**Supplementary material**

Title

# Enhanced nitrogen imbalances in agroecosystems driven by changing cropping systems in a coastal area of Eastern China: from field to watershed scale

Author:

Yanqiang Li[1, 2], Fang Wang[1], Weijin Yan[1*], Shucong Lv[1, 2], Qingqian Li[1, 2], Qibiao Yu[1, 2], Jun Wang[3]

[1] Institute of Geographic Sciences and Natural Resources Research CAS, Beijing, 100101, CN

[2] University of Chinese Academy of Sciences, Beijing, 100049, CN

[3] Qingdao Agricultural Technology Extension Station, Qingdao, 266200, China

*Corresponding authors, yanwj@igsnrr.ac.cn

Yanqiang Li and Fang Wang contribute equally to this work

Including 8 pages, 8 tables.

**Table S1** Cropping system at the Dagu River watershed

| Cropping system | Crop rotation [a] | Harvest frequency [a] |
|---|---|---|
| Traditional crop with traditional crop rotation (G-G) | wheat-maize | 2 times per year |
| | peanut-wheat-maize | 3 times in two years |
| Vegetable with traditional crop rotation (V-G) | garlic – maize | 2 times per year |
| | potato – maize | 2 times per year |
| | carrot – maize | 2 times per year |
| | onion - maize | 2 times per year |
| | garlic – peanut | 2 times per year |
| | onion – peanut | 2 times per year |
| Vegetable with vegetable rotation (V-V) | potato-potato | 2 times per year |
| | carrot - carrot | 2 times per year |
| | potato - scallion | 2 times per year |
| | cabbage - cabbage | 2 times per year |
| | potato - Chinese cabbage | 2 times per year |
| | white turnip - white turnip | 2 times per year |
| | garlic - cabbage | 2 times per year |
| | ginger | 1 time per year |
| | dasheen | 1 time per year |
| Vegetable in facility (GHV) | cucumber | all year |
| | pepper | all year |
| | eggplant | all year |
| | tomato | all year |

[a] Data was collected by household interview

**Table S2** Cultivated areas of cropping systems in sub watersheds between 1995 and 2015

| Sub watershed | Total villages [a] | Sampled villages [b] | Total cultivated area of sampled villages (ha) | | Total cultivated area of cropping system (ha) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | G-G | | V-G | | V-V | | GHV | |
| | | | 1995 | 2015 | 1995 | 2015 | 1995 | 2015 | 1995 | 2015 | 1995 | 2015 |
| JWR | 415 | 40 | 6107 | 5985 | 4548.6 | 2513.7 | 778.1 | 1795.5 | 598.5 | 1496.3 | 59.9 | 179.6 |
| ZR | 201 | 20 | 3122 | 2903 | 2061.1 | 1306.4 | 493.5 | 1016.1 | 290.3 | 435.5 | 58.1 | 145.2 |
| CGR | 116 | 10 | 1890 | 1876 | 1463.3 | 844.2 | 225.1 | 562.8 | 187.6 | 356.4 | 0.0 | 112.6 |
| XGR | 495 | 50 | 7610 | 7506 | 5779.6 | 2326.9 | 750.6 | 2251.8 | 900.7 | 2477.0 | 75.1 | 450.4 |
| WGR | 415 | 40 | 5998 | 5879 | 4468.0 | 2586.8 | 587.9 | 999.4 | 705.5 | 1763.7 | 117.6 | 529.1 |
| CZR | 90 | 10 | 1422 | 1102 | 892.6 | 418.8 | 143.3 | 253.5 | 66.1 | 407.7 | 0.0 | 22.04 |
| LYR | 148 | 15 | 3321 | 3098 | 2323.5 | 1239.2 | 464.7 | 743.5 | 278.8 | 929.4 | 31.0 | 185.9 |
| LHR | 162 | 16 | 3312 | 3120 | 2402.4 | 1029.6 | 468.0 | 1092.0 | 249.6 | 811.2 | 0.0 | 187.2 |
| NJLR | 686 | 50 | 7923 | 7500 | 5250.0 | 3450.0 | 1125.0 | 1650.0 | 975.0 | 1800.0 | 150.0 | 600.0 |
| TYR | 94 | 10 | 1945 | 1521 | 1201.6 | 532.4 | 152.1 | 501.9 | 167.3 | 441.1 | 0.0 | 45.63 |
| YXR | 158 | 16 | 1543 | 1395 | 962.6 | 599.9 | 251.1 | 488.3 | 181.4 | 293.0 | 0.0 | 13.95 |

[a] Number of the total villages in sub-watersheds.

