**Table S1.** The price of water and fertilizer inputs in each region.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | Irrigation (Yuan m-3) | Urea (Yuan kg-1) | Nitrogen (Yuan kg-1) | Irrigation wheat area (ha) |
| **Center** |  |  |  |  |
| Henan | 0.30 | 2.06 | 4.48 | 2,102,596 |
|  |  |  |  |  |
| **East** |  |  |  |  |
| Shandong | 0.15 | 1.90 | 4.13 | 2,227,713 |
|  |  |  |  |  |
| **North** |  |  |  |  |
| Liaoning | 0.18 | 2.16 | 4.70 | 1,183 |
| Hebei | 0.34 | 1.90 | 4.13 | 1,215,716 |
| Shanxi | 0.42 | 1.92 | 4.17 | 200,610 |
| Beijing | 0.75 | 1.94 | 4.22 | 5,474 |
|  |  |  |  |  |
| **Northwest** | |  |  |  |
| Xinjiang | 0.98 | 1.65 | 3.59 | 832,984 |
| Qinghai | 0.21 | 2.30 | 5.00 | 36,363 |
| Gansu | 0.25 | 2.03 | 4.41 | 241,287 |
| Ningxia | 0.35 | 1.97 | 4.28 | 43,722 |
| Shannxi | 0.50 | 1.96 | 4.26 | 309,779 |

**Table S2.** Heterogeneity (Q) and probability (*P*) among n observations of the effect of water and nitrogen inputs on grain yield, water use efficiency (WUE), nitrogen use efficiency (NUE) of wheat.

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
|  | Study size | Publication bias | Test of heterogeneity | | | Random effects model | |
|  |  | *Fail-safe number* | Q | n-1 | *p*-value | *z* | *p*-value |
| Yield | 95 | 14130939 | 41865 | 1019 | < .0001 | 11.7047 | <.001 |
| WUE | 49 | 304396 | 7082 | 436 | < .0001 | 3.3913 | <.001 |
| NUE | 12 | 353 | 680 | 82 | < .0001 | -0.0889 | <.001 |

**Table S3.** Heterogeneity (between group (*Q*B) and within group (*Q*W)) and probability (*P*) among n observations of effect of water and nitrogen inputs on grain yield, water use efficiency (WUE), nitrogen use efficiency (NUE) of wheat. Details of regional classification see section 2.2.

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  |  | Study size | Test of heterogeneity | | | | | Random effects model | |
|  |  |  | n | *Q*B | *p*-value | *Q*W | *p*-value | *z* | *p*-value |
| Yield | Center | 15 | 166 | 13718 | < .0001 | 28146 | < .0001 | 15.971 | <.001 |
| East | 33 | 239 | 9.439 | <.001 |
| North | 21 | 236 | 12.017 | <.001 |
| Northwest | 26 | 378 | 36.795 | <.001 |
| WUE | Center | 6 | 42 | 2005 | < .0001 | 5077 | < .0001 | 2.541 | 0.011 |
| East | 20 | 136 | -0.015 | 0.988 |
| North | 11 | 121 | 3.419 | <.001 |
| Northwest | 12 | 137 | 19.529 | <.001 |
| NUE | Center | 1 | 6 | 108 | < .0001 | 468 | < .0001 | 0.024 | 0.981 |
| East | 8 | 53 | -1.808 | 0.071 |
| North | 3 | 5 | 2.640 | 0.008 |
| Northwest | 2 | 18 | 0.214 | 0.831 |

**Table S4.** Heterogeneity (between group (*Q*B) and within group (*Q*W)) and probability (*P*) among n observations of effect of levels of water and nitrogen inputs on grain yield, water use efficiency (WUE), nitrogen use efficiency (NUE) of wheat. The water levels that were above or below optimal water input were defined as above-optimal and below-optimal water inputs, denoted as W+ and W-, respectively; and above-optimal and below-optimal N inputs were denoted as N+ and N-, respectively. Details of optimal water and nitrogen input see Table 1 and 2.

