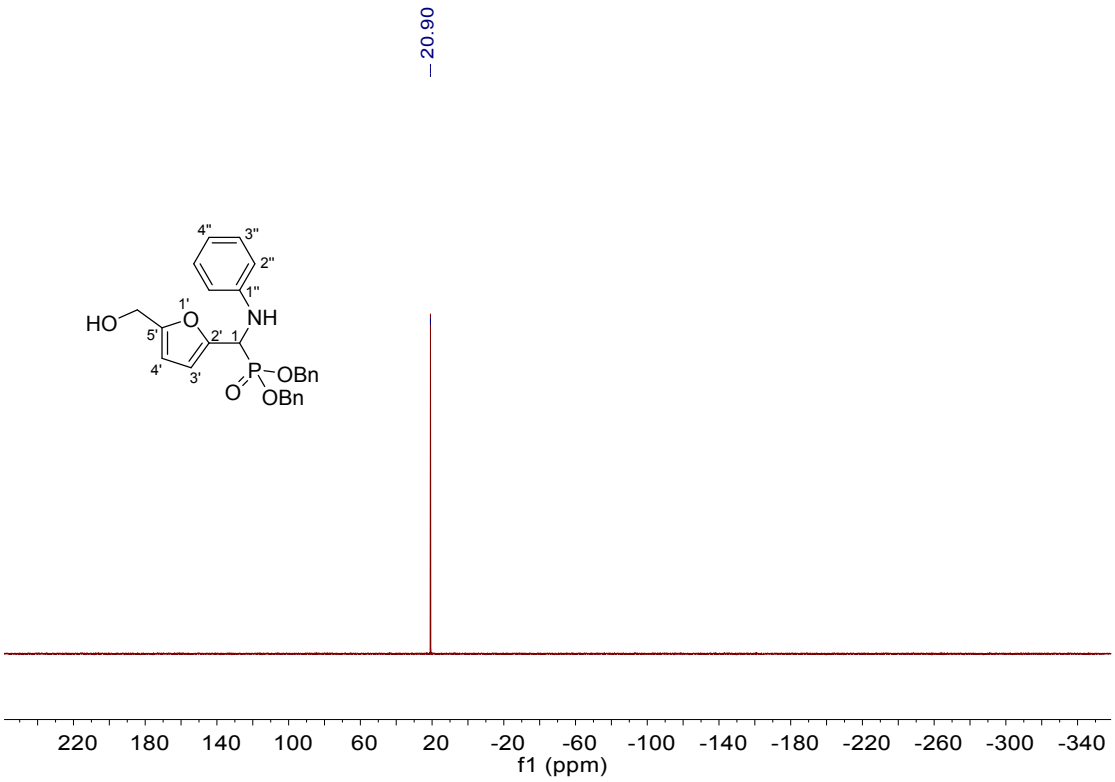

154.81 154.78 149.08 149.06 146.33 146.21 129.17 118.73 113.95 109.47 109.40 108.35 108.32 77.48 77.16 76.84 72.50 72.42 72.35 57.05 51.45 49.84 24.26 24.23 24.22 24.19 23.77 23.71 23.52 23.47
HO
NH
OiPr
OiPr
210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10
f1 (ppm)



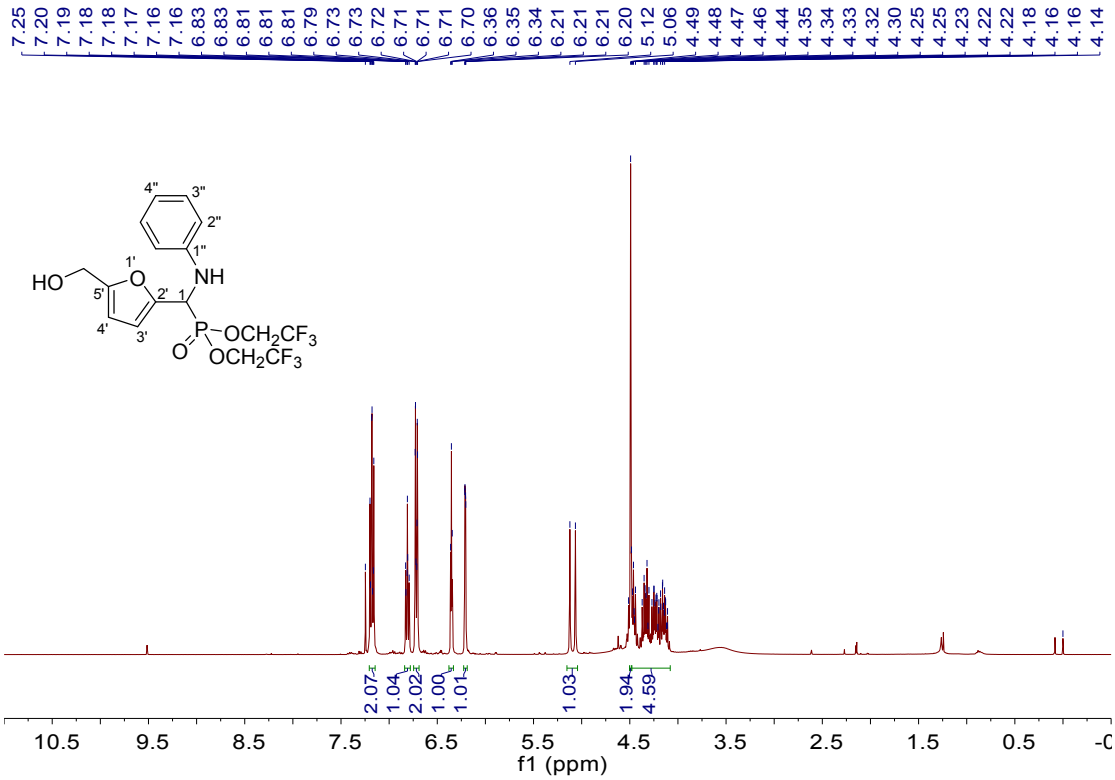
Dibenzyl ((5-(hydroxymethyl)furan-2-yl)(phenylamino)methyl)phosphonate (4v)