[b] Number of the sampled villages in sub-watersheds.

Abbreviations: JWR, Upstream watershed, ZR, Zhu River watershed, CGR, Changguang River watershed, XGR, Xiaogu River watershed, WGR, Wugu River watershed, LYR, Luoyao River watershed, LHR, Liuhao River watershed, NJLR, Nanjiaolai River watershed, YXR, Yunxi River watershed, TYR, Taoyuan River watershed; CZR, Chengzi River watershed; G-G, traditional crop with traditional crop rotation, V-G, vegetable with traditional crop rotation, V-V, vegetable with vegetable rotation, and GHV, greenhouse vegetables.

**Table S3** N fertilizers application to agricultural fields in Dagu River watershed between 1995 and 2015

| Crop | | Inorganic fertilizer (kg ha$^{-1}$) [a] | | | | | | Organic fertilizer (kg ha$^{-1}$) [a] | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1995 | | | 2015 | | | 1995 | | | 2015 | | |
| | | Ave | Min | Max | Ave | Min | Max | Ave | Min | Max | Ave | Min | Max |
| Traditional crop | Wheat | 937.5 | 750.0 | 1124.9 | 1499.9 | 1124.9 | 1874.9 | — | — | — | — | — | — |
| | Maize | 468.7 | 337.5 | 600.0 | 750.0 | 450.0 | 900.0 | — | — | — | — | — | — |
| | Peanut | 1124.9 | 825.0 | 1349.9 | 1499.9 | 1124.9 | 1874.9 | — | — | — | — | — | — |
| Open-field vegetable | Onion | 1312.4 | 1124.9 | 1499.9 | 1874.9 | 1499.9 | 2249.9 | 20249.0 | 17999.1 | 22498.9 | 29998.5 | 22498.9 | 41247.9 |
| | Carrot | 1537.4 | 1199.9 | 1874.9 | 1499.9 | 1124.9 | 2249.9 | 23623.8 | 17999.1 | 29248.5 | 59997.0 | 48747.6 | 67496.6 |
| | Garlic | 1349.9 | 1124.9 | 1724.9 | 1949.9 | 1499.9 | 2399.9 | 22498.9 | 17999.1 | 26998.7 | 44997.8 | 37498.1 | 48747.6 |
| | Cabbage | 1312.4 | 1124.9 | 1499.9 | 1874.9 | 1499.9 | 2249.9 | 14624.3 | 13499.3 | 17999.1 | 59997.0 | 56247.2 | 66746.7 |
| | Ginger | 1499.9 | 1199.9 | 1724.9 | 2249.9 | 1949.9 | 2624.9 | 22498.9 | 17999.1 | 29248.5 | 47997.6 | 44997.8 | 51747.4 |
| | Potato | 1312.4 | 1124.9 | 1724.9 | 1874.9 | 1649.9 | 2249.9 | 13499.3 | 8999.6 | 17999.1 | 29998.5 | 26998.7 | 35998.2 |
| | Dasheen | 1237.4 | 1124.9 | 1499.9 | 2249.9 | 1949.9 | 2249.9 | 24748.8 | 22498.9 | 26998.7 | 40498.0 | 23998.8 | 44997.8 |
| | Chinese cabbage | 862.5 | 675.0 | 1124.9 | 1874.9 | 1649.9 | 2249.9 | 15749.2 | 13499.3 | 17999.1 | 35998.2 | 26248.7 | 50997.5 |
| | White turnip | 862.5 | 1124.9 | 1499.9 | 1874.9 | 1649.9 | 2249.9 | 19124.0 | 15749.2 | 22498.9 | 29998.5 | 26248.7 | 35248.2 |
| | Scallion | 1237.4 | 750.0 | 1499.9 | 1874.9 | 1649.9 | 2249.9 | 14624.3 | 11249.4 | 17999.1 | 59997.0 | 44997.8 | 67496.6 |
| Greenhouse vegetable | Cucumber | 9374.5 | 7499.6 | 11249.4 | 14999.3 | 13499.3 | 18749.1 | 67496.6 | 44997.8 | 89995.5 | 134993.3 | 112494.4 | 149992.5 |
| | Eggplant | 8999.6 | 7499.6 | 11999.4 | 14999.3 | 13499.3 | 18749.1 | 134993.3 | 119994.0 | 149992.5 | 89995.5 | 74996.3 | 134993.3 |
| | Pepper | 9374.5 | 8249.6 | 11999.4 | 14999.3 | 13499.3 | 18749.1 | 101244.9 | 89995.5 | 112494.4 | 104994.8 | 74996.3 | 134993.3 |
| | Tomato | 11249.4 | 7499.6 | 13499.3 | 14999.3 | 13499.3 | 11249.4 | 119994.0 | 104994.8 | 134993.3 | 119994.0 | 74996.3 | 149992.5 |