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  |  | Study size | Test of heterogeneity | | | | | Random effects model | |
|  |  |  | n | *Q*B | *p*-value | *Q*W | *p*-value | *z* | *p*-value |
| Yield | W+ | 45 | 232 | 39182 | < .0001 | 41848 | < .0001 | 76.806 | <.001 |
| W- | 86 | 784 | 182.2 | <.001 |
| N+ | 39 | 201 | 41887 | < .0001 | 39143 | < .0001 | 63.258 | <.001 |
| N- | 79 | 696 | 188.494 | <.001 |
| WUE | W+ | 25 | 116 | 2059 | < .0001 | 6155 | < .0001 | 0.743 | 0.458 |
| W- | 46 | 319 | 45.340 | <.001 |
| N+ | 15 | 86 | 414 | < .0001 | 6668 | < .0001 | 8.044 | <.001 |
| N- | 35 | 255 | 40.923 | <.001 |
| NUE | W+ | 7 | 19 | 15 | < .0001 | 560 | < .0001 | -1.5139 | 0.1300 |
| W- | 12 | 62 | -1.164 | 0.0179 |
| N+ | 3 | 11 | 20 | < .0001 | 555 | < .0001 | -4.013 | <.001 |
| N- | 8 | 40 | -0.598 | 0.550 |

**Table S5.** Heterogeneity (between group (*Q*B) and within group (*Q*W)) and probability (*P*) among n observations of effect of aridity index (AI) on grain yield, water use efficiency (WUE), nitrogen use efficiency (NUE) of wheat.

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | AI | Study size | Test of heterogeneity | | | | | Random effects model | |
|  |  | n | *Q*B | *p*-value | *Q*W | *p*-value | *z* | *p*-value |
| Yield | Arid | 4 | 54 | 1286 | < .0001 | 36157 | < .0001 | 6.280 | <.001 |
| Semi-arid | 10 | 81 | 9.531 | <.001 |
| Semi-humid | 48 | 534 | 24.013 | <.001 |
| Humid | 29 | 316 | 23.992 | <.001 |
| WUE | Arid | 3 | 36 | 175 | < .0001 | 6496 | < .0001 | 5.895 | <.001 |
| Semi-arid | 1 | 10 | 7.283 | <.001 |
| Semi-humid | 23 | 227 | 7.118 | <.001 |
| Humid | 19 | 139 | 5.906 | <.001 |
| NUE | Arid | - | - | 19 | < .001 | 353 | < .0001 |  | <.001 |
| Semi-arid | 1 | 10 | -2.159 | 0.031 |
| Semi-humid | 4 | 27 | -0.245 | 0.605 |
| Humid | 7 | 45 | -3.691 | 0.081 |

**Table S6.** Heterogeneity (between group (*Q*B) and within group (*Q*W)) and probability (*P*) among n observations of effect of irrigation methods on grain yield, water use efficiency (WUE), nitrogen use efficiency (NUE) of wheat.

