Supplemental Information

S1. Supplemental information on APSIM configuration and performance

Experimental treatments at the sites encompassed one or more crop rotation sequences of maize, soybean, wheat and rye cover crop. Management records (planting date and rate, tillage type and timing, and N fertilizer amount and timing), cultivar relative maturity, and drainage system characteristics (depth and spacing) were available (Table S1). Measured data included end-of-season maize and soybean yields, daily water flow in subsurface drainage tiles and NO$_3$ concentrations in drainage, spanning at least five weather years (Table S1). The latter two were used to calculate cumulative annual NO$_3$ loads (kg N ha$^{-1}$) and flow-weighted NO$_3$ concentrations in subsurface drainage (mg N L$^{-1}$). These observations were used to test the robustness of the model predictions.

As a first step, we used the management, soil information and weather data available for each crop rotation treatment at the seven experimental sites (Table S1) to configure APSIM (version 7.8) to replicate the experimental data. All simulations were set up using the following modules: maize, soybean, and wheat (to simulate rye cover crop), SWIM (soil hydrology; Huth et al. 2012), soilN (soil C and N cycling), surfaceom (residue model; Probert et al. 1998; Thorburn et al. 2005, 2001) and manager (Keating et al. 2003).

Maize, Soybean and Wheat

The maize and soybean cultivars used at the experimental sites were represented in the model with generic APSIM cultivars. For maize these corresponded to the “B” cultivars (Archontoulis et al. 2014b), while for soybean these corresponded to the “MG” cultivars (Archontoulis et al. 2014a). These have been previously calibrated to broadly characterize locally adapted commercial genotypes in the region. We selected maturity groups appropriate for at each site based on the management records available. Changes made to the crop cultivar parameters included lowering the critical N concentration in grains (n_conc_crit_grain) from 1.5 to 1.2% in maize and 6.5 to 6% in soybean. This follows
experimental evidence of declining grain N concentrations in new-era maize hybrids (Ciampitti and Vyn 2012) and soybean cultivars (Tamagno et al 2017). These changes have been seen to improve simulation of soil NO$_3$ (Puntel et al 2016) and NO$_3$ leaching (Martinez-Feria et al 2016). The *wheat* module was used to simulate rye cover crop at the KELLEY and GILMORE sites, employing the calibrated *wheat* version developed by Dietzel et al (2016) and improved by Martinez-Feria et al (2016).

Supplemental Table S1. Summary of the experimental datasets used to configure and test the APSIM model. CC = Continuous Maize; CS = Maize-Soybean; SWC = Soybean-Wheat-Maize; MRTN = Maximum Return to N rate.

| Site Name | Location | Soil Classification | Subsurface drain specifications | Cropping System(s) | MRTN$^4$ |
|-----------|----------|---------------------|-------------------------------|-------------------|----------|
|           |          |                     | Depth Spacing                  |                   | CC CS    |
|           |          |                     | cm m                           |                   | kg N ha$^{-1}$ |
| HICKS.B$^1$ | Walnut Grove, MN (44.351, -95.537) | Havelock clay loam, Du Page silt loam, Hawick sandy loam | 120 15 | CC (2011-2015) | 178 138 |
| NASHUA$^2$ | Nashua, IA (42.931, -92.572) | Clyde silty clay loam, Floyd loam, Kenyon loam, Readlyn loam | 120 28.5 | CS* (2007-2015) | 211 157 |
| GILMORE$^3$ | Gilmore City, IA (42.748, -94.495) | Canisteo clay loam, Nicollet loam, Webster silty clay loam | 110 7.6 | CS* with and without tillage (2011-2015), CS* with rye cover crop no tillage (2011-2015) | 211 157 |
| KELLEY$^{2,3}$ | Kelley, IA (41.920, -93.749) | Nicollet loam, Webster silty clay loam | 110 13.5 | CS* (2011-2015), CC (2011-2015), CC with residue Removal and rye cover crop (2011-2015) | 211 157 |
| SERF$^1$ | Crawfordsville, IA (41.193, -91.483) | Kalona silty clay loam, Taintor silty clay loam | 122 18.3 | CC (2012-2015), CS* (2011-2015) | 228 172 |
| DPAC$^1$ | Albany, IN (40.267, -85.161) | Blount silt loam, Pewamo clay loam, Glynwood silt loam | 91 15.2 | CS (2011-2015) | 251 251 |
| STJOHNS$^1$ | St. Johns, OH (40.518, -84.085) | Minster silty clay loam, Blount silt loam | 91 12.2 | SWC (2011-2015) | 221 195 |

* Includes both phases of the rotation every year

$^1$ Abendroth et al (2017)

$^2$ Martinez-Feria et al (2018)

$^3$ Dietzel et al (2016)

$^4$ Sawyer et al (2006)
SWIM, SoilN and surfaceom

Soil hydrological and organic matter parameters were derived from the SSURGO database (Soil Survey Staff n.d.) This was done by conducting database queries using the fields’ geospatial coordinates with the FedData (Bocinsky et al 2018) package in R (R Core Team 2017). Then, we extracted the tabular data of the major components for each of the map units present at the field sites. Given that the soil layer structure for SSURGO components differ across map units, we standardized the soil layers (breaks = 0, 5, 10, 15, 20, 30, 45, 60, 80, 100, 130, 160, 200, 240, and 280 cm) across all sites using linear interpolation. To represent the whole field site, data were aggregated across all map units, using the average weighted with the percent of area occupied by each map unit. Data extracted included estimates for APSIM parameters such as drainage upper limit (DUL, mm mm\(^{-1}\)), drainage lower limit (LL15, mm mm\(^{-1}\)), saturation point (SAT, mm mm\(^{-1}\)) and saturated hydraulic conductivity (Ksat, mm mm\(^{-1}\)), bulk density (BD g cm\(^{-3}\)), and soil organic carbon (SOC; %). The crop lower limit (CLL, mm mm\(^{-1}\)) for maize, soybean, and wheat was assumed equal to LL15, while the soil/root water extraction coefficient (KL, d\(^{-1}\)) was set to 0.08 in the top soil and decreased exponentially to values of 0.03 at 180 cm soil depth (Hammer et al 2009). The root penetration parameter (XF, 0–1) was set to 1 for all sites. Subsurface drainage was set up according to site specifications (Table S1), with lateral saturated soil water conductivity (klat) at 2800 mm d\(^{-1}\) (Dietzel et al 2016). We induced the “water table” option in SWIM to represent water table fluctuation (Singh et al 2006), initialized at the depth of the subsurface drains. The R code used to download, process and write soil files with the APSIM format has been made available through the APssurgo repository (Martinez-Feria and Archontoulis 2018)

Daily atmospheric N deposition was simulated with the implementation of a manager module script that estimates N deposition by multiplying daily precipitation (mm) by a factor of 0.01 (Holland et al 2005). This approach adds on average ~8 kg N ha\(^{-1}\) yr\(^{-1}\) to soils in this region, which is well within measured ranges (Zhang et al 2012). To mitigate exceptionally high denitrification in the deep soil layers (> 1m) we used the change to the soilN module which has been described in detail in Martinez-Feria et al (2018). We used depth_inhibit = 1.0 m (i.e. no denitrification below 1 m depth) and dul_fac_dni = 1.1 (i.e. denitrification is triggered at 10% above field capacity) at all sites.

To remove the confounding effects of buildup or decline in soil organic carbon humic (Hum) or microbial pools (Biom), we ran the model for a “spin-up” period (Dietzel et al 2016, Puntel et al 2016), during which a maize-soybean rotation with fertilizer applied at the MRTN (Table S1) was continuously simulated for 15 years at each site. Initial values for soil nitrate and moisture, and above and below-ground residue amount and C:N were also derived from this step. To avoid introducing bias from a given set of conditions experienced during the last year of the spin-up, we used the average value of these variables at harvesting for the last five simulated years for each crop. The values derived from this step, which were used as the initial conditions in model test runs and scenario experiments are shown on Fig. S1.1.
Supplemental Figure S1.1. Summary of configuration of soils in APSIM. Soil organic carbon pools (a), inorganic N concentrations (b) and hydrological parameters (c) used for model simulation at the seven experimental sites. Values from (a) and (b) were derived from a 15 year spin-up model run, during which a maize-soybean rotation was simulated. Horizontal line in (c) indicates depth of the subsurface drainage tube (tile). FBiom = microbial carbon pool; FHum=humic carbon pool; Fnert=inert carbon pool. DUL=Drainage upper limit (0.3 bar); LL=Lower limit (15 bar); SAT=Saturation point.
Model performance

Having configured APSIM, the goal of this next step was to use the observed crop yields, drainage NO\(_3\) loads and flow-weighted NO\(_3\) concentrations to test the robustness of the predictions. Model fit was evaluated visually by means of plotting the observed vs. simulated values, and statistically by computing root mean squared error (RMSE), relative root mean squared error (RRMSE) and the mean bias error (MBE; Fig. S2). The RMSE and RRMSE are measures of model error and the smaller the value the better. The MBE is a measure of model accuracy, and the closer the value to zero the better. The equations for these indices can be viewed in Archontoulis and Miguez (2013).

Supplemental Figure S1.2. Testing the robustness of the APSIM model at the seven long-term experimental sites. Symbols represent the average for every treatment across years at every site. Solid line represents the 1:1 relationship (i.e. perfect fit), while dotted lines the ±20% error range for maize and soybean yield and ±40% for drainage NO\(_3\) loads and concentrations. RMSE = root mean squared error; RRMSE = relative root mean squared error; MBE = mean bias error.
Considering that configuration and calibration of the simulations were largely based on limited (i.e. publicly available) data and literature values, the APSIM model was able to satisfactorily reproduce the measured crop yields and subsurface drainage NO₃ losses (Fig S2). Grain yields across all sites and crop rotation treatments were simulated with a RMSE of 1.27 and 0.38 Mg ha⁻¹ yr⁻¹, for maize and soybean respectively. This represented a RRMSE of around 13% in both crops. Across all sites and cropping systems, the model simulated subsurface drainage NO₃ loads with a MBE of -3 kg N ha⁻¹ yr⁻¹, although the model slightly under predicted NO₃ loads in the GILMORE and STJOHNS sites. The observed flow weighted NO₃ concentrations were similarly under-predicted across those two sites, which seems to indicate this may be due to an underestimation of drainage water flow. At the rest of the sites, drainage NO₃ loads and concentrations were simulated with good precision; except for drainage NO₃ concentrations at HICKS.B, where the model over-predicted the measured data (Fig. 1.2).

S2. Supplemental information on mean-variance PE calculation

Portfolio theory had its origins in the idea that an efficient financial portfolio should balance the tradeoff between maximizing expected returns and minimizing the risks to the integrity of the investment (Markowitz 1959). In practice, financial managers do this by selecting multiple assets that tend to be weakly or negatively correlated. The contribution of a single asset to the stability of the portfolio can be examined by comparing the average coefficient of variation (CV; standard deviation divided by the mean) of all assets in the portfolio, against the average CV of the portfolio without the specific asset. This approach assumes that investing in an asset stock does not meaningfully affect the asset’s properties, so that the standard deviation of the return increases linearly with the value of the investment (i.e., variance increases by the power of two).