[a] Data of fertilizer applications to fields was collected through household interview.

"-" No data

Ave, average value, Max, maximum value, Min, minimum value

**Table S4** Nitrogen fertilizer application to crops at field of the Dagu River watershed between 1995 and 2015

| Crop | | Inorganic fertilizers (%) | | | | | | | | Organic fertilizers (%) [a] | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Ammonium bicarbonate | | Urea | | Ammonium nitrate | | Compound | | Pig manure | Cow manure | Poultry manure |
| | | 1995 | 2015 | 1995 | 2015 | 1995 | 2015 | 1995 | 2015 | 1995-2015 | | |
| Traditional crop | Wheat | 28.0 | — | — | — | 47.2 | 25.0 | 24.8 | 75.0 | | | |
| | Maize | — | — | 100.0 | 100.0 | — | — | — | — | | | |
| | Peanut | 25.7 | — | — | — | 22.4 | 25.0 | 51.9 | 75.0 | | | |
| Open-field vegetable | Onion | 15.1 | — | — | — | 23.5 | 50.0 | 61.4 | 50.0 | | | |
| | Carrot | — | — | — | — | — | — | 100.0 | 100.0 | | | |
| | Garlic | 12.0 | 20.0 | 10.0 | — | 33.3 | 48.0 | 44.7 | 32.0 | | | |
| | Cabbage | 20.0 | — | — | — | 48.0 | 50.0 | 32.0 | 50.0 | | | |
| | Ginger | 15.1 | — | — | — | 23.5 | 65.0 | 61.4 | 35.0 | | | |
| | Potato | 15.0 | — | 20.0 | — | 42.5 | 50.0 | 22.5 | 50.0 | 35.0 | 10.0 | 55.0 |
| | Dasheen | 0.0 | — | 30.0 | 20.0 | 53.5 | 44.0 | 16.5 | 36.0 | | | |
| | Chinese cabbage | 8.0 | — | — | — | 74.2 | 0.0 | 17.8 | 100.0 | | | |
| | White turnip | 10.0 | — | — | — | 14.0 | 25.0 | 76.0 | 75.0 | | | |
| | Scallion | 5.0 | — | 20.0 | — | 43.5 | — | 31.5 | 100.0 | | | |
| Greenhouse vegetable | Cucumber | — | — | — | — | — | — | 100.0 | 100.0 | | | |
| | Eggplant | — | — | — | — | — | — | 100.0 | 100.0 | | | |
| | Pepper | — | — | — | — | — | — | 100.0 | 100.0 | | | |
| | Tomato | — | — | — | — | — | — | 100.0 | 100.0 | | | |

[a] Organic fertilizer species applied to different vegetables showed no differences between 1995 and 2015.

"-" No data.

