Supplementary Materials for

Contribution of rice variety renewal and agronomic innovations to yield improvement and greenhouse gas mitigation in China

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Effects of irrigation methods on GHG emissions during post-transplanting stage

The irrigation methods during post-transplanting stage also include water saving irrigation (WS) and continuous flooding (CF). Feng et al (2013) investigated the effects of irrigation methods on GHG emissions during post-transplanting period using meta-analysis. Natural log of the response ratio \( (R) \) for each study was calculated as the index of effect size:

\[
\ln R = \ln \left( \frac{x_t}{x_c} \right)
\]

where \( x_t \) and \( x_c \) are the values of the variables (\( \text{CH}_4 \) emissions, \( \text{N}_2\text{O} \) emissions, GWP, and yield scaled GWP) for water saving (WS) irrigation and continuous flooding (CF), respectively. Since standard deviation values were not reported for some observations, the effect sizes (\( \ln R \)) were weighed the same as equation 2 in the main text. Mean effect sizes were calculated using random-effects model, based on the assumption that random variation in GHG emissions occurred between observations. The 95% confidence intervals (CIs) around mean effect sizes were calculated by metawin software using bootstrapping with 4999 iterations (Rosenberg et al 2000; Linquist et al 2011). Treatment effects were considered significant if the 95% CI did not overlap with zero. To ease calculation, the results for the analyses on \( \ln R \) were back-transformed and reported as percentage change under WS conditions relative to continuous flooding \( (P = [R-1]*100) \).
Table S1 Questionnaire on local rice management practices.

| Expert's name | County | Depart | Province | Institute | Tel |
|---------------|--------|--------|----------|-----------|-----|
| What are the major rice cropping systems in your county? | | | | | |
| 1. Single rice | 2. Rice-Wheat/Rape | 3. Double rice (Early & Late rice) | | | |
| What are the major water management practices in post-transplanted stage in your county? | | | | | |
| 1. Continuous flooding (CF) | 2. alternate dry-wetting (AWD) irrigation | | | | |
| What are the major nursery methods in your county? | | | | | |
| 1. Continuous flooding (CF) | 2. alternate dry-wetting (AWD) irrigation | | | | |
| What are the major planting methods in your county? | | | | | |
| 1. Direct-seeding | 2. mechanical transplanting | 3. manual transplanting | | | |
| What are the coverage of different management practices from 1960s to 2000s? | | | | | |

| Systems | Practices | 1960s | 1970s | 1980s | 1990s | 2000s |
|---------|-----------|-------|-------|-------|-------|-------|
| Single rice | Nursery stage | CF | | | | |
| | | AWD | | | | |
| | Post-transplanted stage | CF | | | | |
| | | AWD | | | | |
| | Planting methods | Direct-seeding | | | | |
| | | Mechanical transplanting | | | | |
| | | Manual transplanting | | | | |
| Rice-upland | Nursery stage | CF | | | | |
| | | AWD | | | | |
| | Post-transplanted stage | CF | | | | |
|                | Early rice | Late rice |
|----------------|------------|-----------|
|               | Nursery stage | Nursery stage |
|               | Post-transplanted stage | Post-transplanted stage |
|               | Planting methods | Planting methods |
|               | AWD | AWD |
| Planting methods | Direct-seeding | Direct-seeding |
|                | Mechanical transplanting | Mechanical transplanting |
|                | Manual transplanting | Manual transplanting |
|                | CF | CF |
|                | AWD | AWD |
Table S2 Field observations used in the meta-analysis to evaluate the mean CH₄ and N₂O emissions (kg CO₂ eq ha⁻¹), area-scaled GWP (kg CO₂ eq ha⁻¹), rice yield (Mg ha⁻¹), and yield-scaled GWP (kg CO₂ eq ha⁻¹) of three rice cropping systems. Abbreviations: Single rice cropping system (SR); Rice-upland crop rotation system (RU); Double rice cropping system (DR). n is the number of replicates in the field experiment and f is the number of GHG measurements per month for the weight of GHG emissions, and t is the total number of observations from each experimental site.

