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SUPPLEMENTARY INFORMATION

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Conservation agriculture for sustainable intensification in South Asia

Mangi Lal Jat[1]✉, Debashis Chakraborty[2], Jagdish Kumar Ladha[3], Dharamvir Singh Rana[4], Mahesh Kumar Gathala[5], Andrew McDonald[6] and Bruno Gerard[7]

[1]International Maize and Wheat Improvement Center (CIMMYT), New Delhi, India. [2]ICAR-Indian Agricultural Research Institute, New Delhi, India. [3]Department of Plant Sciences, University of California, Davis, CA, USA. [4]International Rice Research Institute (IRRI), New Delhi, India. [5]International Maize and Wheat Improvement Center (CIMMYT), Dhaka, Bangladesh. [6]Soil and Crop Sciences Section, School of Integrative Plant Science, Cornell University, Ithaca, NY, USA. [7]International Maize and Wheat Improvement Center (CIMMYT), El Batan, Texcoco, Mexico. ✉e-mail: M.Jat@cgiar.org

Supplementary Information for:

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Supplementary Methods

Crude protein content in grains of crops

The crude protein contents in crops were collected from different sources (rice[1, 2], wheat[3, 4, 5], maize[6], and other crops[7, 8, 9, 10, 11]).

Calculation of GWP and CO_2 equivalent emissions

The CH_4 and NO_2 emissions were multiplied with respective GWP coefficients, and added to compute the global warming potential (GWP)[12]. The CO_2-equivalent emissions were the total of all estimated emissions related to crop production. These included the energy used in fuel (land preparation and crop establishment, pumping for irrigation, harvesting of crop and post-harvesting processes), fertilizers and agrochemicals uses, and multiplying each category by its carbon equivalent conversion factor (g CO_2-e MJ^{-1})[13], and summing up[14, 15].

Evaluation of heterogeneity and the publication bias

The between-study variability (heterogeneity) was evaluated through standard chi-squared test (Cochran's Q-statistic[16]), the I^2 statistic[17], and Tau-squared. A statistically significant ($p<0.05$) Cochran Q-test proved heterogeneity. The I^2 statistic described the percentage of variation in effect size estimates, which were due to heterogeneity rather than by chance[18]. We have considered $I^2 > 75\%$ for true heterogeneity. The Tau-squared implied the variance (heterogeneity) of the true effect sizes. We have reported the significant changes at $p<0.05$ or $p<0.01$. Publication bias was assessed through trim and fill method[19], which is a rank based non-parametric method. Funnel plots were generated for log-response ratios of response variables yield, water use efficiency and net economic return (**Supplementary Figure 2**). In case of all response variables, the studies are primarily symmetrical around the effect size (=0, the stripped line), indicating none or negligible publication bias.

Supplementary Results

Crop-based effects of different CA practices in terms of grain yield, protein equivalent yield, water use efficiency, and net economic return

Grain yields were significantly higher in wheat and maize crops under all the CA sublevels (**Supplementary Table 4**). Rice showed no change in yield (0.4%, -0.6 to 1.4%) in CA1, and comparable yield gains in CA2 (2.3%, CI 1.5 to 3.2%) and CA3 (3.7%, CI 0.8 to 6.6%). CA2 had a higher yield advantage in wheat (7.7%, CI 6.8 to 8.6%) compared to CA1 (4.3%, CI 2.6 to 6.0%), but similar to CA3 (5.2%, CI 1.5 to 9.2%). In the maize crop, all CA sublevels had similar yield benefits (CA1 and CA2 6.1%; CA3 16.0%). In the 'others' category, only CA2 had shown a yield increase of 4.2% (CI 1.0 to 7.5%), rest of the CA sublevels had marginal yield difference. In terms of PEY, all the crops followed similar trends as observed in grain yields.

Our analysis revealed higher water use efficiency in all the three CA sublevels (CA1, CA2 and CA3; **Supplementary Table 4**) in wheat and maize. In rice, CA2 only had higher use efficiency (2.7%; CI 0.7 to 4.8%), while CA1 and CA3 had marginal difference compared to conventional practice. In wheat, CA2 had higher use efficiency (24.8%) compared to CA3 (17.3%), but comparable to CA1 (21.3%), while in maize, all three CAs were comparable (12.1 to 23.2%). In 'others' category, CA1 and CA3 showed similar improvements in water use efficiencies, with a marginal change in CA2.

The net economic return in rice were comparable among CA sublevels (15.7-24.1%) (**Supplementary Table 4**). In wheat, however, CA3 led to a larger economic return of 47.7% compared to CA1 (35.6%) and CA2 (33.5%). In maize, on the other hand, CA1 gained higher return of 25.8% compared to CA3 (12.9%), but comparable to (22.4%). The 'others' crops category had a variable results though positive return in all three CA sublevels but higher in CA1 and CA3 (43.3% and 103.5%, respectively) than CA2 (11.1%).

Supplementary Tables

Supplementary Table 1 Comparison (% change over control) of grain yields among the CA sublevels, cropping systems, crops, and soil texture in the on-station and on-farm data

	On-station	On-farm
CA sublevel		
CA1	-0.3 (-3.6 to 3.0)	3.3 (2.3 to 4.2)
CA2	4.3 (1.0 to 7.6)	3.3 (2.3 to 4.2)
CA3	12.9 (5.4 to 20.8)	4.5 (2.0 to 7.1)
Cropping system		
Rice-Wheat	2.3 (-0.7 to 5.4)	4.8 (4.2 to 5.4)
Maize-Wheat	5.8 (1.0 to 10.8)	30.3 (24.8 to 36.1)
Rice-Maize	-3.2 (-10.6 to 4.8)	3.6 (2.7 to 4.5)
Cotton-Wheat	8.0 (-6.4 to 24.7)	-
Soybean-Wheat	0.8 (-12.4 to 15.9)	-
Pigeon pea-Wheat	2.8 (-22.1 to 35.6)	-
Rice-Lentil	-	4.0 (1.1 to 7.0)
Crop		
Rice	-6.0 (-10.5 to -1.3)	0.9 (0.2 to 1.7)
Wheat	5.2 (2.3 to 8.2)	6.9 (6.2 to 7.7)
Maize	5.4 (0.7 to 10.4)	8.0 (6.8 to 9.1)
Cotton	1.7 (-16.1 to 23.3)	-
Soybean	9.7 (-24.3 to 59.0)	-
Pigeon pea	6.7 (-24.3 to 126.8)	-
Lentil	-	4.1 (1.1 to 7.1)
Mung bean	15.8 (-39.4 to 121.5)	2.6 (-3.9 to 9.5)
Soil texture		
Clayey (Fine)	6.4 (-2.8 to 16.5)	1.8 (0.7 to 2.9)
Loamy (Moderately fine)	-1.4 (-5.8 to 3.1)	6.6 (5.5 to 7.7)
Loamy (Medium)	5.1 (0.2 to 10.2)	4.7 (3.9 to 5.5)
Loamy (Moderately coarse)	4.3 (1.0 to 7.7)	5.3 (4.4 to 7.7)
Sandy (Coarse)	-2.1 (-13.8 to 1.1)	6.2 (-4.6 to 18.2)