**Table S5** Grain yield and seed rate of crop at the field scale between 1995 and 2015

| Sampled crop | | Grain yield (kg ha$^{-1}$) [a] | | | | | | Seed rate (kg ha$^{-1}$) [a] | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 1995 | | | 2015 | | | | | |
| | | Ave | Min | Max | Ave | Min | Max | Ave | Min | Max |
| Traditional crop | Wheat | 6749.7 | 4499.8 | 9749.5 | 7499.6 | 5999.7 | 10499.5 | 224.9 | 187.4 | 299.9 |
| | Maize | 7499.6 | 5999.7 | 8999.6 | 8999.6 | 6749.7 | 10874.5 | 37.5 | 33.7 | 41.2 |
| | Peanut | 5249.7 | 3749.8 | 7124.6 | 5999.7 | 4499.8 | 8249.6 | 187.4 | 149.9 | 262.4 |
| Open-field vegetable | Onion | 52497.4 | 18749.1 | 28498.6 | 63746.8 | 26248.7 | 37498.1 | 6.0 | 4.5 | 7.5 |
| | Carrot | 63746.8 | 14999.3 | 18749.1 | 74996.3 | 33748.3 | 44247.8 | 6.0 | 0.0 | 0.0 |
| | Garlic | 14999.3 | 19499.0 | 27748.6 | 18749.1 | 14999.3 | 26248.7 | 2248.9 | 1874.1 | 2623.7 |
| | Cabbage | 48747.6 | 63746.8 | 78746.1 | 59997.0 | 59997.0 | 97495.1 | 6.0 | 4.5 | 7.5 |
| | Ginger | 31498.4 | 20249.0 | 26248.7 | 37498.1 | 25498.7 | 37498.1 | 899.6 | 749.6 | 1124.4 |
| | Potato | 56247.2 | 49497.5 | 60747.0 | 67496.6 | 59247.0 | 75746.2 | 2248.9 | 1874.1 | 2998.5 |
| | Dasheen | 34498.3 | 41247.9 | 56247.2 | 41247.9 | 53247.3 | 71996.4 | 1124.4 | 899.6 | 1499.3 |
| | Chinese cabbage | 59997.0 | 21748.9 | 34498.3 | 71246.4 | 33748.3 | 44247.8 | 6.0 | 4.5 | 9.0 |
| | White turnip | 52497.4 | 30748.5 | 41997.9 | 63746.8 | 38998.1 | 54747.3 | 7.5 | 6.0 | 9.0 |
| | Scallion | 49497.5 | 19499.0 | 27748.6 | 63746.8 | 47997.6 | 59997.0 | 7.5 | 4.5 | 9.0 |
| Greenhouse vegetable | Cucumber | 202489.9 | 187490.6 | 254987.3 | 224988.8 | 194990.3 | 262486.9 | 30.0 | 24.0 | 36.0 |
| | Eggplant | 172491.4 | 172491.4 | 269986.5 | 187490.6 | 224988.8 | 277486.1 | 30.0 | 24.0 | 36.0 |
| | Pepper | 224988.8 | 142492.9 | 194990.3 | 254987.3 | 172491.4 | 217489.1 | 30.0 | 24.0 | 36.0 |
| | Tomato | 239988.0 | 209989.5 | 269986.5 | 299985.0 | 254987.3 | 337483.1 | 30.0 | 24.0 | 36.0 |

[a] Data was collected by household interview.

Ave, average value, Max, maximum value, Min, minimum value.

