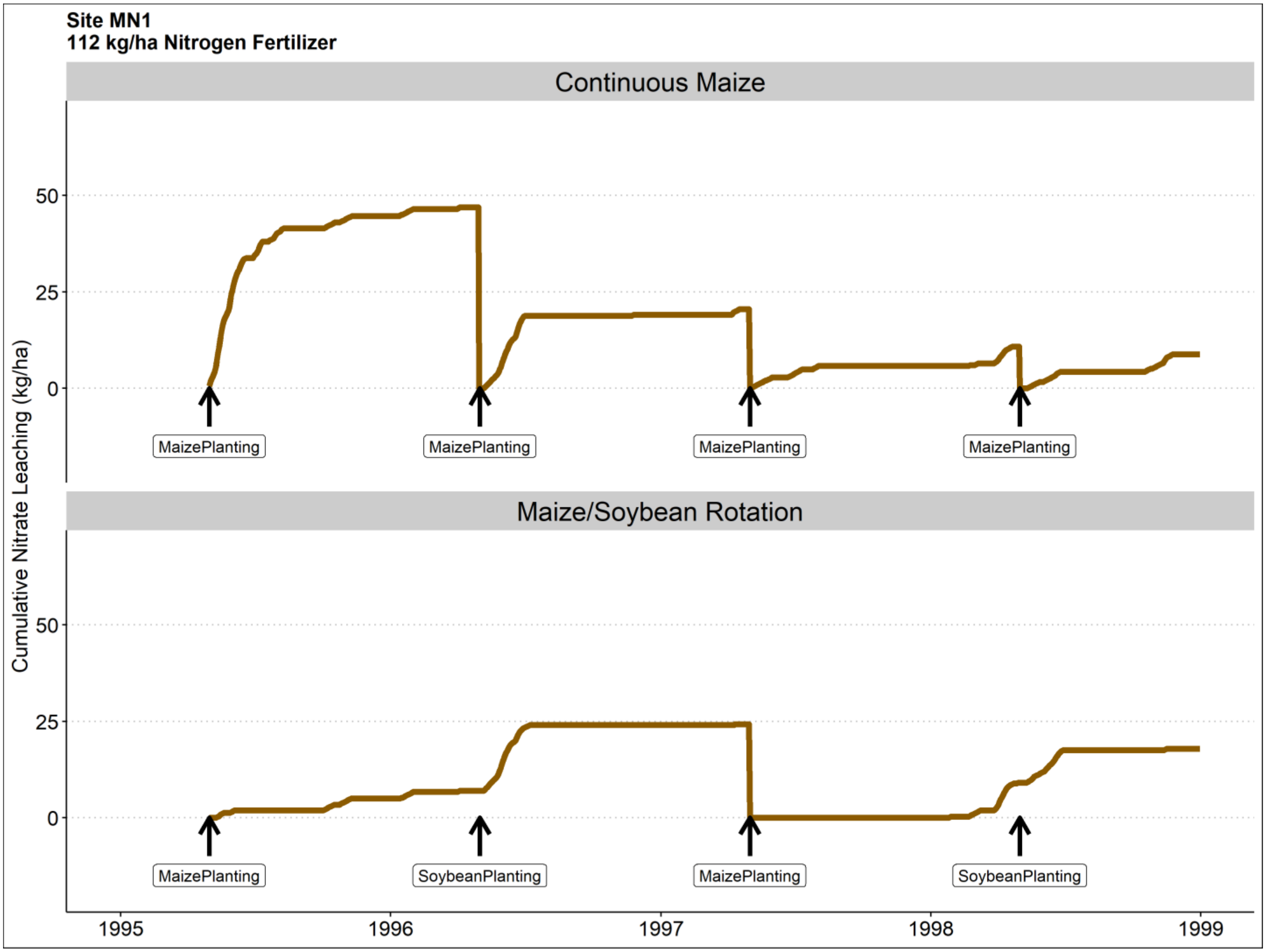
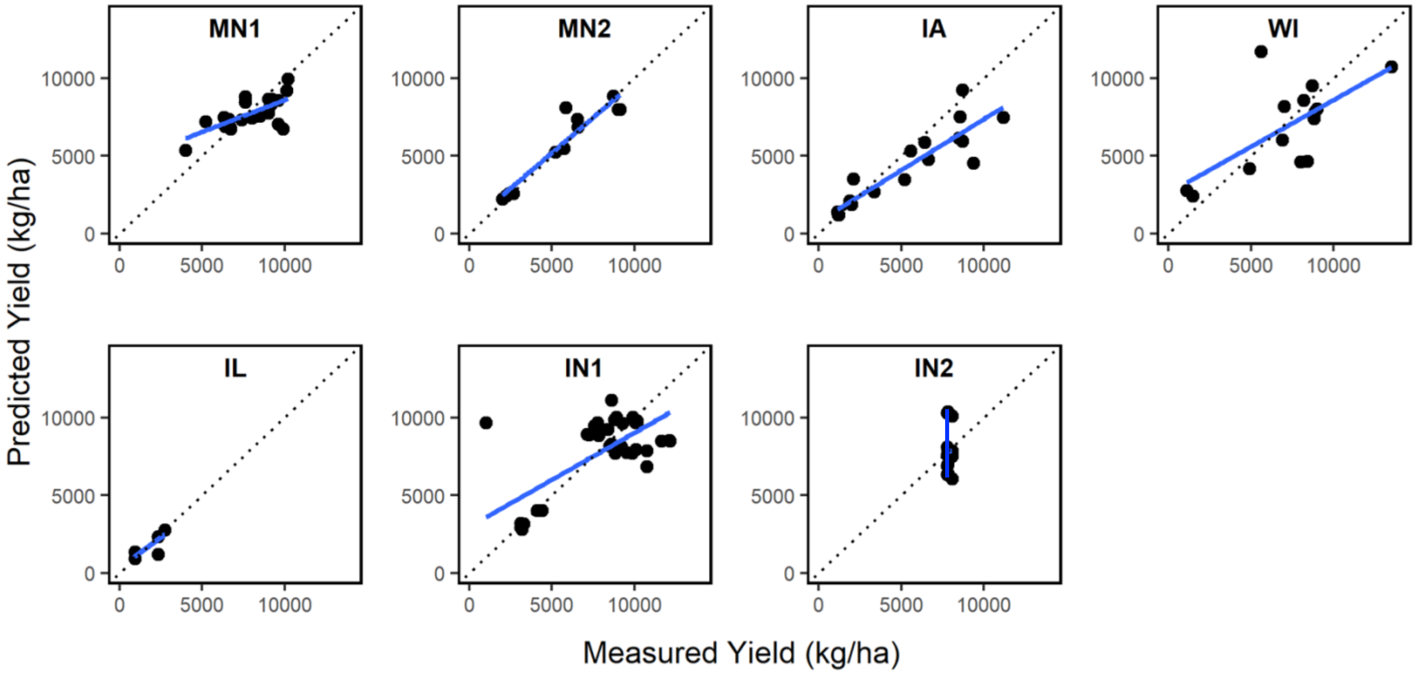
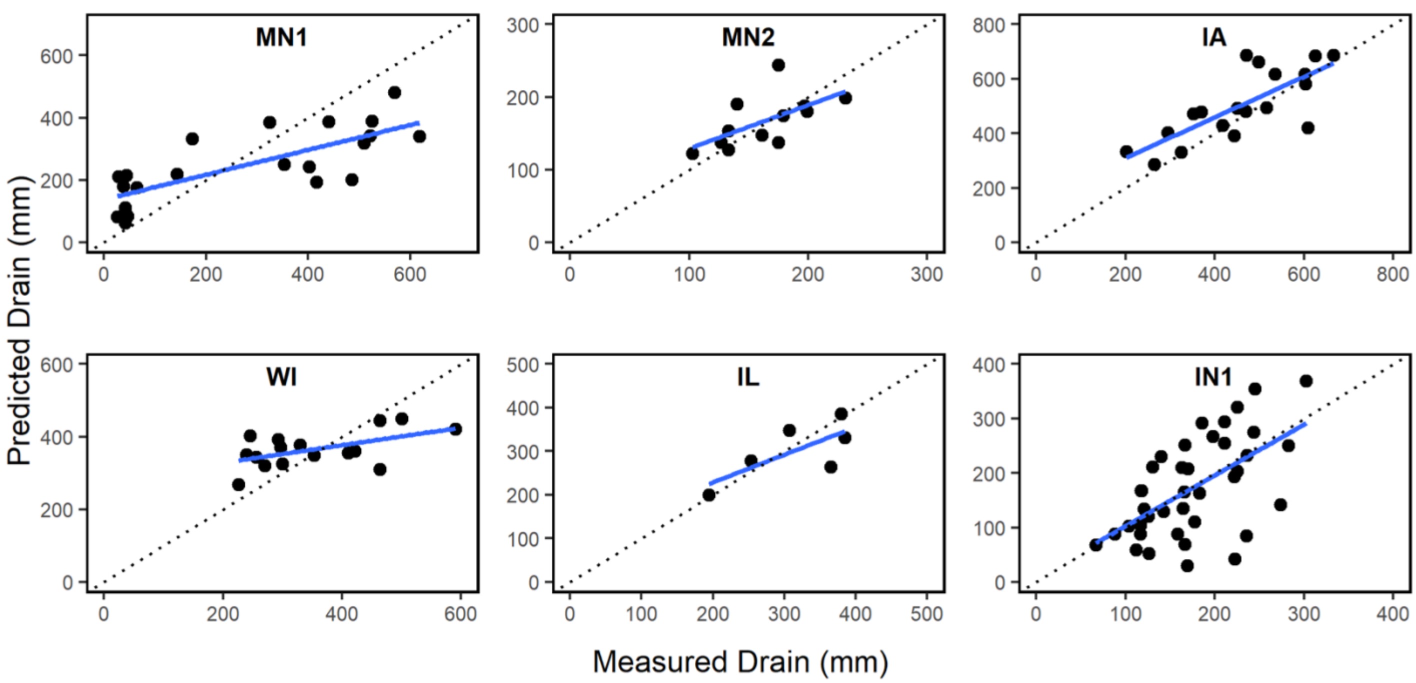


