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Potential impact of elevated atmospheric carbon dioxide and climate change on Victorian wheat marketing grades and value

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SUPPLEMENTARY TABLES

Table S1. Details of wheat delivery records obtained from GrainCorp Ltd for Victorian delivery sites. NRM = natural resource management, SD = standard deviation of the mean

Season	2009	2010	2011	2012	2013	All
Delivery Records	912	851	869	852	855	4339
Delivery sites	47	57	51	51	47	65
GrainCorp Clusters	7	7	7	7	7	7
NRM regions	6	6	6	6	6	6
Classification Grades	8	10	6	6	7	12
Varieties	43	48	41	48	57	75
Months Delivered	4	6	4	3	4	7
Delivery weight (t)						
Mean	23.4	25.7	26.1	26.2	26.3	25.5
SD	8.2	8.3	8.1	8.0	8.1	8.2
Water content (%)						
Mean	9.5	10.1	10.2	9.9	10.0	9.9
SD	1.5	1.2	1.0	1.0	1.1	1.2
Protein content (%)						
Mean	11.8	10.3	10.3	10.4	10.4	10.6
SD	1.5	1.3	1.1	1.4	1.4	1.5
Screenings (%)						
Mean	2.94	2.64	1.84	1.87	2.36	2.34
SD	2.90	1.60	1.09	1.14	1.42	1.83
Test weight (kg/hl)						
Mean	78.2	74.9	80.5	82.1	81.9	79.5
SD	3.5	3.2	2.2	2.0	2.0	3.8

Table S2. Soil parameter constants defining soil characteristics by depth (cm) used to model wheat grain yield and protein content at each representative site. Where, UL = upper limit (g/cm^3), LL= lower limit (g/cm^3), BD = dry bulk density (g/cm^3), PH = pH (water), TN = total nitrogen (%), MN = microbial biomass nitrogen (%), ON = organic matter nitrogen (g/g), CN = organic matter C:N ratio (-), SE = maximum depth of soil evaporation (cm), ALB = soil albedo (-), VPDC = vapour pressure deficit calibration constant (-). VPDS = VPD calibration slope (-), AS = annual bare surface mean temperature (°C), AM = amplitude of annual bare soil surface temperature (°C), CL = clay content (%), AK = Soil surface infiltration rate multiplier due to zero tillage (-), HL = half-life of humus (y) and FE = relative available soil water content threshold for stage 1 evaporation (-), IW = daily wet infiltration capacity of soil surface (mm), ID = daily dry infiltration capacity of soil surface (mm). Model: O'Leary and Connor (1996a; 1996b) Version 9

Mallee																
Depth	**UL**	**LL**	**BD**	**PH**	**SE**	**ALB**	**VPDC**	**VPDS**	**AS**	**AM**	**CL**	**AK**	**HL**	**FE**	**IW**	**ID**
0-10	0.15	0.03	1.58	7.8	40	0.14	-0.1478	0.8190	23.1	12.0	22	2	50	0.3	30.4	304
10-20	0.20	0.07	1.53	8.1												
20-40	0.25	0.11	1.57	9.0												
40-60	0.30	0.12	1.66	9.5												
60-80	0.30	0.12	1.66	9.9												
80-100	0.30	0.12	1.69	9.9												
100-120	0.30	0.12	1.73	9.9												
Wimmera, North-Central and Goulburn-Broken																
Depth	**UL**	**LL**	**BD**	**PH**	**SE**	**ALB**	**VPDC**	**VPDS**	**AS**	**AM**	**CL**	**AK**	**HL**	**FE**	**IW**	**ID**
0-10	0.39	0.15	1.14	8.4	40	0.13	-0.1478	0.8190	23.1	12.0	60	10	50	0.5	7.6	152
10-20	0.40	0.18	1.30	8.4												
20-40	0.42	0.27	1.37	8.9												
40-60	0.43	0.30	1.40	9.0												

60-80	0.45	0.33	1.40	9.0
80-100	0.45	0.35	1.40	9.0
100-120	0.45	0.36	1.40	9.0
120-140	0.45	0.37	1.40	9.1
140-180	0.45	0.37	1.40	9.1

South West

Depth	UL	LL	BD	PH	SE	ALB	VPDC	VPDC	AS	AM	CL	AK	HL	FE	IW	ID
0-10	0.40	0.13	1.15	8.4	50	0.13	-0.1478	0.8190	23.1	12.0	60	10	50	0.5	7.6	152
10-25	0.42	0.20	1.20	8.4												
25-50	0.44	0.26	1.30	8.9												
50-75	0.45	0.27	1.35	9.0												
75-100	0.46	0.28	1.38	9.0												
100-125	0.47	0.29	1.38	9.0												
125-150	0.48	0.30	1.39	9.0												
150-175	0.50	0.34	1.40	9.1												
175-200	0.52	0.35	1.43	9.1												

Table S3. Initial soil and crop variables set at sowing time used to model wheat grain yield and protein content at each representative district. Where, S = initial water content (g/cm^3), N = Initial soil mineral nitrogen (NO_3-N plus NH_4-N) (µg/cm^3), TN = total nitrogen (%), MN = microbial biomass nitrogen (%), ON = organic matter nitrogen (%), CN = organic matter C:N ratio (-), RES = surface residue (t/ha), RCN = surface residue CN ratio, LAT = latitude (° '), LONG = longitude (° '), ELEV = elevation (m), CV = cultivar number (Table S4), SEED = sowing seed rate (kg/ha), SD= sowing depth (cm), TOS= time of sowing (DOY), RMSTM = maximum rooting depth by stem extension (cm), RMAX = maximum rooting depth by anthesis and maturity (cm). Given our fixed sowing date to represent a wide area we used a generic cultivar and the same latitude and elevation for all sites except for the Mallee. Model: O'Leary and Connor (1996a; 1996b) Version 9

