*Supplementary Materials for Article*

# Improving Crop Health, Performance, and Quality in Organic Spring Wheat Production: The Need to Understand Interactions between Pedoclimatic Conditions, Variety, and Fertilization

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**Supplementary Table S1**. Mean daily temperature, and monthly rainfall and solar radiation[1] at Gilchester (GIL), Sheepdrove (SHE) and Courtyard (COU) farm during the spring wheat growing seasons in 2006 and 2007

| | **Mean daily temperature** | | | **Total Rainfall** | | | **Solar Radiation** | | |
|---|---|---|---|---|---|---|---|---|---|
| **Year** | (°C) | | | (mm) | | | (kW/m2) | | |
| month | **GIL** | **SHE** | **COU** | **GIL** | **SHE** | **COU** | **GIL** | **SHE** | **COU** |
| **2006** | | | | | | | | | |
| April | 6.9 | 8.2 | 8.7 | 22 | 32 | 38 | 44 | 107 | 114 |
| May | 9.7 | 11.9 | 12.7 | 74 | 113 | 89 | 53 | 133 | 135 |
| June | 14.0 | 15.9 | 16.1 | 28 | 8 | 10 | 57 | 182 | 178 |
| July | 17.4 | 19.7 | 19.3 | 13 | 30 | 32 | 65 | 186 | 193 |
| August | 14.4 | 15.9 | 16.3 | 60 | 16 | 93 | 40 | 124 | 113 |
| September | 14.8 | 16.2 | 17.6 | 71 | 97 | 71 | 30 | 93 | 97 |
| **Average** | **12.9** | **14.6** | **15.1** | **45** | **49** | **56** | **48** | **138** | **138** |
| **Sum** | | | | **268** | **296** | **333** | **289** | **825** | **830** |
| | | | | | | | | | |
| **2007** | | | | | | | | | |
| April | 9.3 | 10.9 | 11.0 | 13 | 5 | 3 | 44 | 92 | 132 |
| May | 10.0 | 11.5 | 12.2 | 51 | 131 | 111 | 53 | 85 | 119 |
| June | 12.9 | 15.0 | 15.0 | 85 | 120 | 129 | 19 | 80 | 146 |
| July | 13.9 | 15.1 | 16.2 | 11 | 189 | 113 | 20 | 143 | 145 |
| August | 14.0 | 15.7 | 16.4 | 36 | 32 | 53 | 44 | 123 | 134 |
| September | 12.3 | 13.7 | 14.8 | 23 | 25 | 38 | 30 | 95 | 101 |
| **Average** | **12.1** | **13.7** | **14.3** | **36.5** | **83.7** | **74.5** | **35.0** | **103.0** | **129.5** |
| **Sum** | | | | **219** | **502** | **447** | **210** | **618** | **777** |

Data from the weather stations nearest to the trial sites supplied by the UK Met office.

**Supplementary Table S2.** Carbon and macronutrient concentrations in soils at Gilchester (GIL), Sheepdrove (SHE) and Courtyard (COU) farm prior to drilling of spring wheat spring wheat in the 2006 and 2007 growing seasons