**Table S6** N content in grain and straw of sampled crop

| Sampled crop | | N contain in grain g N $kg^{-1}$ [a] | Straw/yield ratio [b] | N content in straw g N $kg^{-1}$ [b] |
|---|---|---|---|---|
| Traditional crop | Wheat | 14.1 | 1.5 | 5.8 |
| | Maize | 17.9 | 1.2 | 5.2 |
| | Peanut | 19.4 | 0.8 | 18 |
| Open-field vegetable | Onion | 1.8 | 0.05 | 1.2 |
| | Carrot | 1.9 | 0.1 | 2.2 |
| | Garlic | 7.2 | 0.5 | 0.6 |
| | Cabbage | 2.4 | 0 | 0 |
| | Ginger | 2.7 | 0.5 | 4.3 |
| | Potato | 3.2 | 0.5 | 3 |
| | Dasheen | 3.5 | 2 | 0.1 |
| | Chinese cabbage | 2.7 | 0 | 0 |
| | White turnip | 1.4 | 0.1 | 1.9 |
| | Scallion | 2.7 | 0 | 0 |
| Greenhouse vegetable | Cucumber | 1.3 | 0.2 | 0.2 |
| | Eggplant | 1.8 | 0.5 | 0.6 |
| | Pepper | 2.2 | 0.5 | 0.4 |
| | Tomato | 1.4 | 0.1 | 0.5 |

[a] Data was obtained from National Institute for Nutrition and Health Chinese Center for Disease Control and Prevention, 2018.

[b] Data was provided by Qingdao Agricultural Technology Extension Station.

**Table S7** Parameters for the calculation of N losses at the field scale between 1995 and 2015

| Sampled crop | | Ammonia volatilization (%) [a] | | | | Denitrification/nitrification (%) [b] | | | | Leaching (%) [b] | | Surface runoff (%) [b] | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Inorganic fertilizers | | Organic fertilizers | | Inorganic fertilizers | | Organic fertilizers | | | | | |
| | | 1995 | 2015 | 1995 | 2015 | 1995 | 2015 | 1995 | 2015 | 1995 | 2015 | 1995 | 2015 |
| Traditional crop | Wheat | 12.2 | 17.1 | — | — | | | | | 9.7 (2.1) [2, 4, 5] | | 1.0 [6] | |
| | Maize | 13.7 | 13.7 | — | — | | | | | | | | |
| | Peanut | 17.2 | 17.1 | — | — | | | | | | | | |
| Open-field vegetable | Onion | 17.1 | 12.1 | 28.0 | 28.0 | 4.2 (0.6) [1-3] | | 2.9 (0.2) [1-3] | | 15.8 (5.6) [7] | | 6.1 (1.3) [8, 9] | |
| | Carrot | 22.1 | 22.1 | 28.0 | 28.0 | | | | | | | | |
| | Garlic | 12.1 | 12.1 | 28.0 | 28.0 | | | | | | | | |
| | Cabbage | 12.1 | 12.1 | 28.0 | 28.0 | | | | | | | | |
| | Ginger | 17.1 | 9.0 | 28.0 | 28.0 | | | | | | | | |
| | Potato | 11.6 | 12.1 | 28.0 | 28.0 | | | | | | | | |
| | Dasheen | 8.8 | 11.6 | 28.0 | 28.0 | | | | | | | | |
| | Chinese cabbage | 7.1 | 22.1 | 28.0 | 28.0 | | | | | | | | |
| | White turnip | 19.1 | 17.1 | 28.0 | 28.0 | | | | | | | | |
| | Scallion | 11.6 | 22.1 | 28.0 | 28.0 | | | | | | | | |
| Greenhouse vegetable | Cucumber | 22.1 | 22.1 | 28.0 | 28.0 | | | | | 42.7 (10.9)[5, 10, 11] | | | |
| | Eggplant | 22.1 | 22.1 | 28.0 | 28.0 | | | | | | | | |
| | Pepper | 22.1 | 22.1 | 28.0 | 28.0 | | | | | | | | |
| | Tomato | 22.1 | 22.1 | 28.0 | 28.0 | | | | | | | | |

[a] Data was calculated based the N loss rates in different fertilizer species.

[b] Data showed no differences between 1995 and 2015.

"-" No data.