| No | Experimental site | Cropping system | n  | f  | t  | CH₄ | N₂O | Area-scaled GWP | Yield | Yield-scaled GWP | Citation                      |
|----|-------------------|----------------|----|----|----|-----|-----|-----------------|-------|------------------|-------------------------------|
| 1  | Hailun            | SR             | 3  | 4  | 2  | 620.0 | 178.8 | 798.8            | 6.33  | 126.1            | Yue et al., 2003*; Yue et al., 2005 |
| 2  | Hailun            | SR             | 3  | 4  | 2  | 420.0 | 238.4 | 658.4            | 6.32  | 104.2            | Yue et al., 2003*; Yue et al., 2005 |
| 3  | Tongjiang         | SR             | 3  | 5  | 3  | 1904.9 | 228.6 | 2133.5           | 5.19  | 410.8            | Chen, 2007*; Wang et al., 2008    |
| 4  | Tongjiang         | SR             | 3  | 5  | 3  | 4094.7 | 525.1 | 4619.8           | 5.92  | 780.3            | Chen, 2007*; Wang et al., 2008    |
| 5  | Tongjiang         | SR             | 3  | 5  | 3  | 4062.2 | 861.4 | 4923.5           | 6.23  | 790.3            | Chen, 2007*; Wang et al., 2008    |
| 6  | Beijing           | SR             | 3  | 5  | 2  | 78.8  | 98.3  | 177.1            | 8.50  | 20.8             | Kreye et al., 2007               |
|    | City     | Type | Width | Height | Length | Age | Load | Current
|---|----------|------|-------|--------|--------|-----|------|----------|
| 7  | Beijing  | SR   | 3     | 5      | 2      | 256.3 | 1180.1 | 1436.3 | 7.40 | 194.1 |
| 8  | Jingtang | RU   | 3     | 3      | 1      | 2310.0 | 931.9  | 3241.9 | 9.10 | 356.3 |
| 9  | Nanjing  | RU   | 3     | 5      | 3      | 2632.5 | 23.4   | 2655.9 | 5.48 | 484.7 |
| 10 | Nanjing  | RU   | 3     | 5      | 3      | 1235.0 | 421.5  | 1656.5 | 6.20 | 267.2 |
| 11 | Nanjing  | RU   | 3     | 5      | 3      | 922.5  | 608.8  | 1531.3 | 6.51 | 235.2 |
| 12 | Nanjing  | RU   | 4     | 4      | 2      | 1142.0 | 622.8  | 1764.8 | 8.13 | 217.1 |
| 13 | Nanjing  | RU   | 4     | 4      | 2      | 1451.0 | 1049.0 | 2500   | 8.91 | 280.6 |
| 14 | Dapu     | RU   | 3     | 5      | 8      | 804.7  | 139.0  | 943.7  | 7.30 | 129.3 |
| 15 | Dapu     | RU   | 3     | 5      | 8      | 1070.0 | 234.6  | 1304.6 | 7.47 | 174.8 |
| 16 | Dapu     | RU   | 3     | 5      | 8      | 4749.6 | 87.1   | 4836.7 | 7.37 | 656.7 |
| 17 | Dapu     | RU   | 3     | 5      | 8      | 5521.3 | 208.6  | 5729.9 | 7.79 | 736.0 |
| 18 | Dapu     | RU   | 3     | 5      | 8      | 1750.3 | 51.5   | 1801.8 | 7.04 | 255.9 |
| 19 | Dapu     | RU   | 3     | 5      | 8      | 2059.2 | 89.8   | 2149   | 6.68 | 321.7 |
| 20 | Dapu     | RU   | 3     | 5      | 8      | 17241.8| 26.9   | 17268.7| 7.03 | 2456.4|
| 21 | Dapu     | RU   | 3     | 5      | 8      | 21677.0| 36.0   | 21713.1| 6.61 | 3284.9|
| 22 | Jiangning| RU   | 3     | 5      | 5      | 975.5  | 1105.6 | 2081.1| 7.92 | 262.7 |