| **Soil** | **Gilchester** | | **Sheepdrove** | | **Courtyard** | |
|---|---|---|---|---|---|---|
| **Parameter** | **2006** | **2007** | **2006** | **2007** | **2006** | **2007** |
| **Carbon** (%) | 2.8 ±0.1 | 3.8 ±0.3 | 5.7 ±0.1 | 8.1 ±0.2 | 1.1 ±0.2 | 1.7 ±0.1 |
| **Macro-nutrients** | | | | | | |
| **N** (%) | 2.6 ±0.1 | 3.8 ±0.5 | 8.4 ±0.6 | 9.8 ±0.7 | 1.1 ±0.2 | 0.9 ±0.1 |
| **P** (mg/kg) | 31 ±2 | 21 ±2 | 44 ±12 | 16 ±2 | 53 ±6 | 60 ±7 |
| **K** (mg/kg) | 204 ±15 | 128 ±6 | 338 ±18 | 145 ±7 | 115 ±22 | 77 ±3 |
| **S** (mg/kg) | 16.4 ±0.7 | 22.2 ±1.4 | 20.8 ±1.9 | 21.2 ±0.7 | 11.4 ±0.4 | 15.4 ±0.3 |
| **Ca** (g/kg) | 1.3 ±0.1 | 4.4 ±1.1 | 15.6 ±1.1 | 15.9 ±1.0 | 3.4 ±0.4 | 2.8 ±0.4 |
| **Mg** (mg/kg) | 193 ±6 | 126 ±18 | 160 ±14 | 147 ±7 | 45 ±2 | 34 ±2 |
| **Na** (mg/kg) | 18 ±3 | 31 ±5 | 50 ±6 | 56 ±1 | 14 ±1 | 28 ±4 |
| **Micro-nutrients** | | | | | | |
| **Fe** (mg/kg) | 455 ±15 | 246 ±33 | 59 ±7 | 41 ±7 | 94 ±8 | 153 ±17 |
| **Mn** (mg/kg) | 59 ±3 | 160 ±15 | 156 ±14 | 126 ±19 | 156 ±5 | 197 ±8 |
| **Zn** (mg/kg) | 2.8 ±0.1 | 4.6 ±0.9 | 7.5 ±0.8 | 5.8 ±0.1 | 2.3 ±0.1 | 2.7 ±0.2 |
| **Cu** (mg/kg) | 2.26 ±0.04 | 3.81 ±0.26 | 2.76 ±0.33 | 1.71 ±0.11 | 0.94 ±0.02 | 1.20 ±0.07 |
| **B** (mg/kg) | 0.21 ±0.02 | 1.87 ±0.47 | 2.19 ±0.05 | 3.53 ±0.22 | 0.65 ±0.10 | 1.09 ±0.06 |
| **Mo** (μg/kg) | 10.2 ±0.8 | 19.0 ±3.9 | 8.0 ±0.0 | 9.0 ±0.0 | 8.0 ±0.0 | 13.3 ±3.5 |
| **Toxic metals** | | | | | | |
| **Al** (mg/kg) | 631 ±22 | 628 ±119 | 149 ±26 | 183 ±46 | 371 ±25 | 322 ±119 |
| **Cd** (μg/kg) | 104 ±3 | 209 ±32 | 347 ±9 | 538 ±15 | 138 ±5 | 159 ±7 |
| **Ni** (mg/kg) | 1.2 ±0.0 | 2.3 ±0.2 | 1.4 ±0.1 | 0.7 ±0.1 | 0.7 ±0.0 | 0.8 ±0.0 |
| **Pb** (mg/kg) | 6.2 ±0.3 | 13.0 ±1.3 | 4.9 ±0.1 | 5.3 ±0.2 | 4.3 ±0.1 | 5.2 ±0.5 |

Soil analyses were carried out by Field Science Ltd. (Bristol, UK) on soil samples taken from the top soil (0-30 cm) prior to sowing.

**Supplementary Table S3.** Dates of incorporation of clover, planting of wheat crops, mechanical weed control and harvest of winter and spring wheat varieties in the three field trial sites

| | Sheepdrove | | Courtyard | | Gilchester | |
|---|---|---|---|---|---|---|
| **Activity** | **2006** | **2007** | **2006** | **2007** | **2006** | **2007** |
| Soil sample collection | 15/02 | 16/02 | 16/02 | 23/02 | 14/02 | 22/02 |
| Clover ley incorporation | 20/03 | 21/03 | 28/03 | 28/03 | 10/040 | 02/04 |
| Spring wheat sowing date | 20/03 | 21/03 | 28/03 | 28/03 | 10/04 | 02/04 |
| 1st mechanical weeding | 26/04 | 20/04 | Not possible[1] | 23/04 | 12/05 | 26/04 |
| 2nd mechanical weeding | 10/05 | 04/05 | 15/05 | 08/05 | 26/05 | 12/05 |
| Harvest | 15/08 | 29/08 | 10/08 | 31/08 | 30/08 | 12/09 |

[1], the ground was too wet.