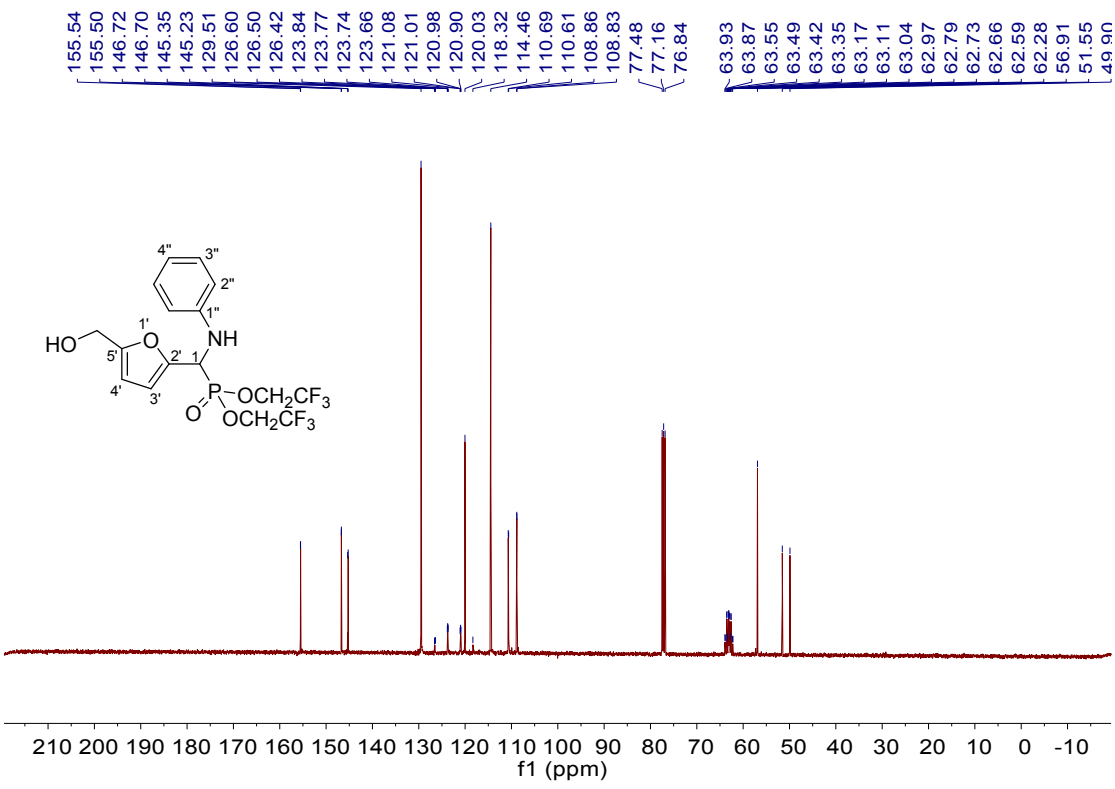


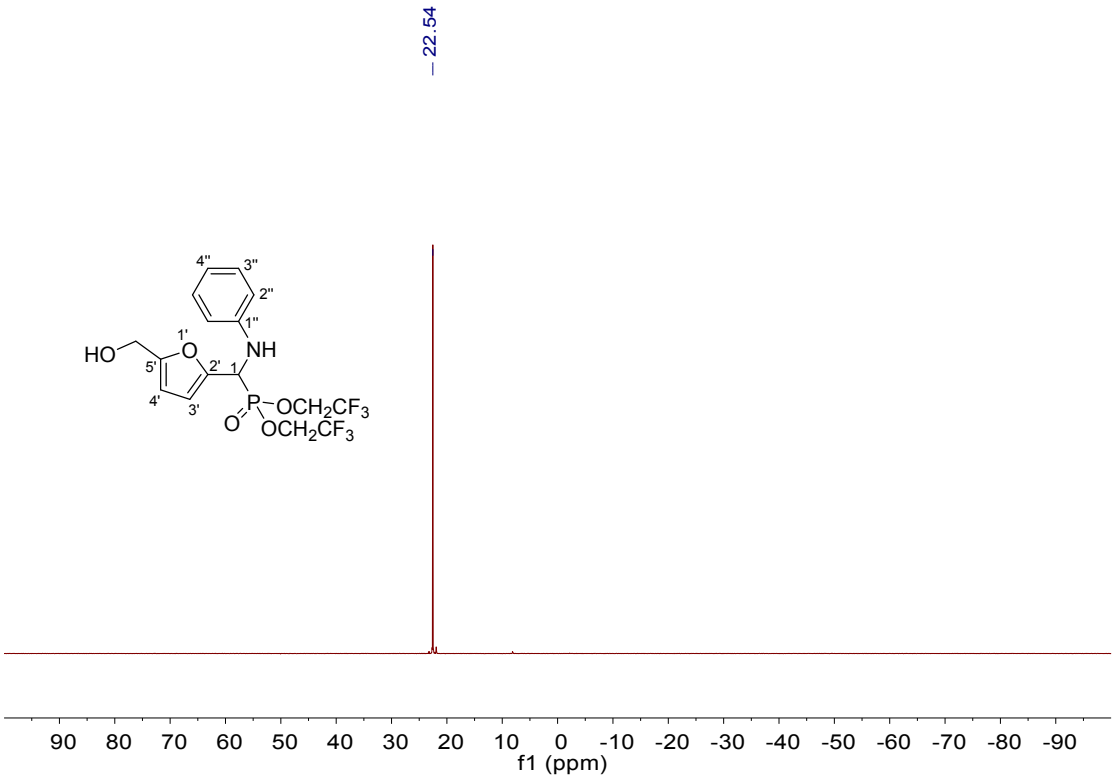

155.04
155.01
148.42
148.40
145.93
145.82
135.92
135.87
135.85
135.79
129.20
128.54
128.52
128.48
128.43
128.06
127.86
118.99
114.04
109.85
109.77
108.55
108.52
77.48
77.16
76.84
68.96
68.89
68.60
68.53
56.99
51.30
49.71
HO
NH
OBn
OBn
210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10
f1 (ppm)


20.90
HO
NH
OBn
OBn
220 180 140 100 60 20 -20 -60 -100 -140 -180 -220 -260 -300 -340
f1 (ppm)

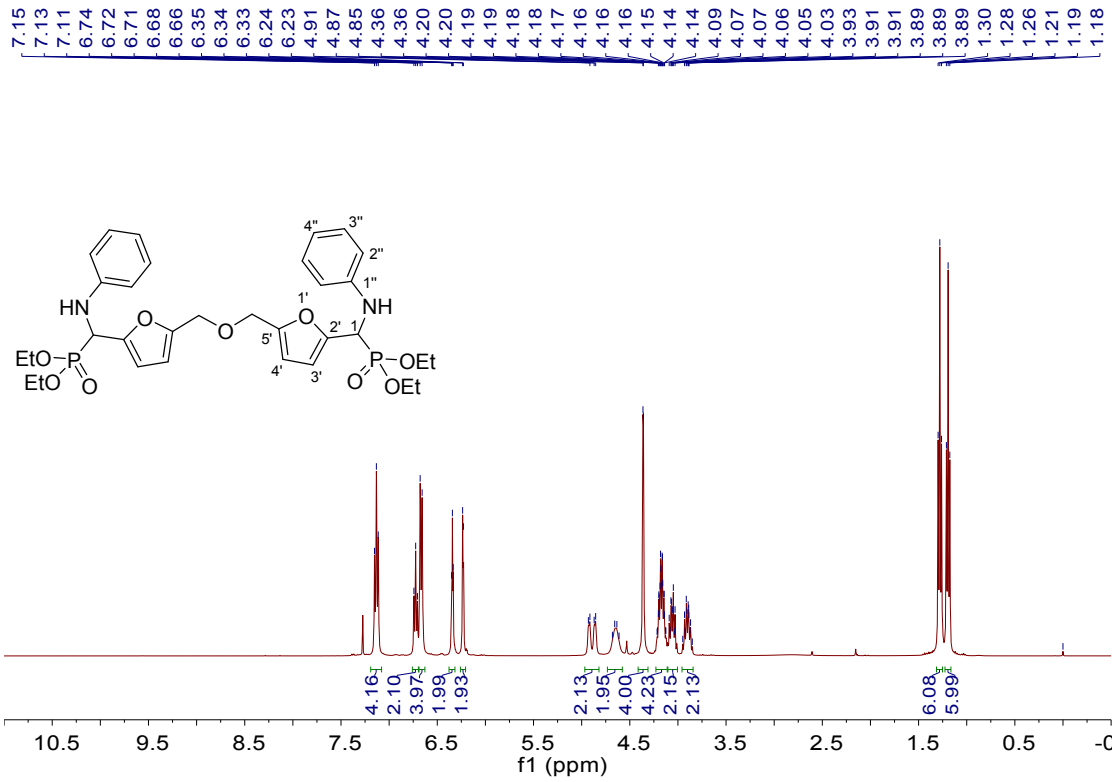
Bis(2,2,2-trifluoroethyl) ((5-(hydroxymethyl)furan-2-yl)(phenylamino)methyl)phosphonate (4w)