References:
- Kreye et al., 2007
- Zhang et al., 2010a
- Qin et al., 2010
- Qin et al., 2010
- Zou et al., 2009
- Zou et al., 2009
- Ma et al., 2007
- Ma et al., 2007
- Ma et al., 2007
- Ma et al., 2007
- Ma et al., 2007
- Zou et al., 2003
|   | Location   | RU | 3   | 5   | 5   | 3435.5 | 1242.7 | 4678.2 | 7.92 | 590.9 | Zou et al., 2003 |
|---|------------|----|-----|-----|-----|--------|--------|--------|------|-------|------------------|
|23 | Jiangning  | RU | 3   | 5   | 5   | 3411.0 | 950.6  | 4361.6 | 7.14 | 610.9 | Zou et al., 2003 |
|24 | Jiangning  | RU | 3   | 5   | 5   | 1413.5 | 935.7  | 2349.2 | 7.55 | 311.3 | Zou et al., 2003 |
|25 | Jiangning  | RU | 3   | 5   | 5   | 932.8  | 1043.0 | 1975.8 | 8.33 | 237.2 | Zou et al., 2003 |
|26 | Kunshan    | RU | 3   | 5   | 2   | 1752.5 | 28.7   | 1781.2 | 7.85 | 226.8 | Peng et al., 2011 |
|29 | Kunshan    | RU | 3   | 5   | 2   | 470.0  | 31.8   | 501.8  | 8.06 | 62.3  | Peng et al., 2011 |
|30 | Changshu   | RU | 3   | 5   | 4   | 10816.3| 554.3  | 11370.5| 10.18| 1116.8| Zhang et al., 2009|
|31 | Changshu   | RU | 3   | 5   | 4   | 4384.0 | 1034.1 | 5418.1 | 9.63 | 562.4 | Zhang et al., 2009|
|32 | Changshu   | RU | 3   | 5   | 4   | 10059.0| 771.8  | 10830.8| 9.78 | 1107.4| Zhang et al., 2009|
|33 | Changshu   | RU | 3   | 5   | 4   | 5076.0 | 1236.7 | 6312.7 | 9.56 | 660.3 | Zhang et al., 2009|
|34 | Changshu   | RU | 3   | 5   | 4   | 14095.0| 1381.3 | 15476.3| 8.92 | 1735.3| Dai et al., 2009 |
|35 | Wuxue      | RU | 3   | 2.5 | 2   | 15672.5| 1362.3 | 17034.8| 8.81 | 1934.3| Dai et al., 2009 |
|36 | Wuxue      | RU | 3   | 2.5 | 2   | 1612.5 | 145.4  | 1757.9 | 6.96 | 252.6 | Ma et al., 2009  |
|37 | Yixing     | RU | 3   | 5   | 4   | 12812.5| 118.7  | 12931.2| 7.05 | 1834.2| Ma et al., 2009  |
|38 | Yixing     | RU | 3   | 5   | 4   | 5450.0 | 190.6  | 5640.6 | 6.91 | 816.3 | Ma et al., 2009  |
|39 | Yixing     | RU | 3   | 5   | 4   | 14025.0| 49.2   | 14074.2| 6.62 | 2126.0| Ma et al., 2009  |
| No. | Location | RU | Site | Depth | Temp (°C) | Dissolved Oxygen (mg/L) | pH | SRP (μg/L) | Reference |
|-----|----------|----|------|-------|-----------|--------------------------|----|------------|-----------|
| 41  | Jurong   | RU | 3    | 5     | 5         | 1725.0                   | 528.7 | 2253.7     | 5.26      | 428.5     | Ma et al., 2009 |
| 42  | Jurong   | RU | 3    | 5     | 5         | 6800.0                   | 117.5 | 6917.5     | 5.73      | 1207.2    | Ma et al., 2009 |
| 43  | Jurong   | RU | 3    | 5     | 5         | 7025.0                   | 368.5 | 7393.5     | 5.31      | 1392.4    | Ma et al., 2009 |
| 44  | Jurong   | RU | 3    | 5     | 5         | 5250.0                   | 429.9 | 5679.9     | 6.15      | 923.6     | Ma et al., 2009 |
| 45  | Jurong   | RU | 3    | 5     | 5         | 4625.0                   | 602.2 | 5227.2     | 6.68      | 782.5     | Ma et al., 2009 |
| 46  | Changshu | RU | 3    | 5     | 2         | 3843.8                   | 1162.2 | 5006       | 9.75      | 513.6     | Zhang et al., 2010b |
| 47  | Changshu | RU | 3    | 5     | 2         | 4384.0                   | 1034.1 | 5418.1     | 9.63      | 562.5     | Zhang et al., 2010b |
| 48  | Rugao    | RU | 3    | 4     | 2         | 1158.5                   | 640.1 | 1798.6     | 9.60      | 187.4     | Li et al., 2003  |
| 49  | Rugao    | RU | 3    | 4     | 2         | 116.7                    | 4112.7 | 4229.3     | 7.80      | 542.2     | Li et al., 2003  |
| 50  | Wuhan    | RU | 3    | 4     | 2         | 10607.5                  | 536.4 | 11143.9    | 8.13      | 1371.6    | Zhan et al., 2009 |
| 51  | Wuhan    | RU | 3    | 4     | 2         | 8537.5                   | 596.0 | 9133.5     | 8.14      | 1122.1    | Zhan et al., 2009 |
| 52  | Wuhan    | RU | 3    | 4     | 3         | 5995.0                   | 625.8 | 6620.8     | 6.59      | 1005.4    | Yuan et al., 2009 |
| 53  | Wuhan    | RU | 3    | 4     | 3         | 4656.3                   | 700.3 | 5356.6     | 6.84      | 782.7     | Yuan et al., 2009 |
| 54  | Wuhan    | RU | 3    | 4     | 3         | 4812.5                   | 625.8 | 5438.3     | 6.79      | 800.5     | Yuan et al., 2009 |
| 55  | Yanting  | RU | 3    | 5     | 2         | 6566.0                   | 834.4 | 7400.4     | 8.61      | 859.9     | Jiang et al., 2006 |
| 56  | Yanting  | RU | 3    | 5     | 2         | 7072.3                   | 953.6 | 8025.9     | 8.86      | 906.3     | Jiang et al., 2006 |
|   |    |    |    |   |   |   |   |
|---|----|----|----|---|---|---|---|
| 57 | Changsha | DR | 3 | 5 | 6 | 13356.2 | 533.8 | 13890 | 13.06 | 1063.3 | Qin, 2011 |
| 58 | Changsha | DR | 3 | 5 | 6 | 5668.7 | 746.9 | 6415.6 | 12.47 | 514.5 | Qin, 2011 |
| 59 | Changsha | DR | 3 | 5 | 6 | 13571.7 | 861.6 | 14433.3 | 12.85 | 1122.9 | Qin, 2011 |
| 60 | Changsha | DR | 3 | 5 | 6 | 13591.3 | 700.1 | 14291.4 | 12.80 | 1116.5 | Qin, 2011 |
| 61 | Changsha | DR | 3 | 5 | 6 | 8537.8 | 742.2 | 9280.1 | 12.19 | 761.4 | Qin, 2011 |
| 62 | Changsha | DR | 3 | 5 | 6 | 26938.8 | 154.5 | 27093.4 | 9.86 | 2746.8 | Qin, 2011 |
| 63 | Changsha | DR | 3 | 5 | 4 | 6682.7 | 391.3 | 7074 | 13.69 | 516.7 | Shi et al., 2011b |
| 64 | Changsha | DR | 3 | 5 | 4 | 6527.0 | 332.9 | 6859.9 | 12.53 | 547.3 | Shi et al., 2011b |
| 65 | Changsha | DR | 3 | 5 | 4 | 7703.8 | 336.2 | 8040 | 10.47 | 767.6 | Shi et al., 2011b |
| 66 | Changsha | DR | 3 | 5 | 4 | 6032.8 | 509.7 | 6542.4 | 14.38 | 455.0 | Shi et al., 2011b |
| 67 | Changsha | DR | 3 | 5 | 5 | 4792.3 | 2295.1 | 7087.4 | 14.72 | 481.4 | Shi et al., 2011a |
| 68 | Changsha | DR | 3 | 5 | 5 | 11523.2 | 1060.0 | 12583.1 | 14.71 | 855.5 | Shi et al., 2011a |
| 69 | Changsha | DR | 3 | 5 | 5 | 4512.7 | 1560.8 | 6073.6 | 14.53 | 417.9 | Shi et al., 2011a |
| 70 | Changsha | DR | 3 | 5 | 5 | 16619.7 | 874.0 | 17493.7 | 14.62 | 1196.8 | Shi et al., 2011a |
| 71 | Changsha | DR | 3 | 5 | 5 | 6831.2 | 1882.8 | 8714 | 14.96 | 582.6 | Shi et al., 2011a |
| 72 | Taoyuan | DR | 3 | 5 | 3 | 19827.5 | 123.3 | 19950.8 | 11.66 | 1711.5 | Shang et al., 2010 |
|   | City     | Code | Layer | Region | Avg Precip. | Rainfall   | Total   | Avg TTR | Temp Max | Temp Min | Refs                           |
|---|----------|------|-------|--------|-------------|------------|---------|---------|---------|---------|--------------------------------|
|73 | Taoyuan  | DR   | 3     | 5      | 3          | 29441.7    | 287.2   | 29728.9 | 12.84   | 2315.3  | Shang et al., 2010            |
|74 | Taoyuan  | DR   | 3     | 5      | 3          | 26964.2    | 190.4   | 27154.6 | 11.57   | 2346.3  | Shang et al., 2010            |
|75 | Wangcheng| DR   | 3     | 5      | 3          | 31308.0    | 733.4   | 32041.4 | 10.64   | 3012.8  | Qin et al., 2006a; Qin et al., 2006b* |
|76 | Wangchen | DR   | 3     | 5      | 3          | 21336.0    | 527.7   | 21863.7 | 11.30   | 1935.7  | Qin et al., 2006a; Qin et al., 2006b* |
|77 | Wangchen | DR   | 3     | 5      | 3          | 12282.0    | 687.6   | 12969.6 | 10.70   | 1212.7  | Qin et al., 2006a; Qin et al., 2006b* |
|78 | Changsha | DR   | 3     | 4      | 5          | 10830.0    | 435.1   | 11265.1 | 14.93   | 754.7   | Tang et al., 2010a; Tang et al., 2010b* |
|79 | Changsha | DR   | 3     | 4      | 5          | 15027.5    | 590.0   | 15617.5 | 15.67   | 996.9   | Tang et al., 2010a; Tang et al., 2010b* |
|80 | Changsha | DR   | 3     | 4      | 5          | 14337.5    | 461.9   | 14799.4 | 15.91   | 930.3   | Tang et al., 2010a; Tang et al., 2010b* |
|81 | Changsha | DR   | 3     | 4      | 5          | 19865.0    | 599.0   | 20464   | 15.16   | 1349.8  | Tang et al., 2010a; Tang et al., 2010b* |
|82 | Changsha | DR   | 3     | 4      | 5          | 18517.5    | 557.3   | 19074.8 | 15.89   | 1200.1  | Tang et al., 2010a; Tang et al., 2010b* |
|   | City       | DR | Month | Year | Total | P1 | P2 | P3 | P4 | P5 | P6 | P7 | P8 | P9 |   |