**Supplementary Table S4.** Interaction means ±SE for effects of site and wheat variety on yellow rust severity (% leaf area infected) at GS65

| **Parameter Assessed** | **Factor 1 variety** | **Factor 2 site** | | |
|---|---|---|---|---|
| | | Gilchester | Sheepdrove | Courtyard |
| ***Septoria* severity on the flag leaf** | Amaretto | 0.0 ±0.0 **A b** | 0.0 ±0.0 **A a** | 0.3 ±0.1 **A a** |
| | Fasan | 0.4 ±0.2 **A b** | 0.9 ±0.6 **A a** | 0.2 ±0.1 **A a** |
| | Monsun | 2.1 ±0.8 **A a** | 0.0 ±0.0 **B a** | 0.4 ±0.2 **B a** |
| | Paragon | 0.1 ±0.1 **A b** | 0.0 ±0.0 **A a** | 0.3 ±0.1 **A a** |
| | Tybalt | 0.5 ±0.2 **A b** | 0.1 ±0.1 **A a** | 0.1 ±0.1 **A a** |
| | Zebra | 0.0 ±0.0 **A b** | 0.0 ±0.0 **A a** | 0.3 ±0.3 **A a** |
| **Yellow rust on the flag leaf** | Amaretto | 4.1 ±1.0 **A b** | 3.4 ±1.1 **A c** | 1.4 ±0.8 **A b** |
| | Fasan | 10.6 ±2.2 **A b** | 12.3 ±4.0 **A b** | 0.8 ±0.3 **B b** |
| | Monsun | 5.0 ±1.6 **A b** | 4.0 ±1.0 **A bc** | 0.5 ±0.3 **A b** |
| | Paragon | 0.1 ±0.1 **A b** | 0.0 ±0.0 **A c** | 0.0 ±0.0 **A b** |
| | Tybalt | 0.0 ±0.0 **A b** | 0.0 ±0.0 **A c** | 0.0 ±0.0 **A b** |
| | Zebra | 56.8 ±11.7 **A a** | 46.9 ±6.5 **B a** | 7.4 ±2.3 **C a** |

For each parameter, means labelled with the same lower case letter within the same column and capital letter within the same row are not significantly different according to Tukey's honestly significant difference (THSD) test ($p < 0.05$).

**Supplementary Table S5.** Main effect means ± SE and *p* -values for the effects of year, site, and fertilizer type and input level on spring wheat cv Paragon disease severity (% of leaf area infected) at GS 65

| | *Septoria* | | Powdery mildew | |
|---|---|---|---|---|
| | **Flag leaf** | **Leaf 2** | **Flag leaf** | **Leaf 2** |
| **Year (YR)** | | | | |
| 2006 | 0.3±0.1 | 5.1 ±0.6 | 0.6±0.1 | 0.8 ±0.1 |
| 2007 | 0.0±0.0 | 3.3 ±0.3 | 0.0±0.0 | 1.0 ±0.2 |
| **Site (ST)** | | | | |
| Courtyard | 0.4 ±0.1 **a** | 4.6 ±0.3 **b** | 0.7 ±0.1 **a** | 2.1 ±0.2 **a** |
| Gilchester | 0.0 ±0.0 **b** | 0.5 ±0.1 **c** | 0.0 ±0.0 **b** | 0.1 ±0.0 **c** |
| Sheepdrove | 0.0 ±0.0 **b** | 7.4 ±0.8 **a** | 0.2 ±0.0 **b** | 0.5 ±0.1 **b** |
| **Fertilizer type** | | | | |
| Chicken manure pellets (CMP) | 0.2±0.1 **a** | 4.4±0.6 | 0.6 ±0.2 **a** | 1.3±0.2 **a** |
| Farm yard manure (FYM) | 0.1±0.0 **b** | 4.8±0.9 | 0.1 ±0.0 **b** | 0.6±0.1 **b** |
| CP + FYM | 0.1±0.0 **b** | 3.9±0.5 | 0.3 ±0.1 **ab** | 1.1±0.2 **a** |
| Greenwaste compost (GWC) | 0.1±0.0 **ab** | 3.7±0.8 | 0.1 ±0.0 **b** | 0.6±0.2 **b** |
| **Fertilizer input level** | | | | |
| 125 kg N/ha | 0.1±0.0 | 3.9±0.5 | 0.3±0.1 | 0.9±0.1 |
| 250 kg N/ha | 0.2±0.1 | 4.4±0.5 | 0.3±0.1 | 0.9±0.1 |
| **ANOVA** (p-values) | | | | |
| ***Main Effects*** | | | | |
| Year (YR) | 0.0244 | 0.0324 | 0.0107 | NS |
| Site (ST) | 0.0002 | <0.0001 | 0.0002 | <0.0001 |
| Fertilizer type (FT) | 0.0267 | NS | 0.0004 | <0.0001 |
| Fertilizer input level (IL) | NS | NS | NS | NS |
| ***Interactions***[1] | | | | |
| YR x ST | 0.0002 | <0.0001 | 0.0002 | NS |
| YR x FT | 0.0267 | NS | 0.0004 | NS |
| ST x FT | 0.0055 | 0.0232 | 0.0034 | 0.0120 |
| YR x ST x FT | 0.0055 | 0.0008 | 0.0033 | 0.0001 |
| YR x FR x IL | NS | NS | NS | 0.0236 |

