**QTL x environment interactions underlie ionome divergence in switchgrass**

**Running title: QTL x E interactions of ionome**

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**Table S1** Phenotypic correlation between ionomic traits at each of the three sites (TX, MO, MI).

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Element | K | Ca | Mg | P | Mn | Fe | Zn | Cu | B | Mo | Co | Se | Sr | Rb | Na | Al | As | Cd | SITE |
| K | 1 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | MI |
| Ca | -0.14 | 1 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | MI |
| Mg | -0.32 | 0.49 | 1 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | MI |
| P | 0.32 | 0.08 | 0.06 | 1 |  |  |  |  |  |  |  |  |  |  |  |  |  |  | MI |
| Mn | -0.02 | 0.24 | 0.32 | 0.27 | 1 |  |  |  |  |  |  |  |  |  |  |  |  |  | MI |
| Fe | 0.08 | 0.29 | 0.04 | 0.5 | 0.3 | 1 |  |  |  |  |  |  |  |  |  |  |  |  | MI |
| Zn | 0.19 | -0.11 | -0.06 | 0.21 | 0.06 | -0.03 | 1 |  |  |  |  |  |  |  |  |  |  |  | MI |
| Cu | -0.19 | 0.15 | 0.26 | 0.33 | 0.2 | 0.31 | 0.08 | 1 |  |  |  |  |  |  |  |  |  |  | MI |
| B | 0.03 | -0.27 | -0.3 | -0.17 | -0.4 | -0.33 | 0.24 | -0.1 | 1 |  |  |  |  |  |  |  |  |  | MI |
| Mo | -0.05 | 0.22 | 0.11 | 0.29 | 0.12 | 0.55 | -0.08 | 0.37 | -0.17 | 1 |  |  |  |  |  |  |  |  | MI |
| Co | -0.17 | 0.25 | 0.09 | 0.21 | 0.5 | 0.51 | 0.05 | 0.44 | -0.25 | 0.4 | 1 |  |  |  |  |  |  |  | MI |
| Se | 0.14 | -0.06 | -0.14 | 0.06 | -0.11 | -0.1 | 0.2 | -0.02 | 0.17 | -0.09 | -0.03 | 1 |  |  |  |  |  |  | MI |
| Sr | -0.25 | 0.86 | 0.55 | 0.09 | 0.41 | 0.33 | -0.16 | 0.33 | -0.33 | 0.22 | 0.41 | -0.14 | 1 |  |  |  |  |  | MI |
| Rb | 0.86 | -0.16 | -0.25 | 0.47 | -0.03 | 0.16 | 0.17 | -0.04 | 0.06 | 0.05 | -0.08 | 0.11 | -0.19 | 1 |  |  |  |  | MI |
| Na | 0.41 | -0.18 | -0.08 | 0.08 | -0.29 | -0.14 | 0.17 | 0.03 | 0.29 | -0.04 | -0.11 | 0.05 | -0.2 | 0.49 | 1 |  |  |  | MI |
| Al | 0.15 | 0.21 | 0.01 | 0.49 | 0.3 | 0.78 | 0.01 | 0.2 | -0.35 | 0.38 | 0.25 | -0.17 | 0.27 | 0.2 | -0.2 | 1 |  |  | MI |
| As | 0 | 0.3 | 0.23 | 0.26 | 0.31 | 0.67 | -0.18 | 0.16 | -0.41 | 0.37 | 0.23 | -0.25 | 0.39 | 0.06 | -0.14 | 0.71 | 1 |  | MI |
| Cd | -0.01 | 0.18 | 0.33 | -0.07 | 0.29 | 0.1 | 0.03 | -0.02 | -0.24 | 0.01 | -0.07 | -0.13 | 0.2 | -0.09 | -0.18 | 0.18 | 0.25 | 1 | MI |
| K | 1 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | MO |
| Ca | 0.02 | 1 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | MO |