|---|------------|----|-------|------|-------|----|----|----|----|----|----|----|----|----|---|
| 83| Changsha   | DR | 3     | 5    | 6     | 11328.3 | 135.8 | 11464.1 | 5.90 | 1942.4 | Qin, 2011 |
| 84| Changsha   | DR | 3     | 5    | 6     | 4399.7   | 210.7  | 4610.4  | 5.47 | 843.6   | Qin, 2011 |
| 85| Changsha   | DR | 3     | 5    | 6     | 11280.8  | 203.7  | 11484.5 | 5.90 | 1945.8  | Qin, 2011 |
| 86| Changsha   | DR | 3     | 5    | 6     | 10051.3  | 180.3  | 10231.6 | 5.97 | 1713.3  | Qin, 2011 |
| 87| Changsha   | DR | 3     | 5    | 6     | 6535.3   | 154.5  | 6689.9  | 5.52 | 1212.5  | Qin, 2011 |
| 88| Changsha   | DR | 3     | 5    | 6     | 19036.0  | 42.1   | 19078.1 | 4.15 | 4592.9  | Qin, 2011 |
| 89| Changsha   | DR | 3     | 5    | 4     | 1919.4   | 266.8  | 2186.2  | 5.34 | 409.6   | Shi et al., 2011b |
| 90| Changsha   | DR | 3     | 5    | 4     | 2276.4   | 161.2  | 2437.6  | 4.80 | 507.6   | Shi et al., 2011b |
| 91| Changsha   | DR | 3     | 5    | 4     | 1974.0   | 250.4  | 2224.4  | 3.61 | 617.0   | Shi et al., 2011b |
| 92| Changsha   | DR | 3     | 5    | 4     | 1953.0   | 250.7  | 2203.7  | 5.25 | 420.2   | Shi et al., 2011b |
| 93| Changsha   | DR | 3     | 5    | 5     | 1256.6   | 1801.9 | 3058.6  | 7.08 | 431.8   | Shi et al., 2011a |
| 94| Changsha   | DR | 3     | 5    | 5     | 3811.5   | 694.4  | 4505.9  | 7.06 | 638.4   | Shi et al., 2011a |
| 95| Changsha   | DR | 3     | 5    | 5     | 2069.8   | 1093.3 | 3163.1  | 6.97 | 454.1   | Shi et al., 2011a |
| 96| Changsha   | DR | 3     | 5    | 5     | 3931.6   | 486.4  | 4418.1  | 6.85 | 645.0   | Shi et al., 2011a |
| 97| Changsha   | DR | 3     | 5    | 5     | 1875.7   | 796.0  | 2671.7  | 6.93 | 385.8   | Shi et al., 2011a |
| 98| Taoyuan    | DR | 3     | 5    | 3     | 6342.5   | 53.1   | 6395.6  | 6.26 | 1022.2  | Shang et al., 2010 |
| No. | Location   | Service | Period | Mean Rainfall | Mean Relative Humidity | Annual Precipitation | Mean Temperature | Mean Wind Speed | Reference                                                                 |
|-----|------------|---------|--------|---------------|------------------------|-----------------------|------------------|----------------|---------------------------------------------------------------------------|
| 99  | Taoyuan    | DR      | 3 5 3  | 8767.5        | 96.8                   | 8864.3                | 7.26             | 1221.0         | Shang et al., 2010                                                        |
| 100 | Taoyuan    | DR      | 3 5 3  | 8194.2        | 89.0                   | 8283.1                | 6.19             | 1337.4         | Shang et al., 2010                                                        |
| 101 | Wangcheng  | DR      | 3 5 3  | 11760.0       | 304.6                  | 12064.6               | 5.39             | 2240.4         | Qin et al., 2006a; Qin et al., 2006b*                                   |
| 102 | Wangcheng  | DR      | 3 5 3  | 10320.0       | 310.7                  | 10630.7               | 5.75             | 1850.4         | Qin et al., 2006a; Qin et al., 2006b*                                   |
| 103 | Wangcheng  | DR      | 3 5 3  | 6720.0        | 434.6                  | 7154.6                | 5.40             | 1324.9         | Qin et al., 2006a; Qin et al., 2006b*                                   |
| 104 | Changsha   | DR      | 3 4 5  | 2620.0        | 122.2                  | 2742.2                | 7.03             | 390.1          | Tang et al., 2010a; Tang et al., 2010b*                                  |
| 105 | Changsha   | DR      | 3 4 5  | 5425.0        | 187.7                  | 5612.7                | 7.44             | 754.5          | Tang et al., 2010a; Tang et al., 2010b*                                  |
| 106 | Changsha   | DR      | 3 4 5  | 5187.5        | 137.1                  | 5324.6                | 7.57             | 703.8          | Tang et al., 2010a; Tang et al., 2010b*                                  |
| 107 | Changsha   | DR      | 3 4 5  | 5140.0        | 178.8                  | 5318.8                | 7.13             | 746.3          | Tang et al., 2010a; Tang et al., 2010b*                                  |
| 108 | Changsha   | DR      | 3 4 5  | 4890.0        | 157.9                  | 5047.9                | 7.33             | 689.0          | Tang et al., 2010a; Tang et al., 2010b*                                  |
| No. | Location | Type | Scale | Depth | Width | Length | Thickness | Area | Waterline | Notes                  |
|-----|----------|------|-------|-------|-------|--------|-----------|------|-----------|------------------------|
| 109 | Changsha | DR   | 3     | 5     | 6     | 1559.3 | 497.9     | 2057.3 | 6.55      | Qin, 2011              |
| 110 | Changsha | DR   | 3     | 5     | 6     | 1063.4 | 543.2     | 1606.7 | 6.25      | Qin, 2011              |
| 111 | Changsha | DR   | 3     | 5     | 6     | 1631.3 | 752.4     | 2383.7 | 6.51      | Qin, 2011              |
| 112 | Changsha | DR   | 3     | 5     | 6     | 2871.6 | 499.5     | 3371.1 | 6.34      | Qin, 2011              |
| 113 | Changsha | DR   | 3     | 5     | 6     | 1500.6 | 613.5     | 2114  | 6.44      | Qin, 2011              |
| 114 | Changsha | DR   | 3     | 5     | 6     | 6920.2 | 142.0     | 7062.3 | 5.91      | Qin, 2011              |
| 115 | Changsha | DR   | 3     | 5     | 4     | 4763.3 | 124.4     | 4887.7 | 8.35      | Shi et al., 2011b      |
| 116 | Changsha | DR   | 3     | 5     | 4     | 4250.6 | 171.7     | 4422.3 | 7.73      | Shi et al., 2011b      |
| 117 | Changsha | DR   | 3     | 5     | 4     | 5729.8 | 85.8      | 5815.6 | 6.87      | Shi et al., 2011b      |
| 118 | Changsha | DR   | 3     | 5     | 4     | 4079.8 | 258.9     | 4338.7 | 9.13      | Shi et al., 2011b      |
| 119 | Changsha | DR   | 3     | 5     | 5     | 3535.7 | 493.2     | 4028.9 | 7.64      | Shi et al., 2011a      |
| 120 | Changsha | DR   | 3     | 5     | 5     | 7711.7 | 365.6     | 8077.2 | 7.65      | Shi et al., 2011a      |
| 121 | Changsha | DR   | 3     | 5     | 5     | 2443.0 | 467.5     | 2910.5 | 7.57      | Shi et al., 2011a      |
| 122 | Changsha | DR   | 3     | 5     | 5     | 12688.1| 387.6     | 13075.7| 7.77      | Shi et al., 2011a      |
| 123 | Changsha | DR   | 3     | 5     | 5     | 4955.5 | 1086.8    | 6042.3 | 8.03      | Shi et al., 2011a      |
| 124 | Taoyuan  | DR   | 3     | 5     | 3     | 13485.0| 70.2      | 13555.2| 5.40      | Shang et al., 2010     |
| No. | Location | DR | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|-----|----------|----|---|---|---|---|---|---|---|---|---|
| 125 | Taoyuan  | DR | 3 | 5 | 3 | 20674.2 | 190.4 | 20864.6 | 5.58 | 3739.2 | Shang et al., 2010 |
| 126 | Taoyuan  | DR | 3 | 5 | 3 | 18770.0 | 101.5 | 18871.5 | 5.38 | 3507.7 | Shang et al., 2010 |
| 127 | Wangcheng | DR | 3 | 5 | 3 | 19548.0 | 428.8 | 19976.8 | 5.25 | 3805.1 | Qin et al., 2006a; Qin et al., 2006b* |
| 128 | Wangcheng | DR | 3 | 5 | 3 | 11016.0 | 217.0 | 11233 | 5.55 | 2024.0 | Qin et al., 2006a; Qin et al., 2006b* |
| 129 | Wangcheng | DR | 3 | 5 | 3 | 5562.0 | 253.0 | 5815 | 5.30 | 1098.2 | Qin et al., 2006a; Qin et al., 2006b* |
| 130 | Changsha | DR | 3 | 4 | 5 | 8210.0 | 312.9 | 8522.9 | 7.90 | 1079.1 | Tang et al., 2010a; Tang et al., 2010b* |
| 131 | Changsha | DR | 3 | 4 | 5 | 9602.5 | 402.3 | 10004.8 | 8.23 | 1216.1 | Tang et al., 2010a; Tang et al., 2010b* |
| 132 | Changsha | DR | 3 | 4 | 5 | 9150.0 | 324.8 | 9474.8 | 8.34 | 1135.7 | Tang et al., 2010a; Tang et al., 2010b* |
| 133 | Changsha | DR | 3 | 4 | 5 | 14725.0 | 420.2 | 15145.2 | 8.03 | 1885.1 | Tang et al., 2010a; Tang et al., 2010b* |
| 134 | Changsha | DR | 3 | 4 | 5 | 13627.5 | 399.3 | 14026.8 | 8.57 | 1637.3 | Tang et al., 2010a; Tang et al., 2010b* |