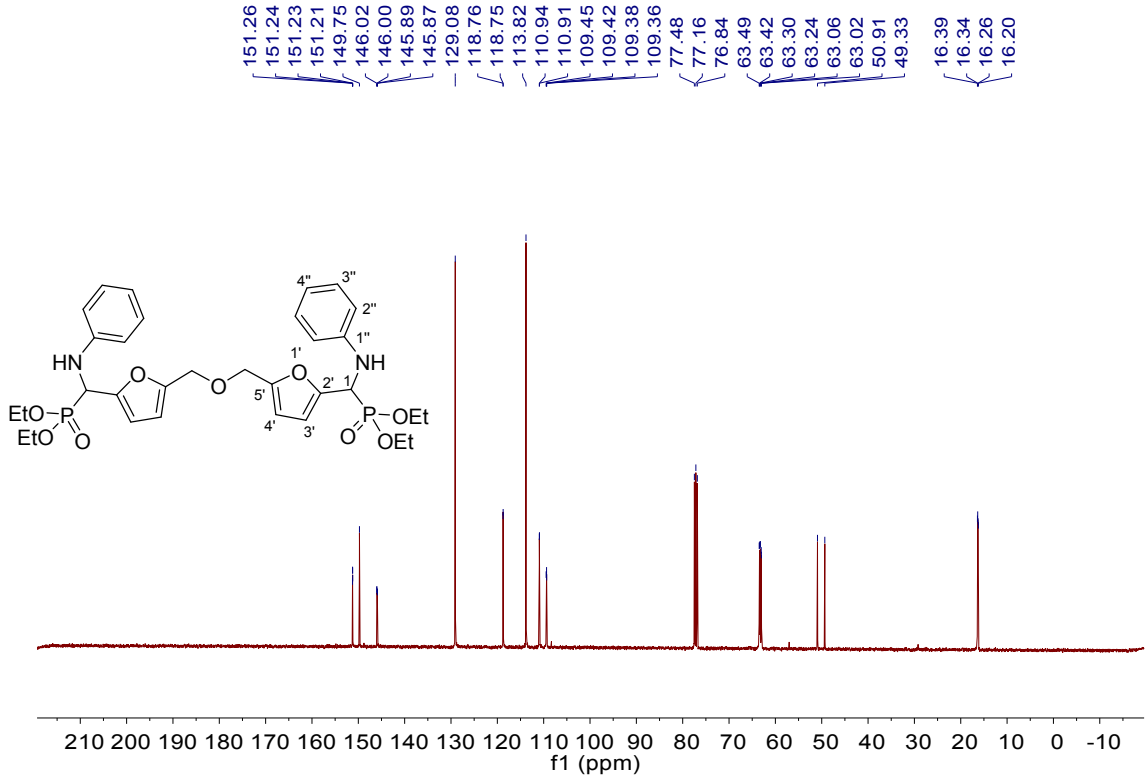


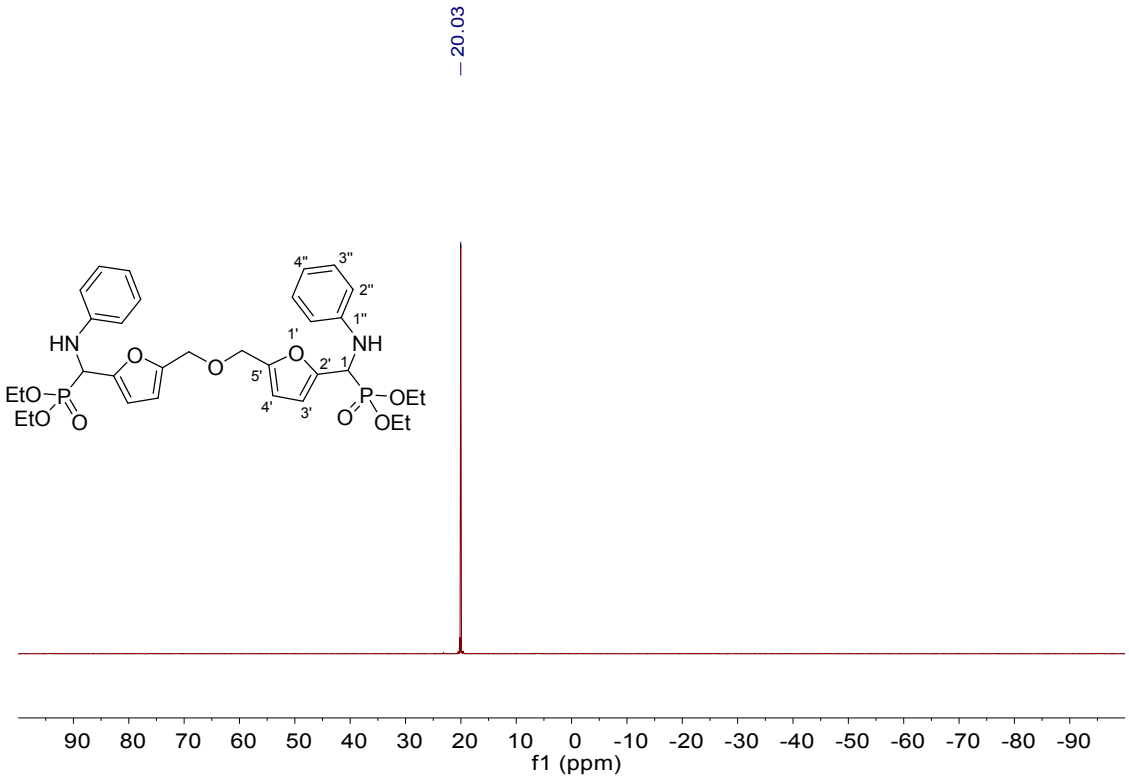




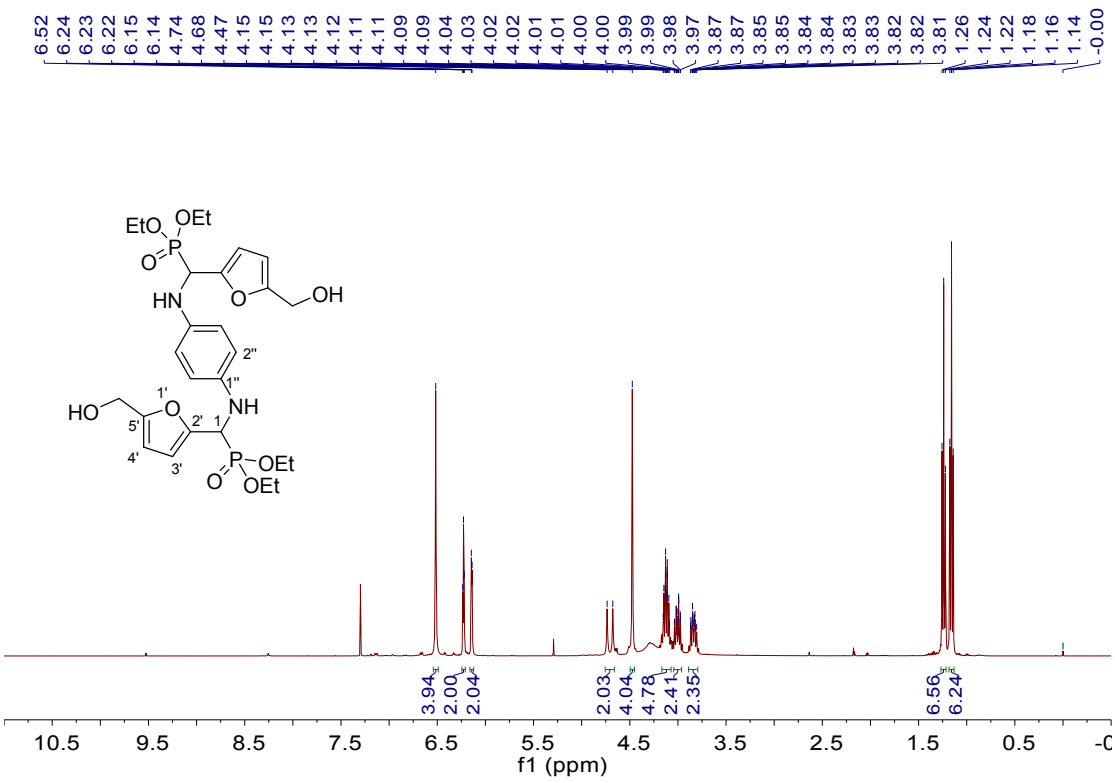
Diethyl ((5-(hydroxymethyl)furan-2-yl)(phenylamino)methyl)phosphonate dimer (4x)