Supplementary Table 2 Comparison (% change over control) of protein equivalent yields among the CA sublevels, cropping systems, crops, and soil texture in the on-station, on-farm and combined (on-station+on-farm) data

	On-station	On-farm	On-station + On-farm
CA sublevel			
CA1	-0.3 (-3.5 to 3.0)	3.3 (2.3 to 4.2)	3.1 (2.1 to 3.8)
CA2	4.3 (1.1 to 7.6)	3.4 (2.5 to 4.2)	5.8 (5.2 to 6.3)
CA3	12.8 (5.4 to 20.7)	4.5 (2.1 to 7.0)	5.6 (3.3 to 7.8)
Cropping system			
Rice-Wheat	2.3 (-0.8 to 5.4)	4.8 (4.3 to 5.4)	5.2 (4.6 to 5. 8)
Maize-Wheat	5.7 (1.0 to 10.8)	30.1 (24.8 to 36.0)	18.6 (14.8 to 22.5)
Rice-Maize	-3.3 (-10.8 to 4.8)	3.4 (2.7 to 4.4)	4.3 (2.8 to 4.6)
Cotton-Wheat	8.1 (-6.3 to 24.7)	-	-
Soybean-Wheat	0.8 (-12.4 to 15.8)	-	-
Pigeon pea-Wheat	2.6 (-22.2 to 35.7)	-	-
Rice-Lentil	-	4.0 (1.2 to 7.0)	-
Crop			
Rice	-6.0 (-10.5 to -1.3)	0.9 (0.2 to 1.7)	1. 6 (0.8 to 2.5)
Wheat	5.2 (2.3 to 8.2)	6.9 (6.2 to 7.7)	6.8 (6.1 to 7.6)
Maize	5.4 (0.7 to 10.4)	8.0 (6.8 to 9.1)	6.2 (5. 1 to 7.4)
Cotton	1.7 (-16.1 to 23.3)	-	
Soybean	9.7 (-24.3 to 59.1)	-	-
Pigeon pea	6.5 (-24.1 to 126.8)	-	
Lentil	-	4.1 (1.1 to 7.1)	-
Mung bean	15.7 (-39.5 to 121.5)	2.6 (-3.9 to 9.4)	-
Soil texture			
Clayey (Fine)	6.4 (-2.8 to 16.5)	1.8 (0.7 to 2.9)	2.4 (1.4 to 3.5)
Loamy (Moderately fine)	-1.4 (-5.8 to 3.1)	6.6 (5.5 to 7.7)	7.5 (6.4 to 8.5)
Loamy (Medium)	5.1 (0.2 to 10.2)	4.7 (3.9 to 5.5)	4.2 (3.4 to 5.0)
Loamy (Moderately coarse)	4.3 (1.0 to 7.7)	5.3 (4.4 to 7.7)	5.5 (4.7 to 6.5)
Sandy (Coarse)	-2.1 (-13.8 to 1.1)	6.2 (-4.6 to 18.2)	0.3 (-9.0 to 10.8)

Supplementary Table 3 Comparison (% change over control) of water use efficiency among the CA sublevels, cropping systems, crops, and soil texture in the on-station and on-farm data

	On-station	On-farm
CA sublevel		
CA1	26.2 (15.1 to 38.4)	7.1 (5.1 to 9.2)
CA2	27.9 (18.2 to 38.4)	11.1 (9.1 to 13.0)
CA3	33.2 (20.0 to 47.8)	10.3 (8.1 to 12.6)
Cropping system		
Rice-Wheat	24.4 (13.2 to 36.9)	11.9 (10.4 to 13.5)
Maize-Wheat	36.4 (19.2 to 56.0)	-
Rice-Maize	-	6.8 (4.7 to 8.8)
Cotton-Wheat	-	-13.66 (-15.41 to -11.87)
Soybean-Wheat	-	-
Pigeon pea-Wheat	-	-
Rice-Lentil	-	-5.38 (-8.86 to 1.80)
Rice-Mung bean	-	-
Crop		
Rice	10.6 (-3.4 to 26.6)	-0.12 (-0.78 to 0.53)
Wheat	31.5 (21.6 to 42.2)	-11.90 (-12.53 to -11.25)
Maize	28.5 (16.1 to 42.1)	-14.56 (-15.33 to -13.79)
Cotton	-	-11.63 (-14.02 to -9.18)
Soybean	-	-3.83 (-11.27 to 4.22)
Pigeon pea	-	-9.81 (-14.56 to -4.79)
Lentil	-	-3.83 (-11.27 to 4.22)
Mung bean	15.8 (-6.1 to 42.9)	-9.81 (-14.56 to -4.79)
Soil texture		
Clayey (Fine)	51.8 (34.6 to 71.2)	-5.45 (-6.56 to -4.31)
Loamy (Moderately fine)	26.0 (9.1 to 45.5)	-11.26 (-12.11 to -10.42)
Loamy (Medium)	29.0 (9.8 to 51.6)	-6.60 (-7.44 to -5.76)
Loamy (Moderately coarse)	26.3 (13.2 to 40.9)	-6.85 (-7.55 to -6.15)
Sandy (Coarse)	-	-5.80 (-9.08 to -2.38)