* Yield data were obtained from these papers. (Similarly hereinafter)
Table S3 Rice varieties used in the multi-field experiment 1 to compare GHG emissions in three cropping systems from 1960s to 2000s. SR, single rice cropping system; RU, rice-upland cropping system; DR, double rice cropping system.

| Cropping system | Time | Rice variety   | Cropping system | Time | Rice variety   | Cropping system | Time | Rice variety   |
|-----------------|------|----------------|-----------------|------|----------------|-----------------|------|----------------|
| SR              | 1960s| Qinsen 5       | RU              | 1960s| Feilaifeng     | DR              | 1960s| Nante          |
|                 |      |                |                 |      |                |                 |      | Nante          |
|                 |      | Ningfeng       |                 |      |                |                 |      | Liantangzao    |
|                 | 1970s| Fengjin        |                 | 1970s| Jinnanfeng     |                 | 1970s| Zhaoyangzao    |
|                 |      |                |                 |      |                |                 |      | Xianfeng 1     |
|                 | 1980s| Liaojing 5     |                 | 1980s| Wufujing       |                 | 1980s| Zhefu 802      |
|                 |      | Liaojing 10    |                 |      | Xudao 2        |                 |      | Ganzaoxian 7   |
|                 | 1990s| Liaojing 454   |                 | 1990s| Yangdao 6      |                 | 1990s| HuHongzao 1    |
|                 |      | Liaojing 9     |                 |      |                |                 |      | Zhongxuan 181  |
|                 | 2000s| Liaojing 9     |                 |      |                |                 |      | Jinzao 47      |
|                 |      | Liaojing 1     |                 |      |                |                 |      |                |
Table S4 Emission scenarios for future rice production. S0 is a conservative scenario with the assumption that “no cropping practice changes”. Scenario S1, S2 and S3 assume that only cropping system changes, only rice variety changes, and only irrigation regime changes were considered, respectively. Scenario S4 is an optimal scenario that incorporates all the improved practices. In all scenarios, a 0.8% annual increase in rice yield was assigned to meet the need for the growing population in 2030s.