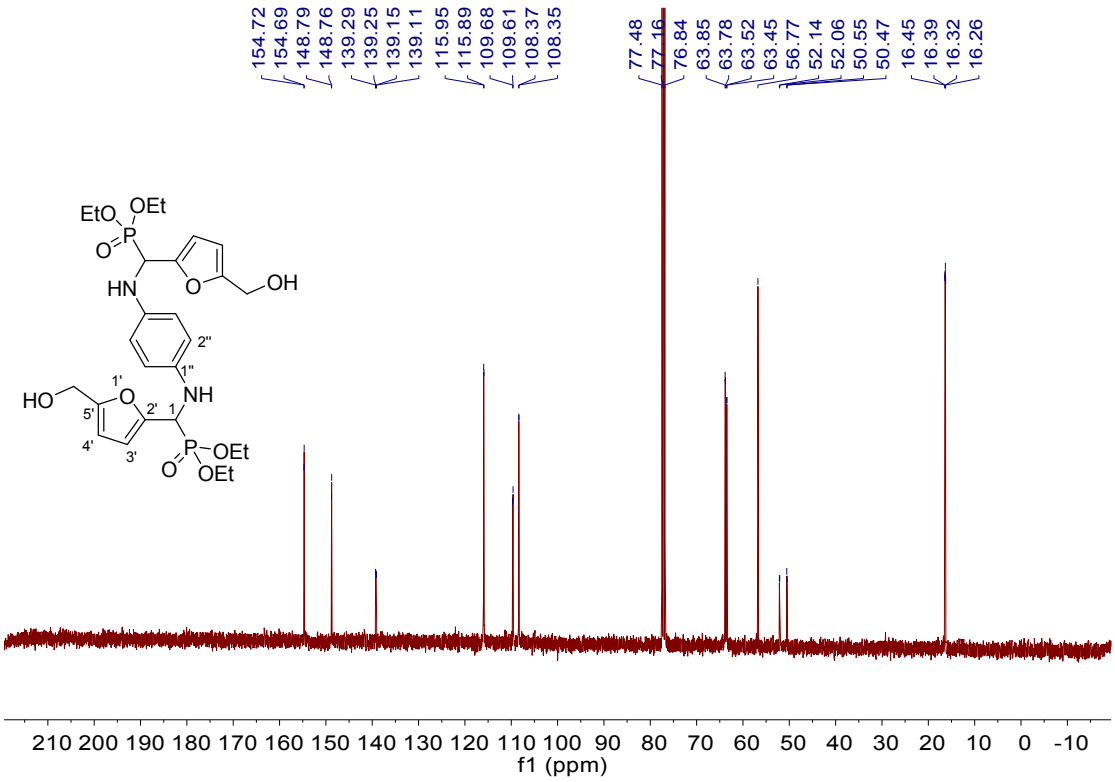


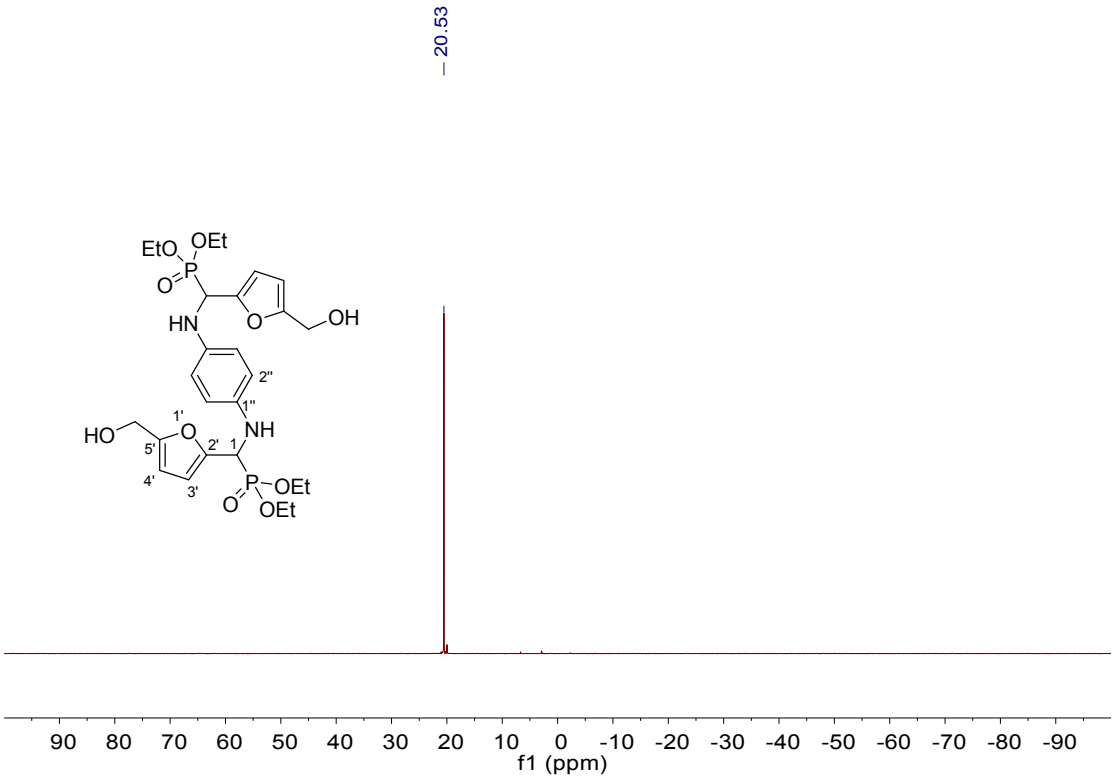

151.26
151.24
151.23
151.21
149.75
146.02
146.00
145.89
145.87
129.08
118.76
118.75
113.82
110.94
110.91
109.45
109.42
109.38
109.36
77.48
77.16
76.84
63.49
63.42
63.30
63.24
63.06
63.02
50.91
49.33
16.39
16.34
16.26
16.20
HN
NH
EtO–P
EtO
O
OEt
OEt