In biological systems, changes to the standard deviation are often non-linear, so that larger populations or greater plant biomass, for example, may be less variable than expected by simply comparing their CV (Anderson et al 2013). In ecological research this is known as Taylor’s law (Taylor and Woiwod 1980), which predicts that the slope of the log-log variance and mean individuals of a species per unit area (z) is less than 2:

$$\log(\sigma^2) = \beta_0 + z \times \log(\mu)$$

This relationship can be used to estimate how we expect the standard variation (σ) of a system to change according to changes in the observed mean (μ). β₀ is the intercept of the log-log mean-variance relationship. Tilman (1999) proposed to use this approach to scale the variance when examining portfolio effects (PE) in ecological systems. For mathematical convenience PE is often calculated as the ratio of the observed and expected CV. Because in both cases, the CV is computed with the same μ, this term cancels out so that PE is simply the ratio of the observed and expected σ. The mean-variance approach has become a well-established methodology to quantify PE of diversification in population dynamics and productivity of natural and managed ecosystems (Anderson et al 2013, Schindler et al 2015, Renard and Tilman 2019).
We applied this methodology to our simulated dataset, by fitting the equation 1 to the mean and variance of management scenarios where only a single improved practice was adopted (Fig. S2). For NO₃ load and soil NO₃ at harvest, the z value of tended to be < 2 across classifications of spring rainfall, although z was generally lower for NO₃ load and higher for soil NO₃ at harvest in years of high rainfall. This was not the case for corn yields where there were wide variations in z value, indicating the log-log mean-variance relationship cannot be adequately modeled in this context. (Fig S2).

Supplemental Figure S2. Modeling the mean-variance relationship. (a) Each data point represents a simulated scenario where only one improved management practice was adopted at each site and spring rainfall classification. Mean and variance are computed across years and sets of initial conditions (see table 1). Line shows the fitted regression, which was used to extrapolate the expected variance to the level of the observed (i.e. simulated) mean (see Fig. 2 in main text for example). (b) Distribution of the Z values (i.e., slope of the log-log mean-variance regression across levels of spring rainfall.)
Supplemental Table S2. Rankings for each simulated multi-management strategy scenario at each level of spring rainfall. Rankings were computed according to the scenario’s PE-adjusted mean, separately for each variable. A combined ranking for each management scenario was developed by computing the Euclidian distance from the origin in the three-dimensional space of each ranking. All ranks are from best to worst (best being the smallest number).

| Apr-Jun Rainfall | Multi-strategy management | Ranking |
|------------------|---------------------------|---------|
|                  | Genotype | Planting time | N rate | N time | Cover crop | NO\textsubscript{3} load | Soil NO\textsubscript{3} at harvest | Yield | Combined (d) |
| Low               | High     | Early         | -30%   | Spring | Overwinter | 15       | 13                  | 20     | 1           |
| Low               | High     | Early         | -30%   | Split  | Overwinter | 14       | 16                  | 19     | 2           |
| Low               | High     | Average       | -30%   | Split  | Overwinter | 4        | 11                  | 47     | 3           |
| Low               | High     | Early         | -30%   | Spring | Winter-kill | 35       | 30                  | 22     | 4           |
| Low               | High     | Early         | -30%   | Split  | Winter-kill | 34       | 32                  | 21     | 5           |
| Low               | High     | Average       | -30%   | Spring | Overwinter | 5        | 10                  | 50     | 6           |
| Low               | High     | Early         | -30%   | Split  | None       | 44       | 33                  | 23     | 7           |
| Low               | High     | Early         | -30%   | Spring | None       | 45       | 31                  | 24     | 8           |
| Low               | Low      | Early         | -30%   | Spring | Overwinter | 22       | 34                  | 44     | 9           |
| Low               | Low      | Early         | -30%   | Split  | Overwinter | 21       | 38                  | 43     | 10          |
| Low               | Low      | Normal        | -30%   | Split  | Overwinter | 17       | 24                  | 62     | 11          |
| Low               | Low      | Normal        | -30%   | Spring | Overwinter | 18       | 23                  | 72     | 12          |
| Low               | Low      | High          | Average | MRTN   | Spring     | 20       | 84                  | 29     | 13          |
| Low               | Low      | High          | Average | MRTN   | Split      | 19       | 88                  | 31     | 14          |
| Low               | Low      | Early         | MRTN   | Spring  | Overwinter | 29       | 97                  | 5      | 15          |
| Low               | Low      | Early         | MRTN   | Split   | Overwinter | 26       | 99                  | 4      | 16          |
| Low               | Low      | High          | Average | -30%   | Split      | 37       | 43                  | 90     | 17          |
| Low               | Low      | High          | Average | -30%   | Spring     | 38       | 39                  | 94     | 18          |
| Low               | Low      | Normal        | Early   | -30%   | Split      | 42       | 49                  | 91     | 19          |
| Low               | Low      | Normal        | Early   | -30%   | Spring     | 43       | 48                  | 95     | 20          |
| Low               | Low      | High          | Average | -30%   | Split      | 53       | 46                  | 92     | 21          |
| Low               | Low      | Normal        | Early   | MRTN   | Spring     | 39       | 102                 | 39     | 22          |
| Low               | Low      | Normal        | Early   | MRTN   | Split      | 36       | 104                 | 41     | 23          |
| Low               | Low      | High          | Average | -30%   | Spring     | 55       | 40                  | 96     | 24          |
| Low               | Low      | Low           | Early   | -30%   | Spring     | 51       | 72                  | 80     | 25          |
| Low               | Low      | Low           | Early   | -30%   | Split      | 50       | 75                  | 79     | 26          |
| Low               | Low      | Low           | Average | -30%   | Spring     | 12       | 26                  | 118    | 27          |
| Low               | Low      | Low           | Average | -30%   | Split      | 11       | 28                  | 119    | 28          |
| Low               | Low      | Normal        | Early   | -30%   | Split      | 56       | 52                  | 97     | 29          |
| Low               | Low      | Low           | Early   | MRTN   | Spring     | 48       | 108                 | 38     | 30          |
| Low               | Low      | Normal        | Early   | -30%   | Spring     | 61       | 50                  | 98     | 31          |
| Low               | Low      | Low           | Early   | MRTN   | Split      | 46       | 111                 | 40     | 32          |
| Low               | Low      | Normal        | Average | -30%   | Split      | 9        | 19                  | 126    | 33          |
| Low               | Low      | Low           | High    | -30%   | Split      | 1        | 5                   | 128    | 34          |
| Low               | Low      | Normal        | Average | -30%   | Spring     | 10       | 17                  | 127    | 35          |
| Low               | Low      | Low           | Early   | -30%   | Spring     | 65       | 77                  | 84     | 36          |
| Low               | Low      | Low           | Early   | -30%   | Spring     | 68       | 74                  | 85     | 37          |
| Low               | Low      | High          | Early   | MRTN   | Split      | 66       | 114                 | 11     | 38          |
| Low               | Low      | Low           | Early   | MRTN   | Spring     | 70       | 112                 | 10     | 39          |
| Low               | Low      | High          | Late    | MRTN   | Spring     | 16       | 58                  | 123    | 40          |
| Low               | Low      | Late          | MRTN   | Split   | Overwinter | 13       | 59                  | 124    | 41          |
| Low               | Low      | High          | Early   | MRTN   | Spring     | 87       | 113                 | 13     | 42          |
| Low               | Low      | High          | Early   | MRTN   | Split      | 86       | 115                 | 14     | 43          |
| Low               | Low      | High          | Late    | -30%   | Spring     | 2        | 4                   | 145    | 44          |
| Low               | Low      | Normal        | Average | MRTN   | Spring     | 30       | 100                 | 115    | 45          |
| Low               | Low      | High          | Average | MRTN   | Spring     | 81       | 122                 | 53     | 46          |
| Low               | Low      | Normal        | Average | MRTN   | Split      | 27       | 101                 | 116    | 47          |
| Low               | Low      | High          | Average | MRTN   | Split      | 76       | 126                 | 55     | 48          |
| Low               | Low      | Low           | Average | MRTN   | Spring     | 33       | 105                 | 114    | 49          |
| Low               | Low      | Low           | Average | MRTN   | Split      | 31       | 106                 | 117    | 50          |
| Low               | Low      | High          | Average | MRTN   | Spring     | 93       | 125                 | 54     | 51          |
| Low               | Low      | High          | Average | MRTN   | Split      | 91       | 130                 | 56     | 52          |
| Low               | Low      | Normal        | Early   | MRTN   | Spring     | 97       | 124                 | 67     | 53          |
| Low               | Low      | High          | Average | 30%    | Split      | 41       | 165                 | 27     | 54          |
| Low               | Low      | High          | Average | 30%    | Spring     | 47       | 164                 | 26     | 55          |
| Low               | Low      | Normal        | Early   | MRTN   | Split      | 92       | 129                 | 71     | 56          |
| Low               | Low      | High          | Early   | -30%   | Fall       | 170      | 27                  | 28     | 57          |
| Low               | Low      | Late          | Split   | 30%    | Overwinter | 32       | 123                 | 121    | 58          |
Supplemental Table S2 (continued).