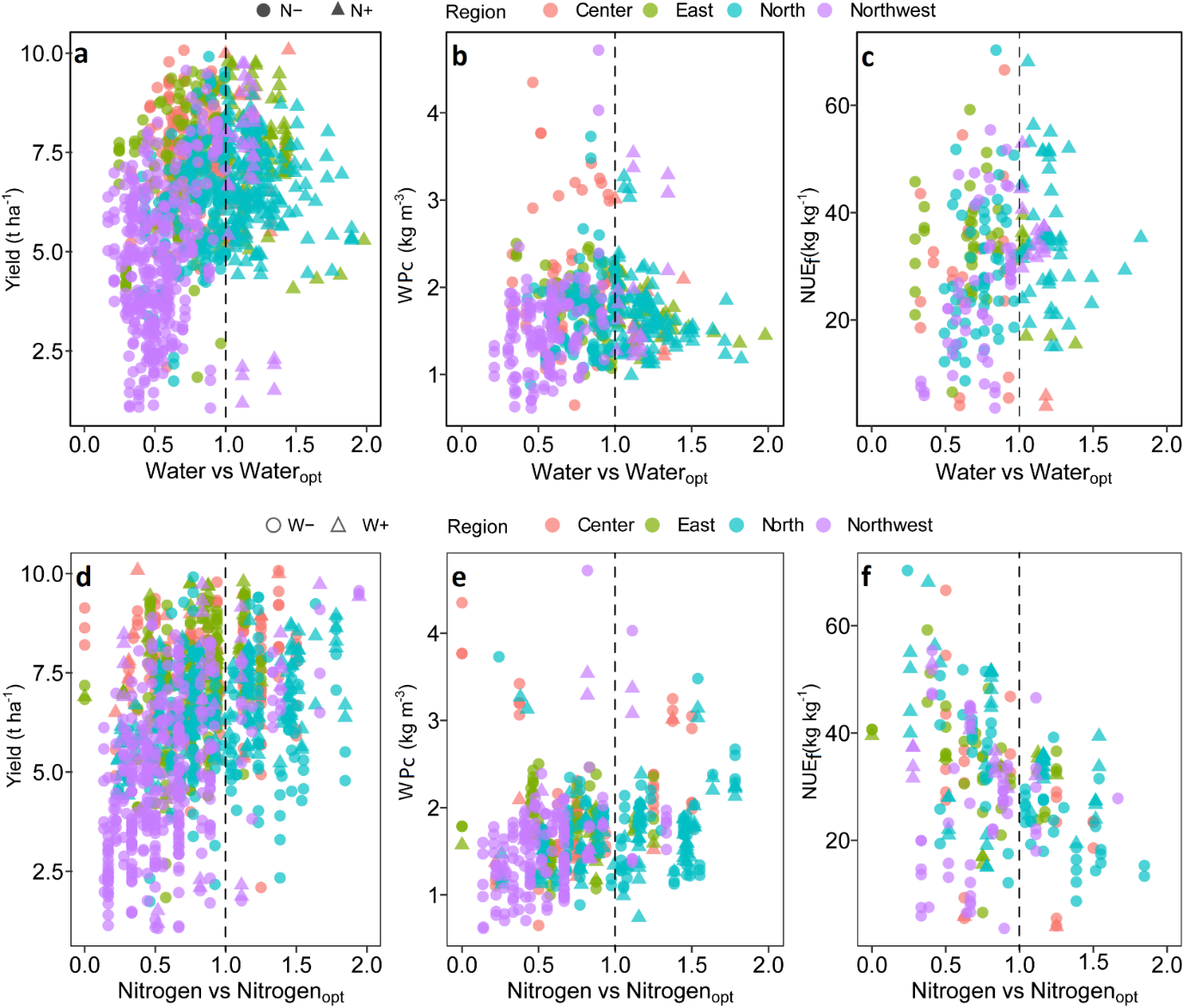
|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | Method | Study size | Test of heterogeneity | | | | | Random effects model | |
|  |  | n | *Q*B | *p*-value | *Q*W | *p*-value | *z* | *p*-value |
| Yield | Drip | 9 | 60 | 1226 | < .001 | 41676 | < .001 | 7.465 | 0.390 |
| Furrow | 39 | 375 | 17.923 | <.001 |
| Sprinkling | 8 | 57 | 8.897 | 0.094 |
| WUE | Drip | 2 | 14 | 149 | < .001 | 6953 | < .001 | 0.859 | 0.390 |
| Furrow | 21 | 184 | 5.496 | <.001 |
| Sprinkling | 7 | 51 | 7.821 | 0.094 |
| NUE | Drip | 1 | 10 | 42 | < .001 | 330 | < .001 | -2.159 | 0.031 |
| Furrow | 6 | 43 | -4.899 | <.001 |
| Sprinkling | 1 | 8 | -2.550 | 0.011 |

**Table S7** Detailed information about the 39 explanatory variables/features included for modelling *RR*Y, *RR*WPc, and *RR*NUEf using Decision Tree-based algorithms. Calculated Evapotranspiration (CET) was estimated based on either directly reported ET values or derived values based on water productivity and yield data from each study.