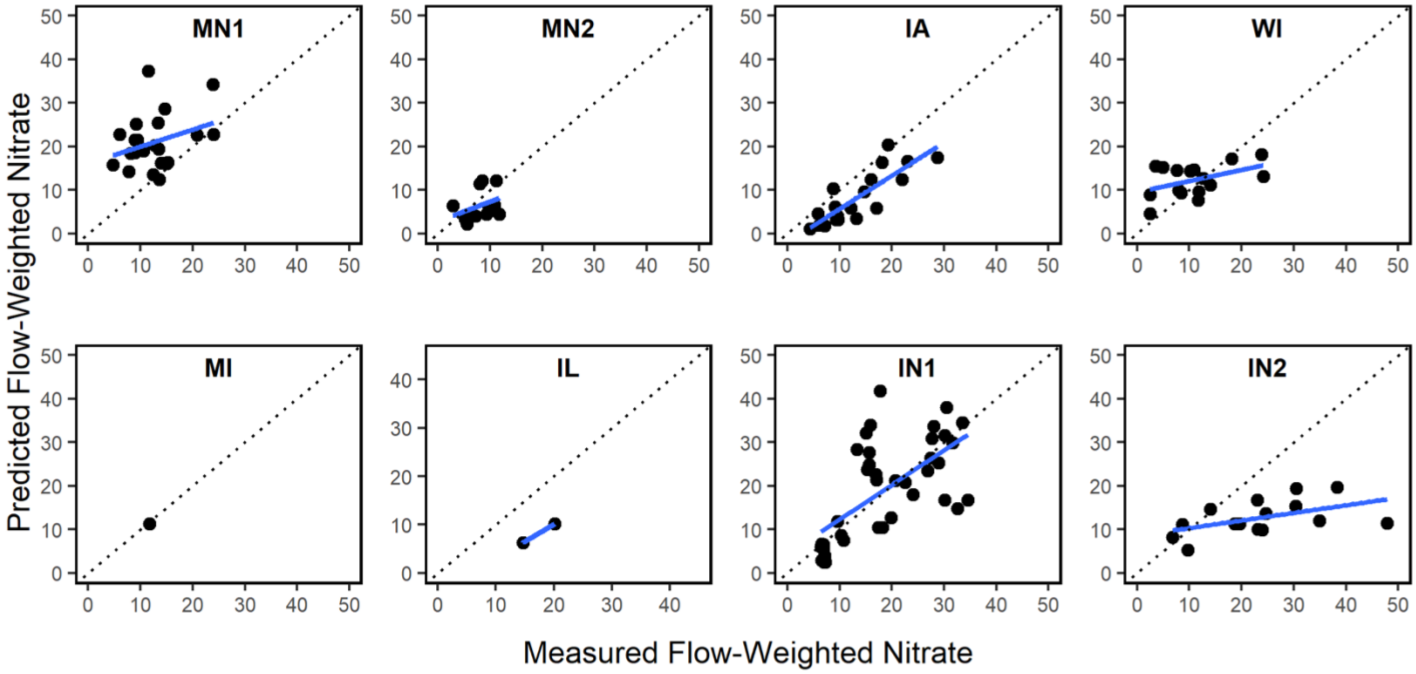
*Supplementary Figure 1: Timeline of APSIM model simulations showing how leaching was summed up over one year of continuous maize and over both years of the maize-soybean 2-year rotation.*



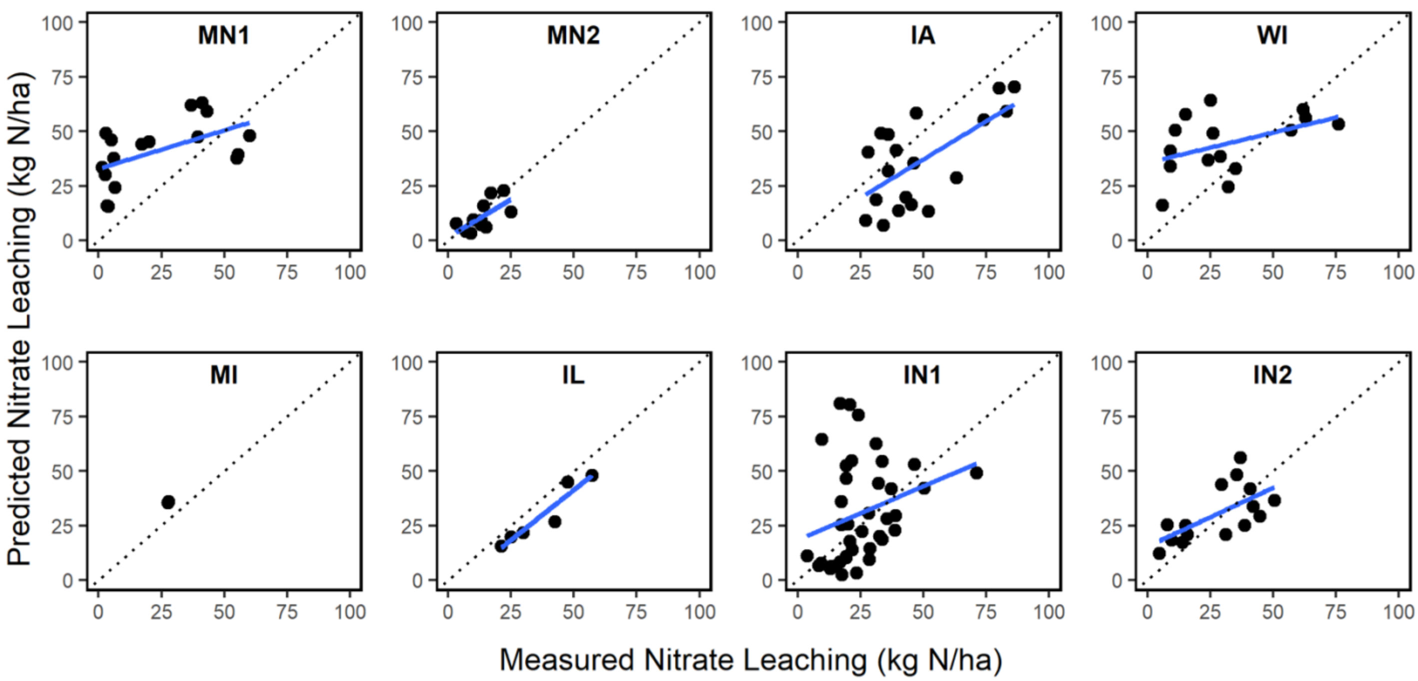

*Supplementary Figure 2: Model calibration for yield data (solid blue line) relative to a 1:1 reference line (dotted black line).*



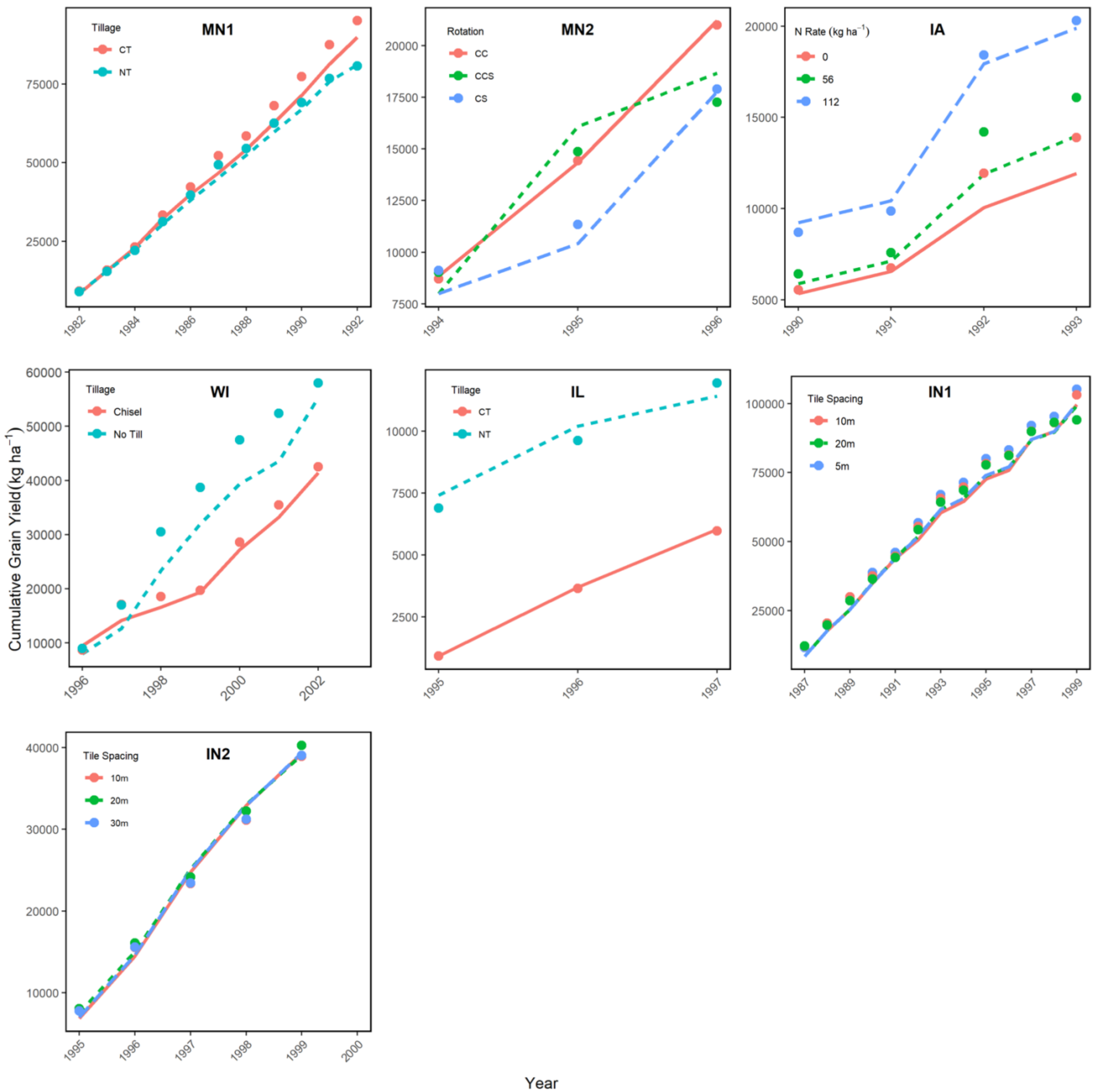

*Supplementary Figure 3: Model calibration for drainage data (solid blue line) relative to a 1:1 reference line (dotted black line).*