Means labelled with the same letter within the same column are not significantly different according to Tukey's honestly significant difference (THSD) test ($p < 0.05$). [1], only interactions that were significant for at least one disease parameter are shown.

**Supplementary Table S6.** Main effect means ± SE and *p*-values for the effects of year, site and fertilizer type and input level on grain yield and protein content, leaf chlorophyll levels (SPAD), and straw length, in spring wheat

| **Factor** | **Grain yield** (t/ha) | **Grain Protein** (%) | **SPAD at GS65** | **Straw length** (cm) |
|---|---|---|---|---|
| **Year (YR)** | | | | |
| 2006 | 4.5 ±0.1 | 13.8 ±0.2 | 49.8 ±0.4 | 94 ±1 |
| 2007 | 2.8 ±0.1 | 15.0 ±0.1 | 42.5 ±0.4 | 84 ±1 |
| **Site (ST)** | | | | |
| Courtyard | 3.6 ±0.1 **b** | 13.1 ±0.3 **b** | 43.9 ±0.4 **b** | 88 ±1 |
| Gilchester | 4.2 ±0.2 **a** | 15.6 ±0.1 **a** | 49.8 ±0.6 **a** | 89 ±1 |
| Sheepdrove | 3.2 ±0.1 **c** | 15.0 ±0.2 **c** | 44.8 ±0.8 **b** | 89 ±2 |
| **Fertilizer type** | | | | |
| CMP[1] | 3.5 ±0.2 **b** | 15.6 ±0.3 **a** | 47.8 ±0.7 **a** | 89 ±1 |
| FYM[2] | 3.8 ±0.2 **ab** | 13.8 ±0.3 **c** | 45.0 ±0.8 **b** | 89 ±1 |
| CP + FYM[3] | 3.6 ±0.2 **ab** | 15.0 ±0.3 **b** | 47.1 ±0.7 **a** | 88 ±1 |
| GWC[4] | 3.8 ±0.1 **a** | 13.8 ±0.3 **c** | 44.9 ±0.9 **b** | 89 ±1 |
| **Input level** | | | | |
| 125 kg N/ha | 3.7 ±0.1 | 14.4 ±0.2 | 45.7±0.55 | 89 ±1 |
| 250 kg N/ha | 3.7 ±0.1 | 14.4 ±0.2 | 46.7±0.57 | 89 ±1 |
| **ANOVA** (p-values) | | | | |
| ***Main Effects*** | | | | |
| Year (YR) | 0.0009 | 0.009 | 0.0010 | 0.0027 |
| Site (ST) | 0.0005 | <0.0001 | <0.0001 | NS |
| Fertilizer type (FT) | 0.0235 | <0.0001 | <0.0001 | NS |
| Input level (IL) | NS | NS | 0.0255 | NS |
| ***Interactions***[1] | | | | |
| YR x ST | <0.0001[5] | 0.0003[6] | 0.0006[6] | <0.0001 |
| YR x FT | 0.0032 | 0.0004 | 0.0136 | NS |
| ST x FT | 0.0005[5] | 0.0001[6] | 0.0136[6] | NS |
| ST x IL | NS | 0.0062[6] | NS | NS |
| FT x IL | NS | 0.0317 | NS | NS |
| YR x ST x FT | NS | <0.0001[6] | NS | NS |
| YR x ST x IL | 0.0139[5] | NS | NS | NS |
| YR x FR x FT | NS | NS | NS | <0.0001 |
| ST x FT x IL | NS | <0.0001[6] | NS | NS |
| YR x ST x FT x IL | NS | 0.0040[6] | NS | NS |

Means labelled with the same letter within the same column are not significantly different according to Tukey's honestly significant difference (THSD) test ($p < 0.05$). [5], see Table 8 for separate ANOVA for the three sites; [6], see Table 9 for separate ANOVA for the three sites.