| Mg | 0.02 | 0.41 | 1 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | MO |
| P | 0.1 | 0.09 | 0.13 | 1 |  |  |  |  |  |  |  |  |  |  |  |  |  |  | MO |
| Mn | -0.12 | 0.35 | 0.33 | 0.11 | 1 |  |  |  |  |  |  |  |  |  |  |  |  |  | MO |
| Fe | 0.07 | 0.28 | 0.08 | 0.21 | 0.09 | 1 |  |  |  |  |  |  |  |  |  |  |  |  | MO |
| Zn | 0.02 | 0.18 | 0.09 | 0.35 | 0.18 | 0.16 | 1 |  |  |  |  |  |  |  |  |  |  |  | MO |
| Cu | 0.08 | 0.12 | 0.05 | 0.33 | 0.3 | 0.22 | 0.3 | 1 |  |  |  |  |  |  |  |  |  |  | MO |
| B | 0.06 | 0.07 | 0.17 | -0.1 | 0.22 | -0.01 | 0.06 | 0.08 | 1 |  |  |  |  |  |  |  |  |  | MO |
| Mo | -0.02 | 0.29 | 0.15 | 0.18 | 0 | 0.07 | 0.24 | 0.17 | -0.01 | 1 |  |  |  |  |  |  |  |  | MO |
| Co | 0.09 | -0.07 | 0.03 | 0.07 | 0.11 | 0.27 | -0.01 | 0.53 | 0.09 | -0.12 | 1 |  |  |  |  |  |  |  | MO |
| Se | 0.09 | 0.09 | -0.04 | 0.02 | -0.13 | 0.07 | 0.02 | 0.05 | 0.03 | -0.06 | -0.07 | 1 |  |  |  |  |  |  | MO |
| Sr | 0 | 0.86 | 0.45 | 0.02 | 0.57 | 0.2 | 0.11 | 0.18 | 0.16 | 0.06 | 0.08 | 0.01 | 1 |  |  |  |  |  | MO |
| Rb | -0.16 | -0.24 | 0.06 | 0.18 | 0.23 | -0.16 | 0.16 | 0.1 | 0.04 | -0.23 | 0.08 | 0.01 | -0.05 | 1 |  |  |  |  | MO |
| Na | -0.08 | -0.21 | -0.02 | -0.07 | -0.06 | -0.08 | 0.05 | -0.08 | 0.08 | -0.13 | -0.09 | 0.16 | -0.19 | 0.2 | 1 |  |  |  | MO |
| Al | 0.11 | 0.18 | 0.01 | 0.22 | 0.07 | 0.63 | 0.21 | 0.51 | 0.1 | 0 | 0.56 | 0.02 | 0.18 | 0.07 | -0.12 | 1 |  |  | MO |
| As | 0.01 | 0.29 | 0.19 | -0.12 | 0.08 | 0.28 | -0.05 | 0.16 | 0.04 | 0.07 | 0.21 | 0.12 | 0.31 | -0.05 | -0.1 | 0.31 | 1 |  | MO |
| Cd | -0.14 | 0.14 | 0.23 | -0.23 | 0.44 | -0.03 | -0.07 | -0.04 | 0.16 | 0.11 | 0.13 | -0.4 | 0.26 | -0.15 | 0.04 | -0.11 | -0.13 | 1 | MO |
| K | 1 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | TX |
| Ca | -0.01 | 1 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | TX |
| Mg | 0.03 | 0.23 | 1 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | TX |
| P | 0.16 | 0.21 | 0.23 | 1 |  |  |  |  |  |  |  |  |  |  |  |  |  |  | TX |
| Mn | -0.02 | 0.32 | 0.19 | 0.14 | 1 |  |  |  |  |  |  |  |  |  |  |  |  |  | TX |
| Fe | -0.14 | 0.23 | 0.11 | 0.31 | 0.18 | 1 |  |  |  |  |  |  |  |  |  |  |  |  | TX |
| Zn | 0.02 | 0.16 | -0.1 | 0.03 | 0.1 | 0.03 | 1 |  |  |  |  |  |  |  |  |  |  |  | TX |
| Cu | -0.05 | 0.01 | 0.04 | 0.15 | 0.17 | 0.29 | 0.23 | 1 |  |  |  |  |  |  |  |  |  |  | TX |