| Apr-Jun Rainfall | Genotype | Planting time | N rate | N time | Cover crop | NO$_3$ load | Soil NO$_3$ at harvest | Yield | Combined |
|------------------|----------|----------------|--------|--------|------------|-------------|------------------------|-------|----------|
| Low              | Normal   | Average        | -30%   | Split  | Winter-kill| 49          | 64                     | 157   | 59       |
| Low              | High     | Normal         | Average| -30%   | Fall       | None        | 172                   | 29    | 30       |
| Low              | Normal   | Average        | -30%   | Spring | Winter-kill| 54          | 61                     | 158   | 61       |
| Low              | Low      | Average        | -30%   | Spring | Winter-kill| 59          | 82                     | 148   | 62       |
| Low              | Low      | Low            | -30%   | Split  | Winter-kill| 57          | 85                     | 150   | 63       |
| Low              | Normal   | Early          | MRTN   | Spring | None       | 107         | 128                    | 74    | 64       |
| Low              | High     | Late           | MRTN   | Spring | Overwinter| 40          | 131                    | 122   | 65       |
| Low              | Normal   | Average        | -30%   | Split  | None       | 67          | 65                     | 159   | 66       |
| Low              | Low      | Average        | -30%   | Spring | None       | 69          | 62                     | 160   | 67       |
| Low              | Low      | Average        | -30%   | Spring | None       | 78          | 83                     | 149   | 68       |
| Low              | Normal   | Early          | MRTN   | Split  | None       | 109         | 132                    | 77    | 69       |
| Low              | High     | Early          | 30%    | Split  | Overwinter| 73          | 174                    | 2     | 70       |
| Low              | Low      | Early          | 30%    | Split  | Overwinter| 64          | 178                    | 3     | 71       |
| Low              | Low      | Average        | -30%   | Split  | None       | 77          | 86                     | 151   | 72       |
| Low              | Low      | High           | 30%    | Split  | Winter-kill| 56          | 54                     | 174   | 73       |
| Low              | High     | Early          | -30%   | Fall   | Overwinter| 167         | 12                     | 93    | 74       |
| Low              | Low      | Early          | MRTN   | Spring | Winter-kill| 105         | 146                    | 66    | 75       |
| Low              | High     | Late           | MRTN   | Spring | Winter-kill| 62          | 51                     | 175   | 76       |
| Low              | Low      | Early          | MRTN   | Split  | Winter-kill| 103         | 150                    | 70    | 77       |
| Low              | Low      | Late           | MRTN   | Spring | Overwinter| 8           | 18                     | 194   | 78       |
| Low              | Normal   | Late           | -30%   | Split  | Overwinter| 6           | 7                      | 196   | 79       |
| Low              | Low      | Late           | -30%   | Split  | Overwinter| 7           | 21                     | 195   | 80       |
| Low              | Low      | Normal         | -30%   | Split  | Overwinter| 3           | 8                      | 197   | 81       |
| Low              | High     | Average        | -30%   | Fall   | None       | 187         | 47                     | 46    | 82       |
| Low              | Low      | High           | MRTN   | Fall   | Overwinter| 193         | 79                     | 8     | 93       |
| Low              | Low      | Normal         | MRTN   | Fall   | Overwinter| 95          | 183                    | 37    | 94       |
| Low              | Low      | Late           | MRTN   | Spring | Overwinter| 28          | 91                     | 187   | 95       |
| Low              | Low      | Early          | MRTN   | Spring | Winter-kill| 173         | 66                     | 99    | 96       |
| Low              | Low      | Early          | -30%   | Fall   | Overwinter| 168         | 20                     | 125   | 97       |
| Low              | Low      | Normal         | -30%   | Spring | Overwinter| 101         | 182                    | 35    | 98       |
| Low              | Normal   | Early          | -30%   | Fall   | None       | 177         | 45                     | 106   | 99       |
| Low              | Low      | Late           | MRTN   | Split  | Overwinter| 25          | 92                     | 192   | 100      |
| Low              | Low      | Early          | MRTN   | Split  | None       | 178         | 68                     | 100   | 101      |
| Low              | Low      | Early          | 30%    | Split  | Overwinter| 104         | 186                    | 36    | 102      |
| Low              | Normal   | Average        | 30%    | Split  | Overwinter| 71          | 171                    | 112   | 103      |
| Low              | Normal   | Average        | 30%    | Spring | Overwinter| 79          | 170                    | 110   | 104      |
| Low              | Low      | Early          | 30%    | Spring | Overwinter| 110         | 185                    | 34    | 105      |
| Low              | Normal   | Early          | MRTN   | Fall   | Overwinter| 195         | 95                     | 45    | 106      |
| Low              | Low      | High           | MRTN   | Fall   | Winter-kill| 194         | 109                    | 17    | 107      |
| Low              | High     | Early          | MRTN   | Split  | Winter-kill| 117         | 190                    | 7     | 108      |
| Low              | Low      | Early          | 30%    | Spring | Winter-kill| 121         | 189                    | 6     | 109      |
| Low              | Normal   | Average        | MRTN   | Spring | Winter-kill| 102         | 145                    | 138   | 110      |
| Low              | High     | Early          | MRTN   | Fall   | None       | 196         | 110                    | 18    | 111      |
| Low              | Low      | Early          | MRTN   | Fall   | Overwinter| 197         | 107                    | 42    | 112      |
| Low              | Normal   | Average        | MRTN   | Split  | Winter-kill| 100         | 148                    | 142   | 113      |
| Low              | Low      | Average        | 30%    | Spring | Overwinter| 88          | 180                    | 111   | 114      |
| Low              | Low      | Average        | 30%    | Split  | Overwinter| 84          | 181                    | 113   | 115      |
| Low              | High     | Early          | 30%    | Spring | None       | 131         | 191                    | 9     | 116      |
| Low              | Normal   | Average        | MRTN   | Split  | Winter-kill| 116         | 147                    | 140   | 117      |
| Low              | High     | Early          | 30%    | Split  | None       | 133         | 192                    | 12    | 118      |
| Low              | Normal   | Average        | MRTN   | Fall   | Overwinter| 190         | 67                      | 120   | 119      |
| Low              | High     | Late           | MRTN   | Spring | Winter-kill| 99          | 133                    | 167   | 120      |
## Supplemental Table S2 (continued).

| Genotype | Planting time | N rate | N time | Cover crop | NO$_3$ load | Soil NO$_3$ at harvest | Yield | Combined |
|----------|---------------|--------|--------|------------|-------------|------------------------|-------|----------|
| Low      | High          | Late   | MRTN   | Split      | Winter-kill | 94                     | 135   | 169      | 121      |
| Low      | Normal        | Average| MRTN   | Split      | None        | 114                    | 149   | 144      | 122      |
| Low      | Normal        | Late   | 30%    | Split      | Overwinter  | 52                     | 134   | 189      | 123      |
| Low      | Average       | MRTN   | Fall   | Overwinter | 192         | 89                     | 109   | 124      |          |
| Low      | High          | Average| -30%   | Fall       | Overwinter  | 152         | 6     | 184      | 125      |
| Low      | Normal        | Late   | 30%    | Spring     | Overwinter  | 63                     | 138   | 185      | 126      |
| Low      | Average       | MRTN   | Spring | Winter-kill| 111         | 162                    | 137   | 127      |          |
| Low      | Normal        | Late   | -30%   | Spring     | Winter-kill | 75                     | 69    | 218      | 128      |
| Low      | High          | Average| 30%    | Split      | Winter-kill | 122                    | 202   | 51       | 129      |
| Low      | Average       | MRTN   | Split   | Winter-kill| 106         | 166                    | 141   | 130      |          |
| Low      | High          | Average| 30%    | Spring     | Winter-kill | 199                    | 116   | 75       | 131      |
| Low      | High          | Average| 30%    | Split      | None        | 124                    | 203   | 48       | 132      |
| Low      | Normal        | Late   | -30%   | Split      | None        | 74                     | 71    | 220      | 133      |
| Low      | High          | Late   | MRTN   | Spring     | None        | 113                    | 136   | 168      | 134      |
| Low      | High          | Late   | MRTN   | Split      | None        | 108                    | 139   | 170      | 135      |
| Low      | Average       | MRTN   | Fall   | None       | 201         | 117                    | 78    | 136      |          |
| Low      | Normal        | Early  | MRTN   | Fall       | Winter-kill | 198                    | 118   | 88       | 137      |
| Low      | Normal        | Late   | -30%   | Spring     | None        | 90                     | 70    | 219      | 138      |
| Low      | High          | Average| 30%    | Split      | None        | 130                    | 205   | 52       | 139      |
| Low      | Low           | Late   | -30%   | Spring     | Winter-kill | 85                     | 93    | 214      | 140      |
| Low      | Normal        | Early  | 30%    | Split      | Winter-kill | 137                    | 198   | 61       | 141      |
| Low      | Low           | Late   | -30%   | Split      | Winter-kill | 89                     | 73    | 221      | 142      |
| Low      | Normal        | Early  | 30%    | Winter-kill| 143         | 196                    | 57    | 143      |          |
| Low      | High          | Average| 30%    | Spring     | None        | 135                    | 204   | 49       | 144      |
| Low      | High          | Average| 30%    | Fall       | Overwinter  | 214                    | 127   | 25       | 145      |
| Low      | Low           | Late   | -30%   | Split      | Winter-kill | 160                    | 96    | 216      | 146      |
| Low      | Low           | Average| -30%   | Fall       | Overwinter  | 159                    | 14    | 193      | 147      |
| Low      | Normal        | Early  | MRTN   | Fall       | None        | 202                    | 119   | 89       | 148      |
| Low      | Normal        | Average| -30%   | Fall       | Winter-kill | 175                    | 56    | 171      | 149      |
| Low      | High          | Late   | 30%    | Fall       | Overwinter  | 208                    | 90    | 108      | 150      |
| Low      | Low           | Average| MRTN   | Spring     | None        | 126                    | 167   | 139      | 151      |
| Low      | Low           | Average| MRTN   | Split      | None        | 125                    | 168   | 143      | 152      |
| Low      | Low           | Average| -30%   | Fall       | Winter-kill | 179                    | 80    | 161      | 153      |
| Low      | Normal        | Average| -30%   | Fall       | Overwinter  | 158                    | 9     | 199      | 154      |
| Low      | Low           | Late   | -30%   | Spring     | None        | 98                     | 94    | 215      | 155      |
| Low      | Low           | Late   | -30%   | Split      | Overwinter  | 160                    | 160   | 190      | 156      |
| Low      | Normal        | Average| -30%   | Fall       | None        | 181                    | 57    | 172      | 157      |
| Low      | Low           | Late   | 30%    | Spring     | Overwinter  | 72                     | 161   | 186      | 158      |
| Low      | Low           | Late   | -30%   | Split      | None        | 96                     | 98    | 217      | 159      |
| Low      | High          | Late   | MRTN   | Fall       | Overwinter  | 180                    | 15    | 183      | 160      |
| Low      | Low           | Average| -30%   | Fall       | None        | 183                    | 81    | 162      | 161      |
| Low      | Normal        | Early  | 30%    | Split      | None        | 149                    | 201   | 69       | 162      |
| Low      | Low           | Early  | MRTN   | Fall       | Winter-kill | 200                    | 142   | 86       | 163      |
| Low      | High          | Late   | -30%   | Fall       | Winter-kill | 182                    | 42    | 181      | 164      |
| Low      | Normal        | Early  | 30%    | Spring     | None        | 156                    | 200   | 64       | 165      |
| Low      | Low           | Early  | MRTN   | Fall       | None        | 204                    | 144   | 87       | 166      |
| Low      | Low           | Early  | 30%    | Split      | Winter-kill | 147                    | 213   | 60       | 167      |
| Low      | High          | Late   | -30%   | Fall       | None        | 189                    | 44    | 182      | 168      |
| Low      | Low           | Early  | 30%    | Spring     | Winter-kill | 153                    | 211   | 58       | 169      |
| Low      | High          | Late   | -30%   | Fall       | Overwinter  | 138                    | 1     | 230      | 170      |
| Low      | Low           | Late   | -30%   | Fall       | Overwinter  | 141                    | 3     | 231      | 171      |
| Low      | High          | Early  | 30%    | Fall       | Overwinter  | 217                    | 163   | 1        | 172      |
| Low      | Normal        | Late   | -30%   | Fall       | Overwinter  | 142                    | 2     | 232      | 173      |
| Low      | Low           | Late   | MRTN   | Fall       | Overwinter  | 185                    | 36    | 198      | 174      |
| Low      | Low           | Early  | 30%    | Spring     | None        | 165                    | 216   | 65       | 175      |
| Low      | Low           | Early  | 30%    | Split      | None        | 183                    | 219   | 68       | 176      |
| Low      | Normal        | Late   | MRTN   | Spring     | Winter-kill | 115                    | 153   | 207      | 177      |
| Low      | Normal        | Late   | MRTN   | Split      | Winter-kill | 112                    | 154   | 210      | 178      |
| Low      | High          | Early  | 30%    | Fall       | Winter-kill | 216                    | 187   | 15       | 179      |
| Low      | Normal        | Average| 30%    | Fall       | Overwinter  | 218                    | 155   | 102      | 180      |
| Low      | Normal        | Early  | 30%    | Fall       | Overwinter  | 222                    | 179   | 33       | 181      |
| Low      | High          | Early  | 30%    | Fall       | None        | 219                    | 188   | 16       | 182      |
### Supplemental Table S2 (continued).

