Supplementary material

Extracted carbon budgets and trait values supporting the main-text synthesis. Tables S1–S6 retain study-level data and calculations; Tables S7–S8 provide additional measurement metadata and quantitative examples. The main article presents the interpretation and rationale for the proposed criteria.

Table S1

Annual carbon budget and seasonal observations in the cover-crop–rice rotation of Haque et al. (2020)

Component (kg C ha^{-1} yr^{-1})	0 Mg DM ha^{-1}	3 Mg DM ha^{-1}	6 Mg DM ha^{-1}	12 Mg DM ha^{-1}
NPP (shoots, roots and litter)	11,470	14,334	13,495	13,414
Root C	1,127	1,378	1,326	1,346
Litter C	291	461	454	522
Incorporated cover-crop C	0	1,276	2,505	4,963
Urea C (study convention)	20	20	20	20
Total C input	11,490	15,630	16,020	18,397
CO_2-C (heterotrophic respiration)	2,870	3,260	4,070	4,955
CH_4-C emissions	113	223	455	702
Harvested C export	9,998	12,441	11,661	11,493
Total C loss	12,981	15,924	16,186	17,150
NECB = inputs − losses	−1,491	−294	−166	+1,247

Annual values refer to 2012–2013. Column headings are incorporated cover-crop dry matter (DM). NPP, net primary production, includes root and litter C; those rows are not added again. Total input = NPP + incorporated cover-crop C + urea C. Total loss = heterotrophic CO_2-C + CH_4-C + harvested C. NECB = total input - total loss. Urea C follows the study convention for 90 kg N ha^{-1}. Annual harvested C includes cover biomass and rice grain and straw.

Experimental context. Silt-loam soil in South Korea; barley–vetch in November–May and rice in June–October. Cover biomass was incorporated seven days before transplanting. Rice was flooded to 5–7 cm and drained three weeks before harvest. Grain and straw were removed. Roots were sampled at harvest, litter at maturity, and gaseous fluxes with chambers.

Seasonal observations pooled across the 2011–2012 and 2012–2013 rotations (kg C ha^{-1} $season^{-1}$): rice roots 660–921; rice litter 276–406; rice harvest export 4,845–7,203; rice NECB −56 to +2,652; cover-crop NECB −1,523 to −1,402. Endpoints from different treatments or years cannot be added to reconstruct an annual budget.

Table S2

Carbon measurements and accounting boundaries in the other studies summarized in main-text Table 1

Study and temporal basis	Reported quantities	Experimental context and interpretation
Mandal et al. (2021) Annual, 2018–2019	NEP 6.18–7.30; CH_4-C 0.133–0.208; harvest C 6.49–7.70; NECB +0.63 to +2.51 Mg C ha^{-1} yr^{-1}.	Rice–rice field trial, coastal West Bengal, 2012–2019; three tillage regimes with and without residue retention. Day/night chambers and CH_4 sampling; NECB also accounts for runoff C. Ranges span treatments, not a single budget.
Yadav et al. (2019) 2013–2015	Biomass inputs 2.0–3.0 Mg C ha^{-1} yr^{-1}; soil-stock change 133.6–444.7 kg C ha^{-1} yr^{-1}.	Rice–rice trial, Tripura; submerged versus rainfed/supplementally irrigated plots; conventional versus reduced/no tillage with 30% residue incorporation/retention. Fixed-depth soil stocks, 0–20 cm; stock-change values are tillage means across water regimes.
Zhu et al. (2017) 30 d after pulse labeling	Estimated C in roots + soil: 2,558; 3,034; 4,583 kg C ha^{-1} for low, moderate and high initial SOC.	Flooded pots, Zhongyou 169; initial SOC 0.5/1.4/3.4%. A 7-h $^{13}CO_2$ pulse at tillering was followed for 30 d. Estimates combine tracer partitioning and shoot C and are scaled to 2.25 × 10^6 kg soil ha^{-1}; these are not measured annual field stock gains.