**Supplementary Table S7.** Main effect means ± SE and *p* -values for the effects of year, site and fertilizer type and input level on phytic acid selected grain mineral micronutrient (Fe, Zn) and toxic metal (Cd, Ni, Pb) concentrations in spring wheat

| | Phytic | Mineral micronutrients | | Toxic metals | | |
|---|---|---|---|---|---|---|
| | acid | Fe | Zn | Cd | Ni | Pb |
| **Factor** | (g/kg) | (mg/kg) | (mg/kg) | (µg/kg) | (µg/kg) | (µg/kg) |
| **Year (YR)** | | | | | | |
| 2006 | 9.9 ±0.1 | 34.8 ±0.4 | 29.9 ±0.6 | 30 ±1 | 89 ±3 | 41 ±3 |
| 2007 | 9.9 ±0.1 | 31.6 ±0.5 | 34.9 ±0.5 | 38 ±1 | 121 ±3 | 115 ±5 |
| **Site (ST)** | | | | | | |
| Courtyard | 10.0 ±0.1 | 29.6 ±0.5 **c** | 27.7±0.6 **c** | 34 ±2 **ab** | 98 ±3 **b** | 77 ±7 |
| Gilchester | 9.9 ±0.1 | 37.0 ±0.4 **a** | 30.6±0.3 **b** | 37 ±2 **a** | 122 ±5 **a** | 72 ±7 |
| Sheepdrove | 9.9 ±0.1 | 33.6 ±0.4 **b** | 38.4±0.4 **a** | 31 ±1 **b** | 96 ±4 **b** | 79 ±7 |
| **Fertilizer type** | | | | | | |
| CMP[1] | 10.0 ±0.1 | 35.1 ±0.6 **a** | 33.0 ±1.0 **a** | 37 ±2 **a** | 110 ±5 | 77 ±8 **b** |
| FYM[2] | 9.8 ±0.1 | 31.6 ±0.6 **c** | 32.0 ±0.8 **bc** | 32 ±2 **b** | 100 ±4 | 72 ±8 **b** |
| CP + FYM[3] | 9.9 ±0.2 | 34.0 ±0.7 **b** | 32.6 ±0.9 **ab** | 34 ±2 **b** | 108 ±6 | 88 ±10 **a** |
| GWC[4] | 10.0 ±0.1 | 32.3 ±0.7 **c** | 31.5 ±0.8 **c** | 32 ±2 **b** | 99 ±5 | 68 ±8 **b** |
| **Input level** | | | | | | |
| 125 kg N/ha | 9.9 ±0.1 | 33.3 ±0.5 | 32.1 ±0.6 | 34 ±1 | 105 ±4 | 72 ±6 |
| 250 kg N/ha | 10.0 ±0.1 | 33.3 ±0.5 | 32.5 ±0.6 | 34 ±1 | 103 ±3 | 81 ±6 |
| **ANOVA** (p-values) | | | | | | |
| ***Main Effects*** | | | | | | |
| Year (YR) | NS | 0.0014 | 0.0529 | 0.0134 | 0.0068 | 0.0012 |
| Site (ST) | NS | <0.0001 | <.0001 | 0.0224 | 0.0008 | NS |
| Fertilizer type (FT) | NS | <0.0001 | <0.0001 | 0.0056 | NS | NS |
| Input level (IL) | NS | NS | NS | NS | NS | NS |
| ***Interactions*** | | | | | | |
| YR x ST | NS | NS | 0.0002[5] | <0.0001[5] | NS | NS |
| YR x FT | NS | 0.0410 | 0.0243 | NS | NS | 0.0030 |
| ST x FT | NS | <0.0001[5] | 0.0306[5] | 0.0229[5] | NS | NS |
| FT x IL | NS | NS | NS | NS | NS | 0.0355[6] |
| YR x ST x FT | NS | 0.0015[5] | NS | NS | NS | NS |
| YR x FT x IL | 0.0443 | NS | NS | NS | NS | NS |
| ST x FT x FL | NS | 0.0056[5] | NS | NS | NS | NS |
| YR x ST x FT x IL | NS | NS | NS | NS | NS | 0.0320 |

Means labelled with the same letter within the same column are not significantly different according to Tukey's honestly significant difference (THSD) test ($p < 0.05$). NS, not significant; [5], see see Supplementary Table 8 for separate ANOVA for the three sites; [6], see Supplementary Table 9 for interaction means ±SE.