| Apr-Jun Rainfall | Genotype  | Planting time | N rate | N time | Cover crop | NO$_3$ load | Soil NO$_3$ at harvest | Yield | Combined |
|------------------|-----------|---------------|--------|--------|------------|-------------|------------------------|-------|----------|
| Low              | Normal    | Average       | MRTN   | Fall   | Winter-kill | 203         | 137                    | 155   | 183      |
| Low              | Normal    | Late          | MRTN   | Spring | None       | 129         | 156                    | 208   | 184      |
| Low              | Low       | Average       | MRTN   | Spring | Winter-kill | 145         | 217                    | 130   | 185      |
| Low              | Low       | Early         | MRTN   | Fall   | Overwinter | 224         | 184                    | 32    | 186      |
| Low              | Normal    | Average       | MRTN   | Fall   | Split      | 140         | 218                    | 134   | 187      |
| Low              | Low       | Late          | MRTN   | Fall   | Overwinter | 184         | 22                     | 226   | 188      |
| Low              | Normal    | Late          | MRTN   | Split  | None       | 127         | 157                    | 212   | 189      |
| Low              | High      | Late          | MRTN   | Split  | Winter-kill | 128         | 206                    | 165   | 190      |
| Low              | Low       | Late          | MRTN   | Spring | Winter-kill | 123         | 172                    | 205   | 191      |
| Low              | Normal    | Average       | MRTN   | Fall   | None       | 207         | 140                    | 156   | 192      |
| Low              | Low       | Late          | MRTN   | Spring | Winter-kill | 134         | 207                    | 163   | 193      |
| Low              | Normal    | Late          | MRTN   | Fall   | Split      | 212         | 103                    | 180   | 194      |
| Low              | High      | Late          | MRTN   | Spring | Split      | 205         | 120                    | 178   | 195      |
| Low              | Low       | Average       | MRTN   | Spring | Winter-kill | 118         | 173                    | 211   | 196      |
| Low              | Low       | Average       | MRTN   | Split  | None       | 220         | 175                    | 101   | 197      |
| Low              | Normal    | Late          | MRTN   | Split  | None       | 186         | 60                     | 228   | 198      |
| Low              | High      | Average       | MRTN   | Fall   | Winter-kill | 221         | 195                    | 59    | 199      |
| Low              | High      | Late          | MRTN   | Split  | None       | 209         | 121                    | 179   | 200      |
| Low              | High      | Late          | MRTN   | Split  | None       | 139         | 209                    | 166   | 201      |
| Low              | Low       | Average       | MRTN   | Fall   | Winter-kill | 206         | 158                    | 153   | 202      |
| Low              | High      | Late          | MRTN   | Spring | None       | 144         | 208                    | 164   | 203      |
| Low              | Normal    | Average       | MRTN   | Split  | None       | 155         | 221                    | 135   | 204      |
| Low              | Low       | Average       | MRTN   | Split  | Winter-kill | 148         | 228                    | 133   | 205      |
| Low              | Low       | Average       | MRTN   | Spring | Winter-kill | 154         | 227                    | 129   | 206      |
| Low              | Low       | Average       | MRTN   | Split  | None       | 162         | 220                    | 132   | 207      |
| Low              | Normal    | Late          | MRTN   | Split  | None       | 191         | 63                     | 229   | 208      |
| Low              | Low       | Average       | MRTN   | Fall   | None       | 210         | 159                    | 154   | 209      |
| Low              | Low       | Late          | MRTN   | Spring | None       | 136         | 176                    | 209   | 210      |
| Low              | High      | Average       | MRTN   | Fall   | None       | 225         | 197                    | 63    | 211      |
| Low              | Normal    | Early         | MRTN   | Fall   | Winter-kill | 223         | 193                    | 82    | 212      |
| Low              | Low       | Late          | MRTN   | Split  | None       | 132         | 177                    | 213   | 213      |
| Low              | Low       | Late          | MRTN   | -30%   | Fall       | 188         | 87                     | 227   | 214      |
| Low              | Normal    | Early         | MRTN   | Fall   | None       | 226         | 194                    | 83    | 215      |
| Low              | Low       | Average       | MRTN   | Spring | None       | 166         | 229                    | 131   | 216      |
| Low              | Low       | Average       | MRTN   | Split  | None       | 163         | 230                    | 136   | 217      |
| Low              | Low       | Early         | MRTN   | Fall   | Winter-kill | 227         | 210                    | 81    | 217      |
| Low              | Normal    | Late          | MRTN   | Split  | Winter-kill | 146         | 222                    | 203   | 219      |
| Low              | Normal    | Late          | MRTN   | Spring | Winter-kill | 151         | 223                    | 201   | 220      |
| Low              | Low       | Late          | MRTN   | Split  | Winter-kill | 211         | 141                    | 224   | 221      |
| Low              | Low       | Late          | MRTN   | Fall   | None       | 215         | 143                    | 225   | 222      |
| Low              | Low       | Late          | MRTN   | Split  | Winter-kill | 150         | 231                    | 204   | 223      |
| Low              | Normal    | Late          | MRTN   | Split  | None       | 160         | 224                    | 206   | 224      |
| Low              | Normal    | Late          | MRTN   | Spring | None       | 164         | 225                    | 202   | 225      |
| Low              | Low       | Late          | MRTN   | Spring | Winter-kill | 157         | 232                    | 200   | 226      |
| Low              | Normal    | Average       | MRTN   | Split  | Winter-kill | 231         | 215                    | 147   | 227      |
| Low              | Normal    | Average       | MRTN   | Fall   | Winter-kill | 229         | 214                    | 152   | 228      |
| Low              | High      | Late          | MRTN   | Fall   | Winter-kill | 228         | 199                    | 173   | 229      |
| Low              | Low       | Late          | MRTN   | Split  | Winter-kill | 213         | 169                    | 223   | 230      |
| Low              | Low       | Average       | MRTN   | Fall   | Winter-kill | 230         | 226                    | 146   | 231      |
| Low              | Normal    | Late          | MRTN   | Fall   | Winter-kill | 232         | 212                    | 222   | 232      |
| Average          | High      | Early         | MRTN   | -30%   | Split      | 18           | 15                     | 23    | 1        |
| Average          | High      | Early         | MRTN   | -30%   | Split      | 21           | 14                     | 24    | 2        |
| Average          | High      | Early         | MRTN   | -30%   | Winter-kill | 51           | 29                     | 19    | 3        |
| Average          | High      | Early         | MRTN   | -30%   | Winter-kill | 52           | 27                     | 21    | 4        |
| Average          | High      | Early         | MRTN   | -30%   | Split      | 55           | 31                     | 20    | 5        |
| Average          | High      | Early         | MRTN   | -30%   | Split      | 59           | 28                     | 32    | 6        |
| Average          | High      | Average       | MRTN   | Spring | Overwinter | 20           | 77                     | 30    | 7        |
| Average          | High      | Average       | MRTN   | Split  | Winter-kill | 54           | 40                     | 58    | 9        |
| Average          | High      | Average       | MRTN   | Split  | Overwinter | 7            | 11                     | 89    | 10       |
| Average          | High      | Early         | MRTN   | Spring | Overwinter | 34           | 87                     | 5     | 11       |
| Average          | High      | Average       | MRTN   | Spring | Winter-kill | 56           | 38                     | 65    | 12       |
### Supplemental Table S2 (continued).