Note. NEP, net ecosystem production; NECB, net ecosystem carbon balance; SOC, soil organic carbon. Ranges span treatments and cannot be combined as one budget. Short-term allocation and positive NECB are not equivalent to persistent soil sequestration.

Table S3

Harvest-index variation in the 203-accession *O. sativa* panel of X. Li et al. (2012)

Site (2009)	Accessions	HI mean ± SD	HI range
Stuttgart, Arkansas	203	0.3044 ± 0.0702	0.0340–0.4506
Beaumont, Texas	203	0.3898 ± 0.1051	0.0625–0.6002

Values from the source Table 1 were divided by 100 to express percentages as fractions; SD was converted in the same way. The same panel was evaluated at both sites. Genotypic groups comprised *indica*, temperate and tropical *japonica*, aus, aromatic and admixed accessions; no group-specific HI range is inferred here.

The field experiments used three randomized blocks, nine plants per plot at 0.3 × 0.6 m spacing, 55 kg N ha^{-1} before permanent flooding at the five-leaf stage, and three sampled plants per plot. HI was based on mature plant and grain masses after air drying, not an explicitly oven-dry mass protocol; no conversion between these mass bases is assumed. Site-specific distributions therefore describe this panel and protocol, not agronomic targets or independent samples of 406 genotypes.

Table S4

Total leaf area index at heading in six *japonica* cultivars from Q. Liu et al. (2022)

Cultivar (semi-waxy *japonica*)	Heading LAI, 2018	Heading LAI, 2019
Nanjing 5718	8.21	8.32
Nanjing 9108	7.64	7.85
Su 1785	8.18	7.99
Songzaoxiang No. 1	6.82	6.90
Changruan 07-5	6.99	6.86
Suxiangjing No. 3	6.69	6.73

Source: Table 4; LAI in m^2 m^{-2}. Field trials in Taizhou, Jiangsu, 2018–2019; three blocks, 3 × 5 m plots, 270 kg N ha^{-1}, 25 × 6 cm hill spacing and two seedlings per hill. The source reports standard agronomic water management without a quantified irrigation threshold. The extracted cultivar-year means span 6.69–8.32; the high-effective LAI column was not used.

Extraction boundary. This study is used only for LAI. Its methods report yield at 14% moisture and define HI using total dry matter; the published HI values were not imported into the dry-mass comparison without resolving that mass-basis issue.

Table S5

Heading leaf area index in the eight rice materials evaluated by Xu et al. (2020)

Cultivar	Genetic category in source	Heading LAI, 2017	Heading LAI, 2018
Chunyou 84	*japonica*/*indica* hybrid	7.52	7.68
Chunyou 927	*japonica*/*indica* hybrid	7.53	7.41
Jiayouzhongke 13-1	*japonica*/*indica* hybrid	7.47	7.51
Jiayouzhongke 10	*japonica*/*indica* hybrid	7.47	7.38
Yongyou 12	*japonica*/*indica* hybrid	7.64	7.68
Yongyou 538*	*japonica*/*indica* hybrid	7.63	7.65
Sujing 9	Conventional *japonica*	6.75	6.84
Wuyunjing 31	Conventional *japonica*	6.83	6.75

Source: Table 3; LAI in m^2 m^{-2}. Ningbo field trials, 2017–2018; three blocks, 25 m^2 plots and 270 kg N ha^{-1}. Hybrid hill spacing was 14.6 × 30.0 cm with two seedlings per hill; conventional *japonica* spacing was 13.1 × 30.0 cm with four seedlings per hill. The irrigation schedule was not quantitatively specified. Ranges across cultivar-year means are 7.38–7.68 for the six hybrids and 6.75–6.84 for the two conventional cultivars.

*The label Yongyou 538 follows the source Table 3. The methods section instead states YY583. This internal naming discrepancy is retained explicitly rather than silently reconciled; it does not change the numeric range extracted from the table.