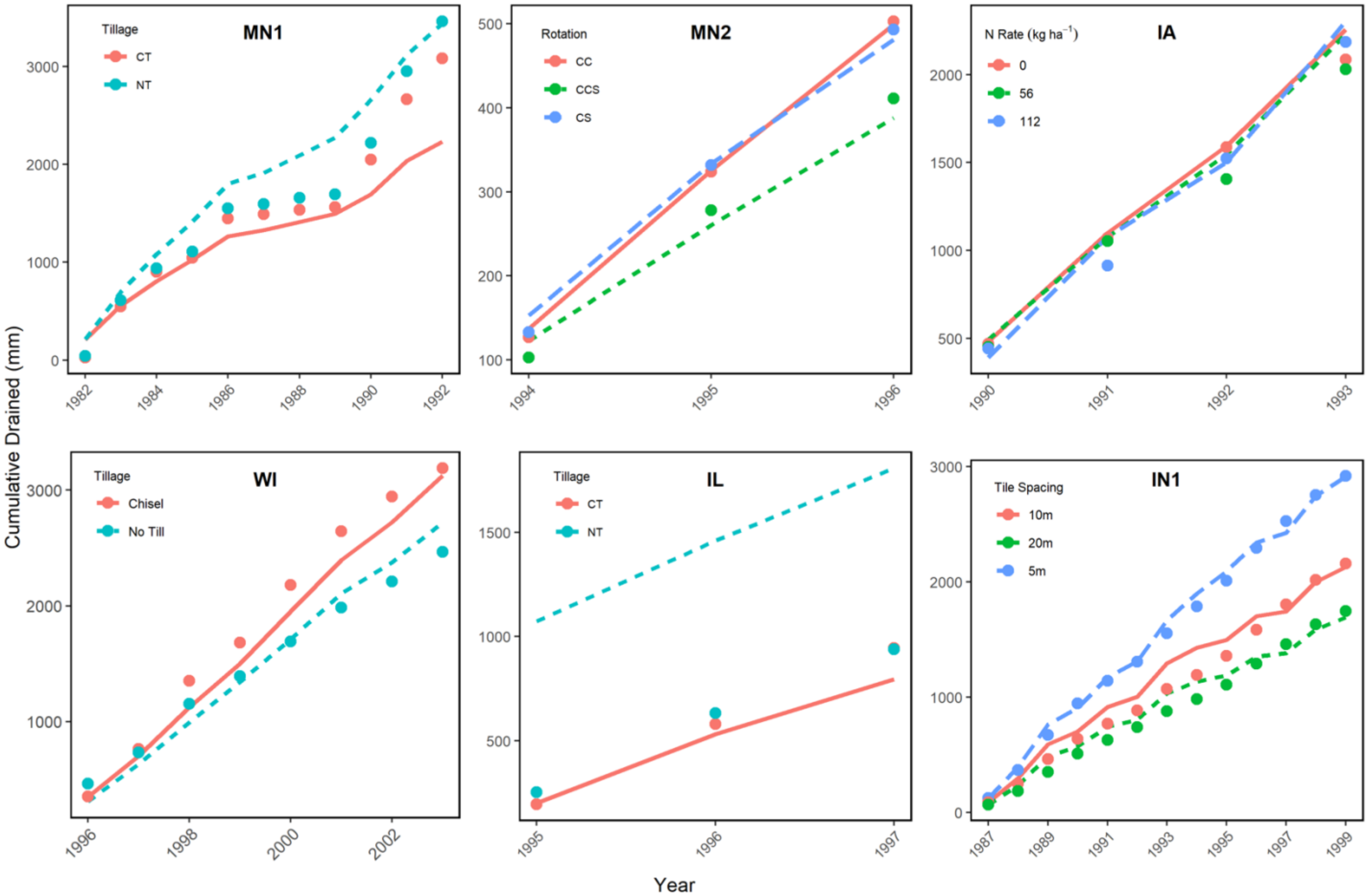

*Supplementary Figure 4: Model calibration for flow-weighted NO3-N data (solid blue line) relative to a 1:1 reference line (dotted black line).*



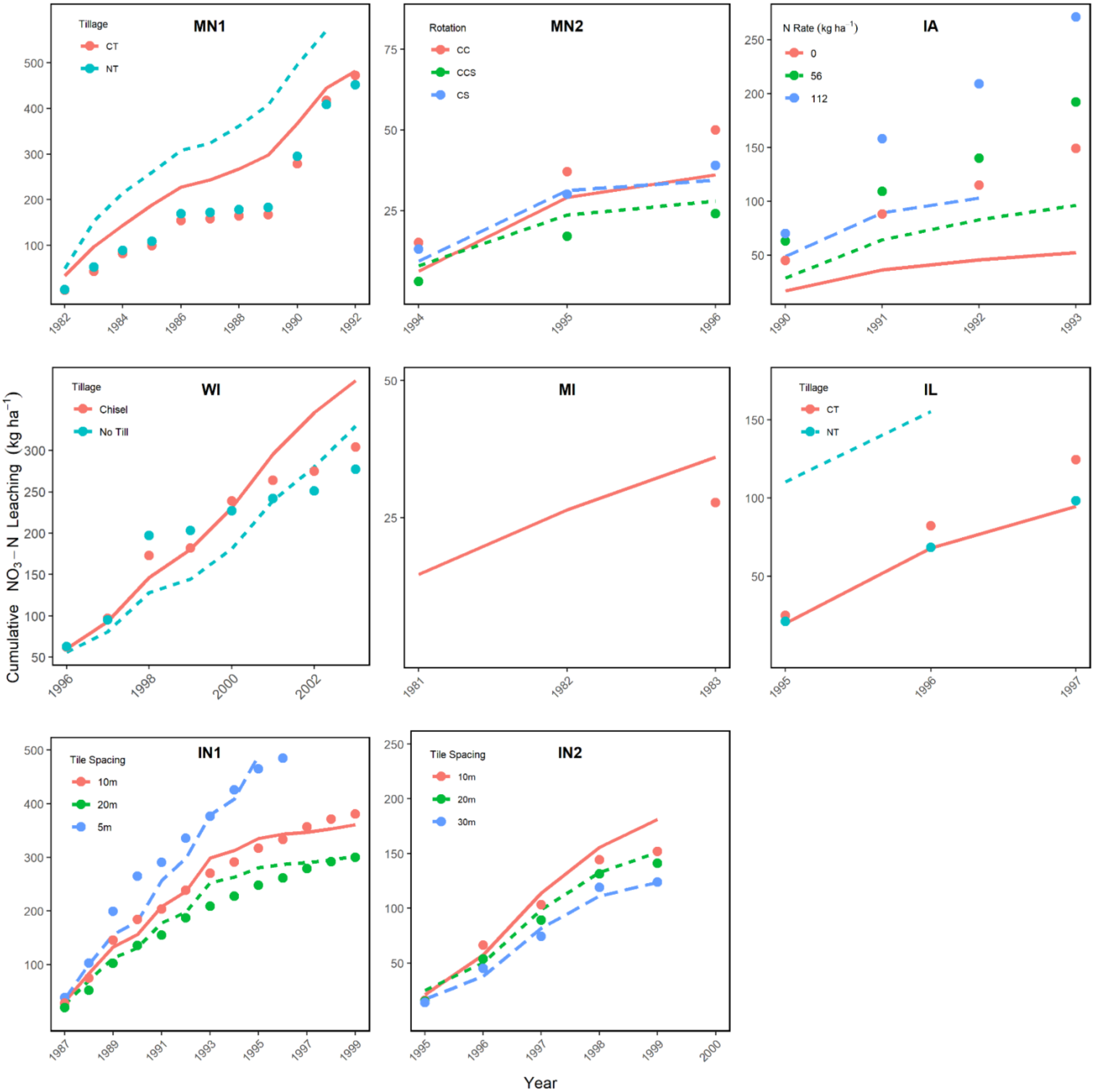

*Supplementary Figure 5: Model calibration for $NO_3$-N leaching load data (solid blue line) relative to a 1:1 reference line (dotted black line).*



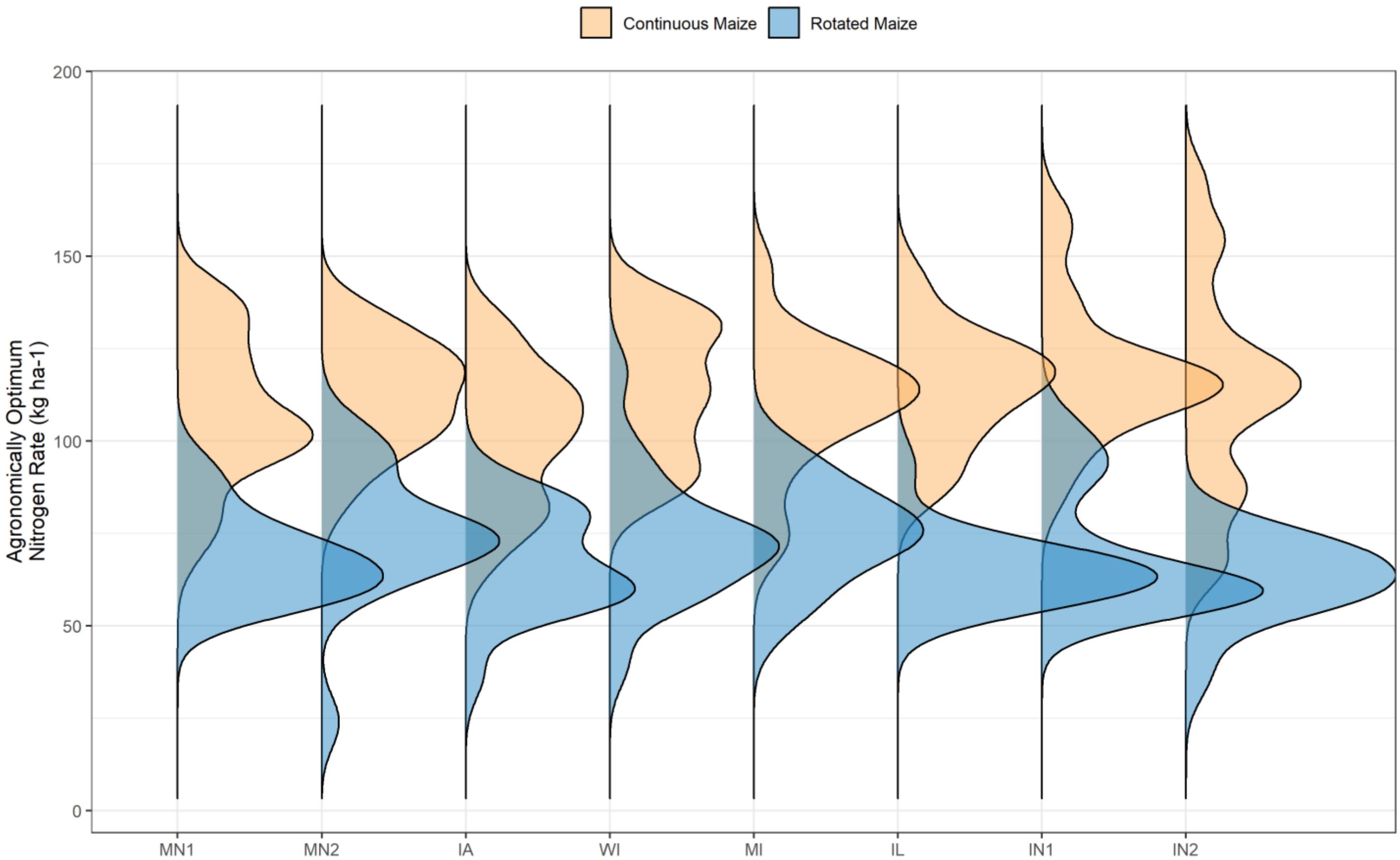

*Supplementary Figure 6: Cumulative grain yield of modelled experiments in which measured yield data was available. Points are real data and lines are simulated data.*