Supplementary Table 4 Comparison (% change over control) of grain yield, protein equivalent yield, water use efficiency and net economic return among different CA categories under the rice, wheat, maize and others (rest of the crops)

Parameters	Rice			Wheat			Maize			Others		
	CA1	CA2	CA3	CA1	CA2	CA3	CA1	CA2	CA3	CA1	CA2	CA3
Grain yield	0.4 (-0.6 to 1.4)	2.3 (1.5 to 3.2)	3.7 (0.8 to 6.6)	4.3 (2.6 to 6.0)	7.7 (6.8 to 8.6)	5.2 (1.5 to 9.2)	6.1 (3.7 to 8.4)	6.1 (4.2 to 7.9)	16.0 (5.3 to 27.9)	2.8 (-1.2 to 6.9)	4.2 (1.0 to 7.5)	3.8 (-4.0 to 12.1)
Protein equivalent yield	0.4 (-0.6 to 1.4)	2.4 (1.6 to 3.2)	3.7 (1.3 to 6.2)	4.3 (2.6 to 6.1)	7.7 (6.6 to 8.6)	5.3 (1.6 to 9.2)	6.1 (3.7 to 8.4)	6.1 (4.2 to 7.8)	16.1 (5.4 to 28.0)	2.8 (-1.1 to 6.9)	4.2 (1.1 to 7.4)	3.7 (-4.0 to 12.1)
Water use efficiency	1.6 (-0.4 to 3.7)	2.7 (0.7 to 4.8)	1.4 (-1.3 to 4.2)	21.3 (16.8 to 26.1)	24.8 (21.3 to 28.4)	17.3 (13.6 to 21.1)	12.1 (4.4 to 20.3)	19.4 (12.5 to 26.7)	23.2 (14.4 to 32.8)	14.3 (5.7 to 23.6)	11.0 (-11.7 to 39.5)	13.0 (6.0 to 20.4)
Net economic return	20.4 (17.5 to 23.4)	15.7 (13.0 to 18.6)	24.1 (18.6 to 27.2)	35.6 (26.8 to 45.0)	33.5 (32.1 to 34.8)	47.7 (46.8 to 48.6)	25.8 (22.7 to 28.9)	22.4 (19.5 to 25.5)	12.9 (10.2 to 15.8)	43.3 (31.7 to 55.9)	11.1 (4.8 to 17.8)	103.5 (69.4 to 144.5)

Supplementary Table 5 Cropping system and soil texture interaction effect on grain yield (% change) under CA compared to conventional practice

Cropping system	Soil textural class	Yield		Water use efficiency		Net economic return	
		Mean (CI)	p-value	Mean (CI)	p-value	Mean (CI)	p-value
Rice-Wheat	Clayey (Fine)	2.9 (1.6 to 4.2)	<0.01	13.3 (10.1 to 16.5)	<0.01	34.1 (27.9 to 40.6)	<0.01
	Loamy (Moderately fine)	13.1 (11.3 to 15.0)	<0.01	17.7 (13.5 to 22.1)	<0.01	39.1 (35.0 to 43.4)	<0.01
	Loamy (Medium)	3.2 (2.3 to 4.1)	<0.01	15.7 (12.5 to 19.1)	<0.01	22.4 (18.1 to 26.8)	<0.01
	Loamy (Moderately coarse)	5.4 (4.3 to 6.5)	<0.01	15.0 (11.7 to 18.4)	<0.01	20.9 (16.8 to 25.2)	<0.01
	Sandy (Coarse)	3.5 (-9.9 to 18.9)	0.63	-	-	-18.8 (-44.3 to 18.4)	0.28
Maize-Wheat	Clayey (Fine)	-	-	-	-	-	-
	Loamy (Moderately fine)	22.5 (13.3 to 32.5)	<0.01	46.8 (35.1 to 59.4)	<0.01	21.5 (11.7 to 32.2)	<0.01
	Loamy (Medium)	34.0 (27.5 to 40.9)	<0.01	14.5 (1.8 to 28.9)	0.03	38.2 (23.3 to 54.8)	<0.01
	Loamy (Moderately coarse)	3.1 (-0.2 to 6.5)	0.06	24.6 (15.9 to 33.8)	<0.01	24.3 (16.1 to 33.1)	<0.01
	Sandy (Coarse)	0.5 (-16.1 to 20.3)	0.96	-	-	-0.1 (-15.6 to 18.2)	0.99
Rice-Maize	Clayey (Fine)	-0.9 (-3.1 to 1.3)	0.41	8.9 (-0.3 to 18.9)	0.06	11.4 (1.6 to 22.2)	0.02
	Loamy (Moderately fine)	5.3 (3.8 to 6.9)	<0.01	11.3 (6.5 to 16.3)	<0.01	23.1 (16.6 to 29.9)	<0.01
	Loamy (Medium)	3.1 (1.6 to 4.6)	<0.01	8.7 (4.9 to 12.5)	<0.01	18.0 (11.2 to 25.3)	<0.01
	Loamy (Moderately coarse)	4.4 (2.7 to 6.1)	<0.01	3.9 (-0.2 to 8.2)	0.06	23.3 (15.9 to 31.2)	<0.01
	Sandy (Coarse)	-	-	-	-	-	-
Others	Clayey (Fine)	1.5 (-2.1 to 5.2)	0.42	13.2 (1.3 to 26.6)	0.03	8.7 (-5.1 to 24.6)	0.23
	Loamy (Moderately fine)	5.4 (1.5 to 9.4)	<0.01	0.5 (-8.2 to 9.9)	0.92	17.8 (6.7 to 29.9)	<0.01
	Loamy (Medium)	2.2 (-1.5 to 6.1)	0.25	3.1 (-4.4 to 11.2)	043	12.4 (-2.8 to 29.9)	0.12
	Loamy (Moderately coarse)	7.9 (3.9 to 12.1)	<0.01	8.2 (1.1 to 15.7)	0.02	31.8 (23.0 to 41.2)	<0.01
	Sandy (Coarse)	0.1 (-17.3 to 21.2)	0.92	9.3 (-8.6 to 30.7	0.33	-2.8 (-17.9 to 15.0)	0.74