Table S6

Source LMA means and calculated SLA for cultivated rice entries in two pot studies

Source and material	N supply (g pot^{-1})	Mean LMA (g m^{-2})	Calculated SLA (m^2 kg^{-1})
M. Ye et al. (2020): Sab Ini	2.0	53.0	18.9
M. Ye et al. (2020): Nucleoryza	2.0	49.2	20.3
M. Ye et al. (2020): Champa	2.0	45.0	22.2
M. Ye et al. (2020): Kirmizi Celtik	2.0	49.8	20.1
M. Ye et al. (2020): Huayou 675	2.0	48.8	20.5
M. Ye et al. (2020): Huanghuazhan	2.0	57.3	17.5
M. Ye et al. (2020): Teqing	2.0	46.9	21.3
M. Ye et al. (2020): Yongyou 12	2.0	71.7	13.9
Xiong et al. (2016): Nipponbare	3.0	40.8	24.5
Xiong et al. (2016): Shanyou 63	3.0	36.1	27.7
Xiong et al. (2016): Huanghuazhan	3.0	43.8	22.8
Xiong et al. (2016): N22	3.0	40.5	24.7
Xiong et al. (2016): Gangyou 118	3.0	43.2	23.1
Xiong et al. (2016): Zhenshan 97B	3.0	42.9	23.3
Xiong et al. (2016): Huanghuazhan	0.5	51.4	19.5
Xiong et al. (2016): N22	0.5	34.8	28.7
Xiong et al. (2016): Gangyou 118	0.5	41.7	24.0
Xiong et al. (2016): Zhenshan 97B	0.5	42.2	23.7

SLA, specific leaf area; LMA, leaf mass per area. SLA = 1000/LMA for the units in the column headings. Calculations use published genotype-treatment mean LMA, retain full precision until final rounding, and do not invert standard errors or imply individual-leaf SLA means. Sources: M. Ye et al. (2020), Table 1; Xiong et al. (2016), Tables 1–2. Five wild Oryza entries in Xiong et al. were excluded; the low-N treatment includes only four of the six cultivated entries.
M. Ye et al.: Wuhan, April–August 2015, outdoor 11-L pots with 10 kg soil, at least 2 cm standing water, three hills per pot and two seedlings per hill. Newly expanded flag leaves were sampled from three pots per genotype. Genetic subgroups were not stratified for this extraction.
Xiong et al.: Wuhan, May–July 2013, outdoor 15-L pots with 13 kg soil, at least 2 cm standing water and three plants per pot. Young, fully expanded leaves were sampled 40 days after transplanting. The cultivated panel includes Nipponbare, Shanyou 63, Huanghuazhan, N22, Gangyou 118 and Zhenshan 97B. No additional subgroup assignment is inferred from cultivar names.

Table S7

Additional growth and measurement metadata for physiological comparisons

Study/measurements	Growth conditions	Additional measurement details
Oue (2023) g_s and ETR	Koshihikari, Himenorin, Nikomaru; loamy-soil boxes; screen house; ~5 cm ponding and midseason drainage. Prior paddy fertilization: 66/36/42 kg ha^{-1} N/P_2O_5/K_2O.	Flag leaves; LI-600PF; 08:30–12:00 JST. Records selected for comparable ambient PAR. CO_2, temperature, and VPD setpoints NR. ETR assumptions appear in main-text Table 4.
Wu et al. (2014) PSII yields and transpiration	ChangBai-9; aerated, daily renewed Yoshida solution. Control versus 30 d at 35 mM $NaHCO_3$:Na_2CO_3 (9:1), pH 8.9. Growth: 27/22°C, 16/8 h light/dark; PPFD 250 µmol photons m^{-2} s^{-1}.	LI-6400x; gas exchange at PPFD 1200 µmol photons m^{-2} s^{-1}; CO_2, leaf temperature, and VPD setpoints NR. Fluorescence: actinic PPFD, saturating-pulse settings, dark-adaptation duration and measurement temperature NR.
Hirayama et al. (2006) Leaf–air temperature	22 varieties/lines; upland field, Mito, 1995; minimum irrigation around heading.	Top unfolded leaves; 13:00–15:00, 15 July; fine, breezy weather. Infrared leaf temperature with concurrent air temperature; ranges represent four group means.
Zhao et al. (2026) Temperature-response model	Huanghua Zhan; naturally lit climate chambers; 5 g N–P_2O_5–K_2O (19–5–8) per 10 kg soil. Water depth 10–50 mm, except late tillering and yellow ripening.	Youngest fully expanded leaves, then flag leaves; 09:00–12:00. Protocol 2 matched prevailing chamber conditions. Model pooled treatments, stages and years using leaf temperature, leaf-to-air VPD, PAR and leaf development.
Ni et al. (2026) Photosynthetic contrast	CSSL #19 and #91, Yangdao 6 background; Yangzhou field, 2023–2024; 0/120/240 kg N ha^{-1}.	Leaf chamber: 30°C; CO_2 400 µmol mol^{-1}; PPFD 1500 µmol photons m^{-2} s^{-1}. The main-text contrast is a relative difference in peak net assimilation.