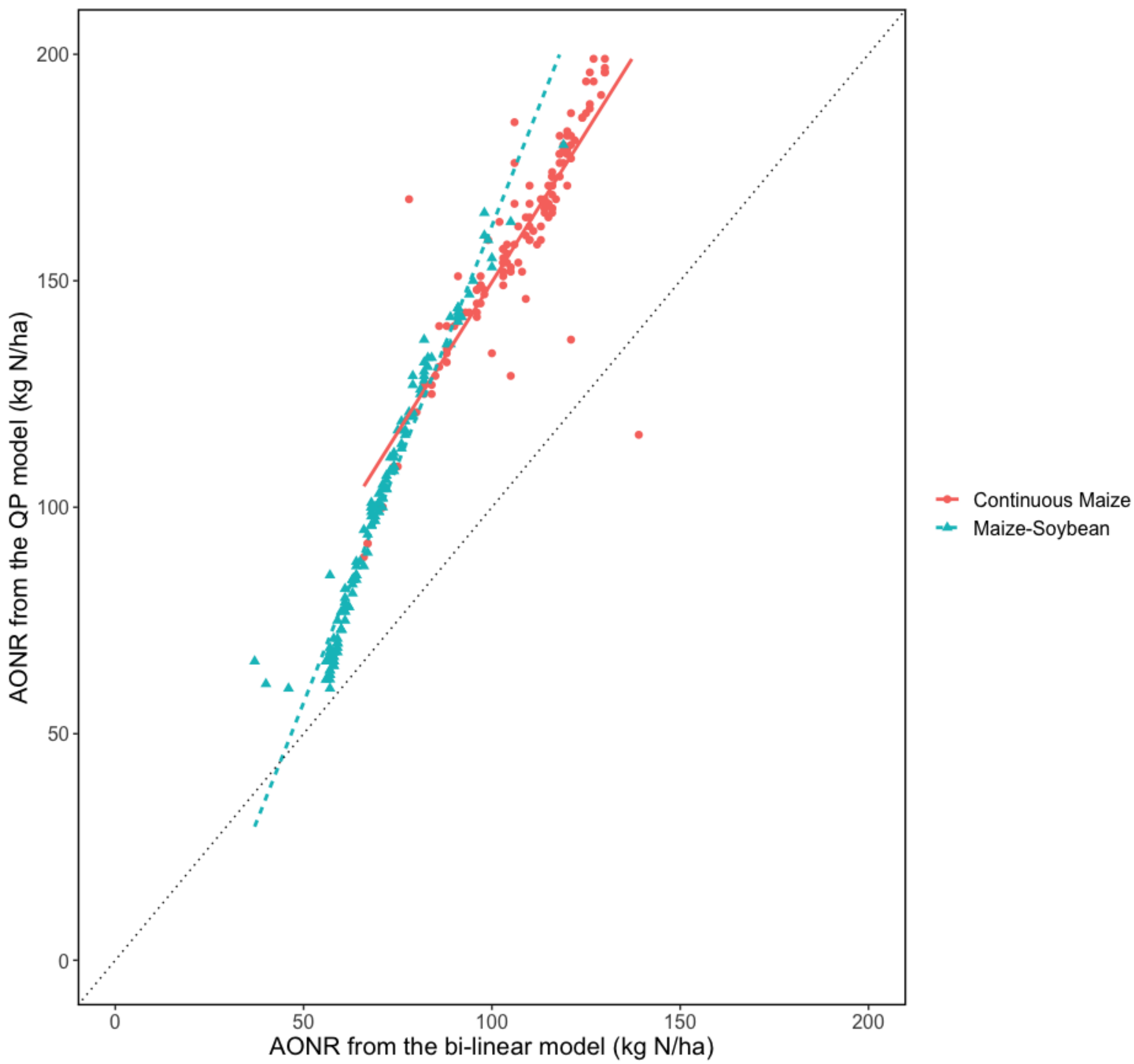

*Supplementary Figure 7: Cumulative drainage of modelled experiments in which measured drainage data was available. Points are real data and lines are simulated data.*




*Supplementary Figure 8: Cumulative $NO_3$-N leaching of modelled experiments in which measured leaching data was available. Points are real data and lines are simulated data.*




*Supplementary Figure 9: Distribution plots of AONR values in study sites.*




*Supplementary Figure 9: AONR (kg N/ha) calculated using the bi-linear model plotted against AONR (kg N/ha) calculated using the quadratic plateau model for each system (Continuous Maize (solid red line; y= 1.5x-0.2) and Maize-Soybean Rotation (dashed blue line; y=2.2x-56.3) relative to a 1:1 reference line (dotted black line).*

*Supplementary Table 1: Overview of the published studies used in this modeling study*

| Site ID | Reference | First/Co Author(s) | Publication Date | State | Lat | Long | Treatment | Experimental Years | Soil Texture |
|---|---|---|---|---|---|---|---|---|---|
| MN1 | [38] | Randall & Iragavarapu | 1995 | Minnesota | 44.07639 | -93.5242 | Tillage | 1982-1992 | Clay Loam |
| MN2 | [39] | Huggins | 2001 | Minnesota | 44.239 | -95.3189 | Rotation | 1994-1996 | Clay Loam |
| IA | [10] | Lawlor | 2008 | Iowa | 42.4024 | -94.8019 | N Rate | 1990-1993 | Clay Loam |
| WI | [40] | Masarik & Norman | 2014 | Wisconsin | 43.283 | -89.367 | Tillage | 1996-2003 | Silt Loam |
| MI | [41] | Gold & Loudon | 1989 | Michigan | 43.39845 | -83.6976 | Tillage | 1981-1983 | Loam |
| IL | [42] | Gentry | 2000 | Illinois | 40.05627 | -88.2175 | Tillage | 1995-1997 | Clay Loam |
| IN1 | [43,44] | Kladivko | 2004; 2005 | Indiana | 39.02583 | -85.54 | Tile Spacing | 1987-1999 | Silt Loam |
| IN2 | [45] | Hofmann | 2004 | Indiana | 40.47137 | -86.9931 | Tile Spacing | 1995-2000 | Silty Clay Loam |

*Supplementary Table 2: Weather data summary (max and min monthly temperatures, monthly precipitation, monthly radiation during the growing season) for modeled sites.*