210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10
f1 (ppm)


20.03
HN
NH
EtO–P
EtO
O
OEt
OEt
90 80 70 60 50 40 30 20 10 0 -10 -20 -30 -40 -50 -60 -70 -80 -90
f1 (ppm)

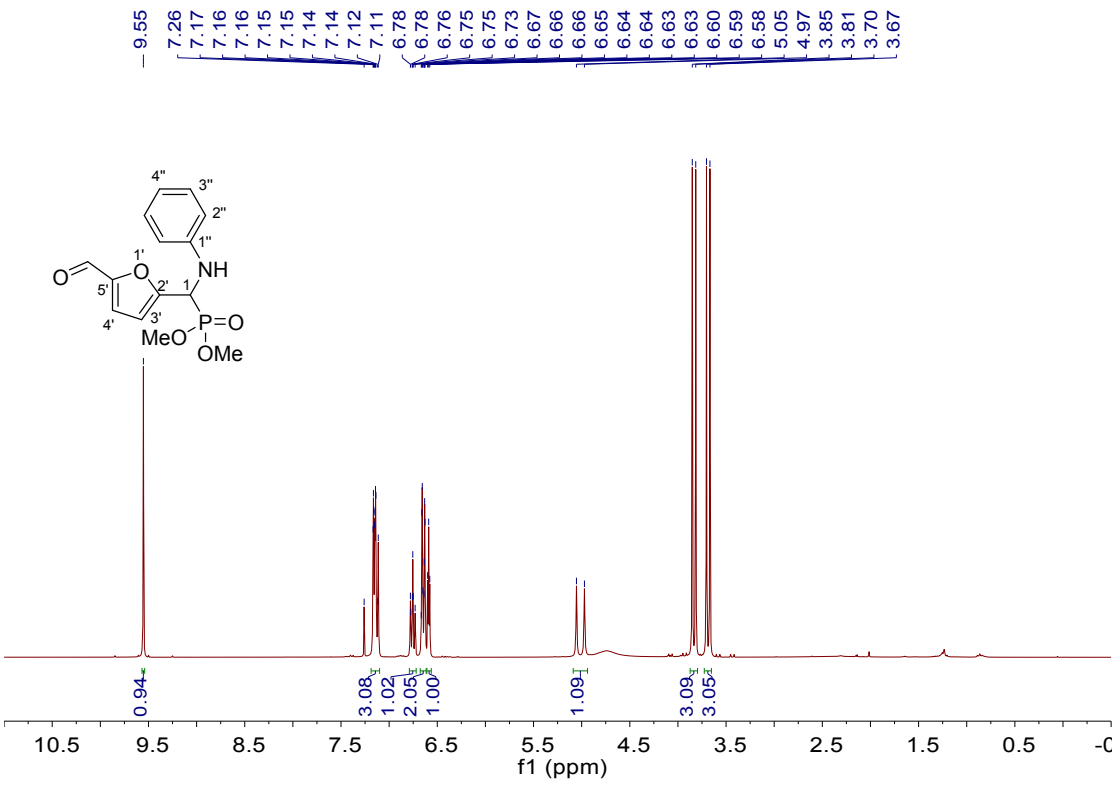
Diethyl (((4-(((diethoxyphosphoryl)(5-(hydroxymethyl)furan-2-yl)methyl)amino)phenyl)amino)(5-(hydroxymethyl)furan-2-yl)methyl)phosphonate (4y)