| Scenario | Yield | Cropping system adjustment | Rice variety improvement | Water regime improvement |
|----------|-------|----------------------------|--------------------------|--------------------------|
| S0       | Constant | Constant                      | Constant                      | Constant                      |
| S1       | +0.8% yr⁻¹ | CH₄, -0.2% yr⁻¹ | Constant | CH₄, -0.5% yr⁻¹ |
|          |         | N₂O, +1.5% yr⁻¹ | | N₂O, +1.0% yr⁻¹ |
| S2       | +0.8% yr⁻¹ | Constant                      | CH₄, -0.5% yr⁻¹ | CH₄, -0.5% yr⁻¹ |
|          |         | N₂O, +1.0% yr⁻¹ | | N₂O, +1.0% yr⁻¹ |
| S3       | +0.8% yr⁻¹ | Constant                      | Constant | CH₄, -0.6% yr⁻¹ |
|          |         |                             | | N₂O, +7.5% yr⁻¹ |
| S4       | +0.8% yr⁻¹ | CH₄, -0.2% yr⁻¹ | CH₄, -0.5% yr⁻¹ | CH₄, -0.6% yr⁻¹ |
|          |         | N₂O, +1.5% yr⁻¹ | N₂O, +1.0% yr⁻¹ | N₂O, +7.5% yr⁻¹ |
Table S5 The estimated coverage (%) of rice planting methods and irrigation methods (post-transplanting stage) under different rice cropping systems from 1960s to 2000s. SR, single rice cropping system; RU, rice-upland cropping system; DR, double rice cropping system. Planting methods include manual transplanting (MAT), mechanized transplanting (MET) and direct seeding (DS). Irrigation methods include continuous flooding (CF) and water-saving irrigation (WS).

| Planting method | SR MAT | MET | DS | RU MAT | MET | DS | DR MAT | MET | DS |
|-----------------|--------|-----|----|--------|-----|----|--------|-----|----|
| 1960s           | 100    | 0   | 0  | 93     | 0   | 7  | 96     | 0   | 4  |
| 1970s           | 100    | 0   | 0  | 93     | 0   | 7  | 96     | 0   | 4  |
| 1980s           | 74     | 26  | 0  | 83     | 9   | 8  | 80     | 16  | 4  |
| 1990s           | 46     | 52  | 2  | 69     | 18  | 13 | 62     | 30  | 8  |
| 2000s           | 23     | 70  | 7  | 43     | 39  | 18 | 38     | 45  | 17 |

| Irrigation method | SR CF | WS | RU CF | WS | DR CF | WS |
|-------------------|-------|----|-------|----|-------|----|
| 1960s             | 100   | 0  | 100   | 0  | 100   | 0  |
| 1970s             | 100   | 0  | 90    | 10 | 95    | 5  |
| 1980s             | 65    | 35 | 68    | 32 | 55    | 45 |
| 1990s             | 35    | 65 | 49    | 51 | 29    | 71 |
| 2000s             | 25    | 75 | 25    | 75 | 12    | 88 |
Table S6 The effects of different rice variety on CH₄ and N₂O emissions and their global warming potentials (GWP) determined by multi-site field experiment 1. Cropping system incudes single rice (SR), rice-upland (RU), and double rice (DR) cropping systems. Data shown are mean values of 2 varieties in each time period and the standard deviation (SD) (n = 6 replicates of rice varieties).