| | Maximum Temperature (°C) | | | | | Minimum Temperature (°C) | | | | | Precipitation (mm) | | | | | Radiation Sum (MJ/m²) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Year | May | Jun | Jul | Aug | Sep | May | Jun | Jul | Aug | Sep | May | Jun | Jul | Aug | Sep | May | Jun | Jul | Aug | Sep |
| | **MN1** | | | | | | | | | | | | | | | | | | | |
| 1982 | 29 | 30 | 35.5 | 34 | 28.5 | 2.5 | 5 | 12 | 6.5 | 0 | 180 | 38 | 68 | 136 | 106 | 617.8 | 598.8 | 708.9 | 528.4 | 380.8 |
| 1983 | 24.5 | 33 | 35.5 | 35 | 32.5 | 0 | 3.5 | 12 | 12 | -1 | 128 | 96 | 126 | 126 | 109 | 623.7 | 669 | 647.9 | 607.4 | 365.7 |
| 1984 | 27.5 | 31 | 32.5 | 35 | 32.5 | -1.5 | 9 | 8 | 8.5 | -4 | 75 | 158 | 124 | 46 | 60 | 638.6 | 616.9 | 671.9 | 598.5 | 428 |
| 1985 | 31.5 | 37 | 34.5 | 30.5 | 32.5 | 4.5 | 4 | 8.5 | 6 | -1 | 55 | 60 | 52 | 161 | 139 | 624.1 | 608.4 | 704.9 | 513.3 | 380.2 |
| 1986 | 31 | 33.5 | 33 | 30.5 | 30 | 1.5 | 6.5 | 12.5 | 4.5 | 3.5 | 85 | 191 | 156 | 71 | 169 | 627.5 | 650.5 | 670.7 | 601.2 | 359.7 |
| 1987 | 33.5 | 37 | 35.5 | 33 | 30.5 | 2.5 | 5 | 10.5 | 6 | 5.5 | 65 | 67 | 180 | 130 | 57 | 658.8 | 727.1 | 697.6 | 528 | 462.9 |
| 1988 | 33 | 37.5 | 39 | 37 | 33 | 1 | 7 | 10.5 | 6 | 4.5 | 46 | 28 | 29 | 94 | 107 | 696.4 | 754.2 | 742.3 | 530.2 | 408.5 |
| 1989 | 29 | 33 | 36 | 33.5 | 28.5 | -4.5 | 4 | 13 | 8.5 | -1.5 | 50 | 65 | 91 | 120 | 33 | 614.2 | 645.1 | 744.3 | 619.6 | 487 |
| 1990 | 31.5 | 32 | 38 | 31 | 32.5 | 1 | 3.5 | 10 | 10 | 1.5 | 138 | 174 | 202 | 106 | 35 | 619.6 | 671.6 | 683.4 | 615.9 | 464.1 |
| 1991 | 30.5 | 35.5 | 34.5 | 32 | 28.5 | 1.5 | 12 | 10.5 | 10 | -1 | 201 | 115 | 195 | 117 | 107 | 447 | 655.7 | 694.7 | 572.5 | 389 |
| 1992 | 29.5 | 32 | 28 | 31.5 | 29.5 | 0 | 3 | 8 | 6 | -1.5 | 61 | 136 | 99 | 112 | 61 | 702.2 | 645.7 | 558.3 | 604.7 | 436.5 |
| | **MN2** | | | | | | | | | | | | | | | | | | | |
| 1994 | 31.5 | 32.5 | 30.5 | 32 | 30.5 | 0.5 | 9.5 | 11 | 7 | 2.5 | 39 | 115 | 55 | 124 | 89 | 718.1 | 597.3 | 623.8 | 510 | 392.1 |
| 1995 | 25.5 | 36 | 38.5 | 33 | 29 | 3 | 3.5 | 9.5 | 11 | -2.5 | 125 | 71 | 184 | 84 | 90 | 558.3 | 617.9 | 710.2 | 551.5 | 458.2 |
| 1996 | 33 | 34.5 | 32 | 32 | 29.5 | 0 | 5 | 8.5 | 10.5 | 1.5 | 116 | 136 | 87 | 124 | 58 | 503 | 677.2 | 670.5 | 663.7 | 432.7 |
| | **IA** | | | | | | | | | | | | | | | | | | | |
| 1990 | 29 | 34 | 36 | 33 | 33.5 | -1.5 | 5 | 11 | 10 | 2 | 185 | 274 | 178 | 93 | 52 | 563.1 | 675.1 | 660.1 | 633.7 | 521.7 |
| 1991 | 31.5 | 34.5 | 35 | 32 | 31 | 1 | 11.5 | 10 | 10.5 | -1 | 179 | 131 | 43 | 100 | 64 | 492.9 | 676.4 | 683 | 594.9 | 446.7 |
| 1992 | 32 | 31 | 31 | 31 | 28.5 | 1.5 | 6.5 | 9.5 | 7.5 | -0.5 | 53 | 66 | 222 | 70 | 80 | 690.3 | 700.8 | 529.5 | 664.1 | 466.9 |
| 1993 | 28 | 30.5 | 31 | 31.5 | 29.5 | 3 | 5.5 | 12.5 | 10 | 0.5 | 124 | 181 | 207 | 187 | 63 | 516.4 | 549.3 | 568.1 | 550.3 | 453.6 |
| 2000 | 30.5 | 34.5 | 32.5 | 33.5 | 36.5 | 3.5 | 8 | 10.5 | 12.5 | 1 | 72 | 81 | 90 | 72 | 24 | 595.2 | 660.5 | 660.7 | 567 | 464 |
| 2001 | 32.5 | 34 | 35 | 34.5 | 29 | 5.5 | 6.5 | 12 | 12 | 1 | 203 | 92 | 80 | 131 | 76 | 507.1 | 671.8 | 616.4 | 609 | 445.8 |
| 2002 | 33 | 35.5 | 36 | 33.5 | 33.5 | -0.5 | 9.5 | 13 | 8 | 1 | 107 | 65 | 90 | 246 | 36 | 681.1 | 735.3 | 726.9 | 594.3 | 478.3 |
| 2003 | 29 | 32.5 | 35 | 36.5 | 31.5 | 4 | 9.5 | 12 | 12.5 | 0.5 | 118 | 127 | 155 | 24 | 52 | 587.9 | 648.8 | 710.3 | 684.3 | 488.8 |
| 2004 | 29.5 | 32.5 | 32 | 31 | 32 | -1 | 6.5 | 10 | 6.5 | 2.5 | 180 | 131 | 77 | 64 | 70 | 585.5 | 646.6 | 689.3 | 606.7 | 506.2 |
| | **WI** | | | | | | | | | | | | | | | | | | | |
| 1996 | 30 | 32.5 | 29.5 | 31 | 30 | -0.5 | 6.5 | 9 | 9.5 | 3.5 | 119 | 208 | 86 | 62 | 28 | 485.6 | 562.8 | 675.4 | 639.2 | 461.3 |
| 1997 | 25.5 | 31.5 | 31.5 | 28 | 27.5 | -1 | 9 | 8.5 | 6.5 | 3 | 42 | 186 | 166 | 78 | 55 | 596.1 | 708.6 | 633.4 | 505.6 | 443.9 |
| 1998 | 30.5 | 32 | 31 | 30.5 | 31 | 6 | 4.5 | 10.5 | 10 | 2 | 73 | 168 | 75 | 112 | 74 | 663 | 587 | 722.4 | 560.7 | 515.8 |
| 1999 | 29 | 31.5 | 35.5 | 31.5 | 31.5 | 3.5 | 6 | 12 | 9 | -0.5 | 142 | 128 | 148 | 76 | 55 | 589.6 | 627 | 710.4 | 574.5 | 483.7 |
| 2000 | 28 | 30.5 | 30 | 33 | 28.5 | 2 | 6.5 | 10 | 11.5 | 2.5 | 348 | 172 | 70 | 69 | 103 | 546.2 | 606.8 | 629.9 | 588.3 | 452.5 |

| Year | Maximum Temperature (°C) | | | | | Minimum Temperature (°C) | | | | | Precipitation (mm) | | | | | Radiation Sum (MJ/m²) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | May | Jun | Jul | Aug | Sep | May | Jun | Jul | Aug | Sep | May | Jun | Jul | Aug | Sep | May | Jun | Jul | Aug | Sep |
| 2001 | 29.5 | 31.5 | 34.5 | 34 | 28 | 4.5 | 7.5 | 10 | 8 | 1.5 | 123 | 137 | 229 | 102 | 149 | 530.2 | 595.4 | 690.6 | 569.5 | 448.7 |
| 2002 | 29.5 | 33.5 | 33.5 | 32 | 32.5 | 0 | 8 | 11 | 10.5 | 2 | 145 | 43 | 64 | 86 | 85 | 603.3 | 629.4 | 700.8 | 620.5 | 483.5 |
| 2003 | 24.5 | 32.5 | 30 | 34 | 31.5 | 3 | 5.5 | 12 | 9 | -4 | 122 | 98 | 118 | 27 | 112 | 643.2 | 654.2 | 643.7 | 636.3 | 476.2 |
| | **MI** | | | | | | | | | | | | | | | | | | | |
| 1981 | 23.2 | 23.8 | 25 | 20.8 | 18.6 | 6 | 21.5 | 20.5 | 21.5 | 13.5 | 77 | 89 | 54 | 116 | 214 | 589.3 | 641.8 | 668.2 | 559.1 | 436 |
| 1982 | 29.5 | 27.5 | 32 | 29.5 | 31 | 2.5 | 5 | 8.5 | 2 | 2 | 51 | 118 | 60 | 86 | 69 | 589.3 | 665.2 | 668.2 | 559.1 | 448.4 |
| 1983 | 24 | 33 | 34.5 | 33.5 | 33.5 | -1 | 3 | 6 | 9.5 | 1 | 144 | 75 | 48 | 81 | 112 | 589.3 | 641.8 | 668.2 | 559.1 | 436 |
| | **IL** | | | | | | | | | | | | | | | | | | | |
| 1995 | 26.5 | 35.5 | 38 | 34.5 | 32 | 3.5 | 10 | 13 | 12 | -1 | 192 | 53 | 46 | 143 | 39 | 489 | 645.4 | 745.7 | 606 | 498.2 |
| 1996 | 32 | 34.5 | 34 | 34 | 29.5 | 3 | 9 | 11 | 13.5 | 5.5 | 294 | 104 | 83 | 71 | 56 | 498.7 | 607.9 | 703.7 | 636.1 | 486.9 |
| 1997 | 29.5 | 34 | 36 | 32 | 31.5 | 1.5 | 10.5 | 11.5 | 9.5 | 6 | 113 | 105 | 35 | 144 | 65 | 596.8 | 627.3 | 724.5 | 534.8 | 500.8 |
| | **IN1** | | | | | | | | | | | | | | | | | | | |
| 1987 | 30.7 | 32.8 | 33.5 | 34 | 32 | 19.1 | 7.4 | 11 | 4 | 4 | 36.8 | 46.7 | 179.8 | 41.6 | 48.7 | 713.7 | 704.3 | 673.4 | 673.7 | 514.9 |
| 1988 | 31.7 | 37.9 | 38.1 | 36.6 | 29.6 | 0.2 | 4.7 | 8.6 | 9.5 | 3.9 | 5.1 | 11.2 | 105.4 | 99.8 | 94.9 | 757 | 763.9 | 727 | 634.7 | 494.2 |
| 1989 | 30.2 | 32.2 | 32.9 | 32 | 30.9 | 0.4 | 8 | 13.2 | 8 | 6 | 118.8 | 125.9 | 77.2 | 114.3 | 73.1 | 700.8 | 700.6 | 653.4 | 608.3 | 475.7 |
| 1990 | 26.1 | 31.9 | 35 | 33 | 33 | 1 | 4.3 | 12 | 11 | 1 | 255.7 | 111.2 | 86.1 | 80.5 | 34.5 | 636.2 | 687.6 | 763.1 | 732.7 | 542.6 |
| 1991 | 31 | 33 | 35 | 36 | 33 | 2 | 11 | 12 | 13 | 0 | 110 | 10.4 | 89.2 | 161.3 | 67.1 | 740.5 | 859 | 812.7 | 729.8 | 575.6 |
| 1992 | 28 | 32 | 32 | 32 | 30 | 1 | 5 | 13 | 8 | 2 | 67.3 | 120.2 | 319.8 | 123.7 | 68.3 | 750.5 | 811.5 | 694.7 | 715.7 | 538 |
| 1993 | 29 | 31 | 35 | 33 | 29 | 5 | 5 | 12 | 12 | -1 | 92.5 | 89.2 | 74.2 | 177.8 | 83.8 | 770.2 | 748.9 | 754.9 | 693.4 | 535.1 |
| 1994 | 30 | 34 | 32 | 31 | 31 | -1 | 9 | 10 | 8 | 5 | 87.9 | 81.5 | 94.7 | 113.3 | 72.1 | 818.6 | 802 | 798.6 | 709.4 | 548.6 |
| 1995 | 28 | 33 | 35 | 33 | 33 | 2 | 7 | 10 | 13 | 0 | 251 | 68.3 | 65.2 | 336.3 | 30.7 | 732.8 | 772.3 | 792.7 | 684.7 | 565.4 |
| 1996 | 31 | 32 | 32 | 32 | 30 | 1 | 10 | 10 | 12 | 3 | 130.6 | 160.5 | 124.7 | 42.7 | 136.7 | 750.8 | 739.5 | 759 | 755.5 | 553.6 |
| 1997 | 29 | 32 | 36 | 32 | 32 | 0 | 9 | 10 | 7 | 3 | 158 | 135.6 | 64.8 | 133.6 | 24.9 | 740.2 | 679 | 831.5 | 677.8 | 594.5 |
| 1998 | 32 | 34 | 34 | 34 | 34 | 6 | 5 | 12 | 11 | 6 | 96.5 | 190 | 143 | 67.1 | 37.6 | 738.7 | 680 | 802.1 | 753.7 | 591.9 |
| 1999 | 31 | 35 | 38 | 36 | 36 | 3 | 8 | 12 | 10 | 1 | 62.5 | 71.1 | 41.1 | 57.4 | 13 | 816.2 | 784.3 | 815.1 | 747.2 | 633.1 |
| | **IN2** | | | | | | | | | | | | | | | | | | | |
| 1995 | 26 | 35 | 36.5 | 34.5 | 32 | 1.5 | 7 | 11.5 | 9.5 | -2.5 | 169 | 67 | 56 | 54 | 33 | 532 | 640.4 | 711.6 | 602.6 | 495.6 |
| 1996 | 31.5 | 33.5 | 32 | 32.5 | 29 | 2 | 8.5 | 9.5 | 12.5 | 4.5 | 166 | 129 | 147 | 24 | 72 | 495.1 | 622.2 | 691.8 | 624.5 | 467.6 |
| 1997 | 28 | 33 | 35 | 31 | 30 | 1 | 10 | 11 | 8.5 | 3 | 112 | 138 | 63 | 63 | 40 | 543.4 | 599.8 | 716.8 | 560.8 | 490.4 |
| 1998 | 32.5 | 34.5 | 33 | 32 | 33.5 | 9 | 4.5 | 12.5 | 12 | 3 | 104 | 231 | 137 | 46 | 25 | 618.7 | 606.4 | 723.4 | 598.1 | 499.2 |
| 1999 | 29.5 | 33.5 | 36 | 33 | 34.5 | 6.5 | 6.5 | 11.5 | 10 | 1 | 113 | 58 | 64 | 74 | 58 | 629.7 | 638.7 | 739.6 | 613.1 | 571.7 |
| 2000 | 30 | 31.5 | 30 | 34 | 30.5 | 4 | 6.5 | 10 | 10.5 | 2 | 141 | 192 | 125 | 28 | 89 | 522.3 | 601.2 | 676.2 | 601.3 | 477.9 |