Note. Growth conditions are not instrument settings. NR, not reported; PAR, photosynthetically active radiation; PPFD, photosynthetic photon flux density; VPD, vapor pressure deficit; ETR, electron transport rate; CSSL, chromosome single-segment substitution line.

Table S8

Additional quantitative observations for the root, source, and sink comparisons

Quantity (unit)	Materials / experimental basis	Study-level values	Source
Subsoil root length (%)	IRRI drought clusters; root length in 20–40 cm relative to 0–40 cm.	10–21	Fonta et al. (2022)
RLD (cm cm^{-3})	IRRI field drought; 30–45 cm; 72 DAS (2008), 92 DAS (2009).	2008: 0.024–0.23 2009: 0.19–0.81	Henry et al. (2011)
RLD (cm cm^{-3})	Thailand, 2011; four check cultivars; 10–30 cm, 44 DAT.	Flooded: 1.07–1.84 Nonflooded: 1.29–2.42	Y. Kato et al. (2013)
Heading LAI (m^2 m^{-2})	Jing 565, Nanjing 9108, Jing Liangyou 4466; Hubei, 2017–2018; 270 kg N ha^{-1}.	6.23–8.16 across all three; main-text Table 3 reports the first two.	Tu et al. (2022), Table 3
Spikelets panicle^{-1}	Zhendao 88; Liangyoupeijiu. Yangzhou, 2006–2008; 150 kg N ha^{-1}; three irrigation regimes.	Zhendao 88: 106–116 Liangyoupeijiu: 181–196	J. Yang and Zhang (2010), Table 4
Filled grains (%)	Same materials, site, years and irrigation regimes as preceding row.	Zhendao 88: 80.4–90.5 Liangyoupeijiu: 73.7–84.3	J. Yang and Zhang (2010), Table 4
Filled grains (%)	CSSL #19 and #91; Yangzhou, 2023; 0/120/240 kg N ha^{-1}.	#19: 77.12–84.12 #91: 92.49–93.78	Ni et al. (2026), Table 2
Apparent NSC remobilization (% of heading pool)	Wuyunjing 24 and Yongyou 2640; Yangzhou, 2018–2019; 270 kg N ha^{-1}; AWMD reirrigation at −15 kPa.	Well-watered: 24.4–35.0 AWMD: 59.7–68.9	Zang et al. (2024), Table 1
Apparent NSC contribution (% of grain yield)	Same experiment; denominator is grain yield, not the heading NSC pool.	7.3–19.4	Zang et al. (2024), Table 1

Note. Ranges retain their study-specific materials and treatments. RLD, root length density; DAS/DAT, days after sowing/transplanting; LAI, leaf area index; CSSL, chromosome single-segment substitution line; NSC, non-structural carbohydrates; AWMD, alternate wetting and moderate drying. Root fractions by length and mass, and percentages with different denominators, measure different things.