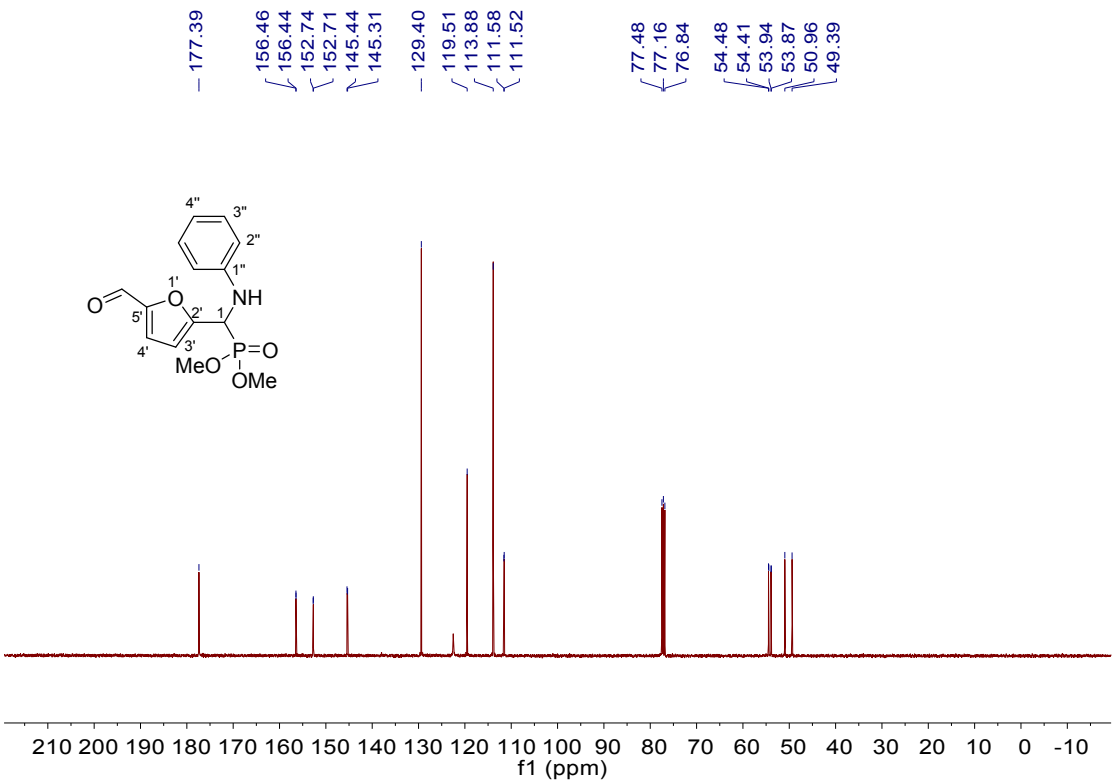


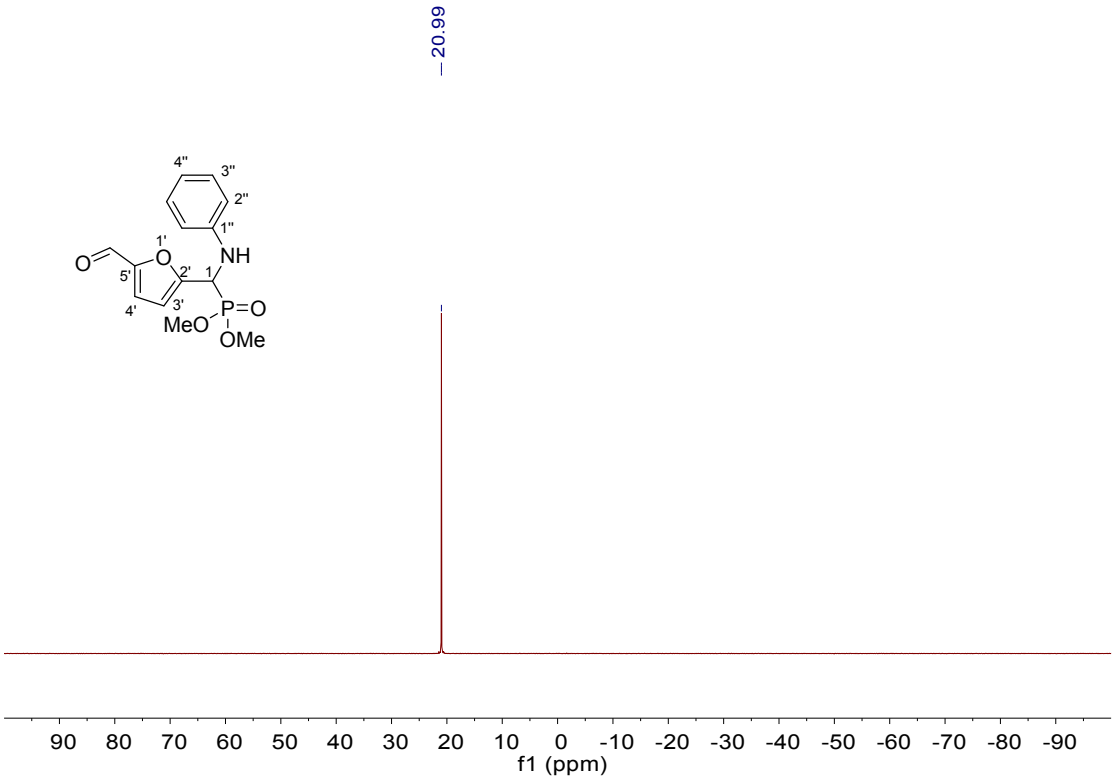




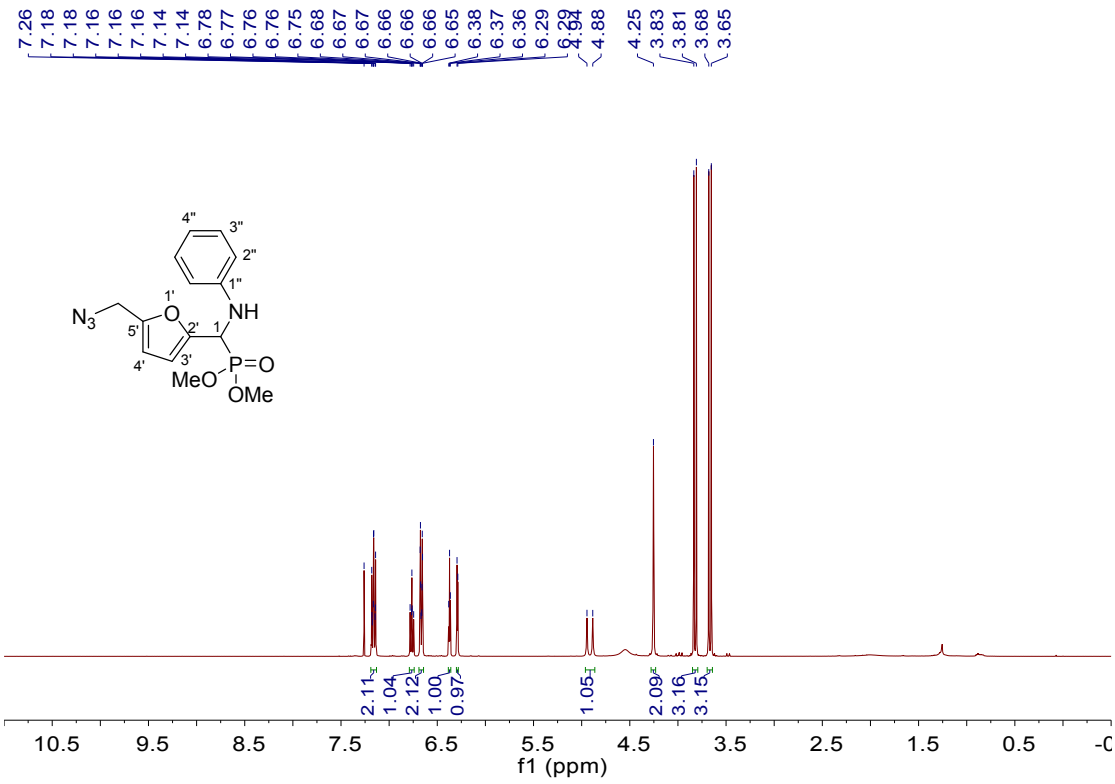
Dimethyl ((5-formylfuran-2-yl)(phenylamino)methyl)phosphonate (4aa)