*Supplementary Table 3: Soil data summary for modeled sites.*

Site = MN1 (Minnesota, lat = 44.08, long = -93.52)

| depth_inc | texture | BD | LL | DUL | SAT | KS | OM | F-inert | pH |
|---|---|---|---|---|---|---|---|---|---|
| cm | - | g/cm3 | mm/mm | mm/mm | mm/mm | mm/d | % | fraction | |
| 0-30 | Clay Loam | 1.1 | 0.2 | 0.4 | 0.5 | 212 | 3 | 0.394 | 7.5 |
| 30-60 | Clay Loam | 1.3 | 0.2 | 0.35 | 0.5 | 146 | 2.6 | 0.72 | 7.9 |
| 60-100 | Clay Loam | 1.4 | 0.2 | 0.3 | 0.4 | 1334 | 1 | 0.754 | 8.3 |
| 100-150 | Clay Loam | 1.55 | 0.1 | 0.3 | 0.4 | 133 | 0.25 | 0.888 | 8.75 |
| 150-210 | Clay Loam | 1.6 | 0.1 | 0.3 | 0.35 | 16.5 | 0 | 0.999 | 9 |
| 210-300 | Clay Loam | 1.6 | 0.1 | 0.3 | 0.3 | 10 | 0 | 0.999 | 9 |
| 300-390 | Clay Loam | 1.6 | 0.1 | 0.3 | 0.3 | 5.7 | 0 | 0.999 | 9 |

Site = MN2 (Minnesota, lat = 44.24, long = -95.32)

| depth_inc | texture | BD | LL | DUL | SAT | KS | OM | F-inert | pH |
|---|---|---|---|---|---|---|---|---|---|
| cm | - | g/cm3 | mm/mm | mm/mm | mm/mm | mm/d | % | fraction | |
| 0-30 | Clay Loam | 1.5 | 0.1 | 0.2 | 0.3 | 176 | 1.85 | 0.444 | 6.7 |
| 30-60 | Clay Loam | 1.5 | 0.1 | 0.2 | 0.3 | 140 | 1.1 | 0.709 | 6.5 |
| 60-100 | Clay Loam | 1.6 | 0.1 | 0.2 | 0.3 | 165 | 0.65 | 0.754 | 7 |
| 100-150 | Clay Loam | 1.6 | 0.1 | 0.2 | 0.3 | 130 | 0.25 | 0.809 | 7.95 |
| 150-210 | Clay Loam | 1.6 | 0.1 | 0.2 | 0.3 | 10 | 0 | 0.999 | 8 |
| 210-300 | Clay Loam | 1.6 | 0.1 | 0.2 | 0.3 | 5.7 | 0 | 0.999 | 8 |
| 300-390 | Clay Loam | 1.6 | 0.1 | 0.2 | 0.3 | 3.5 | 0 | 0.999 | 8 |

Site = IA (Iowa, lat = 42.4, long = -94.8)

| depth_inc | texture | BD | LL | DUL | SAT | KS | OM | F-inert | pH |
|---|---|---|---|---|---|---|---|---|---|
| cm | - | g/cm3 | mm/mm | mm/mm | mm/mm | mm/d | % | fraction | |
| 0-30 | Clay Loam | 1.3 | 0.2 | 0.4 | 0.5 | 130 | 2.75 | 0.545 | 7.9 |
| 30-60 | Clay Loam | 1.6 | 0.2 | 0.4 | 0.5 | 87 | 1.65 | 0.831 | 8 |
| 60-100 | Clay Loam | 1.6 | 0.2 | 0.3 | 0.4 | 58 | 0.4 | 0.976 | 7.9 |
| 100-150 | Clay Loam | 1.6 | 0.2 | 0.3 | 0.4 | 52 | 0.1 | 0.999 | 8.1 |
| 150-210 | Clay Loam | 1.6 | 0.2 | 0.3 | 0.4 | 15.5 | 0 | 0.999 | 8.1 |
| 210-300 | Clay Loam | 1.6 | 0.2 | 0.3 | 0.4 | 10 | 0 | 0.999 | 8.1 |
| 300-390 | Clay Loam | 1.6 | 0.2 | 0.3 | 0.4 | 5 | 0 | 0.999 | 8.1 |

Site = WI (Wisconsin, lat = 43.28, long = -89.37)

| depth_inc | texture | BD | LL | DUL | SAT | KS | OM | F-inert | pH |
|---|---|---|---|---|---|---|---|---|---|
| cm | - | g/cm3 | mm/mm | mm/mm | mm/mm | mm/d | % | fraction | |
| 0-30 | Clay Loam | 1.4 | 0.2 | 0.4 | 0.5 | 203 | 1.4 | 0.545 | 6.5 |
| 30-60 | Clay Loam | 1.4 | 0.2 | 0.4 | 0.5 | 104 | 0.55 | 0.831 | 6.2 |
| 60-100 | Clay Loam | 1.5 | 0.2 | 0.3 | 0.45 | 81 | 0.45 | 0.976 | 6.4 |
| 100-150 | Clay Loam | 1.5 | 0.1 | 0.3 | 0.4 | 58 | 0.35 | 0.999 | 6.55 |
| 150-210 | Clay Loam | 1.6 | 0.1 | 0.25 | 0.4 | 15 | 0.3 | 0.999 | 6.85 |
| 210-300 | Clay Loam | 1.6 | 0.1 | 0.2 | 0.3 | 9.7 | 0 | 0.999 | 7 |
| 300-390 | Clay Loam | 1.6 | 0.1 | 0.2 | 0.3 | 6 | 0 | 0.999 | 7 |

Site = MI (Michigan, lat = 43.4, long = -83.7)

| depth_inc | texture | BD | LL | DUL | SAT | KS | OM | F-inert | pH |
|---|---|---|---|---|---|---|---|---|---|
| cm | - | g/cm3 | mm/mm | mm/mm | mm/mm | mm/d | % | fraction | |
| 0-30 | Clay Loam | 1.5 | 0.2 | 0.3 | 0.4 | 39 | 1.77 | 0.545 | 7.6 |
| 30-60 | Clay Loam | 1.5 | 0.2 | 0.4 | 0.4 | 40 | 1.1 | 0.831 | 7.8 |
| 60-100 | Clay Loam | 1.5 | 0.3 | 0.4 | 0.4 | 36 | 0.65 | 0.976 | 7.9 |
| 100-150 | Clay Loam | 1.5 | 0.2 | 0.4 | 0.4 | 33 | 0.25 | 0.999 | 7.9 |
| 150-210 | Clay Loam | 1.5 | 0.2 | 0.35 | 0.4 | 9 | 0 | 0.999 | 7.9 |
| 210-300 | Clay Loam | 1.5 | 0.2 | 0.3 | 0.4 | 6 | 0 | 0.999 | 7.9 |
| 300-390 | Clay Loam | 1.5 | 0.2 | 0.3 | 0.4 | 3.3 | 0 | 0.999 | 7.9 |