| B | -0.07 | 0.29 | 0.33 | 0.33 | 0.28 | 0.29 | -0.02 | 0.11 | 1 |  |  |  |  |  |  |  |  |  | TX |
| Mo | -0.06 | 0.15 | -0.05 | 0.09 | 0.05 | 0.31 | 0.06 | 0.29 | 0.23 | 1 |  |  |  |  |  |  |  |  | TX |
| Co | 0.1 | 0.18 | 0.09 | 0.13 | 0.25 | 0.35 | 0.14 | 0.32 | 0.31 | 0.2 | 1 |  |  |  |  |  |  |  | TX |
| Se | 0.02 | 0.29 | 0.18 | 0.16 | 0.08 | 0.18 | 0.04 | 0.17 | 0.16 | 0.19 | 0.14 | 1 |  |  |  |  |  |  | TX |
| Sr | -0.1 | 0.79 | 0.3 | 0.15 | 0.29 | 0.14 | 0.13 | 0.13 | 0.27 | 0.15 | 0.1 | 0.35 | 1 |  |  |  |  |  | TX |
| Rb | 0.51 | 0.04 | 0.33 | 0.36 | 0.1 | 0.02 | -0.07 | -0.03 | 0.39 | -0.02 | 0.13 | 0.06 | 0.01 | 1 |  |  |  |  | TX |
| Na | -0.05 | -0.02 | 0.21 | 0.05 | 0.04 | 0.2 | -0.01 | 0.08 | 0.28 | 0.1 | 0.07 | 0.1 | -0.01 | 0.23 | 1 |  |  |  | TX |
| Al | -0.04 | 0.24 | 0.01 | 0.2 | 0.11 | 0.5 | 0.02 | 0.1 | 0.1 | 0.11 | 0.08 | 0.02 | 0.14 | 0.01 | -0.07 | 1 |  |  | TX |
| As | -0.21 | 0.24 | 0.2 | 0.15 | 0.18 | 0.49 | 0.01 | 0.03 | 0.46 | 0.21 | 0.19 | 0.11 | 0.13 | 0.2 | 0.39 | 0.26 | 1 |  | TX |
| Cd | -0.12 | 0.11 | 0.06 | -0.03 | 0.13 | 0.17 | 0.05 | -0.01 | 0.07 | 0.07 | 0.09 | -0.08 | 0.09 | -0.07 | 0.05 | 0.14 | 0.2 | 1 | TX |

**Table S2** Variance partitioning between genetic variance (Vg) and environmental variance (Ve) for each ionomic trait at each site (TX, MO, and MI).

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| SITE | TRAIT | VARIANCE | VarComp | VarCompSE | Zratio |
| MI | K | Vg | 321202693 | 66019310.2 | 4.86528399 |
| MI | K | Ve | 376607274 | 25450405.6 | 14.7976924 |
| MI | Ca | Vg | 61309.0186 | 14067.4291 | 4.35822483 |
| MI | Ca | Ve | 100772.382 | 6703.36395 | 15.0331061 |
| MI | Mg | Vg | 43193.0358 | 8983.37797 | 4.80810625 |
| MI | Mg | Ve | 52766.1793 | 3554.24276 | 14.8459694 |
| MI | P | Vg | 4032.23478 | 825.66062 | 4.88364672 |
| MI | P | Ve | 4637.54408 | 314.73039 | 14.7349739 |
| MI | Mn | Vg | 79.3218991 | 19.3963515 | 4.08952679 |
| MI | Mn | Ve | 159.885448 | 10.4013714 | 15.3715738 |
| MI | Fe | Vg | 8.25078694 | 2.69245608 | 3.06440911 |
| MI | Fe | Ve | 33.5696673 | 2.12358838 | 15.8079916 |
| MI | Zn | Vg | 2.344378 | 0.5554265 | 4.22086094 |
| MI | Zn | Ve | 3.89855755 | 0.27105643 | 14.3828265 |
| MI | Cu | Vg | 0.44606452 | 0.09332027 | 4.77993157 |
| MI | Cu | Ve | 0.55676731 | 0.03740349 | 14.8854367 |
| MI | B | Vg | 0 | 0.07278824 | 0 |
| MI | B | Ve | 2.22375434 | 0.13485776 | 16.4896282 |
| MI | Mo | Vg | 2.24E-05 | 6.17E-06 | 3.62762679 |