Values in brackets are the standard deviations. Superscript number is reference

**Table S8** N fertilizer N input and grain N removal in response to crop type between 1995 and 2015

| Crop type | | N fertilizer input, kg N ha$^{-1}$ | | | | | | | | | | | | Grain N removal, kg N ha$^{-1}$ | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Inorganic fertilizer | | | | | | Organic fertilizer | | | | | | | | | | | |
| | | 1995 | | | 2015 | | | 1995 | | | 2015 | | | 1995 | | | 2015 | | |
| | | Ave | Min | Max | Ave | Min | Max | Ave | Min | Max | Ave | Min | Max | Ave | Min | Max | Ave | Min | Max |
| Traditional crop | Wheat | 234.4 | 187.5 | 281.2 | 300.0 | 225.0 | 375.0 | — | — | — | — | — | — | 120.8 | 80.5 | 174.5 | 134.2 | 107.4 | 187.9 |
| | Maize | 215.6 | 155.2 | 276.0 | 345.0 | 207.0 | 414.0 | — | — | — | — | — | — | 105.7 | 84.6 | 126.9 | 126.9 | 95.2 | 153.3 |
| | Peanut | 225.0 | 165.0 | 270.0 | 300.0 | 225.0 | 375.0 | — | — | — | — | — | — | 101.8 | 72.7 | 138.2 | 116.4 | 87.3 | 160.0 |
| Open-field vegetable | Onion | 262.5 | 225.0 | 300.0 | 468.7 | 375.0 | 562.5 | 147.3 | 130.9 | 163.6 | 218.2 | 163.6 | 300.0 | 94.5 | 33.7 | 51.3 | 114.7 | 47.2 | 67.5 |
| | Carrot | 230.6 | 180.0 | 281.2 | 225.0 | 168.7 | 337.5 | 171.8 | 130.9 | 212.7 | 436.4 | 354.5 | 490.9 | 121.1 | 28.5 | 35.6 | 142.5 | 64.1 | 84.1 |
| | Garlic | 337.5 | 281.2 | 431.2 | 487.5 | 375.0 | 600.0 | 163.6 | 130.9 | 196.4 | 327.3 | 272.7 | 354.5 | 108.0 | 140.4 | 199.8 | 135.0 | 108.0 | 189.0 |
| | Cabbage | 328.1 | 281.2 | 375.0 | 468.7 | 375.0 | 562.5 | 106.4 | 98.2 | 130.9 | 436.4 | 409.1 | 485.4 | 117.0 | 153.0 | 189.0 | 144.0 | 144.0 | 234.0 |
| | Ginger | 300.0 | 240.0 | 345.0 | 630.0 | 546.0 | 735.0 | 163.6 | 130.9 | 212.7 | 349.1 | 327.3 | 376.4 | 85.0 | 54.7 | 70.9 | 101.2 | 68.8 | 101.2 |
| | Potato | 393.7 | 337.5 | 517.5 | 468.7 | 412.5 | 562.5 | 98.2 | 65.5 | 130.9 | 218.2 | 196.4 | 261.8 | 180.0 | 158.4 | 194.4 | 216.0 | 189.6 | 242.4 |
| | Dasheen | 433.1 | 393.7 | 525.0 | 675.0 | 585.0 | 675.0 | 180.0 | 163.6 | 196.4 | 294.5 | 174.5 | 327.3 | 120.7 | 144.4 | 196.9 | 144.4 | 186.4 | 252.0 |
| | Chinese cabbage | 258.7 | 202.5 | 337.5 | 281.2 | 247.5 | 337.5 | 114.5 | 98.2 | 130.9 | 261.8 | 190.9 | 370.9 | 162.0 | 58.7 | 93.1 | 192.4 | 91.1 | 119.5 |
| | White turnip | 155.2 | 202.5 | 270.0 | 375.0 | 330.0 | 450.0 | 139.1 | 114.5 | 163.6 | 218.2 | 190.9 | 256.4 | 73.5 | 43.0 | 58.8 | 89.2 | 54.6 | 76.6 |
| | Scallion | 371.2 | 225.0 | 450.0 | 281.2 | 247.5 | 337.5 | 106.4 | 81.8 | 130.9 | 436.4 | 327.3 | 490.9 | 133.6 | 52.6 | 74.9 | 172.1 | 129.6 | 162.0 |
| Greenhouse vegetable | Cucumber | 1406.2 | 1124.9 | 1687.4 | 2249.9 | 2024.9 | 2812.4 | 490.9 | 327.3 | 654.5 | 981.8 | 818.2 | 1090.9 | 263.2 | 243.7 | 331.5 | 292.5 | 253.5 | 341.2 |
| | Eggplant | 1349.9 | 1124.9 | 1799.9 | 2249.9 | 2024.9 | 2812.4 | 981.8 | 872.7 | 1090.9 | 654.5 | 545.4 | 981.8 | 310.5 | 310.5 | 486.0 | 337.5 | 405.0 | 499.5 |
| | Pepper | 1406.2 | 1237.4 | 1799.9 | 2249.9 | 2024.9 | 2812.4 | 736.4 | 654.5 | 818.2 | 763.6 | 545.4 | 981.8 | 405.0 | 256.5 | 351.0 | 459.0 | 310.5 | 526.5 |
| | Tomato | 1687.4 | 1124.9 | 2024.9 | 2249.9 | 2024.9 | 2812.4 | 872.7 | 763.6 | 981.8 | 872.7 | 545.4 | 1090.9 | 336.0 | 294.0 | 378.0 | 420.0 | 357.0 | 472.5 |