**Supplementary Table S8.** Effect means ± SE and *p* -values for the effects of harvest year and variety on Vitamin E isomer concentrations in spring wheat at Gilchester

| **Factor** | **α-tocopherol** (μg/g) | **α-tocotrienol** (μg/g) | **β-tocopherol** (μg/g) | **β-tocotrienol** (μg/g) |
|---|---|---|---|---|
| **Year (YR)** | | | | |
| 2006 | 12.4 ±0.4 | 3.1 ±0.1 | 7.81±0.37 | 26.3 ±0.6 |
| 2007 | 10.5 ±0.4 | 3.1 ±0.2 | 3.49±0.22 | 15.2 ±0.7 |
| **Variety (VR)** | | | | |
| Amaretto | 12.8 ±0.6 **a** | 3.1 ±0.2 | 7.3 ±1.4 **a** | 19.7 ±2.0 **cd** |
| Fasan | 10.3 ±0.7 **c** | 3.1 ±0.4 | 4.4 ±0.5 **c** | 20.0 ±1.7**cd** |
| Monsun | 9.7 ±0.7 **c** | 3.2 ±0.2 | 4.7 ±0.7 **c** | 19.4 ±2.3 **d** |
| Paragon | 12.5 ±0.4 **ab** | 3.2 ±0.2 | 6.6 ±0.9 **ab** | 23.0 ±2.7 **abc** |
| Tybalt | 11.2 ±0.5 **bc** | 2.7 ±0.1 | 5.3 ±0.8 **bc** | 23.2 ±2.4 **a** |
| Zebra | 13.0 ±0.9 **a** | 3.4 ±0.3 | 6.2 ±1.1 **b** | 20.9 ±2.9 **bc** |
| **ANOVA** | | | | |
| **Main Effects** | | | | |
| YR | T | NS | <0.001 | 0.003 |
| VR | <0.001 | NS | <0.001 | 0.023 |
| **Interactions**[1] | | | | |
| YR:VR | 0.035 | NS | 0.002 | NS |

NS, not significnat; T, tend (*P*>0.05 and <0.10); means labelled with the same letter within the same column are not significantly different (General Linear Hypothesis test, $p < 0.05$); [1], for interaction means see Supplementary Table 2;

**Supplementary Table S9.** Interaction means for effects of year and variety on α- and β-tocopherol concentrations in spring wheat grain

| | **α-tocopherol** (μg/g) | | **β- tocopherol** (μg/g) | |
|---|---|---|---|---|
| **Factors** | **2006** | **2007** | **2006** | **2007** |
| **Variety (VR)** | | | | |
| Amaretto | 13.9 ±0.5 **ab A** | 11.6 ±0.6 **a B** | 10.6 ±0.6 **a A** | 4.0 ±1.0 **c B** |
| Fasan | 10.0 ±0.1 **d A** | 10.6 ±1.4 **bc A** | 5.6 ±0.4 **e A** | 3.2 ±0.2 **c B** |
| Monsun | 11.0 ±0.6 **c A** | 8.4 ±0.8 **d B** | 6.5 ±0.1 **d A** | 2.9 ±0.2 **c B** |
| Paragon | 13.1 ±0.5 **b A** | 11.7 ±0.4 **a A** | 8.3 ±0.6 **b A** | 4.3 ±0.2 **a B** |
| Tybalt | 12.2 ±0.4 **c A** | 10.2 ±0.4 **c B** | 7.5 ±0.3 **c A** | 3.2 ±0.2 **b B** |
| Zebra | 14.3 ±0.6 **a A** | 11.2 ±1.3 **ab B** | 8.4 ±0.6 **b A** | 3.4 ±0.6 **a B** |

For each parameter means labelled with the same lower case letter within the same column and capital letter within the same row are not significantly different (General Linear Hypothesis test, $p < 0.05$)