| System | Rice varieties | CH₄ (kg CO₂-eq ha⁻¹) | N₂O (kg CO₂-eq ha⁻¹) | Area-scaled GWP (kg CO₂-eq ha⁻¹) | Yield-scaled GWP (kg CO₂ eq Mg⁻¹) |
|--------|----------------|-----------------------|-----------------------|-----------------------------------|----------------------------------|
| SR     | 1960S          | 3899.5 592.5          | 616.3 141.1           | 4515.9 643.1                      | 597.5 163.6                     |
|        | 1970S          | 4097.1 764.1          | 545.8 64.6            | 4642.9 743.8                      | 664.9 280.3                     |
|        | 1980S          | 3847.4 1009.0         | 497.7 161.6           | 4372.1 1056.8                     | 489.7 106.8                     |
|        | 1990S          | 3699.5 639.3          | 364.7 91.4            | 4064.2 640.0                      | 434.4 83.2                      |
|        | 2000S          | 2926.7 511.0          | 441.1 90.3            | 3367.7 526.2                      | 353.5 61.6                      |
| RU     | 1960S          | 5487.2 532.1          | 89.9 39.6             | 5577.1 514.6                      | 988.1 80.5                      |
|        | 1970S          | 5770.4 701.6          | 135.5 57.9            | 5905.8 729.3                      | 965.5 131.0                     |
|        | 1980S          | 3649.3 680.7          | 141.9 32.0            | 3791.2 678.6                      | 536.4 114.4                     |
|        | 1990S          | 3738.3 680.4          | 124.4 27.6            | 3862.8 675.5                      | 524.8 140.0                     |
|        | 2000S          | 3487.9 460.8          | 141.8 27.0            | 3639.6 455.3                      | 439.5 64.5                      |
| DR     | 1960S          | 9243.7 1110.3         | 141.4 78.9            | 9385.0 1039.9                     | 2071.6 207.0                    |
|        | 1970S          | 8760.2 805.1          | 130.2 37.4            | 8890.4 830.5                      | 1666.1 172.5                    |
|        | 1980S          | 9094.2 1009.6         | 164.8 53.9            | 9259.0 999.0                      | 1610.2 147.7                    |
|        | 1990S          | 8420.9 653.3          | 187.4 58.6            | 8608.3 688.4                      | 1462.6 86.2                     |
|        | 2000S          | 7135.8 616.2          | 175.2 70.0            | 7311.0 658.9                      | 1197.4 131.7                    |
Table S7 The effect of water management on CH₄ and N₂O emissions and their global warming potentials (GWP) during rice nursery and post-transplanting stage determined by multi-site field experiment. Cropping system includes single rice (SR), rice-upland (RU), and double rice (DR) cropping systems. Water regimes includes continuous flooding (CF) and water-saving irrigation (WS). Data shown are mean values of each irrigation practice and the standard deviation (SD) (n = 3).

| System | Practice | CH₄ (kg CO₂-eq ha⁻¹) | N₂O (kg CO₂-eq ha⁻¹) | Area-scaled GWP (kg CO₂-eq ha⁻¹) | Yield-scaled GWP (kg CO₂ eq Mg⁻¹) |
|--------|----------|----------------------|-----------------------|-----------------------------------|----------------------------------|
| Nursery stage |
| SR | CF | 1093.4 | 98.3 | 122.0 | 7.2 | 1215.5 | 96.6 | - | - |
| | WS | 9.0 | 1 | 153.9 | 9.7 | 162.9 | 8.7 | - | - |
| RU | CF | 1133.4 | 43.1 | 35.7 | 1.2 | 1169.1 | 43.9 | - | - |
| | WS | 166.0 | 28.6 | 126.9 | 6.2 | 292.9 | 25.9 | - | - |
| DR | CF | 1016.0 | 52.9 | 89.4 | 5.8 | 1105.4 | 53.9 | - | - |
| | WS | 180.3 | 7.3 | 193.9 | 6.8 | 374.2 | 14.2 | - | - |
| Post-transplanting stage |
| SR | CF | 5618.1 | 614.7 | 53.5 | 9.1 | 5671.6 | 632.9 | 799.4 | 178.1 |
| | WS | 2696.7 | 295.0 | 198.5 | 34.3 | 2895.2 | 303.8 | 319.8 | 85.5 |
| RU | CF | 7039.3 | 554.2 | 40.3 | 6.9 | 7079.6 | 547.6 | 1103.4 | 167.0 |
| | WS | 3378.9 | 266.0 | 152.9 | 26.0 | 3531.8 | 262.7 | 460.9 | 80.2 |
| DR | CF | 14903.4 | 741.3 | 41.6 | 5.3 | 14945.0 | 792.5 | 2911.8 | 318.8 |
| | WS | 7153.8 | 355.8 | 157.2 | 20.0 | 7311.0 | 380.4 | 1256.0 | 318.8 |
Fig. S1 Locations of studies included in our meta-analysis, field experiments and expert survey.
Fig. S2 The coverage of water saving nursery from expert survey (A) and the effect of water saving nursery on greenhouse gas emission from multi-field experiment (B). SR, annually single rice cropping system. RU, annually rice-upland rotation cropping system. DR, annually double rice cropping system.
References:

Chen, W., 2007. N2O emissions from Paddy field ecosystem in Sanjiang Plain. MD thesis, Jilin Agricultural University, Changchun

Dai, G., Li, C., Cao, C., Zhan, M., Tong, L., Mei, S., Zhai, Z., Fan, D., 2009. Effect of no-till age and fertilization on paddy soil CH4 and N2O emissions and their greenhouse effect in Central China. Chinese Journal of Applied Ecology 20, 2166-2172.

Jiang, C., Wang, Y., Zheng, X., Zhu, B., Huang, Y., Hao, Q., 2006. Methane and nitrous oxide emissions from three paddy rice based cultivation systems in Southwest China. Advances in Atmospheric Sciences 23, 415-424.

Kreye, C., Dittert, K., Zheng, X., Zhang, X., Lin, S., Tao, H., Sattelmacher, B., 2007. Fluxes of methane and nitrous oxide in water-saving rice production in north China. Nutrient Cycling in Agroecosystems 77, 293-304.

Li, M., Xu, Y., Shen, Q., Zhou, C., Huang, X., Yin, X., Yin, J., Dittert, K., 2003. Methane and Nitrous oxide fluxes in aerobic and waterlogged production systems of rice crop. Acta Pedologica Sinica 40, 864-870.