| MI | Mo | Ve | 6.21E-05 | 3.98E-06 | 15.6047959 |
| MI | Co | Vg | 8.99E-06 | 3.93E-06 | 2.28956543 |
| MI | Co | Ve | 6.23E-05 | 3.95E-06 | 15.7985964 |
| MI | Se | Vg | 1.22E-05 | 7.81E-06 | 1.56151166 |
| MI | Se | Ve | 4.48E-05 | 6.00E-06 | 7.46893232 |
| MI | Sr | Vg | 0.3958146 | 0.09422661 | 4.20066704 |
| MI | Sr | Ve | 0.7332159 | 0.04812722 | 15.2349525 |
| MI | Rb | Vg | 0.12169069 | 0.0260206 | 4.67670617 |
| MI | Rb | Ve | 0.16179559 | 0.0108653 | 14.8910407 |
| MI | Na | Vg | 5.93014774 | 1.54258512 | 3.84429208 |
| MI | Na | Ve | 13.1332225 | 0.88377929 | 14.8602966 |
| MI | Al | Vg | 43.856513 | 12.5228802 | 3.50211071 |
| MI | Al | Ve | 131.680199 | 8.428086 | 15.6239743 |
| MI | As | Vg | 2.26E-07 | 5.79E-07 | 0.38971312 |
| MI | As | Ve | 1.55E-05 | 9.65E-07 | 16.0445053 |
| MI | Cd | Vg | 0.00020842 | 3.89E-05 | 5.36357156 |
| MI | Cd | Ve | 0.00016879 | 1.19E-05 | 14.1722364 |
| MO | K | Vg | 8580956.06 | 22560646.1 | 0.38035063 |
| MO | K | Ve | 650760022 | 38916435.2 | 16.7219844 |
| MO | Ca | Vg | 58928.12 | 11738.1229 | 5.02023367 |
| MO | Ca | Ve | 61976.6814 | 4226.20867 | 14.6648417 |
| MO | Mg | Vg | 19995.6295 | 4607.61095 | 4.33969571 |
| MO | Mg | Ve | 33885.2054 | 2229.925 | 15.1956704 |
| MO | P | Vg | 13331.9984 | 3166.18218 | 4.21074898 |
| MO | P | Ve | 24728.2205 | 1616.42387 | 15.298104 |
| MO | Mn | Vg | 286.399453 | 62.8424507 | 4.55742019 |
| MO | Mn | Ve | 419.440073 | 27.7755108 | 15.101075 |
| MO | Fe | Vg | 20.4595357 | 7.04682264 | 2.90337031 |
| MO | Fe | Ve | 89.8979984 | 5.78683957 | 15.5349042 |
| MO | Zn | Vg | 2.97373206 | 0.95751119 | 3.10568908 |
| MO | Zn | Ve | 11.1766608 | 0.7290482 | 15.3304828 |
| MO | Cu | Vg | 2.58819938 | 0.70586833 | 3.66668861 |
| MO | Cu | Ve | 6.93657639 | 0.4462513 | 15.5441035 |
| MO | B | Vg | 0.00318655 | 0.04289246 | 0.07429166 |
| MO | B | Ve | 1.23195721 | 0.07665906 | 16.0706011 |
| MO | Mo | Vg | 0.00010417 | 3.16E-05 | 3.29194829 |
| MO | Mo | Ve | 0.00036643 | 2.31E-05 | 15.8361223 |
| MO | Co | Vg | 0.0007595 | 0.00040264 | 1.8862993 |
| MO | Co | Ve | 0.00681673 | 0.00044472 | 15.3282551 |
| MO | Se | Vg | 0 | 2.62E-05 | 0 |
| MO | Se | Ve | 0.0002332 | 3.00E-05 | 7.77152747 |
| MO | Sr | Vg | 2.04231832 | 0.42749592 | 4.77739843 |
| MO | Sr | Ve | 2.53119787 | 0.17068186 | 14.8299176 |
| MO | Rb | Vg | 0.21592686 | 0.04736051 | 4.55921697 |
| MO | Rb | Ve | 0.31599033 | 0.02092675 | 15.0998309 |