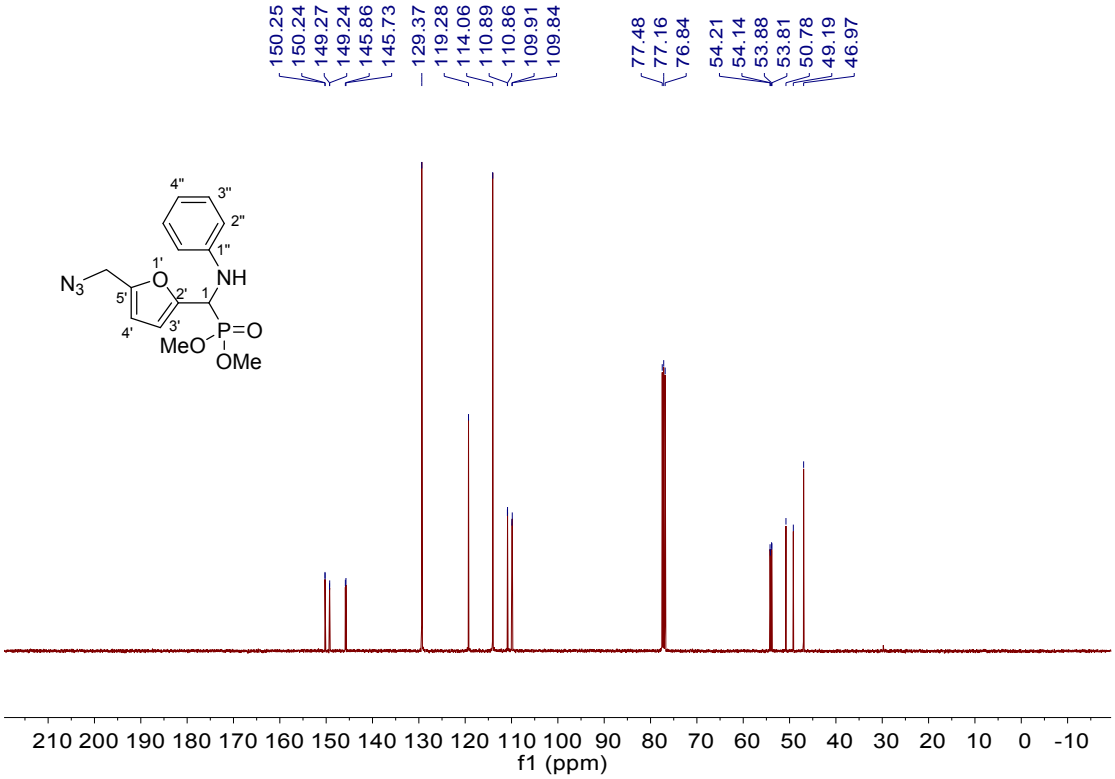


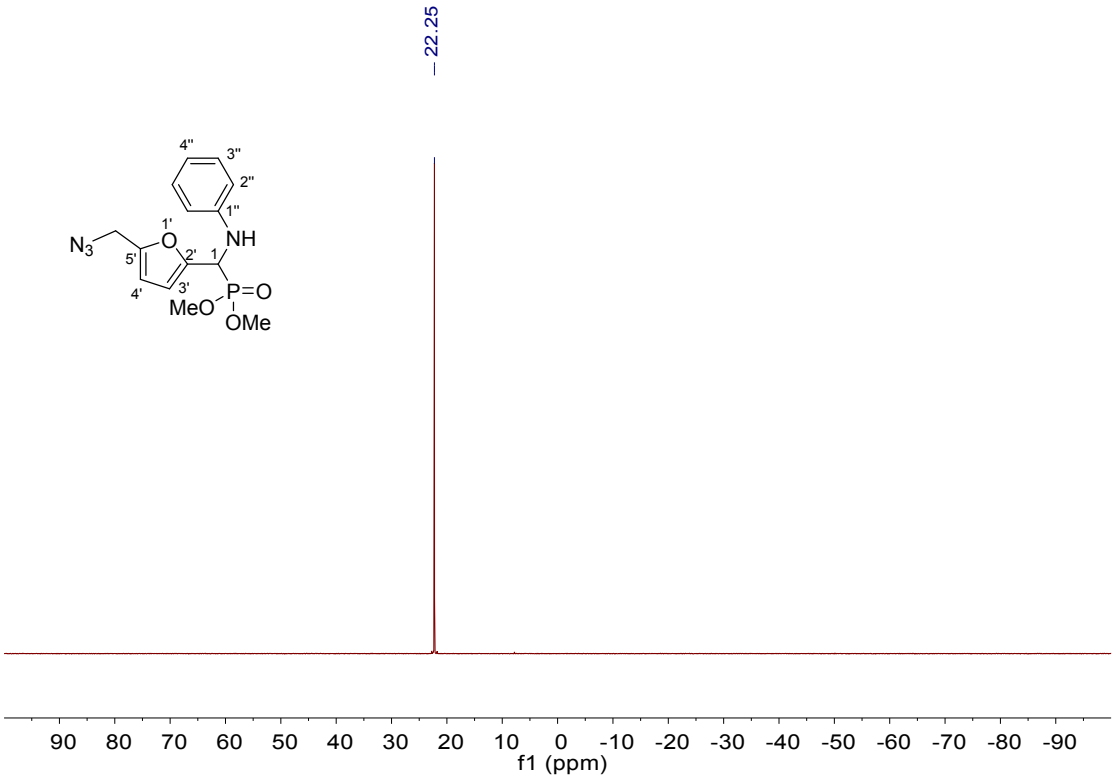

177.39
156.46
156.44
152.74
152.71
145.44
145.31
129.40
119.51
113.88
111.58
111.52
77.48
77.16
76.84
54.48
54.41
53.94
53.87
50.96
49.39
4"
3"
2"
1"
1'
O
NH
5'
2'
1
4'
3'
MeO
P=O
OMe
210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10
f1 (ppm)


20.99
4"
3"
2"
1"
1'
O
NH
5'
2'
1
4'
3'
MeO
P=O
OMe
90 80 70 60 50 40 30 20 10 0 -10 -20 -30 -40 -50 -60 -70 -80 -90
f1 (ppm)

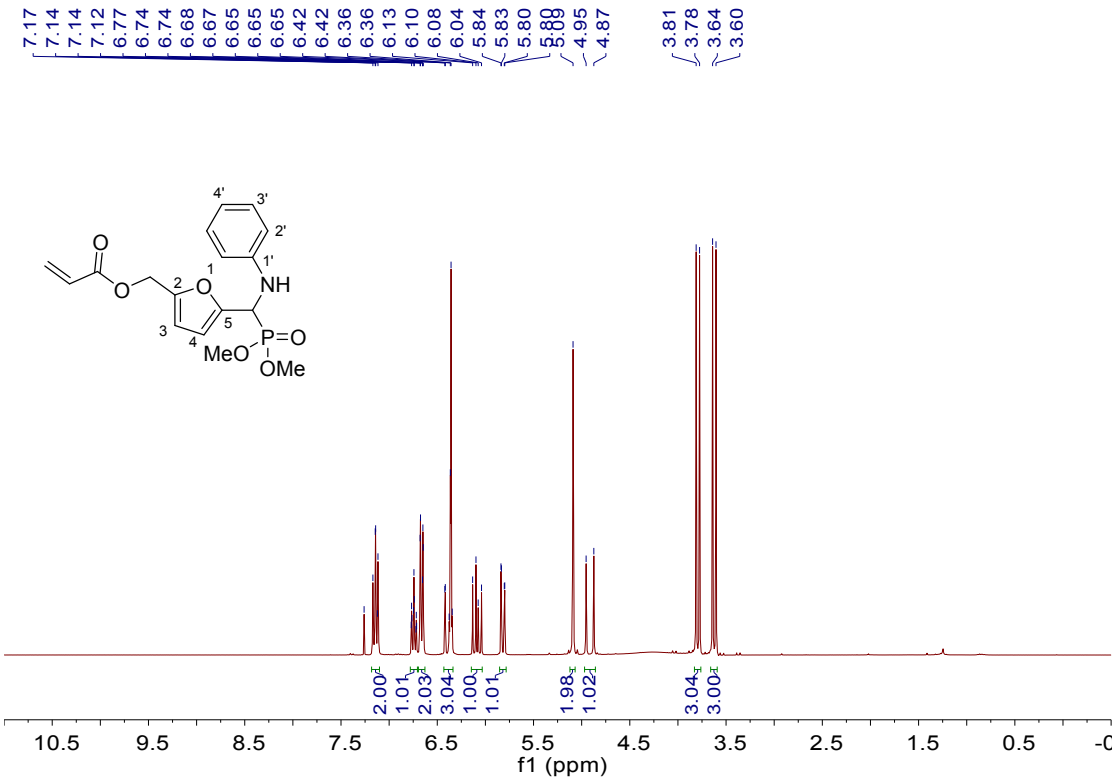
Dimethyl ((5-(azidomethyl)furan-2-yl)(phenylamino)methyl)phosphonate (4ab)