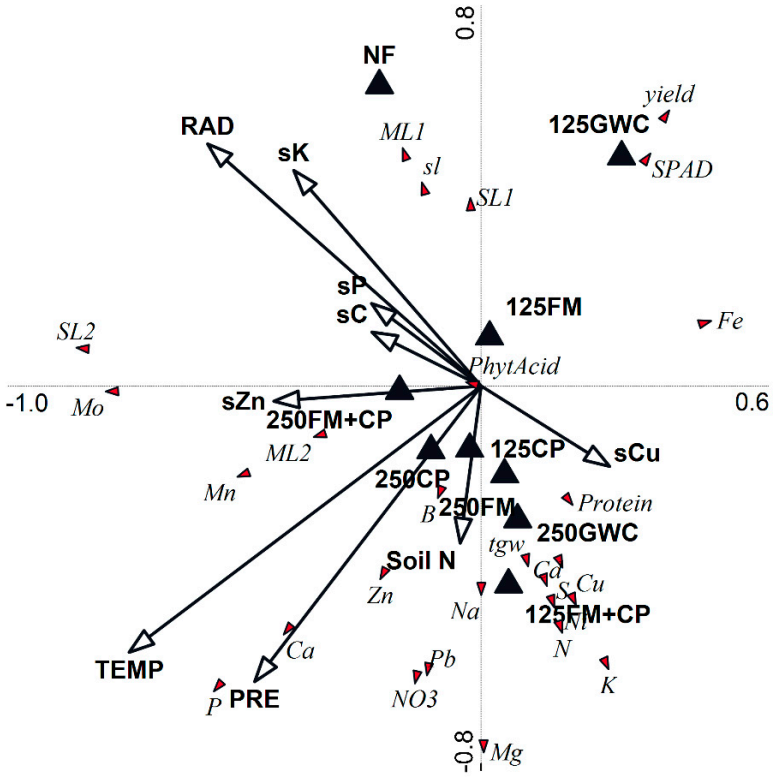
**Supplementary Table S10.** Proportion of variation explained and pseudo F-values and *p*-values for the climatic, soil mineral content, and fertilizer treatment (RDA 1) or fertilizer mineral input (RDA 2) explanatory variables included in the redundancy analyses of the fertilizer trial data

| **Explanatory** | *p*-value | | pseudo F-value | | % variation explained | |
|---|---|---|---|---|---|---|
| **variables/drivers** | RDA 1 | RDA 2 | RDA 1 | RDA 2 | RDA 1 | RDA 2 |
| **Climate** | | | | | | |
| Radiation (RAD) | **0.002** | **0.002** | 39.4 | 39.4 | 13.6 | 13.6 |
| Precipitation (PRE) | **0.002** | **0.002** | 6.7 | 6.5 | 1.7 | 1.7 |
| Temperature (TEMP) | **0.002** | **0.002** | 48.5 | 48.5 | 20.1 | 20.1 |
| ***Total climate*** | | | **94.6** | **94.4** | **35.4** | **35.4** |
| **Soil mineral content** | | | | | | |
| Carbon (sC) | **0.002** | **0.002** | 5.5 | 9.2 | 1.3 | 2.3 |
| Nitrogen (sN) | 0.266 | 0.150 | 1.2 | 1.5 | 0.3 | 0.4 |
| Phosphorus (sP) | **0.002** | **0.002** | 20.3 | 20.3 | **5.7** | 5.7 |
| Potassium (sK) | 0.068 | 0.222 | 2.2 | 1.4 | 0.5 | 0.3 |
| Copper (sCu) | **0.010** | **0.014** | 3.1 | 3.0 | 0.7 | 0.7 |
| Zinc (sZn) | **0.002** | **0.002** | 23.8 | 23.8 | 7.4 | 7.4 |
| ***Total soil minerals*** | | | | **59.2** | | **16.8** |
| **Fertilizer treatment:** | | | | | | |
| NF | **0.002** | | 21.1 | | 5.3 | |
| 125CP | 0.062 | | 2.1 | | 0.5 | |
| 250CP | 0.098 | | 2.1 | | 0.5 | |
| 125FYM | 0.162 | | 1.6 | | 0.4 | |
| 250 FYM | NC | | NC | | **NC** | |
| 125 FYM+CP | 0.440 | | 0.9 | | 0.2 | |
| 250 FYM+CP | 0.248 | | 1.2 | | 0.3 | |
| 125 GWC | **0.004** | | 5.5 | | 1.3 | |
| 250 GWC | 0.872 | | 0.4 | | 0.1 | |
| ***Total fertilizer treatment*** | | | **34.9** | | **8.6** | |
| **Fertilizer mineral input** | | | | | | |
| Total Nitrogen (N) | | **0.002** | | 10.3 | | 2.8 |
| $NH_4/NO_3$-nitrogen (fN) | | **0.004** | | 1.0 | | 1.0 |
| Phosphorus (fP) | | **0.006** | | 4.3 | | 1.0 |
| Potassium (fK) | | **0.050** | | 2.5 | | 0.6 |
| Copper (fCu) | | **0.038** | | 2.6 | | 0.6 |
| Zinc (fZn) | | 0.472 | | 0.9 | | 0.2 |
| ***Total fertilizer treatment:*** | | | | | | |
| ***Total fertilizer minerals:*** | | | | **21.6** | | **6.2** |
| **Total variation explained :** | | | | | **60.5** | **58.3** |