| MO | Na | Vg | 105.242857 | 20.9258252 | 5.02932889 |
| MO | Na | Ve | 99.5742201 | 7.20629296 | 13.8176758 |
| MO | Al | Vg | 131.628948 | 31.0121154 | 4.2444363 |
| MO | Al | Ve | 235.788816 | 15.5502851 | 15.1629899 |
| MO | As | Vg | 4.99E-07 | 2.03E-06 | 0.24538503 |
| MO | As | Ve | 4.82E-05 | 3.27E-06 | 14.7411128 |
| MO | Cd | Vg | 5.28E-05 | 1.59E-05 | 3.31674351 |
| MO | Cd | Ve | 0.00017885 | 1.15E-05 | 15.6194 |
| TX | K | Vg | 86473060.1 | 31245037.3 | 2.76757744 |
| TX | K | Ve | 435679692 | 27325576.7 | 15.9440255 |
| TX | Ca | Vg | 259747.376 | 66551.1918 | 3.90297107 |
| TX | Ca | Ve | 600309.064 | 38605.1045 | 15.5499919 |
| TX | Mg | Vg | 62767.9429 | 13282.6822 | 4.72554729 |
| TX | Mg | Ve | 81654.4079 | 5455.98627 | 14.9660215 |
| TX | P | Vg | 6980.72348 | 1332.22104 | 5.23991386 |
| TX | P | Ve | 6253.18972 | 433.154225 | 14.4364048 |
| TX | Mn | Vg | 18.1763039 | 5.00204743 | 3.6337728 |
| TX | Mn | Ve | 50.1300588 | 3.21237021 | 15.605318 |
| TX | Fe | Vg | 10.6370204 | 5.26001211 | 2.02224258 |
| TX | Fe | Ve | 93.0639757 | 5.79182807 | 16.0681523 |
| TX | Zn | Vg | 12.2371094 | 4.66888052 | 2.62099434 |
| TX | Zn | Ve | 59.6679593 | 4.03970034 | 14.7703924 |
| TX | Cu | Vg | 0.95425641 | 0.21732483 | 4.39092209 |
| TX | Cu | Ve | 1.54063494 | 0.10232371 | 15.0564799 |
| TX | B | Vg | 0.13875269 | 0.09868552 | 1.40600869 |
| TX | B | Ve | 2.15800337 | 0.13097987 | 16.4758394 |
| TX | Mo | Vg | 6.58E-05 | 3.14E-05 | 2.09539592 |
| TX | Mo | Ve | 0.00051295 | 3.30E-05 | 15.5326246 |
| TX | Co | Vg | 0 | 1.60E-05 | 0 |
| TX | Co | Ve | 0.00045987 | 2.89E-05 | 15.9015287 |
| TX | Se | Vg | 4.98E-06 | 1.26E-05 | 0.39630243 |
| TX | Se | Ve | 0.00035785 | 2.15E-05 | 16.6442107 |
| TX | Sr | Vg | 1.5668682 | 0.34773311 | 4.50595054 |
| TX | Sr | Ve | 2.38533657 | 0.15725852 | 15.1682505 |
| TX | Rb | Vg | 0.16082864 | 0.04051115 | 3.96998487 |
| TX | Rb | Ve | 0.35414433 | 0.02287954 | 15.4786467 |
| TX | Na | Vg | 258.890122 | 89.7445074 | 2.88474614 |
| TX | Na | Ve | 1199.92502 | 75.4820615 | 15.8968236 |
| TX | Al | Vg | 15.9381226 | 14.0099732 | 1.13762692 |
| TX | Al | Ve | 317.870079 | 19.6500608 | 16.1765444 |
| TX | As | Vg | 0 | 3.15E-07 | 0 |
| TX | As | Ve | 9.76E-06 | 5.88E-07 | 16.5971269 |
| TX | Cd | Vg | 7.71E-07 | 1.72E-07 | 4.47523754 |
| TX | Cd | Ve | 1.15E-06 | 7.76E-08 | 14.834363 |