Supplementary Table 6 Crop and soil texture interaction effect on grain yield (% change) under CA compared to conventional practice

Crop	Soil textural class	Yield		Water use efficiency		Net economic return	
		Mean (CI)	p-value	Mean (CI)	p-value	Mean (CI)	p-value
Rice	Clayey (Fine)	1.1 (-0.5 to 2.6)	0.17	3.3 (-0.7 to 7.4)	0.11	25.2 (17.9 to 32.9)	<0.01
	Loamy (Moderately fine)	3.6 (2.0 to 5.3)	<0.01	1.6 (-2.1 to 5.5)	0.40	19.3 (14.8 to 23.9)	<0.01
	Loamy (Medium)	1.5 (0.2 to 2.8)	0.02	3.7 (0.8 to 6.6)	0.01	15.1 (10.2 to 20.3)	<0.01
	Loamy (Moderately coarse)	0.9 (-0.5 to 2.3)	0.21	0.7 (-2.0 to 3.4)	0.63	10.3 (5.3 to 15.5)	<0.01
	Sandy (Coarse)	-10.8 (-33.3 to 19.3)	0.44	-	-	-18.8 (-43.6 to 17.0)	0.26
Wheat	Clayey (Fine)	3.8 (2.0 to 5.7)	<0.1	19.8 (15.9 to 23.8)	<0.01	38.9 (30.6 to 47.6)	<0.01
	Loamy (Moderately fine)	15.9 (13.8 to 18.1)	<0.01	23.5 (19.2 to 27.8)	<0.01	49.6 (44.2 to 55.3)	<0.01
	Loamy (Medium)	4.6 (3.6 to 5.7)	<0.01	22.1 (18.2 to 26.0)	<0.01	26.3 (20.9 to 32.0)	<0.01
	Loamy (Moderately coarse)	7.0 (5.8 to 8.3)	<0.01	26.7 (22.8 to 30.8)	<0.01	26.4 (21.6 to 31.4)	<0.01
	Sandy (Coarse)	1.6 (-8.5 to 12.9)	0.76	9.5 (-8.1 to 30.5)	0.81	5.9 (-10.1 to 24.7)	0.49
Maize	Clayey (Fine)	0.2 (-2.8 to 3.2)	0.90	8.9 (0.6 to 17.8)	0.03	11.7 (-1.4 to 26.5)	0.08
	Loamy (Moderately fine)	6.1 (4.0 to 8.2)	<0.01	29.8 (23.0 to 36.9)	<0.01	24.6 (17.3 to 32.3)	<0.01
	Loamy (Medium)	6.6 (4.6 to 8.6)	<0.01	14.7 (10.0 to 19.6)	<0.01	20.1 (11.5 to 29.3)	<0.01
	Loamy (Moderately coarse)	8.9 (6.6 to 11.3)	<0.01	17.2 (9.2 to 25.7)	<0.01	30.0 (22.9 to 37.5)	<0.01
	Sandy (Coarse)	1.5 (-21.2 to 30.8)	0.91	-	-	-5.2 (-24.8 to 19.4)	0.65
Others	Clayey (Fine)	1.0 (-3.4 to 5.5)	0.67	19.7 (8.4 to 32.1)	<0.01	-2.2 (-16.1 to 14.0)	0.77
	Loamy (Moderately fine)	10.8 (3.8 to 18.2)	<0.01	17.8 (-4.1 to 44.8)	0.12	40.7 (27.6 to 55.2)	<0.01
	Loamy (Medium)	2.0 (-3.1 to 7.5)	0.45	12.2 (2.0 to 23.5)	0.02	54.8 (35.2 to 77.1)	<0.01
	Loamy (Moderately coarse)	4.5 (0.3 to 8.9)	0.04	9.4 (-0.4 to 20.1)	0.06	39.8 (28.6 to 51.9)	<0.01
	Sandy (Coarse)	2.7 (-36.3 to 65.4)	0.91	7.9 (-42.9 to 103.8)	0.31	-11.3 (-29.6 to 11.7)	0.31

Supplementary Table 7 Comparison of CO_2-equivalent emissions between CA sublevels, cropping systems, crops and soil textural classes

	Change in CO_2 equivalent emission (% change over conventional system
CA sublevel	
CA1	-7.32 (-8.55 to -6.06)
CA2	-12.65 (-13.55 to -11.75)
CA3	-11.04 (-13.55 to -8.47)
Cropping system	
Rice-Wheat	-13.57 (-14.83 to -12.28)
Maize-Wheat	-9.37 (-10.66 to -8.07)
Rice-Maize	-6.53 (-8.78 to -4.22)
Rice-Lentil	-10.83 (-12.07 to -9.58)
Crop	
Rice	-12.16 (-13.31 to -11.01)
Wheat	-15.13 (-16.30 to -13.96)
Maize	-14.12 (-15.94 to -12.26)
Lentil	-8.41 (-12.15 to -4.50)
Soil texture	
Clayey (Fine)	-15.99 (-17.90 to -14.04)
Loamy (Moderately fine)	-11.70 (-13.50 to -9.86)
Loamy (Medium)	-13.16 (-14.63 to -11.66)
Loamy (Moderately coarse)	-14.17 (-15.63 to -12.68)

Supplementary Table 8 Response of conservation agriculture (CA) in terms of increase in grain and protein equivalent yields, water saving, economic return and reduction in global warming potential under major cropping systems prevalent in South Asia