| Apr-Jun Rainfall | Genotype | Planting time | N rate | N time | Cover crop | NO$_3$ load | Soil NO$_3$ at harvest | Yield | Combined |
|------------------|----------|---------------|--------|--------|------------|-------------|------------------------|-------|----------|
| Average          | High     | Average       | -30%   | Spring | Overwinter | 10          | 10                     | 93    | 13       |
| Average          | High     | Average       | -30%   | Split  | None       | 60          | 41                     | 61    | 14       |
| Average          | High     | Early         | MRTN   | Split  | Overwinter | 31          | 92                     | 4     | 15       |
| Average          | Low      | Early         | -30%   | Split  | Overwinter | 24          | 48                     | 82    | 16       |
| Average          | Low      | Early         | -30%   | Spring | Overwinter | 27          | 46                     | 83    | 17       |
| Average          | High     | Average       | -30%   | Spring | None       | 68          | 39                     | 68    | 18       |
| Average          | Normal   | Early         | -30%   | Split  | Overwinter | 22          | 24                     | 100   | 19       |
| Average          | Normal   | Early         | -30%   | Spring | Overwinter | 26          | 23                     | 101   | 20       |
| Average          | High     | Late          | MRTN   | Spring | Overwinter | 13          | 50                     | 107   | 21       |
| Average          | Normal   | Early         | MRTN   | Spring | Overwinter | 40          | 105                    | 51    | 22       |
| Average          | High     | Late          | MRTN   | Split  | Overwinter | 9           | 59                     | 108   | 23       |
| Average          | Normal   | Early         | -30%   | Split  | Winter-kill| 57          | 53                     | 96    | 24       |
| Average          | Normal   | Early         | MRTN   | Split  | Overwinter | 37          | 106                    | 53    | 25       |
| Average          | Normal   | Early         | -30%   | Spring | Winter-kill| 62          | 47                     | 98    | 26       |
| Average          | Normal   | Early         | -30%   | Split  | None       | 69          | 55                     | 97    | 27       |
| Average          | Normal   | Early         | -30%   | Spring | None       | 75          | 49                     | 99    | 28       |
| Average          | Low      | Early         | -30%   | Split  | Winter-kill| 64          | 83                     | 85    | 29       |
| Average          | Low      | Early         | -30%   | Spring | Winter-kill| 70          | 78                     | 86    | 30       |
| Average          | Low      | Early         | MRTN   | Spring | Overwinter | 43          | 123                    | 49    | 31       |
| Average          | Low      | Early         | MRTN   | Split  | Overwinter | 41          | 125                    | 52    | 32       |
| Average          | High     | Early         | MRTN   | Spring | Overwinter | 91          | 108                    | 13    | 33       |
| Average          | High     | Early         | MRTN   | Split  | Overwinter | 85          | 114                    | 12    | 34       |
| Average          | Low      | Early         | -30%   | Split  | None       | 76          | 84                     | 87    | 35       |
| Average          | Low      | Early         | -30%   | Spring | None       | 83          | 81                     | 88    | 36       |
| Average          | High     | Early         | MRTN   | Spring | None       | 98          | 110                    | 14    | 37       |
| Average          | High     | Early         | MRTN   | Split  | None       | 94          | 115                    | 15    | 38       |
| Average          | Normal   | Average       | MRTN   | Spring | Overwinter | 29          | 94                     | 118   | 39       |
| Average          | Low      | Average       | -30%   | Split  | Overwinter | 11          | 36                     | 149   | 40       |
| Average          | Low      | Average       | -30%   | Spring | Overwinter | 14          | 30                     | 151   | 41       |
| Average          | High     | Average       | MRTN   | Spring | Winter-kill| 96          | 120                    | 37    | 42       |
| Average          | Normal   | Average       | MRTN   | Split  | Overwinter | 25          | 100                    | 120   | 43       |
| Average          | High     | Average       | MRTN   | Split  | Winter-kill| 90          | 126                    | 41    | 44       |
| Average          | High     | Average       | 30%    | Spring | Overwinter | 39          | 154                    | 27    | 45       |
| Average          | Low      | Average       | MRTN   | Spring | Overwinter | 33          | 107                    | 117   | 46       |
| Average          | High     | Late          | -30%   | Split  | Overwinter | 1           | 4                      | 162   | 47       |
| Average          | High     | Average       | MRTN   | Spring | None       | 101         | 132                    | 36    | 48       |
| Average          | High     | Average       | MRTN   | Split  | None       | 97          | 127                    | 39    | 49       |
| Average          | Low      | Average       | MRTN   | Split  | Overwinter | 30          | 111                    | 119   | 50       |
| Average          | High     | Late          | 30%    | Spring | Overwinter | 32          | 124                    | 105   | 51       |
| Average          | High     | Average       | 30%    | Split  | Overwinter | 35          | 161                    | 28    | 52       |
| Average          | High     | Late          | 30%    | Split  | Overwinter | 28          | 128                    | 106   | 53       |
| Average          | High     | Late          | -30%   | Spring | Overwinter | 3           | 3                      | 169   | 54       |
| Average          | Normal   | Average       | -30%   | Split  | Overwinter | 8           | 18                     | 170   | 55       |
| Average          | High     | Early         | -30%   | Fall   | Winter-kill| 168         | 25                     | 25    | 56       |
| Average          | High     | Early         | -30%   | Fall   | None       | 170         | 26                     | 26    | 57       |
| Average          | Normal   | Average       | -30%   | Spring | Overwinter | 12          | 16                     | 173   | 58       |
| Average          | High     | Early         | 30%    | Spring | Overwinter | 49          | 171                    | 1     | 59       |
| Average          | High     | Early         | -30%   | Fall   | Overwinter | 145         | 13                     | 104   | 60       |
| Average          | High     | Early         | 30%    | Split  | Overwinter | 46          | 173                    | 2     | 61       |
| Average          | Normal   | Early         | MRTN   | Spring | Winter-kill| 106         | 130                    | 66    | 62       |
| Average          | Normal   | Early         | MRTN   | Split  | Winter-kill| 103         | 133                    | 73    | 63       |
| Average          | Normal   | Average       | -30%   | Split  | Winter-kill| 67          | 64                     | 163   | 64       |
| Average          | Low      | Early         | -30%   | Fall   | Overwinter | 149         | 34                     | 109   | 65       |
| Average          | Normal   | Early         | MRTN   | Split  | None       | 107         | 135                    | 77    | 66       |
| Average          | High     | Late          | -30%   | Split  | Winter-kill| 58          | 57                     | 171   | 67       |
| Average          | Normal   | Early         | MRTN   | Spring | None       | 118         | 132                    | 69    | 68       |
| Average          | Normal   | Average       | -30%   | Spring | Winter-kill| 73          | 61                     | 165   | 69       |
| Average          | High     | Late          | -30%   | Spring | Winter-kill| 61          | 51                     | 174   | 70       |
| Average          | Low      | Late          | -30%   | Spring | Overwinter | 6           | 19                     | 191   | 71       |
| Average          | High     | Late          | -30%   | Split  | None       | 66          | 58                     | 172   | 72       |
| Average          | Normal   | Late          | -30%   | Split  | Overwinter | 2           | 8                      | 193   | 73       |
| Average          | Normal   | Average       | -30%   | Split  | None       | 78          | 66                     | 164   | 74       |
| Apr-Jun Rainfall | Genotype | Planting time | N rate | N time | Cover crop | NO₃ load | Soil NO₃ at harvest | Yield | Combined |
|-----------------|----------|---------------|--------|--------|------------|----------|---------------------|-------|----------|
| Average         | Low      | Late          | -30%   | Split  | Winter-overwinter | 4        | 22                  | 192   | 75       |
| Average         | Normal   | Late          | -30%   | Spring | Winter-overwinter | 5        | 7                   | 194   | 76       |
| Average         | Low      | Average       | -30%   | Spring | Winter-kill    | 80       | 86                  | 156   | 77       |
| Average         | Normal   | Early         | 30%    | Split  | Winter-overwinter | 53       | 182                 | 47    | 78       |
| Average         | Normal   | Early         | 30%    | Spring | Overwinter     | 63       | 183                 | 44    | 79       |
| Average         | High     | Late          | -30%   | Spring | None          | 72       | 52                  | 175   | 80       |
| Average         | Low      | Average       | -30%   | Split  | Winter-kill    | 74       | 90                  | 158   | 81       |
| Average         | Normal   | Average       | -30%   | Spring | None          | 86       | 62                  | 166   | 82       |
| Average         | High     | Average       | -30%   | Fall   | Winter-kill    | 173      | 32                  | 90    | 83       |
| Average         | Normal   | Late          | MRTN   | Spring | Overwinter     | 19       | 68                  | 185   | 84       |
| Average         | High     | Early         | MRTN   | Fall   | Winter-overwinter | 187      | 67                  | 18    | 85       |
| Average         | Low      | Average       | -30%   | Spring | None          | 92       | 88                  | 155   | 86       |
| Average         | Low      | Average       | -30%   | Split  | None          | 87       | 91                  | 157   | 87       |
| Average         | High     | Average       | -30%   | Fall   | None          | 176      | 33                  | 92    | 88       |
| Average         | Normal   | Late          | MRTN   | Split  | Winter-overwinter | 15       | 75                  | 189   | 89       |
| Average         | Normal   | Early         | -30%   | Fall   | Winter-kill    | 171      | 44                  | 102   | 90       |
| Average         | Low      | Early         | MRTN   | Spring | Winter-kill    | 120      | 153                 | 64    | 91       |
| Average         | Low      | Early         | MRTN   | Split  | Winter-kill    | 112      | 159                 | 70    | 92       |
| Average         | Normal   | Early         | -30%   | Fall   | None          | 175      | 45                  | 103   | 93       |
| Average         | Low      | Late          | MRTN   | Spring | Overwinter     | 23       | 95                  | 184   | 94       |
| Average         | Low      | Early         | -30%   | Fall   | Winter-kill    | 174      | 70                  | 94    | 95       |
| Average         | Normal   | Average       | 30%    | Spring | Winter-overwinter | 48       | 170                 | 114   | 96       |
| Average         | Low      | Early         | 30%    | Split  | Winter-overwinter | 65       | 196                 | 46    | 97       |
| Average         | Normal   | Average       | 30%    | Split  | Winter-overwinter | 45       | 172                 | 116   | 98       |
| Average         | Low      | Early         | -30%   | Fall   | None          | 177      | 72                  | 95    | 99       |
| Average         | Low      | Early         | 30%    | Spring | Overwinter     | 81       | 193                 | 45    | 100      |
| Average         | Low      | Early         | MRTN   | Spring | Overwinter     | None      | 130                 | 157   | 67       |
| Average         | Low      | Late          | MRTN   | Split  | Winter-overwinter | 17       | 99                  | 190   | 102      |
| Average         | High     | Average       | MRTN   | Fall   | Overwinter     | 194      | 35                  | 91    | 103      |
| Average         | Low      | Early         | MRTN   | Split  | None          | 123      | 162                 | 76    | 104      |
| Average         | High     | Early         | MRTN   | Fall   | Winter-kill    | 191      | 103                 | 16    | 105      |
| Average         | Low      | Average       | 30%    | Spring | Overwinter     | 50       | 181                 | 113   | 106      |
| Average         | High     | Early         | MRTN   | Fall   | None          | 193      | 104                 | 17    | 107      |
| Average         | High     | Late          | MRTN   | Spring | Winter-kill    | 99       | 134                 | 146   | 108      |
| Average         | Low      | Average       | 30%    | Split  | Winter-overwinter | 47       | 185                 | 115   | 109      |
| Average         | High     | Late          | MRTN   | Spring | None          | 102      | 136                 | 145   | 110      |
| Average         | Normal   | Average       | MRTN   | Spring | Winter-kill    | 145      | 143                 | 132   | 111      |
| Average         | High     | Late          | MRTN   | Split  | Winter-kill    | 95       | 137                 | 153   | 112      |
| Average         | Normal   | Average       | MRTN   | Split  | Winter-kill    | 104      | 146                 | 139   | 113      |
| Average         | Normal   | Early         | MRTN   | Fall   | Overwinter     | 190      | 93                  | 84    | 114      |
| Average         | Normal   | Average       | MRTN   | Spring | None          | 119      | 145                 | 130   | 115      |
| Average         | High     | Average       | MRTN   | Fall   | Winter-kill    | 196      | 109                 | 43    | 116      |
| Average         | High     | Late          | MRTN   | Split  | None          | 100      | 138                 | 152   | 117      |
| Average         | Normal   | Early         | -30%   | Fall   | Winter-overwinter | 147      | 20                  | 176   | 118      |
| Average         | High     | Average       | MRTN   | Fall   | None          | 197      | 112                 | 42    | 119      |
| Average         | Normal   | Average       | MRTN   | Split  | None          | 113      | 147                 | 137   | 120      |
| Average         | High     | Early         | 30%    | Split  | Winter-kill    | 129      | 191                 | 8     | 121      |
| Average         | High     | Early         | 30%    | Spring | Winter-kill    | 138      | 186                 | 6     | 122      |
| Average         | Normal   | Late          | 30%    | Spring | Overwinter     | 42       | 139                 | 183   | 123      |
| Average         | High     | Early         | 30%    | Split  | None          | 137      | 192                 | 9     | 124      |
| Average         | High     | Early         | 30%    | Spring | None          | 142      | 189                 | 7     | 125      |
| Average         | Low      | Early         | MRTN   | Fall   | Overwinter     | 195      | 113                 | 74    | 126      |
| Average         | Normal   | Late          | 30%    | Split  | Winter-overwinter | 36       | 142                 | 187   | 127      |
| Average         | High     | Average       | 30%    | Split  | Winter-kill    | 127      | 200                 | 35    | 128      |
| Average         | Normal   | Late          | -30%   | Spring | Winter-kill    | 77       | 69                  | 218   | 129      |
| Average         | Low      | Average       | MRTN   | Spring | Winter-kill    | 122      | 163                 | 131   | 130      |
| Average         | High     | Average       | 30%    | Spring | Winter-kill    | 136      | 198                 | 33    | 131      |
| Average         | Normal   | Late          | -30%   | Split  | Winter-kill    | 71       | 74                  | 220   | 132      |
| Average         | Normal   | Early         | MRTN   | Fall   | Winter-kill    | 199      | 117                 | 80    | 133      |
| Average         | High     | Average       | 30%    | Split  | None          | 134      | 202                 | 34    | 134      |
| Average         | Low      | Average       | MRTN   | Split  | Winter-kill    | 115      | 167                 | 138   | 135      |
| Average         | High     | Average       | 30%    | Spring | None          | 141      | 199                 | 32    | 136      |
| Genotype | Planting time | N rate | N time | Cover crop | NO$_3$ load | Soil NO$_3$ at harvest | Yield | Combined |
|----------|---------------|--------|--------|------------|-------------|------------------------|--------|----------|
| Average | Normal | Late | -30% | Spring | None | 88 | 71 | 219 | 137 |
| Average | Normal | Early | MRTN | Fall | None | 201 | 119 | 81 | 138 |
| Average | Normal | Late | -30% | Split | None | 82 | 76 | 221 | 139 |
| Average | Low | Average | MRTN | Spring | None | 131 | 166 | 129 | 140 |
| Average | Low | Late | -30% | Spring | Winter-kill | 84 | 97 | 212 | 141 |
| Average | Low | Late | 30% | Spring | Overwinter | 44 | 164 | 182 | 142 |
| Average | Low | Average | MRTN | Split | None | 125 | 169 | 136 | 143 |
| Average | Low | Late | -30% | Spring | None | 93 | 98 | 211 | 144 |
| Average | Low | Late | -30% | Split | Winter-kill | 79 | 101 | 217 | 145 |
| Average | High | Average | 30% | Fall | Overwinter | 223 | 116 | 29 | 146 |
| Average | Low | Late | 30% | Split | Overwinter | 38 | 168 | 186 | 147 |
| Average | Low | Late | -30% | Fall | Overwinter | 109 | 5 | 230 | 148 |
| Average | Low | Late | -30% | Split | None | 89 | 102 | 216 | 149 |
| Average | Normal | Late | -30% | Fall | Overwinter | 108 | 2 | 232 | 150 |
| Average | High | Late | -30% | Fall | Overwinter | 111 | 1 | 231 | 151 |
| Average | High | Late | -30% | Fall | Winter-kill | 179 | 42 | 180 | 152 |
| Average | Normal | Average | -30% | Fall | Winter-kill | 178 | 54 | 178 | 153 |
| Average | Low | Average | -30% | Fall | Winter-kill | 180 | 79 | 168 | 154 |
| Average | High | Late | -30% | Fall | None | 182 | 43 | 181 | 155 |
| Average | Normal | Average | -30% | Fall | None | 181 | 56 | 179 | 156 |
| Average | Low | Average | -30% | Fall | None | 183 | 82 | 167 | 157 |
| Average | Normal | Early | 30% | Split | Winter-kill | 150 | 206 | 60 | 158 |
| Average | High | Average | -30% | Fall | Overwinter | 140 | 6 | 222 | 159 |
| Average | Normal | Early | 30% | Spring | Winter-kill | 158 | 203 | 54 | 160 |
| Average | High | Late | 30% | Fall | Overwinter | 227 | 73 | 111 | 161 |
| Average | Low | Early | MRTN | Fall | Winter-kill | 203 | 148 | 78 | 162 |
| Average | High | Early | 30% | Fall | Overwinter | 213 | 155 | 3 | 163 |
| Average | Low | Early | MRTN | Fall | None | 205 | 149 | 79 | 164 |
| Average | Low | Average | -30% | Fall | Overwinter | 144 | 17 | 223 | 165 |
| Average | Normal | Early | 30% | Split | Winter-kill | 157 | 207 | 62 | 166 |
| Average | Normal | Early | 30% | Spring | None | 165 | 205 | 56 | 167 |
| Average | Normal | Average | -30% | Fall | Overwinter | 143 | 9 | 228 | 168 |
| Average | Normal | Average | MRTN | Fall | Overwinter | 200 | 85 | 161 | 169 |
| Average | Low | Average | MRTN | Fall | Overwinter | 198 | 60 | 177 | 170 |
| Average | High | Late | MRTN | Fall | Overwinter | 168 | 12 | 198 | 171 |
| Average | Normal | Late | MRTN | Spring | Winter-kill | 114 | 150 | 199 | 172 |
| Average | Normal | Late | MRTN | Split | Winter-kill | 152 | 208 | 173 |
| Average | Normal | Late | MRTN | Spring | None | 124 | 151 | 202 | 174 |
| Average | High | Early | 30% | Fall | Winter-kill | 214 | 183 | 10 | 175 |
| Average | Low | Early | 30% | Spring | Winter-kill | 167 | 221 | 55 | 176 |
| Average | High | Late | MRTN | Fall | Winter-kill | 202 | 118 | 159 | 177 |
| Average | Low | Early | 30% | Split | Winter-kill | 161 | 225 | 59 | 178 |
| Average | High | Early | 30% | Fall | None | 215 | 184 | 11 | 179 |
| Average | Normal | Late | MRTN | Split | None | 117 | 156 | 206 | 180 |
| Average | High | Late | 30% | Split | Winter-kill | 126 | 211 | 142 | 181 |
| Average | High | Late | 30% | Spring | Winter-kill | 135 | 208 | 141 | 182 |
| Average | Normal | Average | MRTN | Fall | Winter-kill | 206 | 129 | 150 | 183 |
| Average | High | Late | MRTN | Fall | None | 204 | 121 | 160 | 184 |
| Average | Normal | Average | MRTN | Fall | None | 207 | 131 | 148 | 185 |
| Average | Low | Early | 30% | Spring | None | 172 | 222 | 57 | 186 |
| Average | Normal | Early | 30% | Fall | Overwinter | 219 | 178 | 50 | 187 |
| Average | Low | Early | 30% | Split | None | 166 | 226 | 63 | 188 |
| Average | High | Late | 30% | Spring | None | 139 | 209 | 140 | 189 |
| Average | High | Late | 30% | Split | None | 133 | 212 | 143 | 190 |
| Average | High | Average | 30% | Fall | Winter-kill | 216 | 187 | 40 | 191 |
| Average | High | Average | 30% | Fall | None | 208 | 197 | 38 | 192 |
| Average | Normal | Average | 30% | Split | Winter-kill | 148 | 216 | 127 | 193 |
| Average | Normal | Average | 30% | Spring | Winter-kill | 156 | 213 | 124 | 194 |
| Average | Low | Late | MRTN | Spring | Winter-kill | 121 | 175 | 200 | 195 |
| Average | Normal | Average | 30% | Fall | Overwinter | 230 | 144 | 112 | 196 |
| Average | Low | Early | 30% | Fall | Overwinter | 221 | 188 | 48 | 197 |
| Average | Normal | Average | 30% | Split | None | 154 | 217 | 126 | 198 |
Supplemental Table S2 (continued).