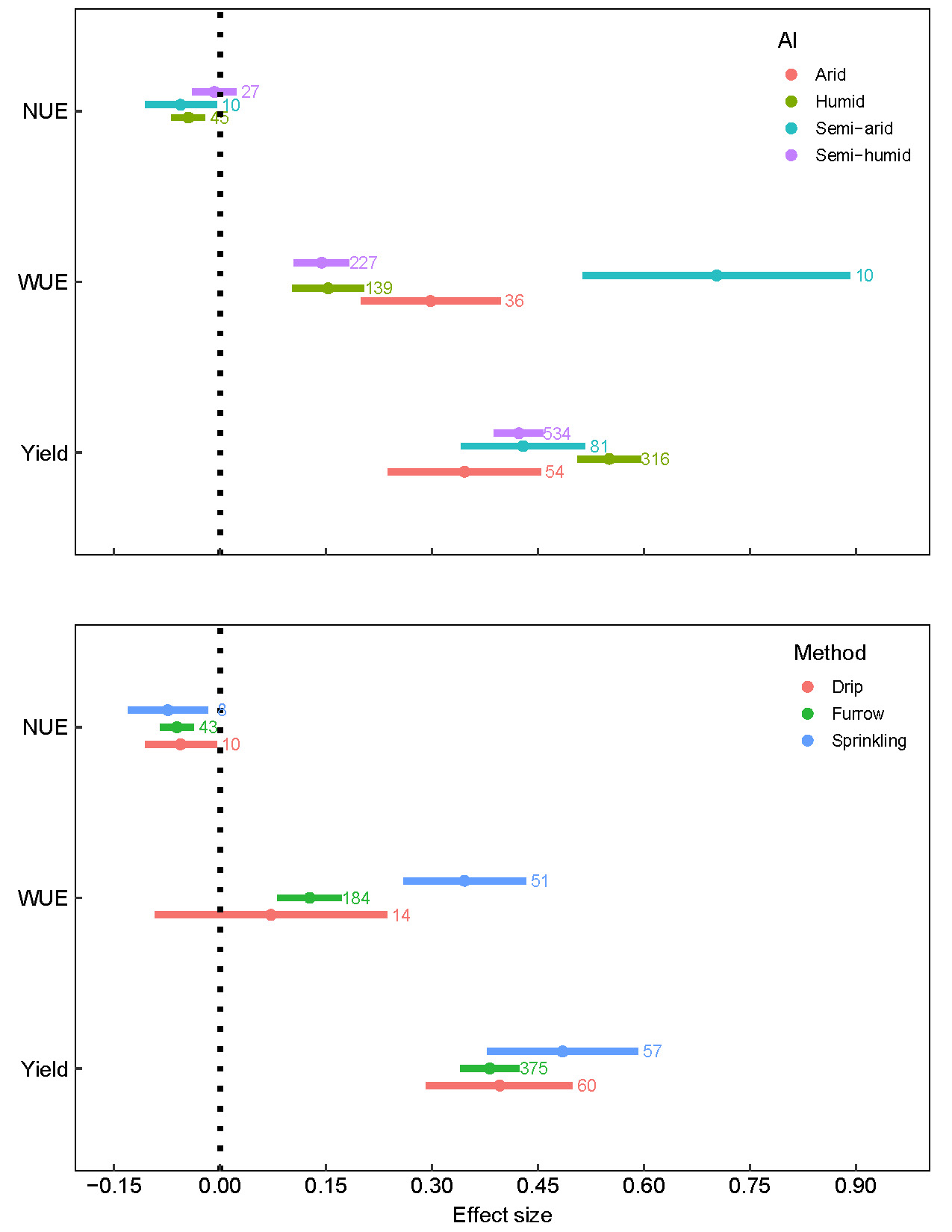
|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Feature Name** | **Abbreviation** | **Mean (if continuous)** | **Range (if continuous)** | **Labels (if discrete)** |
| Study Identification | Study ID | NA | NA | 1-143 |
| Region | Region | NA | NA | 1 (North), 2 (East), 3 (Center), 4 (Northwest) |
| Mean Annual Precipitation | MAP | 541.2 | 683.2 | NA |
| Mean Annual Temperature | MAT | 11.9 | 10.9 | NA |
| Soil Texture | Soil Texture | NA | NA | 1 (Loam), 2 (Silty loam), 3(Clay loam), 4 (Sandy loam), 5 (Sandy) |
| Wheat Type | Wheat type | NA | MA | 1 (Winter wheat) 2 (Spring wheat) |
| Highest Growing Season Temperature | HGT | 36.1 | 13.0 | NA |
| Lowest Growing Season Temperature | LGT | -11.7 | 24.2 | NA |
| Mean Growing Season Temperature | MGT | 12.4 | 19 | NA |
| Climate Conditions | Climate | NA | NA | 1 (Humid), 2 (Semi-humid), 3(Semi-arid), 4 (Arid) |
| Initial Soil Organic Carbon | SOC | 9.3 | 16.2 | NA |
| Initial Soil Total N | Total N | 0.95 | 1.5 | NA |
| Initial Soil Available N | AN | 68.7 | 139.1 | NA |
| Initial Soil Available P | AP | 23.9 | 64.6 | NA |
| Initial Soil Available K | AK | 143.7 | 320.8 | NA |
| Irrigation Method | Irrigation | NA | NA | 1 (Sprinkling), 2 (Furrow), 3 (Drip) |
| Cumulative Growing-season Precipitation | CGP | 167.5 | 359.0 | NA |
| Before Sowing Irrigation | BSI | 13.6 | 181.0 | NA |