**Table S3** Genetic correlation among sites (TX, MO, and MI) for each ionomic trait.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| TRAIT | SITE | TX | MO | MI |
|  | TX | 1.00 |  |  |
| K | MO | NA | 1.00 |  |
|  | MI | 0.45 | NA | 1.00 |
|  | TX | 1.00 |  |  |
| Ca | MO | 0.86 | 1.00 |  |
|  | MI | 0.85 | 0.89 | 1.00 |
|  | TX | 1.00 |  |  |
| Mg | MO | 0.68 | 1.00 |  |
|  | MI | 0.60 | 0.76 | 1.00 |
|  | TX | 1.00 |  |  |
| P | MO | 0.42 | 1.00 |  |
|  | MI | 0.54 | 0.61 | 1.00 |
|  | TX | 1.00 |  |  |
| Mn | MO | 0.65 | 1.00 |  |
|  | MI | 0.61 | 0.67 | 1.00 |
|  | TX | 1.00 |  |  |
| Fe | MO | 0.90 | 1.00 |  |
|  | MI | 0.56 | 1.00 | 1.00 |
|  | TX | 1.00 |  |  |
| Zn | MO | 0.63 | 1.00 |  |
|  | MI | 0.67 | 0.70 | 1.00 |
|  | TX | 1.00 |  |  |
| Cu | MO | 0.59 | 1.00 |  |
|  | MI | 0.74 | 0.54 | 1.00 |
|  | TX | 1.00 |  |  |
| B | MO | -0.46 | 1.00 |  |
|  | MI | NA | NA | 1.00 |
|  | TX | 1.00 |  |  |
| Mo | MO | 0.53 | 1.00 |  |
|  | MI | 0.77 | 0.92 | 1.00 |
|  | TX | 1.00 |  |  |
| Co | MO | NA | 1.00 |  |
|  | MI | NA | 0.78 | 1.00 |
|  | TX | 1.00 |  |  |
| Se | MO | NA | 1.00 |  |
|  | MI | NA | NA | 1.00 |
|  | TX | 1.00 |  |  |
| Sr | MO | 0.66 | 1.00 |  |
|  | MI | 0.75 | 0.86 | 1.00 |
|  | TX | 1.00 |  |  |
| Rb | MO | 0.71 | 1.00 |  |
|  | MI | 0.34 | 0.64 | 1.00 |
|  | TX | 1.00 |  |  |
| Na | MO | 0.91 | 1.00 |  |
|  | MI | 0.75 | 0.88 | 1.00 |
|  | TX | 1.00 |  |  |
| Al | MO | 0.24 | 1.00 |  |
|  | MI | 0.17 | 0.99 | 1.00 |
|  | TX | 1.00 |  |  |
| As | MO | NA | 1.00 |  |
|  | MI | NA | NA | 1.00 |
|  | TX | 1.00 |  |  |
| Cd | MO | 0.66 | 1.00 |  |
|  | MI | 0.76 | 0.95 | 1.00 |

**Table S4** . The identified QTL with the marker name, marker position, the LOD scores, the 1.5-LOD confidence intervals, and Yes/No of QTL by environment interactions (QxE) for each of the 14 ionomic elements, obtained from the multi-environment QTL modeling using Genstat.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Element | Marker Name | Marker Position | LOD | Confidence Interval | QxE |
| K | Chr01K\_10.834845 | 23.9 | 4.53 | 15.84-30.11 | No |
| K | Chr02N\_45.425692 | 54.01 | 5.37 | 49.9-62.08 | Yes |
| K | Chr04N\_2.907577 | 5.74 | 3.62 | 0-14.09 | No |
| K | Chr08K\_15.801886 | 14.04 | 5.59 | 4.16-22.09 | No |
| K | Chr09K\_68.623849 | 103.91 | 3.98 | 96.09-105.8 | Yes |
| K | Chr09N\_16.482124 | 34.17 | 4.28 | 32.03-42.2 | Yes |
| K | Chr09N\_60.322362 | 77.93 | 5.27 | 73.99-90.1 | No |