Site = IL (Illinois, lat = 40.06, long = -88.22)

| depth_inc | texture | BD | LL | DUL | SAT | KS | OM | F-inert | pH |
|---|---|---|---|---|---|---|---|---|---|
| cm | - | g/cm3 | mm/mm | mm/mm | mm/mm | mm/d | % | fraction | |
| 0-30 | Clay Loam | 1.5 | 0.2 | 0.3 | 0.4 | 466 | 2.3 | 0.545 | 6.7 |
| 30-60 | Clay Loam | 1.5 | 0.2 | 0.3 | 0.4 | 306 | 1.05 | 0.831 | 6.3 |
| 60-100 | Clay Loam | 1.5 | 0.2 | 0.3 | 0.4 | 285 | 0.3 | 0.976 | 6 |
| 100-150 | Clay Loam | 1.5 | 0.2 | 0.3 | 0.4 | 174 | 0.25 | 0.999 | 6.15 |
| 150-210 | Clay Loam | 1.5 | 0.15 | 0.3 | 0.35 | 25.5 | 0.1 | 0.999 | 7.1 |
| 210-300 | Clay Loam | 1.5 | 0.1 | 0.3 | 0.3 | 0.7 | 0.1 | 0.999 | 7.2 |
| 300-390 | Clay Loam | 1.5 | 0.1 | 0.3 | 0.3 | 0.4 | 0.1 | 0.999 | 7.2 |

Site = IN1 (Indiana, lat = 39.03, long = -85.54)

| depth_inc | texture | BD | LL | DUL | SAT | KS | OM | F-inert | pH |
|---|---|---|---|---|---|---|---|---|---|
| cm | - | g/cm3 | mm/mm | mm/mm | mm/mm | mm/d | % | fraction | |
| 0-30 | Clay Loam | 1.4 | 0.1 | 0.3 | 0.4 | 278 | 1.1 | 0.545 | 5.7 |
| 30-60 | Clay Loam | 1.7 | 0.1 | 0.3 | 0.4 | 150 | 0.6 | 0.831 | 4.5 |
| 60-100 | Clay Loam | 1.6 | 0.2 | 0.3 | 0.4 | 87 | 0.15 | 0.976 | 4.4 |
| 100-150 | Clay Loam | 1.6 | 0.2 | 0.3 | 0.4 | 70 | 0.1 | 0.999 | 4.4 |
| 150-210 | Clay Loam | 1.6 | 0.2 | 0.3 | 0.4 | 45.5 | 0.05 | 0.999 | 4.4 |
| 210-300 | Clay Loam | 1.6 | 0.2 | 0.3 | 0.4 | 15 | 0 | 0.999 | 4.4 |
| 300-390 | Clay Loam | 1.6 | 0.2 | 0.3 | 0.3 | 8,3 | 0 | 0.999 | 4.4 |

Site = IN2 (Indiana, lat = 40.47, long = -86.99)

| depth_inc | texture | BD | LL | DUL | SAT | KS | OM | F-inert | pH |
|---|---|---|---|---|---|---|---|---|---|
| cm | - | g/cm3 | mm/mm | mm/mm | mm/mm | mm/d | % | fraction | |
| 0-30 | Clay Loam | 1.4 | 0.1 | 0.3 | 0.4 | 282 | 1.4 | 0.545 | 7.2 |
| 30-60 | Clay Loam | 1.4 | 0.2 | 0.3 | 0.4 | 115 | 0.7 | 0.831 | 6.9 |
| 60-100 | Clay Loam | 1.5 | 0.2 | 0.3 | 0.4 | 59 | 0.4 | 0.976 | 7.7 |
| 100-150 | Clay Loam | 1.8 | 0.1 | 0.3 | 0.3 | 8 | 0.2 | 0.999 | 8.2 |
| 150-210 | Clay Loam | 1.8 | 0.1 | 0.3 | 0.3 | 0.6 | 0.2 | 0.999 | 8.2 |
| 210-300 | Clay Loam | 1.8 | 0.1 | 0.3 | 0.3 | 0.2 | 0.2 | 0.999 | 8.2 |
| 300-390 | Clay Loam | 1.8 | 0.1 | 0.3 | 0.3 | 0.03 | 0.2 | 0.999 | 8.2 |

*Supplementary Table 4: Soybean cultivar details for simulations*

| Cultivar Parameters | Units | Array of Values |
|---|---|---|
| **Maturity Group 1 (MN1, MN2, WI, MI)** | | |
| node_sen_rate | °C-days/node | 120 |
| x_pp | Daylight | 13.84, 15.1, 16.3, 17.5 |
| tt_end_of_juvenile | °C-days | 100, 133, 200, 400 |
| tt_floral_initiation | °C-days | 120, 160, 240, 480 |
| tt_flowering | °C-days | 239, 318, 478, 1274 |
| tt_start_grain_fill | °C-days | 485, 646, 970, 2586 |
| **Maturity Group 2 (IA, IN1, IN2)** | | |
| node_sen_rate | °C-days/node | 120 |
| x_pp | Daylight | 13.59, 14.6, 15.6, 16.6 |
| tt_end_of_juvenile | °C-days | 100, 133, 200, 400 |
| tt_floral_initiation | °C-days | 128, 171, 256, 512 |
| tt_flowering | °C-days | 246, 328, 492, 1312 |
| tt_start_grain_fill | °C-days | 499, 666, 999, 2664 |
| **Maturity Group 3 (MI)** | | |
| node_sen_rate | °C-days/node | 120 |
| x_pp | Daylight | 13.4, 14.3, 15.2, 16.0 |
| tt_end_of_juvenile | °C-days | 100, 133, 200, 400 |
| tt_floral_initiation | °C-days | 160, 213, 320, 640 |
| tt_flowering | °C-days | 253, 338, 506, 1350 |
| tt_start_grain_fill | °C-days | 514, 685, 1028, 2741 |

Supplementary Table 6: Maize cultivar details for simulations

| Cultivar Parameters | Units | Array of Values |
|---|---|---|
| **95 Day Relative Maturity (MN1, MI)** | | |
| tt_emerg_to_endjuv | °C-days | 190 |
| tt_flower_to_maturity | °C-days | 680 |
| head_grain_no_max | °C-days | 750 |
| grain_gth_rate | °C-days | 7.7 |
| **100 Day Relative Maturity (IN2)** | | |
| tt_emerg_to_endjuv | °C-days | 228 |
| tt_flower_to_maturity | °C-days | 745 |
| head_grain_no_max | °C-days | 770 |
| grain_gth_rate | °C-days | 7.7 |
| **103 Day Relative Maturity (MN2)** | | |
| tt_emerg_to_endjuv | °C-days | 230 |
| tt_flower_to_maturity | °C-days | 660 |
| head_grain_no_max | °C-days | 700 |

| | | |
|---|---|---|
| grain_gth_rate | °C-days | 7.7 |
| **105 Day Relative Maturity (IA, WI)** | | |
| tt_emerg_to_endjuv | °C-days | 240 |
| tt_flower_to_maturity | °C-days | 785 |
| head_grain_no_max | °C-days | 770 |
| grain_gth_rate | °C-days | 7.7 |
| **110 Day Relative Maturity (IN1)** | | |
| tt_emerg_to_endjuv | °C-days | 250 |
| tt_flower_to_maturity | °C-days | 820 |
| head_grain_no_max | °C-days | 770 |
| grain_gth_rate | °C-days | 7.7 |
| **115 Day Relative Maturity (MI)** | | |
| tt_emerg_to_endjuv | °C-days | 262 |
| tt_flower_to_maturity | °C-days | 860 |
| head_grain_no_max | °C-days | 770 |
| grain_gth_rate | °C-days | 7.7 |

*Supplementary Table 5: Model evaluation Statistics*

| Site ID | $r^2$ | ME | $RSME_{Yield}$ | $RSME_{Drain}$ | $RSME_{FlowWtNO3}$ | $RSME_{LeachLoad}$ |
|---|---|---|---|---|---|---|
| MN1 | 0.79 | 0.74 | 2.15 | 2.43 | 2.43 | 2.66 |
| MN2 | 0.94 | 0.94 | 1.35 | 1.28 | 1.28 | 1.2 |
| IA | 0.95 | 0.93 | 2.38 | 4.65 | 1.26 | 2.67 |
| WI | 0.88 | 0.88 | 2.97 | 1.28 | 1.28 | 2.7 |
| MI | 1 | 0.46 | N/A | N/A | N/A | N/A |
| IL | 0.96 | 0.95 | 1.58 | 3.94 | 3.94 | 1.44 |
| IN1 | 0.75 | 0.71 | 2.77 | 1.66 | 1.66 | 2.86 |
| IN2 | 0.92 | 0.9 | 11.22 | 2.29 | 2.29 | 1.76 |

*Supplementary Table 6: AONR (kg N $ha^{-1}$) calculated using the bi-linear model and the quadratic plateau model. "N/A" indicated that the model did not converge.*

| | | Continuous Maize | | Maize-Soybean Rotation | |
|---|---|---|---|---|---|
| Site | Year | Bi-linear AONR (kg N $ha^{-1}$) | Quadratic Plateau AONR (kg N $ha^{-1}$) | Bi-linear AONR (kg N $ha^{-1}$) | Quadratic Plateau AONR (kg N $ha^{-1}$) |
| MN1 | 2000 | 82 | 127 | 57 | 68 |
| MN1 | 2001 | 71 | 100 | 57 | 85 |
| MN1 | 2002 | 80 | 121 | 57 | 68 |
| MN1 | 2003 | 96 | 148 | 81 | 125 |
| MN1 | 2004 | 119 | 179 | 72 | 104 |
| MN1 | 2005 | 118 | 176 | 59 | 75 |
| MN1 | 2006 | 116 | 171 | 68 | 96 |
| MN1 | 2007 | 139 | 210 | 91 | 144 |
| MN1 | 2008 | 103 | 155 | 71 | 104 |
| MN1 | 2009 | 130 | 196 | 70 | 101 |
| MN1 | 2010 | 127 | 194 | 63 | 84 |
| MN1 | 2011 | 98 | 148 | 60 | 73 |
| MN1 | 2012 | 107 | 162 | 79 | 129 |
| MN1 | 2013 | 97 | 149 | 60 | 73 |
| MN1 | 2014 | 138 | 209 | 91 | 144 |
| MN1 | 2015 | 136 | 204 | 66 | 95 |
| MN1 | 2016 | 106 | 167 | 61 | 80 |
| MN1 | 2017 | 96 | 145 | 59 | 70 |
| MN1 | 2018 | 104 | 158 | 69 | 100 |
| MN1 | 2019 | 103 | 157 | 71 | 104 |
| MN2 | 2000 | 94 | 143 | 68 | 98 |
| MN2 | 2001 | 84 | 125 | 24 | N/A |
| MN2 | 2002 | 93 | 143 | 76 | 119 |
| MN2 | 2003 | 103 | 152 | 78 | 121 |
| MN2 | 2004 | 116 | 171 | 68 | 100 |
| MN2 | 2005 | 121 | 180 | 83 | 133 |
| MN2 | 2006 | 109 | 164 | 61 | 82 |
| MN2 | 2007 | 122 | 181 | 99 | 159 |