Cropping systems	Total area[ψ]	Response of CA (per hectare)					Response of CA (in millions)∗				
		Grain yield increase	Protein yield increase	Economic return increase	Water saving	GWP reduction	Grain yield increase	Protein yield increase	Economic return increase	Water saving	GWP reduction
	m ha	-------------kg-------------		$	cm	kg CO_2	---------------tons---------------		$	ha-cm	ton CO_2
Rice-Wheat	12.60	222 (194 to 250)	39 (34 to 44)	80 (78 to 84)	7.8 (6.9 to 8.7)	466 (386 to 541)	1.40 (1.22 to 1.58)	0.24 (0.21 to 0.27)	504 (491 to 529)	49 (43 to 55)	2.94 (2.43 to 3.41)
Maize-Wheat	2.84	967 (770 to 1169)	107 (85 to 129)	130 (115 to 144)	25.6 (23.4 to 27.7)	-	1.37 (1.09 to 1.66)	0.15 (0.12 to 0.18)	185 (163 to 204)	36 (33 to 39)	-
Rice- Maize	1.50	238 (176 to 301)	23 (17 to 29)	159 (145 to 174)	2.6 (1.8 to 3.3)	-	0.18 (0.13 to 0.23)	0.02 (0.01 to 0.02)	119 (109 to 131)	2 (1 to 3)	-
Cotton-Wheat	4.19	253 (-202 to 777)	27 (-21 to 82)	410 (364 to 457)	20.6 (15.0 to 25.9)	-	0.53 (-0.42 to 1.63)	0.06 (-0.04 to 0.17)	859 (763 to 957)	43 (31 to 54)	-
Soybean-Wheat	2.23	22 (-362 to 464)	4 (-68 to 88)	-12 (-32 to 10)	3.9 (0.6 to 6.9)	-	0.02 (0.40 to 0.52)	0.005 (-0.08 to 0.10)	-13 (-36 to 11)	4 (1 to 8)	-
Pigeon pea-Wheat	1.39	90 (-712 to 1147)	16 (-96 to 1550)	105 (-651 to 2126)	10.7 (5.2 to 15.9)	-	0.06 (-0.49 to 0.80)	0.01 (-0.07 to 0.11)	117 (-726 to 1478)	7 (4 to 11)	-

∗ Assuming that 50% of the area will be under CA in 2030

ψ Source: Rice-Wheat[20]; Maize-Wheat[21]; Rice-Maize[22]; Cotton-Wheat[23]; Pigeon pea-Wheat; and Soybean-Wheat[24]

Supplementary Table 9 Detail information in terms of range of tillage and CE options observed in the dataset

Crop	Tillage			Crop establishment method		
	Conventional (CT)	Conservation		Conventional (CT)	Conservation	
		No tillage	No tillage + Residue		No tillage	No tillage + Residue
Rice	Two to three dry tillage (harrow/tyne cultivator/rotavator) followed by two-three wet tillage (flooding) operations. The land was levelled by one to two wooden plankings. In a few cases, laser land levelling was followed. Residue of previous wheat/maize/legume crops were removed/partial incorporation/burnt	Direct seeding on flat soil or on beds; Residues of previous crops were removed/burnt/retained ~5 cm stubbles	Direct seeding on flat soil or on beds; retained full/partial crop residues (3-8 t/ha) which were either anchored (30 to 40 cm height) or loose left over the ground after harvest	3-4-week-old seedlings were transplanted manually either in 15-20 cm row-to-row and 15-20 cm plant-to-plant spacings or randomly by maintaining 25-30 hills in one square metre (20 cm X 5-cm for DSR) on the dry tillage/puddled soil at 2-cm depth placement; Seed rate 10-12 kg/ha (TPR), 20-30 kg/ha (DSR); Normally, continuous submergence (~5 cm water) is maintained from transplanting until maturity or 1-2 weeks before harvest. But in some studies, full saturation initially with 3-5 cm flooding and then at irrigation on appearance of hairline cracks or soil matric potential (SMP) of -15 kPa till 1-2 weeks prior to harvest. In DSR, light irrigation after sowing and then followed same as above. Crop harvested near ground level (5-10 cm height) manually, and stubbles and loose straw were removed/burnt/incorporated in case of mechanical harvesting. Fertilizer application: 120-150:18-33:0-50 kg/ha N:P:K;	Dry seeds were drill-sown (@20-30 kg/ha, 2-3-cm deep) or in slits opened by a zero-till drill either on moist soil with pre-sowing irrigation or in dry soil followed by irrigation for proper seed germination. First irrigation (4-5 cm) was applied immediately after seeding, 2nd irrigation a week after seeding, and subsequent irrigation on appearance of hairline cracks on surface if necessary, depending on rainfall pattern; In some studies, unpuddled (without any dry and wet tillage) rice seedling were transplanted either manually or mechanically with rice transplanter. Normally, irrigation with the appearance of hairline cracks in the soil surface and occasional flooding. Fertilizer applications: 120-150, 20-30, and 20-50 kg/ha N, P and K; All basal P applied through NPK/DAP complex fertilizer at sowing and remaining K applied at panicle initiation and N in 3 equal splits (15-20, 30-35 and 50-55 days after seeding); 30 kg S and 5 kg	Dry seeds were sown in the presence of full/partial previous crop residue (2-5 t/ha) by using advanced no-till planter called Turbo Happy Seeder with inclined plate seed metering system in addition to normal zero-till planter @ seed rate 20-30 kg/ha and 20-cm row spacing; The remaining other steps for irrigation, fertilizer followed same as in no tillage