| Genotype | Planting time | N rate | N time | Cover crop | NO$_3$ load | Soil NO$_3$ at harvest | Yield | Combined |
|----------|---------------|--------|--------|------------|-------------|------------------------|-------|----------|
| Average  | Normal Average | 30%    | Spring | None       | 163         | 215                    | 121   | 199      |
| Average  | Normal Late   | -30%    | Fall   | Winter-kill| 184         | 63                     | 225   | 200      |
| Average  | Low Late      | MRTN   | Fall   | Winter-kill| 116         | 177                    | 209   | 201      |
| Average  | Normal Late   | MRTN   | Fall   | Overwinter | 189         | 21                     | 229   | 202      |
| Average  | Low Late      | MRTN   | Spring | None       | 182         | 176                    | 202   | 203      |
| Average  | Low Late      | MRTN   | Fall   | Overwinter | 192         | 37                     | 227   | 204      |
| Average  | Low Average   | MRTN   | Fall   | Winter-kill| 208         | 158                    | 147   | 205      |
| Average  | Normal Late   | -30%    | Fall   | None       | 186         | 65                     | 226   | 206      |
| Average  | Low Average   | MRTN   | Fall   | None       | 209         | 160                    | 144   | 207      |
| Average  | Normal Early  | 30%    | Fall   | Winter-kill| 220         | 194                    | 72    | 208      |
| Average  | Low Late      | MRTN   | Spring | Fall       | 128         | 179                    | 207   | 209      |
| Average  | Low Low       | -30%    | Fall   | Winter-kill| 185         | 89                     | 224   | 210      |
| Average  | Low Average   | 30%    | Spring | None       | 155         | 229                    | 128   | 211      |
| Average  | Normal Early  | 30%    | Fall   | None       | 222         | 195                    | 75    | 212      |
| Average  | Low Average   | 30%    | Spring | Winter-kill| 164         | 227                    | 123   | 213      |
| Average  | Low Average   | 30%    | Spring | Split     | None        | 162         | 230                    | 125   | 214      |
| Average  | Low Average   | 30%    | Spring | None       | 169         | 228                    | 122   | 215      |
| Average  | Low Average   | 30%    | Split  | Winter-kill| 232         | 174                    | 110   | 216      |
| Average  | Normal Late   | 30%    | Fall   | Overwinter | 231         | 96                     | 188   | 217      |
| Average  | Low Early     | 30%    | Fall   | Winter-kill| 225         | 214                    | 71    | 218      |
| Average  | Normal Average| 30%    | Fall   | Winter-kill| 224         | 201                    | 135   | 219      |
| Average  | Normal Late   | MRTN   | Fall   | Winter-kill| 210         | 140                    | 214   | 220      |
| Average  | Normal Late   | 30%    | Spring | Winter-kill| 153         | 218                    | 197   | 221      |
| Average  | High Late     | 30%    | Fall   | Winter-kill| 218         | 197                    | 154   | 222      |
| Average  | Normal Average| 30%    | Fall   | None       | 226         | 204                    | 133   | 223      |
| Average  | Normal Late   | MRTN   | Fall   | None       | 211         | 141                    | 215   | 224      |
| Average  | Normal Late   | 30%    | Spring | None       | 169         | 228                    | 122   | 215      |
| Average  | Normal Late   | 30%    | Spring | None       | 160         | 219                    | 195   | 226      |
| Average  | Normal Late   | 30%    | Spring | Split     | None        | 152         | 224                    | 203   | 227      |
| Average  | Low Late      | 30%    | Spring | Winter-kill| 159         | 231                    | 196   | 228      |
| Average  | Low Low       | -30%    | Spring | Winter-kill| 212         | 165                    | 213   | 229      |
| Average  | Low Average   | 30%    | Split  | Winter-kill| 151         | 232                    | 205   | 230      |
| Average  | Low Average   | 30%    | Fall   | Winter-kill| 228         | 223                    | 134   | 231      |
| Average  | High High     | 30%    | Split  | Winter-kill| 229         | 210                    | 210   | 232      |
| Average  | High High     | 30%    | Split  | Winter-kill| 16         | 15                     | 28    | 1        |
| Average  | High High     | 30%    | Spring | Winter-kill| 20         | 14                     | 39    | 2        |
| Average  | High High     | 30%    | Split  | Winter-kill| 41         | 32                     | 39    | 3        |
| Average  | High High     | 30%    | Split  | None       | 44         | 31                     | 20    | 4        |
| Average  | High High     | 30%    | Spring | Winter-kill| 49         | 27                     | 24    | 5        |
| Average  | High High     | 30%    | Spring | None       | 57         | 28                     | 26    | 6        |
| Average  | High High     | 30%    | Split  | Winter-kill| 47         | 43                     | 48    | 7        |
| Average  | High High     | 30%    | Split  | Winter-kill| 11         | 82                     | 15    | 16        |
| Average  | High High     | 30%    | Spring | Overwinter | 26         | 75                     | 25    | 9        |
| Average  | High High     | -30%    | Spring | None       | 52         | 44                     | 49    | 10       |
| Average  | High High     | -30%    | Spring | Overwinter | 17         | 84                     | 23    | 11       |
| Average  | High High     | -30%    | Spring | Overwinter | 11         | 8                     | 90    | 12       |
| Average  | High High     | MRTN   | Spring | Overwinter | 36         | 88                     | 9     | 13       |
| Average  | High High     | MRTN   | Split  | Overwinter | 30         | 92                     | 7     | 14       |
| Average  | Normal Early  | -30%    | Split  | Overwinter | 18         | 26                     | 100   | 15       |
| Average  | Low Early     | -30%    | Split  | Overwinter | 21         | 58                     | 85    | 16       |
| Average  | Low Early     | -30%    | Spring | Overwinter | 25         | 52                     | 88    | 17       |
| Average  | High High     | -30%    | Spring | Winter-kill| 66         | 36                     | 75    | 18       |
| Average  | High Normal   | -30%    | Spring | Overwinter | 24         | 24                     | 105   | 19       |
| Average  | High High     | -30%    | Spring | None       | 73         | 38                     | 78    | 20       |
| Average  | High Normal   | -30%    | Spring | Winter-kill| 51         | 53                     | 91    | 21       |
| Average  | High Low      | MRTN   | Spring | Overwinter | 19         | 59                     | 103   | 22       |
| Average  | High Low      | -30%    | Spring | None       | 62         | 54                     | 92    | 23       |
| Average  | High Low      | MRTN   | Split  | Overwinter | 9          | 68                     | 104   | 24       |
| Average  | High Normal   | MRTN   | Spring | Overwinter | 42         | 104                    | 60    | 25       |
| Average  | High Normal   | MRTN   | Split  | Winter-kill| 37         | 106                    | 61    | 26       |
| Average  | High Normal   | MRTN   | Spring | Winter-kill| 71         | 46                     | 98    | 27       |
| Average  | High Low      | -30%    | Split  | Winter-kill| 58         | 83                     | 83    | 28       |
| Apr-Jun Rainfall | Genotype | Planting time | N rate | N time | Cover crop | NO$_3$ load | Soil NO$_3$ at harvest | Yield | Combined |
|-----------------|----------|---------------|--------|--------|------------|------------|------------------------|-------|---------|
| High            | Normal   | Early         | -30%   | Spring | None       | 77         | 47                     | 99    | 29      |
| High            | Low      | Early         | -30%   | Split  | None       | 67         | 85                     | 84    | 30      |
| High            | Low      | Early         | -30%   | Spring | Winter-kill| 76         | 79                     | 86    | 31      |
| High            | Low      | Average       | -30%   | Split  | Overwinter | 10        | 45                     | 135   | 32      |
| High            | Low      | Early         | -30%   | Spring | None       | 81         | 80                     | 87    | 33      |
| High            | Low      | Early         | MRTN   | Spring | Overwinter | 48        | 123                    | 58    | 34      |
| High            | High     | Early         | MRTN   | Split  | Winter-kill| 88        | 115                    | 11    | 35      |
| High            | Low      | Early         | MRTN   | Split  | Overwinter | 38        | 130                    | 59    | 36      |
| High            | High     | Early         | -30%   | Fall   | Winter-kill| 140       | 22                     | 42    | 37      |
| High            | High     | Early         | MRTN   | Split  | None       | 94        | 114                    | 13    | 38      |
| High            | High     | Early         | -30%   | Fall   | None       | 143       | 23                     | 43    | 39      |
| High            | Normal   | Average       | MRTN   | Spring | Winter-kill| 104       | 111                    | 14    | 41      |
| High            | High     | Early         | MRTN   | Spring | Winter-kill| 107       | 121                    | 35    | 50      |
| High            | High     | Average       | MRTN   | Split  | Overwinter | 7         | 20                     | 164   | 51      |
| High            | High     | Late          | -30%   | Split  | Overwinter | 1         | 4                      | 166   | 52      |
| High            | Low      | Average       | MRTN   | Split  | Overwinter | 14        | 40                     | 149   | 43      |
| High            | High     | Early         | MRTN   | Split  | None       | 112       | 110                    | 15    | 44      |
| High            | High     | Average       | MRTN   | Split  | Winter-kill| 91        | 125                    | 33    | 45      |
| High            | High     | Average       | 30%    | Spring | Overwinter | 45        | 153                    | 21    | 46      |
| High            | High     | Average       | MRTN   | Split  | None       | 97        | 126                    | 34    | 47      |
| High            | Low      | Average       | MRTN   | Spring | Overwinter | 35        | 113                    | 114   | 48      |
| High            | High     | Average       | 30%    | Split  | Overwinter | 107       | 160                    | 22    | 49      |
| High            | High     | Average       | MRTN   | Spring | Winter-kill| 104       | 121                    | 35    | 50      |
| High            | Low      | Average       | 30%    | Split  | Overwinter | 7         | 20                     | 164   | 51      |
| High            | High     | Average       | 30%    | Split  | Winter-kill| 1         | 4                      | 166   | 52      |
| High            | High     | Average       | 30%    | Fall   | Winter-kill| 155       | 29                     | 93    | 62      |
| High            | High     | Early         | MRTN   | Fall   | Overwinter | 172       | 64                     | 18    | 63      |
| High            | High     | Average       | 30%    | Split  | Winter-kill| 59        | 65                     | 163   | 64      |
| High            | High     | Late          | -30%   | Spring | Winter-kill| 64        | 50                     | 167   | 65      |
| High            | High     | Early         | -30%   | Fall   | Overwinter | 100       | 12                     | 159   | 66      |
| High            | Normal   | Early         | MRTN   | Split  | Winter-kill| 113       | 134                    | 69    | 67      |
| High            | High     | Early         | 30%    | Spring | Overwinter | 90        | 166                    | 2     | 68      |
| High            | High     | Average       | 30%    | Fall   | None       | 160       | 30                     | 96    | 69      |
| High            | High     | Early         | -30%   | Fall   | Winter-kill| 148       | 41                     | 111   | 70      |
| High            | High     | Late          | -30%   | Spring | None       | 74        | 51                     | 168   | 71      |
| High            | Low      | Early         | -30%   | Fall   | Winter-kill| 150       | 71                     | 94    | 72      |
| High            | Low      | Average       | -30%   | Split  | None       | 70        | 66                     | 165   | 73      |
| High            | Low      | Late          | -30%   | Split  | Overwinter | 3         | 25                     | 190   | 74      |
| High            | Low      | Average       | -30%   | Split  | Winter-kill| 65        | 93                     | 155   | 75      |
| High            | Low      | Late          | -30%   | Spring | Overwinter | 8         | 21                     | 191   | 76      |
| High            | Normal   | Early         | -30%   | Fall   | None       | 151       | 42                     | 112   | 77      |
| High            | Normal   | Early         | MRTN   | Spring | Winter-kill| 129       | 128                    | 66    | 78      |
| High            | Normal   | Early         | MRTN   | Split  | None       | 118       | 136                    | 71    | 79      |
| High            | Low      | Early         | -30%   | Fall   | None       | 154       | 72                     | 95    | 80      |
| High            | Normal   | Average       | -30%   | Spring | Winter-kill| 78        | 62                     | 169   | 81      |
| High            | Low      | Average       | -30%   | Spring | Winter-kill| 75        | 94                     | 156   | 82      |
| High            | Low      | Average       | -30%   | Spring | Winter-kill| 80        | 91                     | 157   | 83      |
| High            | Normal   | Early         | MRTN   | Spring | None       | 125       | 129                    | 68    | 84      |
| High            | Normal   | Average       | -30%   | Spring | None       | 85        | 63                     | 170   | 85      |
| High            | Normal   | Late          | MRTN   | Spring | Overwinter | 28        | 76                     | 185   | 86      |
| High            | Low      | Average       | -30%   | Spring | None       | 89        | 90                     | 158   | 87      |
| High            | Normal   | Late          | -30%   | Split  | Overwinter | 2         | 10                     | 203   | 88      |
| High            | High     | Average       | MRTN   | Fall   | Overwinter | 177       | 35                     | 97    | 89      |
| High            | High     | Late          | MRTN   | Split  | Winter-kill| 84        | 139                    | 125   | 90      |
Supplemental Table S2 (continued).