Liu, S., Zhang, L., Jiang, J., Chen, N., Yang, X., Xiong, Z., Zou, J., 2012. Methane and nitrous oxide emissions from rice seedling nurseries under flooding and moist irrigation regimes in Southeast China. Sci. Total Environ. 426, 166–171.

Liu, Y., Dokohely, M., Fan, C., Li, Q., Zhang, X., Zhao, H., Xiong, Z., 2016. Influence of different seedling-nursing methods on methane and nitrous oxide emissions in the double rice cropping system of South China. CLEAN–Soil, Air, Water 44, 1733–1738.

Ma, J., Li, X.L., Xu, H., Han, Y., Cai, Z.C., Yagi, K., 2007. Effects of nitrogen fertiliser and wheat straw application on CH4 and N2O emissions from a paddy rice field. Australian Journal of Soil Research 45, 359-367.

Ma, J., Ma, E., Xu, H., Yagi, K., Cai, Z., 2009. Wheat straw management affects CH4 and N2O emissions from rice fields. Soil Biology and Biochemistry 41, 1022-1028.

Peng, S., Yang, S., Xu, J., Gao, H., 2011. Field experiments on greenhouse gas emissions and nitrogen and phosphorus losses from rice paddy with efficient irrigation and drainage management. Science China-Technological Sciences 54, 1581-1587.

Qin, X., 2011. Mitigation of greenhouse gas intensity from typical double rice field of central China. PhD thesis, Chinese Academy of Agricultural Sciences, Beijing
Qin, X., Li, Y., Liu, K., Wan, Y., 2006a. Methane and nitrous oxide emission from paddy field under different fertilization treatments. Transcations of the CSAE 22, 143-149.

Qin, X., Li, Y., Liu, K., Wan, Y., Gao, Q., 2006b. The effect of long-term fertilization treatment on methane emission from rice field in Hunan. Chinese Journal of Agrometeorology 27, 19-22.

Qin, Y., Liu, S., Guo, Y., Liu, Q., Zou, J., 2010. Methane and nitrous oxide emissions from organic and conventional rice cropping systems in Southeast China. Biology and Fertility of Soils 46, 825-834.

Shang, Q., Yang, X., Gao, C., Wu, P., Liu, J., Xu, Y., Shen, Q., Zou, J., Guo, S., 2010. Net annual global warming potential and greenhouse gas intensity in Chinese double rice-cropping systems: a 3-year field measurement in long-term fertilizer experiments. Global Change Biology, 2196-2210.

Shi, S., Li, Y., Li, M., Wan, Y., Gao, Q., Peng, H., Qin, X., 2011a. Anual CH₄ and N₂O emissions from double rice cropping systems under various fertilizer regimes in Hunan Province, China. Chinese Journal of Atmospheric Sciences 35, 707-720.

Shi, S., Li, Y., Wan, Y., Qin, X., Gao, Q., 2011b. Obsevation for CH₄ and N₂O emissions under different rates of nitrogen and phosphate fertilization in double rice fields. Environmental science 32, 1989-1998.

Tang, H., Tang, W., Shuai, X., Yang, G., Tang, H., Xiao, X., 2010a. Effects of winter cover crop on methane and nitrous oxide emission from paddy field. Chinese Journal of Applied Ecology 21, 3191-3199.

Tang, H., Tang, W., Xiao, X., Tang, H., Yang, G., 2010b. Effects of different winter cover plants on biological characteristics and yield traits of rice in Southern China. Journal of Agricultural Science and Technology 12, 108-113.

Wang, Y., Chen, W., Zhao, Z., Gu, J., 2008. Charateristics and estimation of CH₄, N₂O emission from cold paddy field in the Sanjiang Plain. Transcations of the CSAE 24, 170-176.

Yuan, W., Cao, C., Li, C., Zhan, M., Cai, M., Wang, J., 2009. Methane and nitrous oxide emissions from rice-fish and rice-duck complex ecosystems and the evaluation of their economic significance. Scientia Agricultura Sinica 42, 2052-2060.

Yue, J., Liang, W., Wu, J., Shi, Y., Huang, G., 2003. CH₄ and N₂O emission from phaeozem rice field and their mitigative measures. Chinese
Yue, J., Shi, Y., Liang, W., Wu, J., Wang, C., Huang, G., 2005. Methane and Nitrous Oxide Emissions from Rice Field and Related Microorganism in Black Soil, Northeastern China. Nutrient Cycling in Agroecosystems 73, 293-301.

Zhan, M., Cao, C., Wang, J., Li, C., Yuan, W., 2009. Greenhouse gas emissions from an integrated rice-duck system and its Global Warming Potentials. Acta Scientiae Circumstantiae 29, 420-426.

Zhang, A., Cui, L., Pan, G., Li, L., Hussain, Q., Zhang, X., Zheng, J., Crowley, D., 2010a. Effect of biochar amendment on yield and methane and nitrous oxide emissions from a rice paddy from Tai Lake plain, China. Agriculture, Ecosystems & Environment 139, 469-475.

Zhang, Y., Chen, L., Wang, Z., Zhang, C., Zhu, P., Shen, J., Zheng, J., 2010b. Characteristics of CH$_4$ and N$_2$O emissions and greenhouse effects for mechanical transplanting rice in rice-wheat rotation system. Journal of Agro-Environment Science 29, 1403-1409.

Zhang, Y., Zheng, J., Chen, L., Wang, Z., Zhu, P., Shen, J., Wang, Y., 2009. Effects of wheat straw returning and soil tillage on CH$_4$ and N$_2$O emissions in paddy season. Ecology and Environmental Sciences 18, 2334-2338.

Zou, J., Huang, Y., Zong, L., Wang, Y., L.Sass, R., 2003. Integrated effect of incorporation with different organic manures on CH4 and N2O emissions from rice paddy. Environmental science 24, 7-13.

Zou, J., Liu, S., Qin, Y., Pan, G., Zhu, D., 2009. Sewage irrigation increased methane and nitrous oxide emissions from rice paddies in southeast China. Agriculture, Ecosystems & Environment 129, 516-522.