| Over Winter Irrigation | OWI | 7.2 | 120.0 | NA |
| Reviving-stage (Feekes-3) Irrigation | RI | 2.5 | 91.3 | NA |
| Erection-stage (Feekes-4) Irrigation | EI | 2.5 | 164.9 | NA |
| Jointing-stage (Feekes-6) Irrigation | JI | 35.9 | 280.0 | NA |
| Booting-stage (Feekes-10) Irrigation | BI | 5.9 | 120.0 | NA |
| Heading-stage (Feekes-10.3) Irrigation | HI | 4.7 | 105.0 | NA |
| Anthesis-stage (Feekes-10.5.2) Irrigation | AI | 16.8 | 120.0 | NA |
| Filling-stage (Feekes-10.5.4) Irrigation | FI | 12.1 | 165.0 | NA |
| Milking-stage (Feekes-11.1) Irrigation | MI | 3.6 | 187.5 | NA |
| Cumulative Growing-season Irrigation | CGI | 126.0 | 705.1 | NA |
| Cumulative Growing-season Water Input (Precipitation + Irrigation) | CGWI | 293.5 | 660.3 | NA |
| Calculated Evapotranspiration | CET | 415.0 | 1157.9 | NA |
| Before Sowing N Input | BSNI | 104.6 | 450.0 | NA |
| Tillering-stage (Feekes-2) N Input | TNI | 1.4 | 142.5 | NA |
| Reviving-stage (Feekes-3) N Input | RNI | 10.1 | 345.0 | NA |
| Jointing-stage (Feekes-6) N Input | JNI | 55.9 | 337.5 | NA |
| Booting-stage (Feekes-10) N Input | BNI | 1.2 | 75.0 | NA |
| Heading-stage (Feekes-10.3) N Input | HNI | 1.9 | 111.0 | NA |
| Anthesis-stage (Feekes-10.5.2) N Input | ANI | 3.7 | 180.0 | NA |
| Filling-stage (Feekes-10.5.4) N Input | FINI | 2.2 | 90.0 | NA |
| Cumulative Growing-season N Input | CGNI | 187.7 | 525.0 | NA |