| Apr-Jun Rainfall | Genotype | Planting time | N rate | N time | Cover crop | Ranking |
|------------------|----------|---------------|--------|--------|------------|---------|
| High             | Normal   | Late          | MRTN   | Split  | Winter-over | 13      |
| High             | Low      | Early         | -30% Fall | Overwinter | 111      |
| High             | High     | Late          | MRTN   | Split  | Winter-kill | 103     |
| High             | Normal   | Average       | -30%   | Split  | Overwinter | 40      |
| High             | High     | Late          | MRTN   | Split  | None       | 92      |
| High             | High     | Early         | -30% Fall | Overwinter | 106     |
| High             | Low      | Late          | MRTN   | Spring | Overwinter | 29      |
| High             | Low      | Early         | MRTN   | Split  | Winter-kill | 119     |
| High             | Normal   | Early         | 30%    | Split  | Overwinter | 96      |
| High             | High     | Late          | MRTN   | Spring | None       | 110     |
| High             | Low      | Late          | MRTN   | Split  | Overwinter | 15      |
| High             | Low      | Early         | MRTN   | Split  | None       | 123     |
| High             | Normal   | Late          | -30%   | Spring | Overwinter | 6       |
| High             | Low      | Early         | 30%    | Split  | Overwinter | 101     |
| High             | High     | Average       |      |       |            | 198     |
| High             | High     | Average       |      |       |            | 108     |
| High             | Low      | Early         | MRTN   | Fall   | Winter-kill | 138     |
| High             | High     | Early         | MRTN   | Fall   | None       | 194     |
| High             | Low      | Average       |      |       |            | 195     |
| High             | Normal   | Average       |      |       |            | 43      |
| High             | Low      | Early         | MRTN   | Fall   | Overwinter | 186     |
| High             | High     | Early         | MRTN   | Spring | None       | 142     |
| High             | Low      | Early         | MRTN   | Spring | Overwinter | 124     |
| High             | High     | Average       |      |       |            | 101     |
| High             | High     | Average       |      |       |            | 198     |
| High             | High     | Average       |      |       |            | 108     |
| High             | Low      | Early         | MRTN   | Fall   | Overwinter | 189     |
| High             | Low      | Average       |      |       |            | 95      |
| High             | High     | Average       |      |       |            | 126     |
| High             | High     | Early         | 30%    | Split  | Winter-kill | 137     |
| High             | Normal   | Average       |      |       |            | 117     |
| High             | Low      | Late          | -30% Fall | Overwinter | 56      |
| High             | High     | Late          | -30% Fall | Overwinter | 54      |
| High             | High     | Early         | -30% Split | None       | 141     |
| High             | Normal   | Late          | -30% Fall | Overwinter | 55      |
| High             | High     | Late          | -30% Split | None       | 132     |
| High             | Low      | Average       |      |       |            | 134     |
| High             | High     | Average       |      |       |            | 130     |
| High             | Normal   | Late          | 30%    | Split  | Overwinter | 31      |
| High             | Normal   | Late          | 30%    | Spring | Overwinter | 61      |
| High             | High     | Late          | -30% Spring | Winter-kil | 79      |
| High             | High     | Average       |      |       |            | 214     |
| High             | High     | Average       |      |       |            | 93      |
| High             | High     | Late          | -30% Fall | Winter-kil | 162     |
| High             | High     | Normal        | MRTN Fall | Winter-kil | 200     |
| High             | High     | Late          | -30% Split | None       | 83      |
| High             | High     | Average       |      |       |            | 163     |
| High             | Low      | Late          | -30% Spring | Winter-kil | 82      |
| High             | Low      | Late          | -30% Split | Winter-kil | 63      |
| High             | High     | Early         | 30%    | Spring | Winter-kil | 158     |
| High             | High     | Average       |      |       |            | 136     |
| High             | Low      | Average       |      |       |            | 99      |
| High             | Normal   | Early         | MRTN Fall | None       | 201     |
| High             | Low      | Late          | -30% Split | None       | 72      |
| High             | Low      | Late          | -30% Spring | None       | 87      |
| High             | High     | Average       |      |       |            | 98      |
| High             | High     | Late          | -30% Fall | Overwinter | 116     |
| High             | High     | Average       |      |       |            | 152     |
| High             | High     | Early         | 30%    | Spring | None       | 164     |
| High             | Low      | Average       |      |       |            | 166     |
## Supplemental Table S2 (continued).