| | | Continuous Maize | | Maize-Soybean Rotation | |
|---|---|---|---|---|---|
| Site | Year | Bi-linear AONR (kg ha$^{-1}$) | Quadratic Plateau AONR (kg ha$^{-1}$) | Bi-linear AONR (kg ha$^{-1}$) | Quadratic Plateau AONR (kg ha$^{-1}$) |
| MN2 | 2008 | 103 | 151 | 59 | 70 |
| MN2 | 2010 | 134 | 203 | 77 | 117 |
| MN2 | 2011 | 103 | 157 | 71 | 102 |
| MN2 | 2012 | 106 | 176 | 98 | 165 |
| MN2 | 2013 | 112 | 158 | 74 | 109 |
| MN2 | 2014 | 119 | 176 | 91 | 142 |
| MN2 | 2015 | 126 | 189 | 76 | 113 |
| MN2 | 2016 | 121 | 177 | 74 | 111 |
| MN2 | 2017 | 120 | 171 | 74 | 108 |
| MN2 | 2018 | 130 | 196 | 92 | 142 |
| MN2 | 2019 | 105 | 152 | 67 | 90 |
| IA | 2000 | 67 | 92 | 56 | 66 |
| IA | 2001 | 74 | 109 | 37 | 66 |
| IA | 2002 | 115 | 167 | 62 | 78 |
| IA | 2003 | 106 | 158 | 82 | 132 |
| IA | 2004 | 130 | 199 | 89 | 136 |
| IA | 2005 | 96 | 148 | 61 | 78 |
| IA | 2006 | 82 | 127 | 68 | 96 |
| IA | 2007 | 97 | 151 | 71 | 102 |
| IA | 2008 | 104 | 156 | 57 | 64 |
| IA | 2009 | 124 | 186 | 82 | 128 |
| IA | 2010 | 133 | 205 | 70 | 101 |
| IA | 2011 | 82 | 125 | 57 | 60 |
| IA | 2012 | 110 | 162 | 79 | 127 |
| IA | 2013 | 113 | 168 | 82 | 130 |
| IA | 2014 | 118 | 173 | 82 | 129 |
| IA | 2015 | 113 | 162 | 58 | 65 |
| IA | 2016 | 97 | 149 | 59 | 69 |
| IA | 2017 | 103 | 154 | 79 | 121 |

| | | Continuous Maize | | Maize-Soybean Rotation | |
|---|---|---|---|---|---|
| Site | Year | Bi-linear AONR (kg ha$^{-1}$) | Quadratic Plateau AONR (kg ha$^{-1}$) | Bi-linear AONR (kg ha$^{-1}$) | Quadratic Plateau AONR (kg ha$^{-1}$) |
| IA | 2018 | 84 | 127 | 61 | 77 |
| WI | 2000 | 109 | 160 | 40 | 61 |
| WI | 2001 | 102 | 163 | 56 | 62 |
| WI | 2002 | 115 | 171 | 73 | 111 |
| WI | 2003 | 88 | 132 | 91 | 144 |
| WI | 2004 | 138 | 220 | 89 | 142 |
| WI | 2005 | 138 | 206 | 119 | 180 |
| WI | 2006 | 88 | 135 | 70 | 101 |
| WI | 2007 | 133 | 211 | 100 | 155 |
| WI | 2008 | 133 | 202 | 82 | 137 |
| WI | 2009 | 97 | 145 | 79 | 120 |
| WI | 2010 | 129 | 201 | 57 | 69 |
| WI | 2011 | 86 | 131 | 73 | 108 |
| WI | 2012 | 109 | 146 | 61 | 75 |
| WI | 2013 | 129 | 191 | 72 | 104 |
| WI | 2014 | 130 | 197 | 74 | 112 |
| WI | 2015 | 115 | 164 | 71 | 100 |
| WI | 2016 | 120 | 178 | 62 | 78 |
| WI | 2017 | 116 | 165 | 69 | 98 |
| WI | 2018 | 98 | 147 | 73 | 108 |
| WI | 2019 | 91 | 151 | 58 | 68 |
| MI | 2000 | 123 | 202 | 61 | 77 |
| MI | 2001 | 126 | 196 | 95 | 150 |
| MI | 2002 | 71 | 100 | 57 | 67 |
| MI | 2003 | 104 | 154 | 83 | 131 |
| MI | 2004 | 114 | 168 | 72 | 104 |
| MI | 2005 | 114 | 167 | 73 | 108 |
| MI | 2006 | 88 | 140 | 70 | 99 |
| MI | 2007 | 116 | 166 | 88 | 136 |

| | | Continuous Maize | | Maize-Soybean Rotation | |
|---|---|---|---|---|---|
| Site | Year | Bi-linear AONR (kg ha$^{-1}$) | Quadratic Plateau AONR (kg ha$^{-1}$) | Bi-linear AONR (kg ha$^{-1}$) | Quadratic Plateau AONR (kg ha$^{-1}$) |
| MI | 2008 | 121 | 187 | 78 | 120 |
| MI | 2010 | 120 | 183 | 75 | 117 |
| MI | 2011 | 103 | 149 | 98 | 160 |
| MI | 2012 | 103 | 152 | 68 | 101 |
| MI | 2013 | 96 | 142 | 77 | 119 |
| MI | 2014 | 130 | 215 | 57 | 62 |
| MI | 2015 | 114 | 166 | 77 | 116 |
| MI | 2016 | 114 | 166 | 81 | 126 |
| MI | 2017 | 110 | 159 | 69 | 97 |
| MI | 2018 | 75 | 109 | 49 | N/A |
| MI | 2019 | 110 | 159 | 84 | 133 |
| IL | 2000 | 120 | 179 | 64 | 85 |
| IL | 2001 | 100 | 134 | 59 | 70 |
| IL | 2002 | 127 | 199 | 64 | 88 |
| IL | 2003 | 115 | 167 | 64 | 84 |
| IL | 2004 | 137 | 215 | 70 | 99 |
| IL | 2005 | 121 | 182 | 64 | 85 |
| IL | 2006 | 90 | 140 | 56 | 66 |
| IL | 2007 | 116 | 173 | 66 | 87 |
| IL | 2008 | 145 | 223 | 72 | 106 |
| IL | 2009 | 125 | 187 | 71 | 105 |
| IL | 2010 | 116 | 173 | 60 | 73 |
| IL | 2011 | 106 | 185 | 57 | 66 |
| IL | 2012 | 91 | 141 | 93 | 282 |
| IL | 2013 | 105 | 153 | 57 | 63 |
| IL | 2014 | 124 | 186 | 65 | 88 |
| IL | 2015 | 126 | 188 | 70 | 103 |
| IL | 2016 | 86 | 140 | 58 | 66 |
| IL | 2017 | 103 | 154 | 68 | 100 |

| | | Continuous Maize | | Maize-Soybean Rotation | |
|---|---|---|---|---|---|
| Site | Year | Bi-linear AONR (kg $ha^{-1}$) | Quadratic Plateau AONR (kg $ha^{-1}$) | Bi-linear AONR (kg $ha^{-1}$) | Quadratic Plateau AONR (kg $ha^{-1}$) |
| IL | 2018 | 114 | 165 | 63 | 81 |
| IN1 | 2000 | 118 | 178 | 60 | 77 |
| IN1 | 2001 | 119 | 180 | 58 | 67 |
| IN1 | 2002 | 110 | 164 | 68 | 99 |
| IN1 | 2003 | 113 | 159 | 58 | 67 |
| IN1 | 2004 | 139 | 215 | 100 | 153 |
| IN1 | 2005 | 117 | 168 | 57 | 67 |
| IN1 | 2006 | 111 | 161 | 58 | 66 |
| IN1 | 2007 | 99 | 159 | 64 | 87 |
| IN1 | 2008 | 162 | 243 | 91 | 141 |
| IN1 | 2009 | 110 | 171 | 58 | 66 |
| IN1 | 2010 | 125 | 194 | 94 | 147 |
| IN1 | 2011 | 155 | 233 | 91 | 143 |
| IN1 | 2012 | 136 | 204 | 105 | 163 |
| IN1 | 2013 | 120 | 182 | 56 | 62 |
| IN1 | 2014 | 116 | 169 | 60 | 73 |
| IN1 | 2015 | 96 | 143 | 58 | 71 |
| IN1 | 2016 | 85 | 129 | 58 | 68 |
| IN1 | 2017 | 107 | 154 | 63 | 83 |
| IN1 | 2018 | 116 | 166 | 76 | 114 |
| IN1 | 2019 | 120 | 178 | 62 | 78 |
| IN2 | 2000 | 118 | 182 | 76 | 117 |
| IN2 | 2001 | 86 | 235 | 63 | 84 |
| IN2 | 2002 | 67 | 92 | 46 | 60 |
| IN2 | 2003 | 118 | 178 | 59 | 71 |
| IN2 | 2004 | 170 | 264 | 70 | 101 |
| IN2 | 2005 | 66 | 89 | 63 | 84 |
| IN2 | 2006 | 88 | 134 | 68 | 96 |
| IN2 | 2007 | 108 | 152 | 36 | N/A |

| | | Continuous Maize | | Maize-Soybean Rotation | |
|---|---|---|---|---|---|
| Site | Year | Bi-linear AONR (kg ha$^{-1}$) | Quadratic Plateau AONR (kg ha$^{-1}$) | Bi-linear AONR (kg ha$^{-1}$) | Quadratic Plateau AONR (kg ha$^{-1}$) |
| IN2 | 2008 | 155 | 236 | 74 | 109 |
| IN2 | 2010 | 154 | 235 | 67 | 94 |
| IN2 | 2011 | 110 | 167 | 57 | 64 |
| IN2 | 2012 | N/A | 152 | N/A | N/A |
| IN2 | 2013 | 105 | 129 | 56 | N/A |
| IN2 | 2014 | 117 | 218 | 59 | 68 |
| IN2 | 2015 | 139 | 116 | 69 | 100 |
| IN2 | 2016 | 78 | 168 | 58 | 65 |
| IN2 | 2017 | 116 | 174 | 57 | 63 |
| IN2 | 2018 | 121 | 137 | 61 | 79 |
| IN2 | 2019 | 91 | N/A | 72 | 107 |