				N in 3 equal splits (sowing/transplanting, maximum tillering and at panicle initiation); 30 kg S and 5 kg Zn were also applied in some study, full K and P as basal or ½ K as basal + remaining as top-dressing at panicle initiation.	Zn were also applied in some study at early tillering.	
Wheat	Four dry ploughings (Two passes cross harrow + one-two cultivator/rotavator) + 1 planking. Laser levelling was done in a majority of studies. Residues of previous rice/ maize/cotton/soybean/ or pigeon pea were removed/burnt/incorporated	Direct drilling of wheat without any preparatory (primary as well as secondary) tillage operations either in absence of crop residues (removed/burnt) or partial anchored stubbles (~5 cm)	Direct drilling of wheat without any preparatory (primary as well as secondary) tillage operations but in presence of anchored or anchored+ loose residues (3-10 t/ha) of the previous crops in rotation using happy seeder or zero till seed-cum-fertilizer drills or double disc planters	Sowing with 20-22.5 cm row-to-row/random broadcast seeding (Seed rate: 100-150 kg/ha) with 3-5 cm depth placement; Harvested manually (5-10 cm from ground level) or in mechanically harvested field, loose straw and anchored stubbles were retrieval/burnt/incorporated. Irrigation at critical growth stages and varied according to geography (2-6) or when SMP at -60-75 kPa (5-8 cm depth of irrigation). For beds, the depth of irrigation was 5 cm (2-8 irrigations at critical growth stages). Fertilizer application: 120-150 kg/ha N+ 26-30 P + 33-42 kg K/ha (Entire P and K and 33% N as basal, N as 2 equal splits (at CRI and during 2nd/3rd irrigation or at maximum tillering)	Zero till planter or zero till seed-cum-ferti drill was used for direct drilling in no-tilled soil at 20-22.5 cm row spacing and seed rate @100-120 kg/ha and seed placement. depth ~3-4 cm. A few studies used indigenous zero till seed-cum-fertilizer drill with inverted T type slit opener to deep place fertilizer and seed in a single operation. In some studies, the two wheel tractor operated zero-till /strip till seed-cum fertilizer planter was used with same seed rate 100-120 kg/ha for relay planting in cotton/eastern gangetic plains. Raised bed planter was used for permanent beds (PB; Beds were 37 cm wide at top, 10-15 cm in height, separated by 30 cm wide-top furrows; Permanent broad beds (PBB) were 110 cm wide with 30 cm furrow width. Seed rate 75-100 kg/ha; two rows per bed - drilling of seeds (for PBB 5 rows); Beds were reshaped only (no ploughing) at	All or partial residue (3-10 t/ha) was retained. In some study 25-30 cm stubbles were left where combined harvester was used. After combine harvesting, the loose straw was distributed uniformly; Hapy seeder Zero-till planter/ drill was used for sowing of seeds @100 kg/ha at 3-4 cm depth. Fertilizer application was same as ZT but the urea top dressing was done before the irrigation event

					the end of every cropping cycle. Fertilizer application was same as above Irrigation was applied using same criteria as in CT	
Maize	Four-five dry ploughings (at least two harrow + two-three cultivators/rotavators + one planking or laser levelling); previous crops residue removed/incorporation/burnt; and manual/mechanical seed planting	Direct planting of maize seed without any preparatory (primary as well as secondary) tillage operations either in absence of crop residues (removed/burnt) or partial anchored stubbles (~5 cm)	Direct planting of maize seed without any preparatory (primary as well as secondary) tillage operations but in presence of anchored or anchored+ loose residues (3-10 t/ha) of the previous crops in rotation using happy seeder or zero till seed-cum-fertilizer multi-crop planters or double disc planters but in some studies, it was manually dibbled	Manually/mechanically seeded on flat land at 50-75 cm row-to-row and 15-25 cm plant-to-plant spacings. 20-25 kg/ha seed rate, seeding depth 5-7 cm Irrigation at critical growth stages depending on the growing season (2-8 irrigations) Fertilizer application: 120-250 kg/ha N + 25-40 kg/ha P + 40-80 kg K/ha (P and ½ to 1/3 K and N as basal, remaining N as topdressing during V5-V7 and V7-V10 growth stages and K at V10 or silking stages)	Zero till planter or zero till maize/multi-crop seed-cum-fertilizer planter was used (60-67 cm row spacing and ~20 cm plant spacing @20 kg/ha seed). Raised bed planter was used for permanent beds (37 cm wide at top, ~10 cm in height, separated by furrows with 30-cm wide top), left for 30 days to settle; Sowing of 1 row of maize on each bed. Fertilizer application same as CT	All or partial residue (3-10 t/ha) was retained. In some study 25-30 cm stubbles were left where combined harvester was used. After combine harvesting, the loose straw was distributed uniformly; Maize was seeded as in no tillage except additional turbo happy seeder was used in addition of normal zero-till planter or in some studies maize was manually dibbled and all other steps followed as in no-tillage
Cotton	Four-five dry ploughings (at least two harrow + two-three cultivators/rotavators + one planking or laser levelling); previous crops residue removed/incorporated/burnt; manual/mechanical seed planting	Direct planting of cotton seed without any preparatory (primary as well as secondary) tillage operations either in absence of crop residues (removed/burnt) or partial anchored stubbles (~5 cm)	Direct planting of cotton seed without any preparatory (primary as well as secondary) tillage operations but in presence of anchored or anchored+ loose residues (3-10 t/ha) of the previous crops in rotation using happy seeder or zero till seed-cum-fertilizer multi-crop planters or double	Sown manually at 70 row-to-row and 50 cm plant-to-plant spacings 8-9 irrigations were given Fertilizer application: 100-150 kg N +26-30 kg P + 40 kg K)/ha (P, K and ½ N as basal, remaining N after 1 month). In few studies, interactive computer based Nutrient Expert® system was used for site specific nutrient management.	Cotton seed were sown manually in no till field by using the wooden cone to make whole for seed or mechanically seed and fertilizer placement by using no-till cotton planter at 70 cm row spacing. Irrigation and fertilizer applied as like CT.	Cotton seeds were planted in presence of 3-5 t/ha previous crop residues using same technique as in ZT/NT

			disc planters or manual dibbling			
Soybean	Four dry ploughings (Two passes cross harrow + one-two cultivator/rotavator) + 1 planking. Residues of previous crops removed/burnt/incorporated	Direct planting of soybean seed in no-till field in a single pass using zero till seed-cum fertilizer planter/drill either in absence of crop residues (removed/burnt) or partial anchored stubbles (~5 cm)	Direct planting of soybean seed in presence of anchored or anchored+ loose residues (3-7 t/ha) of the previous crops in rotation using happy seeder or zero till seed-cum-fertilizer multi-crop planters or double disc planters or manual dibbling	Pre-sowing of irrigation applied followed by sowing in rows 40 cm apart (flat sowing). Usually seeds were inoculated with Rhizobium culture. Beds were reshaped in a single pass using tractor-driven bed planter with little disturbance to beds. Sowing was done in a single pass with bed planter (@ 60 kg seeds/ha). Fertilizer 20-30, 26, 25 kg/ ha of N, P and K applied at time of sowing. Mostly manual harvesting where stubbles were removed completely; Mostly grown under water limited areas using rain water and supplementary irrigation if necessary.	Pre showers rainfall or pre sowing irrigation followed seed placement by using no-till seed cum fertilizer planter at 40 cm row spacing @ 60 kg/ha seed or manual seeding. The other remaining operations inoculations, irrigation and fertilizer was followed as in CT	Residues were mostly leaf fall, and dried stem left after harvest; 3t/ha stover mulch was applied Soybean was planted same as in NT/ZT except retained 30% of previous crop residue.
Pigeon pea	Three-four dry ploughings (Two passes cross harrow + one-two cultivator) + 1 planking. Residues of previous crops removed/burnt/incorporated; line seeding	Same as above	Same as above	Seeds were sown @20 kg/ha with 70 cm between rows and 15-20 cm plant-to-plant spacing either mechanically or manually.	Manually seeded (dibbling) using a narrow slit opener (4–5 cm deep seed placement), followed by thinning later; 5 irrigations were given.	Pigeonpea was planted same as in NT/ZT except retained 30% of previous crop residue.