| Apr-Jun Rainfall | Genotype | Planting time | N rate | N time | Cover crop | NO$_3$ load | Soil NO$_3$ at harvest | Yield | Combined |
|------------------|----------|---------------|--------|--------|------------|-------------|------------------------|-------|----------|
| High             | Normal   | Average       | -30%   | Fall   | None       | 171         | 49                     | 178   | 153      |
| High             | Low      | Average       | MRTN   | Spring | Winter-kill| 131         | 168                    | 136   | 154      |
| High             | Low      | Average       | MRTN   | Split  | None       | 120         | 172                    | 142   | 155      |
| High             | High     | Average       | MRTN   | Fall   | Winter-kill| 156         | 198                    | 30    | 156      |
| High             | High     | Early         | MRTN   | Split  | Overwinter | 211         | 141                    | 117   | 157      |
| High             | Low      | Average       | -30%   | Fall   | None       | 173         | 78                     | 173   | 158      |
| High             | Low      | Late          | MRTN   | Split  | Overwinter | 34          | 175                    | 186   | 159      |
| High             | Low      | Average       | MRTN   | Spring | None       | 139         | 169                    | 138   | 160      |
| High             | Low      | Average       | MRTN   | Fall   | Overwinter | 187         | 86                     | 160   | 161      |
| High             | Low      | Late          | 30%    | Spring | Overwinter | 68          | 174                    | 182   | 162      |
| High             | Normal   | Average       | MRTN   | Fall   | Overwinter | 185         | 57                     | 176   | 163      |
| High             | Low      | Early         | MRTN   | Fall   | Winter-kill| 203         | 148                    | 76    | 164      |
| High             | Low      | Early         | MRTN   | Fall   | None       | 205         | 149                    | 77    | 165      |
| High             | High     | Late          | 30%    | Split  | Winter-kill| 121         | 211                    | 120   | 166      |
| High             | High     | Late          | 30%    | Fall   | Overwinter | 215         | 67                     | 152   | 168      |
| High             | Normal   | Early         | 30%    | Split  | Winter-kill| 169         | 206                    | 55    | 168      |
| High             | High     | Late          | MRTN   | Fall   | Overwinter | 157         | 13                     | 224   | 169      |
| High             | High     | Late          | 30%    | Split  | Winter-kill| 202         | 117                    | 145   | 170      |
| High             | High     | Late          | 30%    | Fall   | None       | 125         | 213                    | 121   | 171      |
| High             | Normal   | Late          | MRTN   | Spring | Winter-kill| 122         | 150                    | 198   | 172      |
| High             | Normal   | Early         | 30%    | Split  | None       | 176         | 207                    | 56    | 173      |
| High             | Normal   | Late          | MRTN   | Split  | Winter-kill| 102         | 154                    | 207   | 174      |
| High             | High     | Late          | MRTN   | Fall   | None       | 204         | 116                    | 148   | 175      |
| High             | High     | Early         | MRTN   | Fall   | Overwinter | 217         | 162                    | 63    | 176      |
| High             | High     | Normal        | MRTN   | Fall   | Overwinter | 219         | 131                    | 113   | 177      |
| High             | Normal   | Late          | MRTN   | Split  | None       | 109         | 155                    | 205   | 178      |
| High             | Normal   | Late          | MRTN   | Spring | None       | 128         | 152                    | 197   | 179      |
| High             | High     | Late          | 30%    | Spring | Winter-kill| 145         | 209                    | 119   | 180      |
| High             | High     | Early         | 30%    | Fall   | Winter-kill| 216         | 181                    | 10    | 181      |
| High             | Normal   | Late          | MRTN   | Fall   | Overwinter | 165         | 19                     | 228   | 182      |
| High             | High     | Late          | 30%    | Spring | None       | 149         | 210                    | 118   | 183      |
| High             | Normal   | Early         | 30%    | Spring | Winter-kill| 191         | 204                    | 51    | 184      |
| High             | High     | Early         | 30%    | Fall   | None       | 218         | 182                    | 12    | 185      |
| High             | Low      | Late          | MRTN   | Fall   | Overwinter | 168         | 34                     | 227   | 186      |
| High             | High     | Average       | MRTN   | Fall   | Winter-kill| 206         | 124                    | 153   | 187      |
| High             | Normal   | Early         | MRTN   | Spring | None       | 193         | 205                    | 52    | 183      |
| High             | Normal   | Average       | MRTN   | Split  | None       | 208         | 127                    | 154   | 189      |
| High             | Normal   | Late          | -30%   | Fall   | Winter-kill| 174         | 60                     | 222   | 190      |
| High             | Low      | Late          | MRTN   | Split  | Winter-kill| 105         | 178                    | 206   | 191      |
| High             | High     | Average       | MRTN   | Fall   | Winter-kill| 222         | 186                    | 37    | 192      |
| High             | Low      | Early         | 30%    | Split  | Winter-kill| 179         | 225                    | 54    | 193      |
| High             | Low      | Early         | 30%    | Fall   | Winter-kill| 221         | 184                    | 62    | 194      |
| High             | High     | Late          | -30%   | Fall   | None       | 182         | 61                     | 223   | 195      |
| High             | High     | Average       | 30%    | Fall   | None       | 224         | 187                    | 38    | 196      |
| High             | Low      | Late          | MRTN   | Split  | None       | 114         | 179                    | 204   | 197      |
| High             | Low      | Late          | MRTN   | Spring | Winter-kill| 127         | 176                    | 199   | 198      |
| High             | High     | Average       | 30%    | Split  | Winter-kill| 153         | 215                    | 131   | 199      |
| High             | Low      | Late          | MRTN   | Spring | None       | 133         | 177                    | 196   | 200      |
| High             | Low      | Early         | 30%    | Split  | None       | 183         | 226                    | 57    | 201      |
| High             | Low      | Average       | 30%    | Fall   | Overwinter | 223         | 164                    | 106   | 202      |
| High             | Low      | Late          | -30%   | Fall   | Winter-kill| 178         | 89                     | 221   | 203      |
| High             | Low      | Average       | MRTN   | Fall   | Winter-kill| 207         | 157                    | 150   | 204      |
| High             | Normal   | Average       | 30%    | Split  | None       | 161         | 216                    | 133   | 205      |
| High             | Low      | Early         | 30%    | Spring | Winter-kill| 196         | 223                    | 50    | 206      |
| High             | Low      | Average       | MRTN   | Fall   | None       | 209         | 159                    | 151   | 207      |
| High             | Low      | Early         | 30%    | Spring | None       | 197         | 214                    | 53    | 208      |
| High             | Normal   | Late          | 30%    | Fall   | Overwinter | 220         | 87                     | 192   | 209      |
| High             | Normal   | Early         | 30%    | Fall   | Winter-kill| 226         | 194                    | 73    | 210      |
| High             | Normal   | Average       | 30%    | Spring | Winter-kill| 184         | 212                    | 127   | 211      |
| High             | Normal   | Early         | 30%    | Fall   | None       | 227         | 195                    | 74    | 212      |
| High             | Low      | Average       | 30%    | Split  | Winter-kill| 159         | 229                    | 132   | 213      |
| High             | Normal   | Average       | 30%    | Spring | None       | 190         | 214                    | 129   | 214      |
## Supplemental Table S2 (continued).

| Apr-Jun Rainfall | Genotype  | Planting time | N rate  | N time  | Cover crop | NO\textsubscript{3} load | Soil NO\textsubscript{3} at harvest | Yield | Combined |
|------------------|-----------|----------------|---------|---------|------------|---------------------------|-------------------------------------|-------|----------|
| High             | Low       | Average        | 30%     | Split   | None       | 167                       | 230                                 | 134   | 215      |
| High             | Low       | Average        | 30%     | Spring  | Winter-kill| 188                       | 227                                 | 128   | 216      |
| High             | High      | Late           | 30%     | Fall    | Winter-kill| 225                       | 193                                 | 126   | 217      |
| High             | Low       | Average        | 30%     | Fall    | Winter-kill| 229                       | 217                                 | 72    | 218      |
| High             | Low       | Average        | 30%     | Spring  | None       | 192                       | 228                                 | 130   | 219      |
| High             | Normal    | Late           | MRTN    | Fall    | Winter-kill| 210                       | 137                                 | 211   | 220      |
| High             | Normal    | Late           | MRTN    | Fall    | None       | 213                       | 138                                 | 213   | 222      |
| High             | Normal    | Late           | 30%     | Split   | None       | 147                       | 221                                 | 200   | 223      |
| High             | Normal    | Average        | 30%     | Fall    | Winter-kill| 228                       | 200                                 | 144   | 224      |
| High             | Normal    | Average        | 30%     | Fall    | None       | 230                       | 202                                 | 147   | 225      |
| High             | Normal    | Late           | 30%     | Spring  | Winter-kill| 175                       | 218                                 | 193   | 226      |
| High             | Low       | Late           | 30%     | Split   | Winter-kill| 146                       | 232                                 | 201   | 227      |
| High             | Low       | Late           | MRTN    | Fall    | Winter-kill| 212                       | 165                                 | 209   | 228      |
| High             | Normal    | Late           | MRTN    | Fall    | None       | 181                       | 220                                 | 195   | 229      |
| High             | Low       | Late           | 30%     | Spring  | Winter-kill| 180                       | 231                                 | 194   | 230      |
| High             | Low       | Average        | 30%     | Fall    | Winter-kill| 231                       | 222                                 | 146   | 231      |
| High             | Normal    | Late           | 30%     | Fall    | Winter-kill| 232                       | 208                                 | 208   | 232      |
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