Supplementary Materials For

Carbon neutrality potential embodied in different agricultural management practices

Table S1. Groundwater elevation in different provinces

Province	Raise (m)
Beijing	39.09
Tianjin	58.31
Hebei	55.1
Jiangsu	32.33
Anhui	28.19
Shandong	58
Henan	25.8

Methods

Nutrient resources of crop straw

In this study, the calculations of crop straw yield and nutrient resources were used only to parameterize the residue return scenarios. The crop straw yield is defined as the quantity of air-dried residues after harvest, including stalks, stubbles, and leaves [60]. Process residues such as rice hulls or corn cobs are excluded. The total straw yield (SY_{total}) in the North China Plain (NCP) was estimated by multiplying the crop yield (CY) by the field residue index (FR) for each crop:

$$SY_{total}=\sum CY_{ij} \times FR_{ij} \quad (1)$$

where i represents the crop type and j the NCP province. FR values for the three crops were obtained from the literature and listed in Table S2 [60,61].

Table S2. Field residue indices (FR) of the three crops (wheat, rice, corn) of the provinces in the North China Plain (NCP)

Province	Rice	Wheat	Corn
Beijing	1.10	1.29	1.02
Tianjin	1.33	1.16	0.99
Hebei	0.95	1.22	1.05
Jiangsu	1.24	1.41	1.00
Anhui	1.09	1.12	1.00
Shandong	1.29	1.39	0.96
Henan	0.97	1.29	1.07

Straw nutrient resources (SNR) were defined as the theoretical quantities of N, P_2O_5, and K_2O contained in the crop straw. Here, we calculated the SNR from the three crops to obtain total SNR values for each chemical in the NCP:

$$SNR_{N,i}=\sum SY_i \times NC_{N,i} \quad (2)$$

$$SNR_{P_2O_5,i}=\sum SY_i \times NC_{P,i} \times 2.29 \quad (3)$$

$$SNR_{K_2O,i}=\sum SY_i \times NC_{K,i} \times 1.2 \quad (4)$$

where i represents the crop type and $NC_{N,i}$, $NC_{P,i}$, and $NC_{K,i}$ are the straw nutrient content coefficients for N, P and K (Table S3) [14]. The coefficients 2.29 in equation (3) and 1.2 in equation (4) are conversion factors from P to P_2O_5 and K to K_2O, respectively [62,63].

Table S3. Nutrient content coefficients (NC_N, NC_P, and NC_K) of the three crops straw in the NCP.

Crop	NC_N	NC_P	NC_K
Rice	0.0091	0.0013	0.0189
Wheat	0.0065	0.0008	0.0105
Corn	0.0092	0.0015	0.0118

Table S4. Scenario settings for agricultural management practices in the NCP and percentage changes of water footprint, energy use, and GHG emissions in different scenarios relative to the 2018 baseline scenario (S0). Scenarios are grouped as baseline (S0), single-measure (S1–S5), two-measure (S6–S14), three-measure (S15–S19), and integrated four-measure (S20–S21) cases. ("-" indicates no change on the sector; "↑" indicates an increase on the sector; and "↓" represents a decrease on the sector.)

Combination of measures	Scenarios	Settings	Water footprint	Energy use	GHG emissions
Single measure	S0	Actual situation in 2018	-	-	-
	S1	A 30% reduction in nitrogen fertilizer	-	↓16%	↓20.3%
	S2	Advanced technology for nitrogen fertilizer production	-	↓7.5%	↓14.2%
	S3	Irrigation method changes to drip irrigation	↓5.9%	↑6.8%	↑12.9%
	S4	Irrigation method changes to sprinkler irrigation	↓4.9%	↓0.01%	↓0.03%
	S5	Straw return rate changes to 50%	-	↓9.7%	↓10.6%
Two measures	S6	S1+S2	-	↓21.3%	↓30.3%
	S7	S1+S3	↓5.9%	↓9.2%	↓7.1%
	S8	S1+S4	↓4.9%	↓21.3%	↓20.4%
	S9	S1+S5	-	↓25.6%	↓30.9%
	S10	S2+S3	↓5.9%	↓0.7%	↓1.3%
	S11	S2+S4	↓4.9%	↓7.5%	↓14.3%
	S12	S2+S5	-	↓16%	↓23.2%
	S13	S3+S5	↓5.9%	↓2.8%	↓2.3%
	S14	S4+S5	↓4.9%	↓9.7%	↓10.6%
Three measures	S15	S1+S2+S3	↓5.9%	↓14.5%	↓18.5%
	S16	S1+S2+S4	↓4.9%	↓21.3%	↓30.3%
	S17	S1+S2+S5	-	↓27.6%	↓39.2%
	S18	S2+S3+S5	↓5.9%	↓7%	↓10.3%
	S19	S2+S4+S5	↓4.9%	↓16%	↓23.2%

integrated	S20	S1+S2+S3+S5	↓5.9%	↓23%	↓26.3%
scenarios	S21	S1+S2+S4+S5	↓4.9%	↓28.5%	↓39.2%

Table S5. Crop straw yield (SY) of the three crops of the provinces in the NCP in 2018

Province	**SY_{wheat} (10^6 kg)**	**SY_{rice} (10^6 kg)**	**SY_{corn} (10^6 kg)**
Beijing	68.4	1.1	276.4
Tianjin	662.7	497.4	1094.4
Hebei	17698.9	463	18536.2
Jiangsu	12947	14732.2	2697.1
Anhui	13663.7	3405.6	5445
Shandong	34306.4	1271.8	24843.2
Henan	45988	4847.9	23864.2

Table S6. Straw nutrient resources (SNR_N, $SNR_{P_2O_5}$, and SNR_{K_2O}) of the three crops straw in the NCP

Crop type	**SNR_N (10^7 kg)**	**$SNR_{P_2O_5}$ (10^7 kg)**	**SNR_{K_2O} (10^7 kg)**
Wheat	81.5	23	157.9
Rice	22.9	7.5	57.2
Corn	70.6	26.7	108.7

References

60. Wang, X., Yang, L., Steinberger, Y., Liu, Z., Liao, S., Xie, G. Field crop residue estimate and availability for biofuel production in China. *Ren. Sustain. Energy Rev*. **2013**, 27, 864-875.
61. Wang, X.Y., Xue, S., Xie, G.H. Value-taking for residue factor as a parameter to assess the field residue of field crops. *J. China Agricul. Univ*. **2012**, 17, 1, 1–8 (in Chinese).
14. Yin, H., Zhao, W., Li, T., Cheng, X., Liu, Q. Balancing straw returning and chemical fertilizers in China: Role of straw nutrient resources. *Ren. Sustain. Energy Rev*. **2018**, 81, 2695-2702.
62. Gao, L.W., Ma, L., Zhang, W.F., Wang, F.H., Ma, W.Q., Zhang, F.S. Estimation of nutrient resource quantity of crop straw and its utilization situation in China. *Transactions of the Chinese Society of Agricultural Engineering* **2009**, 25, (7) (in Chinese).
63. He, P.A.; Li, R. Organic Fertilizer Nutrient in China. National Agro-Tech Extension and Service Center (NATESC). Beijing: China Agriculture Press, **1999** (in Chinese).