Mung bean	Two-three dry ploughings (one-two harrow + one-two cultivator/rotavator) + 1 planking. Residues of previous crops removed/burnt/incorporated; line seeding	Direct planting of mung bean seed in no-till field in a single pass using zero till seed-cum fertilizer planter/drill in absence of crop residues (removed/burnt)	Direct planting of mung bean seed in presence of anchored or anchored+ loose residues (3-5 t/ha) of the previous crops in rotation using happy seeder or zero till seed-cum-fertilizer multi-crop planters or double disc planters	Pre sowing irrigation after harvest of previous crop. Manually broadcasted or drilled at 20-30 cm row spacing using 20-25 seed kg/ha. Fertilizer 20-25 P and K kg/ha as basal. Need based supplementary irrigation (1-2 irrigations). One-three pod picking manually.	No-till seed cum fertilizer drill/planter was used at 20-30 cm row spacing @20-25 kg/ha seed. Fertilizer and irrigations as in CT	Mung bean was drilled in the 20-25 cm anchored stubbles of previous crop after manual/combine harvest by using happy seeder/no-till seed cum fertilizer drill as in ZT, In some studies it was relayed

Supplementary Table 10 Number of on-station and on-farm data points of the performance parameters used in the meta-analysis; Study numbers are given in parentheses

	Yield		Water use efficiency		Net economic return		CH_4 emission	N_2O emission	Global warming potential	CO2-equivalent
	On-station	On-farm	On-station	On-farm	On-station	On-farm	On-station	On-station	On-station	On-farm
CA sublevel										
CA1	583 (57)	375 (327)	91 (10)	209	157 (34)	327 (325)	19 (6)	34 (7)	35 (7)	282 (280)
CA2	702 (54)	747 (717)	281 (26)	261	366 (38)	667 (662)	24 (6)	30 (6)	32 (6)	478 (472)
CA3	178 (11)	75 (66)	128 (2)	201	63 (2)	66 (66)	6 (2)	6 (2)	6 (2)	66 (66)
Cropping system										
Rice-Wheat	915 (77)	734 (673)	292 (25)	408	389 (43)	630 (622)	49 (6)	70 (7)	70 (10)	493 (486)
Maize-Wheat	308 (24)	40 (26)	157 (9)	-	118 (15)	25 (25)	-	-	-	-
Rice-Maize	34 (6)	324 (321)	-	204	16 (6)	314 (314)	-	-	-	241 (241)
Cotton-Wheat	60 (6)	-	39 (2)	-	48 (6)	-	-	-	-	-
Soybean-Wheat	110 (8)	-	-	-	15 (3)	-	-	-	-	-
Pigeon pea-Wheat	36 (2)	-	-	-	-	-	-	-	-	-
Rice-Lentil	-	90 (90)	-	56	-	87 (87)	-	-	-	90 (90)
Rice-Mung bean	-	-	-	-	-	-	-	-	-	-
Crop										
Rice	355 (44)	447 (430)	121 (14)	299	189 (31)	434 (430)	11 (4)	11 (4)	38 (6)	400 (398)
Wheat	791 (61)	503 (443)	223 (8)	258	267 (30)	395 (391)	6 (1)	21 (3)	35 (8)	235 (231)
Maize	203 (11)	175 (165)	99 (9)	82	90 (8)	162 (162)	-	-	-	121 (121)
Cotton	33 (3)	-	24 (2)	-	30 (5)	-	-	-	-	-
Soybean	49 (5)	-	-	-	6 (2)	-	-	-	-	-
Pigeon pea	16 (2)	-	-	-	-	-	-	-	-	-
Lentil	-	45 (45)	-	32	-	45 (41)	-	-	-	45 (45)
Mung bean	16 (5)	27 (25)	25 (4)	-	3 (1)	24 (20)	-	-	-	24 (24)
Soil texture										
Clayey (Fine)	69 (12)	184 (176)	21 (3)	146	35 (7)	177 (173)	-	-	-	182 (178)
Loamy (Moderately fine)	471 (37)	265 (232)	142 (12)	122	298 (24)	233 (231)	4 (1)	4 (1)	21 (4)	144 (142)
Loamy (Medium)	293 (19)	384 (373)	89 (8)	210	73 (13)	323 (321)	6 (1)	15 (3)	49 (5)	278 (276)
Loamy (Moderately coarse)	504 (48)	360 (328)	248 (19)	190	158 (27)	327 (327)	2 (2)	2 (2)	3 (3)	222 (222)
Sandy (Coarse)	126 (6)	-	-	-	22 (3)	-	-	-	-	-