**Table S8.** Meta-regression for the response ratio of grain yield (*RR*Y), water use efficiency (*RR*WUE), and nitrogen use efficiency (*RR*NUE) of wheat against to concentration (*x*) of soil initial available nitrogen (AN) and initial available potassium (AK). n shorts for the number of observations.

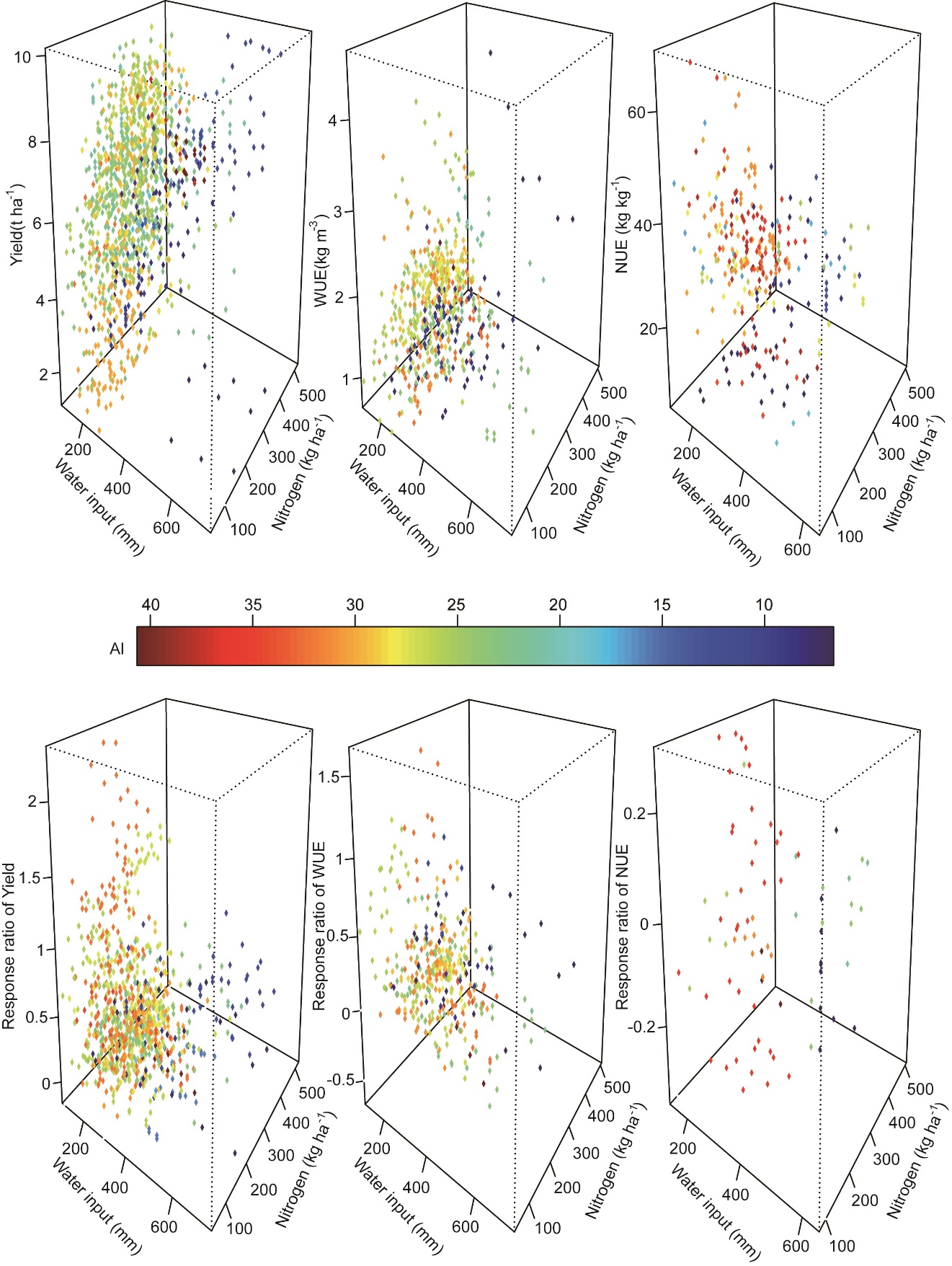
|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Property | Concentration | Equation | *p* | *R*2 | n |
| *RR*Y | AN | *y* = - 0.006 *x* + 0.766 | <.0001 | 0.26 | 594 |
| AK | *y* = 0.001 *x* + 0.192 | <.0001 | 0.06 | 747 |
| *RR*WUE | AN | *y* = - 0.005 *x* + 0.521 | <.0001 | 0.26 | 269 |
| AK | *y* = 0.001 *x* + 0.015 | <.0001 | 0.03 | 362 |
| *RR*NUE | AN | *y* = 0.002 *x* - 0.207 | 0.006 | 0.11 | 71 |
| AK | *y* = 0.001 *x* - 0.115 | 0.03 | 0.06 | 79 |

****

**Fig. S1.** Scatter plots show the effect of the ratio of total water input to the optimal water input on wheat a) grain yield, b) water productivity (WPc), c) fertiliser nitrogen use efficiency (NUEf) and the ratio of total N input to the optimal nitrogen input on d) grain yield, e) WPc, and f) NUEf. The optimal water and nitrogen inputs depend on regions (check Table 2−2). The grey line indicates that the total water or nitrogen input equal to optimal water or nitrogen input. Note the different scales among the graphs.

****

**Fig. S2.** The effect size of climate conditions (upper panel) and irrigation methods (lower panel) on grain yield, water use efficiency (WUE), and nitrogen use efficiency (NUE) of wheat. Effect size stands for the weighted effect size between treatment and control. Error bars represent the 95% confidence intervals. The sample size of each variable was displayed adjacent to each bar. AI shorts for aridity index.

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**Fig. S3.** 3D plot shows grain yield, water use efficiency (WUE), nitrogen use efficiency (NUE), and the response ratio of grain yield (*RR*Y), water use efficiency (*RR*WUE), and nitrogen use efficiency (*RR*NUE) of wheat in relation with total water and nitrogen input. AI indicates aridity index, the AI values of 0-10, 10-20, 20-30, and >30 correspond to arid or semi-arid, semi-humid, and humid environments, respectively.

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