| Ca | Chr02N\_12.293047 | 24.04 | 4.41 | 12.06-33.93 | Yes |
| Ca | Chr07K\_49.631374 | 45.81 | 8.17 | 36.02-53.22 | No |
| Ca | Chr08K\_17.935264 | 16.12 | 9.04 | 10.06-24.19 | No |
| Ca | Chr09K\_6.619969 | 20.05 | 4.54 | 1.99-23.9 | Yes |
| Ca | Chr09K\_63.87085 | 93.88 | 10.42 | 92-98.78 | No |
| Mg | Chr01N\_60.145498 | 69.84 | 6.35 | 61.91-72.89 | No |
| Mg | Chr02K\_1.973728 | 0 | 6.13 | 0-5.96 | Yes |
| Mg | Chr02K\_64.045891 | 81.9 | 4.96 | 67.6-85.74 | Yes |
| Mg | Chr03K\_29.471122 | 54.02 | 4.02 | 41.85-72.11 | No |
| Mg | Chr03N\_5.79304 | 9.89 | 3.95 | 0-20.56 | No |
| Mg | Chr04N\_49.931439 | 70.9 | 3.6 | 2.07-23.93 | No |
| Mg | Chr05N\_53.34 | 70.14 | 4.18 | 64.01-73.95 | No |
| Mg | Chr07N\_44.798104 | 36.06 | 4.18 | 29.74-40.11 | No |
| Mg | Chr09K\_5.979988 | 18.15 | 11.53 | 13.87-20.05 | Yes |
| P | Chr01K\_4.12849 | 8.08 | 4.3 | 4.14-21.7 | No |
| P | Chr01K\_52.348357 | 75.9 | 5.91 | 66.27-81.84 | No |
| P | Chr02N\_4.265218 | 3.99 | 4.2 | 0-12.06 | No |
| P | Chr02N\_60.798034 | 78.05 | 8.43 | 74.08-92.15 | Yes |
| P | Chr03K\_11.631115 | 26.18 | 10.98 | 9.98-27.89 | Yes |
| P | Chr03K\_60.850482 | 90.02 | 6.08 | 85.74-94.01 | No |
| P | Chr03N\_22.226482 | 56.03 | 5.1 | 44.16-63.97 | Yes |
| P | Chr04K\_4.084507 | 6.08 | 7.72 | 0-7.96 | Yes |
| P | Chr04K\_42.325822 | 50 | 3.97 | 35.96-57.92 | Yes |
| P | Chr05K\_51.027693 | 65.91 | 13.59 | 51.99-69.97 | No |
| P | Chr05N\_2.601559 | 3.81 | 4.86 | 0-11.92 | No |
| P | Chr08K\_17.935264 | 16.12 | 7.34 | 10.06-17.72 | No |
| P | Chr09K\_62.204842 | 89.93 | 8.06 | 86.09-93.88 | No |
| P | Chr09N\_13.689487 | 28.06 | 3.56 | 4.06-38.02 | No |
| Mn | Chr02N\_6.096466 | 10.06 | 9.1 | 0-12.06 | Yes |
| Mn | Chr03N\_19.912717 | 51.93 | 4.71 | 44.16-57.73 | Yes |
| Mn | Chr05K\_6.599395 | 12.07 | 3.55 | 0-23.93 | No |
| Mn | Chr07K\_47.708677 | 40.02 | 8.11 | 36.02-43.95 | No |
| Mn | Chr09K\_6.619969 | 20.05 | 6.13 | 12.1-26.04 | No |
| Fe | Chr04N\_7.669243 | 24.17 | 3.79 | 11.72-31.99 | No |
| Fe | Chr07K\_47.165572 | 38 | 6.51 | 34.12-45.81 | No |
| Zn | Chr02N\_17.133607 | 31.96 | 6.41 | 22.08-38.07 | Yes |
| Zn | Chr03K\_16.690132 | 36.09 | 4.37 | 34.02-43.94 | Yes |
| Zn | Chr07K\_36.952768 | 21.97 | 3.57 | 18.12-40.02 | No |
| Cu | Chr01K\_6.649291 | 14.42 | 7.37 | 8.08-20.11 | No |
| Cu | Chr01K\_50.995576 | 71.78 | 6.63 | 66.27-80.53 | No |
| Cu | Chr03K\_23.275513 | 46.01 | 8.86 | 39.82-49.99 | No |
| Cu | Chr04K\_6.22639 | 12.1 | 4.42 | 7.96-26.26 | No |