Supplementary Note

List of on-station studies used for the meta-analysis

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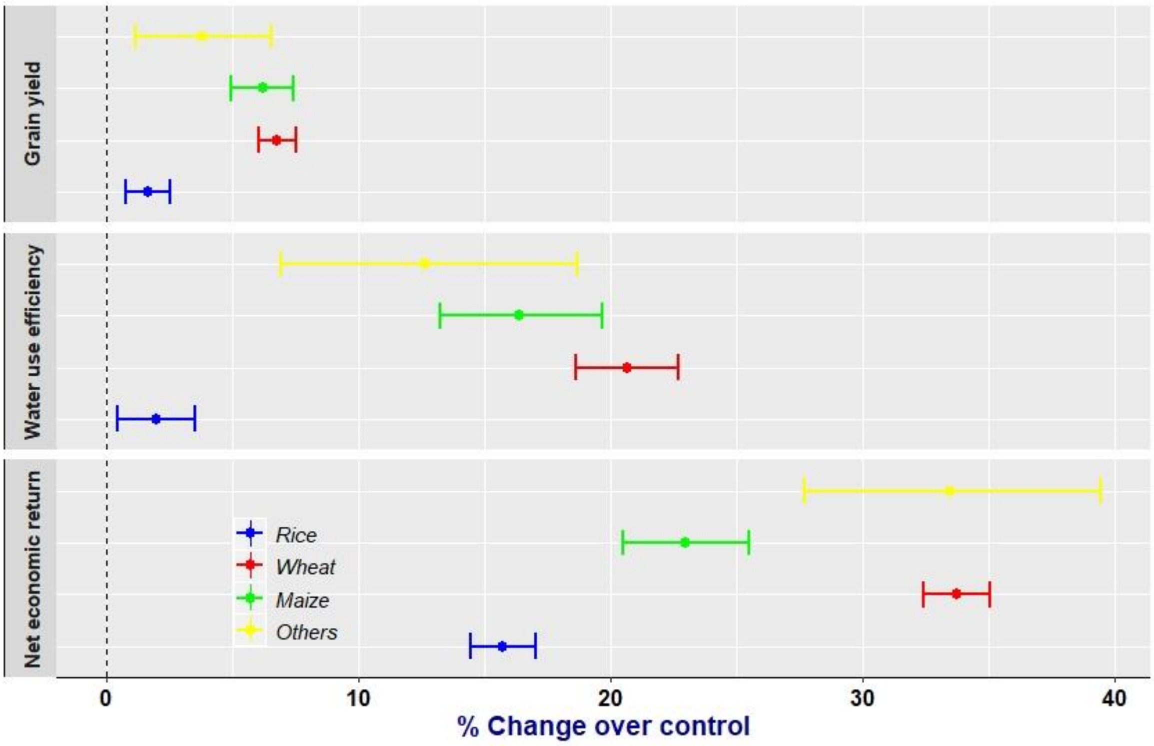
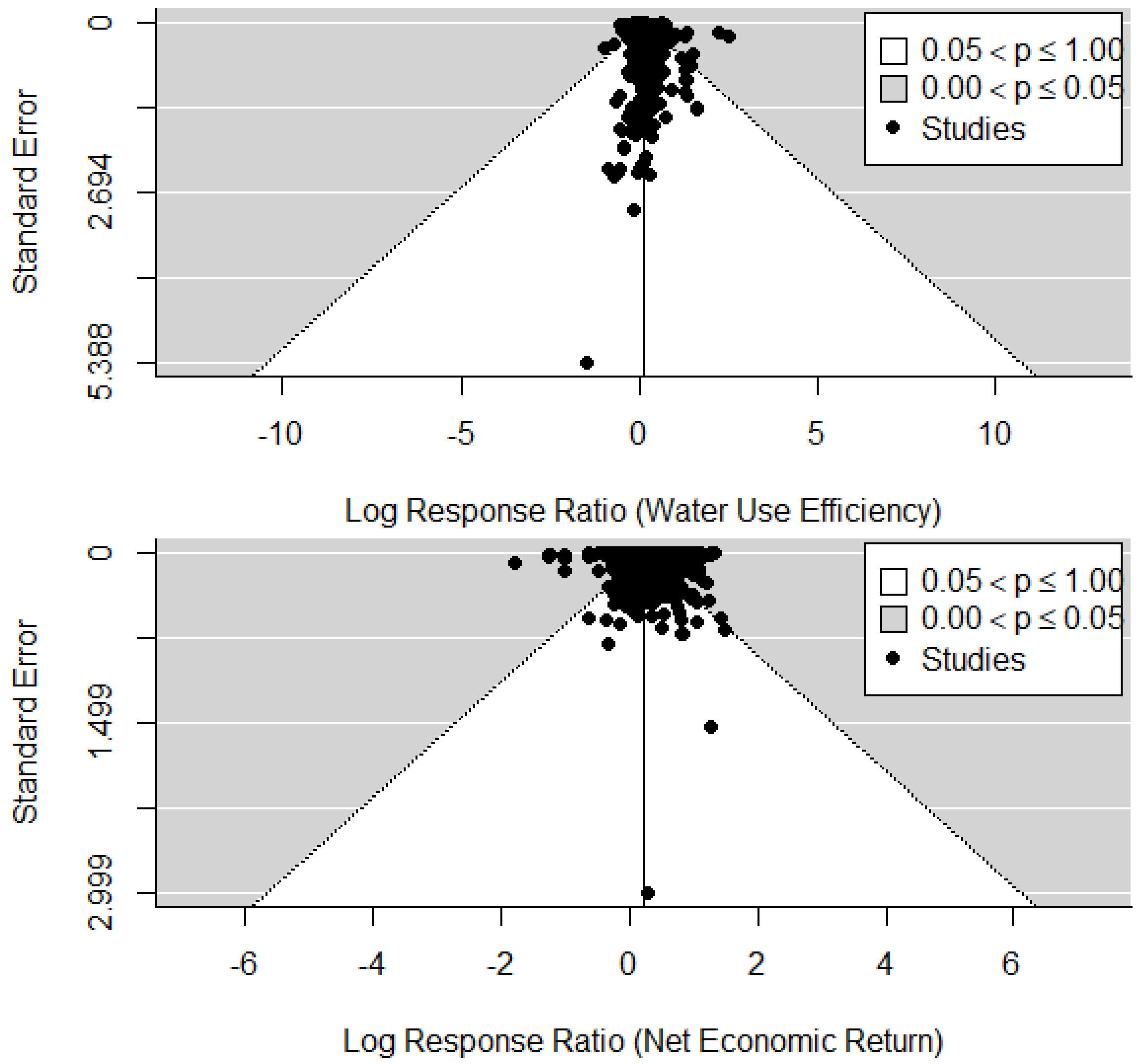
Supplementary Figures



Supplementary Figure 1 Performance of CA in terms of grain yield (a) water use efficiency (b), and net economic return (c) of the major crops. Error bars indicate 95% confidence intervals; Effect was significant at $p<0.05$ if CI covers zero



Supplementary Figure 2 Funnel plots for log-response ratios of yield, water use efficiency and net economic return

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