[1], Biplot shown in Figure 2; [2], Biplot shown in Supplementary Figure 1; NC, not computed; **NF,** no fertilizer; **125CP**, chicken manure pellets equivalent to 125 kg N/ha; 250CP, chicken manure pellets equivalent to 250 kgN/ha; **125 FYM**, farm yard manure equivalent to 125 kg N/ha; **250FYM,** farm yard manure equivalent to 250 kgN/ha; **125FYM+CP,** FYM equivalent to 62.5 kg N/ha plus CP equivalent to 62.5 kg N/ha or 250 kgN/ha; **250FYM+CP**, FYM equivalent to 125 kg N/ha plus CP equivalent to 125 kg N/ha; **125GWC**, green waste compost equivalent to 125 kg N/ha; **250 GWC**, green waste compost equivalent to 250 kg N/ha.

**Continuous explanatory variables/ drivers** are shown as arrows and included the **(i)** climatic parameters total radiation (**RAD**), total precipitation **(PRE)** and average daily temperature (**TEMP**) during the growing period and **(ii)** total top soil concentrations of C (**sC**), N (**sN**), P (**sP**), K (**sK**), S (**sS**), Ca (**sCa**), Mg (**sMg**), Cu (**sCu**), Fe (**sFe**), Zn (**sZn**), Cd (**sCd**).

**Fixed explanatory variables/drivers** are shown as black triangles (▲) and included the different fertilizer inputs: no fertilizer (**NF**), chicken manure pellets equivalent to 125 kg N/ha (**125 CP**) or 250 kgN/ha chicken (**250 CP**), farm yard manure equivalent to 125 kg N/ha (**125 FM)** or 250 kgN/ha chicken (**250 FM**), FYM+CP equivalent to 125 kg N/ha (**125 FM+CP**) or 250 kgN/ha chicken (**250 FM+CP**), green waste compost equivalent to 125 kg N/ha (**125 GWC**) or 250 kgN/ha chicken (**250 GWC**).




**Supplementary Figure S1.** Biplot derived from redundancy analysis showing the relationship between climate, soil chemical content and fertilizer mineral input wheat variety explanatory variables/drivers, and plant health, crop performance and grain composition parameters as response variables. In the biplot the horizontal axis 1 explained 24.5% of the variation and the vertical axis 2 a further 17.5%. F- and P-values and the proportions of variation explained by different explanatory variables/drivers and F are shown in Supplementary Table 10.

**Response variables** are shown as red arrow tips and included the (i) crop health parameters *Septoria* disease severity on the flag leaf (*SL1*) and the 2nd leaf (*SL2*), yellow rust on the flag leaf (*YRL1*) and 2nd leaf (*YRL2*), (ii) crop performance parameters grain yield (*yield*) (ii) grain protein content (*pr*), straw length (*sl*), thousand grain weight (*tgw*), (iii) grain concentrations of phytic acid (*PhytAcid*), the minerals N (*N*), P (*P*), K (*K*), S (*S*), Ca (*Ca*), Mg (*Mg*), Fe (*Fe*), Cu (*Cu*), Mn (*Mn*), Zn (*Zn*), B (*B*) and Mo (*Mo*) and the toxic metal Cd (*Cd*), Ni (*Ni*) and Pb (*Pb*).