"-" No data.

Ave, average value, Max, maximum value, Min, minimum value.

**Reference**


1. E. A. Davidson, The contribution of manure and fertilizer nitrogen to atmospheric nitrous oxide since 1860, *Nature Geoscience*, 2009, **2**, 659-662.
2. X. T. Ju, G. X. Xing, X. P. Chen, S. L. Zhang, L. J. Zhang, X. Liu, Z. L. Cui, B. Yin, P. Christie, Z. L. Zhu and F. Zhang, Reducing environmental risk by improving N management in intensive Chinese agricultural systems *PNAS*, 2009, **106**, 3041-3046.
3. B. Gu, X. Ju, J. Chang, Y. Ge and P. M. Vitousek, Integrated reactive nitrogen budgets and future trends in China, *Proceedings of the National Academy of Sciences of the United States of America*, 2015, **112**, 8792-8797.
4. G. X. Xing and Z. L. Zhu, Regional nitrogen budgets for China and its major watersheds, *Biogeochemistry*, 2002, **57-58**, 405-427.
5. Z. Fan, S. Lin, X. Zhang, Z. Jiang, K. Yang, D. Jian, Y. Chen, J. Li, Q. Chen and J. Wang, Conventional flooding irrigation causes an overuse of nitrogen fertilizer and low nitrogen use efficiency in intensively used solar greenhouse vegetable production, *Agricultural Water Management*, 2014, **144**, 11-19.
6. U. M. Sainju, A. W. Lenssen, B. L. Allen, W. B. Stevens and J. D. Jabro, Nitrogen balance in response to dryland crop rotations and cultural practices, *Agriculture Ecosystems & Environment*, 2016, **233**, 25-32.
7. C. Zhao, C. Hu, W. Huang, X. Sun, Q. Tan and H. Di, A lysimeter study of nitrate leaching and optimum nitrogen application rates for intensively irrigated vegetable production systems in Central China, *Journal of Soils and Sediments*, 2009, **10**, 9-17.
8. B. Yi, Q. Zhang, C. Gu, J. Li, T. Abbas and H. Di, Effects of different fertilization regimes on nitrogen and phosphorus losses by surface runoff and bacterial community in a vegetable soil, *Journal of Soils and Sediments*, 2018, **18**, 3186-3196.
9. R. Wang, J. Min, H. J. Kronzucker, Y. Li and W. Shi, N and P runoff losses in China's vegetable production systems: Loss characteristics, impact, and management practices, *The Science of the total environment*, 2019, **663**, 971-979.
10. W. Zhang, H. Li and Y. Li, Spatio-temporal dynamics of nitrogen and phosphorus input budgets in a global hotspot of anthropogenic inputs, *The Science of the total environment*, 2019, **656**, 1108-1120.
11. Y. Chen, J. Zhang, X. Xu, H. Qu, M. Hou, K. Zhou, X.-g. Jiao and Y.-y. Sui, Effects of different irrigation and fertilization practices on nitrogen leaching in facility vegetable production in northeastern China, *Agricultural Water Management*, 2018, **210**, 165-170.