| Cu | Chr07K\_41.193685 | 26.27 | 22.71 | 20.04-30.07 | Yes |
| Mo | Chr05K\_42.854833 | 56.02 | 6.36 | 51.99-64.46 | Yes |
| Mo | Chr09N\_21.588445 | 43.81 | 14.97 | 38.02-49.99 | Yes |
| Sr | Chr02K\_14.054433 | 25.73 | 4.83 | 21.91-30.01 | Yes |
| Sr | Chr02N\_17.133607 | 31.96 | 4.61 | 20.06-36 | Yes |
| Sr | Chr05K\_7.723311 | 15.72 | 4.75 | 5.94-28.08 | No |
| Sr | Chr07K\_49.631374 | 45.81 | 7.09 | 34.12-49.75 | Yes |
| Sr | Chr07N\_26.098039 | 9.79 | 4.95 | 3.98-14.09 | Yes |
| Sr | Chr08K\_51.991471 | 39.99 | 9.34 | 36.06-41.1 | Yes |
| Sr | Chr09K\_13.655791 | 37.99 | 6.79 | 36.04-42.24 | No |
| Sr | Chr09K\_53.691256 | 74.08 | 17.51 | 72.18-76.29 | Yes |
| Sr | Chr09N\_26.905609 | 52.1 | 4.95 | 47.97-59.86 | Yes |
| Rb | Chr01K\_22.02949 | 34.1 | 6.84 | 31.97-35.82 | No |
| Rb | Chr02N\_21.383677 | 39.46 | 8.85 | 36-42.29 | Yes |
| Rb | Chr02N\_58.696003 | 72.03 | 6.68 | 70.02-79.78 | Yes |
| Rb | Chr05K\_60.232411 | 95.5 | 4.24 | 84.08-95.5 | Yes |
| Rb | Chr07N\_32.095441 | 17.86 | 4.33 | 5.98-25.94 | No |
| Rb | Chr08N\_3.180385 | 0 | 4.09 | 0-14.01 | Yes |
| Rb | Chr09N\_10.880731 | 24.08 | 6.78 | 22.11-28.06 | Yes |
| Rb | Chr09N\_45.532045 | 62.13 | 3.87 | 54-67.9 | No |
| Na | Chr05K\_38.385172 | 51.99 | 38.42 | 49.89-56.02 | Yes |
| Na | Chr05N\_27.577261 | 47.97 | 36.86 | 46.03-50.15 | Yes |
| Al | Chr04N\_12.617209 | 31.99 | 4.53 | 20.16-44.09 | Yes |
| Al | Chr05K\_20.045881 | 37.73 | 3.71 | 23.93-45.91 | No |
| Al | Chr07K\_48.236716 | 41.91 | 8.72 | 36.02-43.95 | Yes |
| Al | Chr09K\_55.282015 | 76.29 | 6.39 | 67.94-83.94 | No |
| Cd | Chr02K\_18.103258 | 32.06 | 55.07 | 28.03-34.15 | Yes |
| Cd | Chr02N\_63.711847 | 85.72 | 4.29 | 76.08-102.61 | Yes |

**Table S5** QTL effects (including additive and dominance terms) at each site (TX, MO, and MI) for each element. A x B represents the lowland AP13 x upland DAC cross, C x D represents the lowland WBC x upland VS16 cross.

**Table S6** Candidate gene lists for all ionomic traits.

**Table S7** Significant (*p* < 0.05) GO enrichment terms across all ionomic traits.

**Fig. S1** QTL identified for each element within each category (macronutrient, micronutrient, analogue, and other)

**Fig. S2** QTL effects (reaction norms) across the three field sites (TX, MO, and MI) for each element. A x B represents the lowland AP13 x upland DAC cross, C x D represents the lowland WBC x upland VS16 cross.