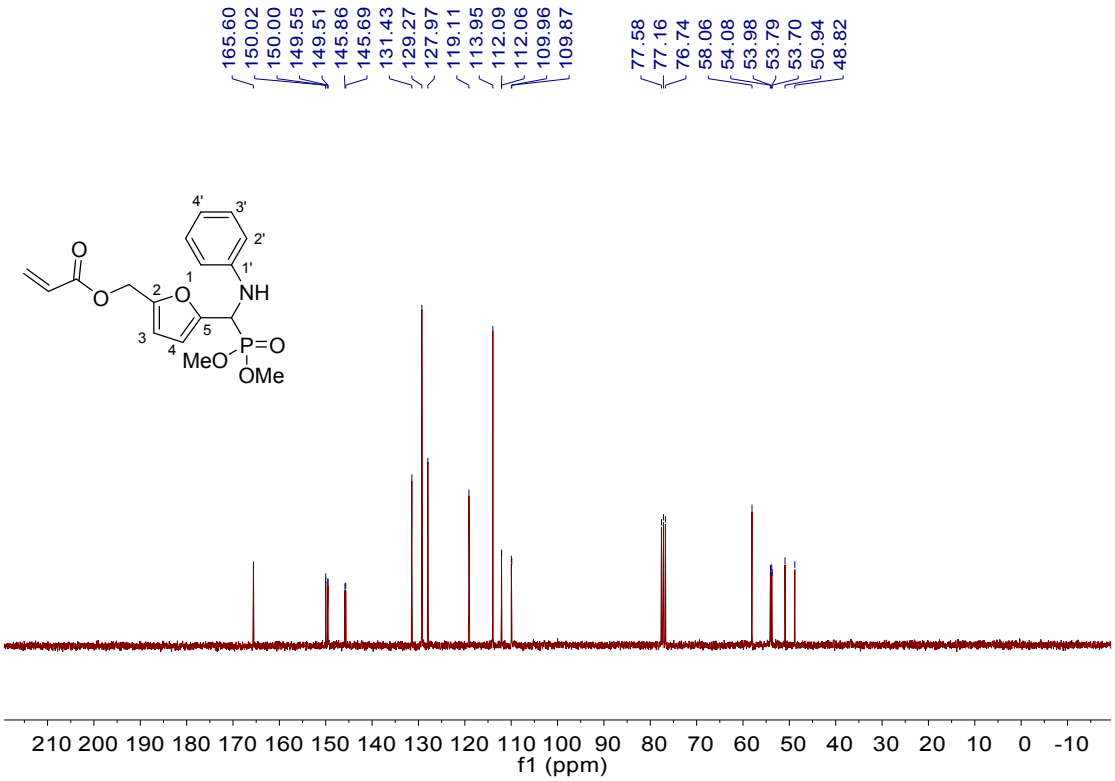


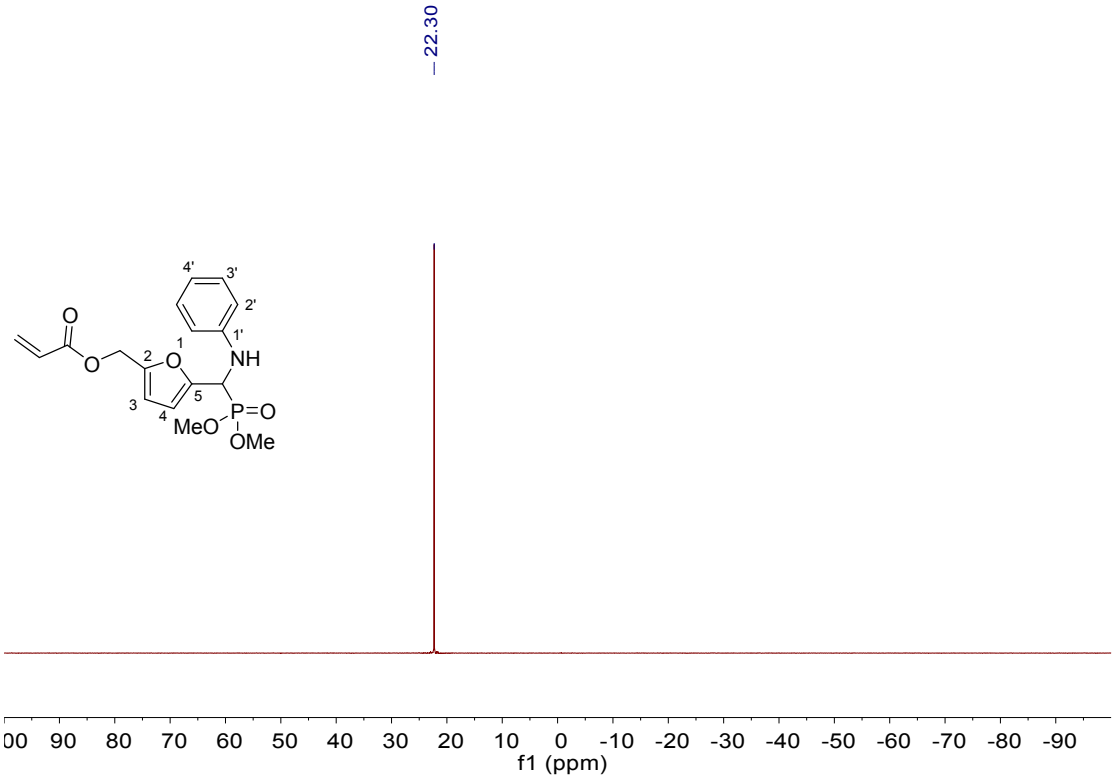




(5-((Dimethoxyphosphoryl)(phenylamino)methyl)furan-2-yl)methyl acrylate (4ac)




165.60
150.02
150.00
149.55
149.51
145.86
145.69
131.43
129.27
127.97
119.11
113.95
112.09
112.06
109.96
109.87
77.58
77.16
76.74
58.06
54.08
53.98
53.79
53.70
50.94
48.82
O
O
1
2
O
NH
1'
2'
3'
4'
3
4
5
MeO
P=O
OMe
210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10
f1 (ppm)


22.30
O
O
1
2
O
NH
1'
2'
3'
4'
3
4
5
MeO
P=O
OMe
00 90 80 70 60 50 40 30 20 10 0 -10 -20 -30 -40 -50 -60 -70 -80 -90
f1 (ppm)