Mallee (BOM Weather station 76064 Walpeup)																	
Depth	**S**	**N**	**TN**	**MN**	**ON**	**CN**	**RES**	**RCN**	**LAT**	**LONG**	**ELEV**	**CV**	**SEED**	**SD**	**TOS**	**RMSTM**	**RMAX**
0-10	0.051	15.0	0.050	2.4	1.0	15	0.5	65	-35 08	142 01	107	1	45	3	138	28	100
10-20	0.154	40.0	0.025	2.4	1.0	15											
20-40	0.196	30.0	0.010	2.4	1.0	15											
40-60	0.200	5.0	0.005	2.4	1.0	15											
60-80	0.222	6.0	0.005	2.4	1.0	15											
80-100	0.218	8.0	0.003	2.4	1.0	15											
100-120	0.212	10.0	0.001	2.4	1.0	15											
Wimmera (BOM Weather station 79028 Dooen)																	
Depth	**S**	**N**	**TN**	**MN**	**ON**	**CN**	**RES**	**RCN**	**LAT**	**LONG**	**ELEV**	**CV**	**SEED**	**SD**	**TOS**	**RMSTM**	**RMAX**
0-10	0.343	36.5	0.104	2.4	1.0	15	1.5	65	-36 45	142 18	128	2	75	3	175	38	230
10-20	0.302	25.0	0.059	2.4	1.0	15											
20-40	0.303	20.0	0.030	2.4	1.0	15											
40-60	0.313	21.8	0.015	2.4	1.0	15											

60-80	0.350	20.1	0.007	2.4	1.0	15
80-100	0.427	4.9	0.004	2.4	1.0	15
100-120	0.228	4.2	0.002	2.4	1.0	15
120-140	0.428	2.8	0.001	2.4	1.0	15
140-180	0.408	2.8	0.001	2.4	1.0	15

North-Central (BOM Weather station 80006 Charlton)

Depth	S	N	TN	MN	ON	CN	RES	RCN	LAT	LONG	ELEV	CV	SEED	SD	TOS	RMSTM	RMAX
0-10	0.303	57.5	0.104	2.4	1.0	15	1.5	65	-36 45	143 24	128	2	58	3	169	38	230
10-20	0.412	39.0	0.059	2.4	1.0	15											
20-40	0.413	24.7	0.030	2.4	1.0	15											
40-60	0.423	21.8	0.015	2.4	1.0	15											
60-80	0.411	201	0.007	2.4	1.0	15											
80-100	0.427	4.9	0.004	2.4	1.0	15											
100-120	0.428	4.2	0.002	2.4	1.0	15											
120-140	0.428	2.8	0.001	2.4	1.0	15											
140-180	0.408	2.8	0.001	2.4	1.0	15											

Goulburn-Broken (BOM Weather station 81049 Tatura)

Depth	S	N	TN	MN	ON	CN	RES	RCN	LAT	LONG	ELEV	CV	SEED	SD	TOS	RMSTM	RMAX
0-10	0.283	47.5	0.104	2.4	1.0	15	1.0	65	-36 45	145 16	128	1	50	3	150	38	230
10-20	0.292	39.0	0.059	2.4	1.0	15											

20-40	0.272	34.7	0.030	2.4	1.0	15											
40-60	0.353	31.8	0.015	2.4	1.0	15											
60-80	0.411	20.1	0.007	2.4	1.0	15											
80-100	0.427	4.9	0.004	2.4	1.0	15											
100-120	0.428	4.2	0.002	2.4	1.0	15											
120-140	0.428	2.8	0.001	2.4	1.0	15											
140-180	0.408	2.8	0.001	2.4	1.0	15											

South West (BOM Weather station 89018 and 89032 Westmere)

Depth	S	N	TN	MN	ON	CN	RES	RCN	LAT	LONG	ELEV	CV	SEED	SD	TOS	RMSTM	RMAX
0-10	0.393	57.5	0.104	2.4	1.0	15	0.5	65	-36 45	143 00	128	3	75	3	169	38	200
10-25	0.412	42.0	0.059	2.4	1.0	15											
25-50	0.413	44.7	0.030	2.4	1.0	15											
50-75	0.423	21.8	0.015	2.4	1.0	15											
75-100	0.381	20.1	0.007	2.4	1.0	15											
100-125	0.380	24.9	0.004	2.4	1.0	15											
125-150	0.428	14.2	0.002	2.4	1.0	15											
150-175	0.428	2.8	0.001	2.4	1.0	15											
175-200	0.408	2.8	0.001	2.4	1.0	15											

Table S4. Three crop cultivar definitions used to simulate wheat grain yield and protein content at each representative site with the O'Leary and Connor (1996a; 1996b) Version 9 model

Cultivar number		1	2	3
TH	Critical water content below which emergence does not advance (g/cm^3)	0.3	0.3	0.3
TL	Relative available water content below which LAI growth is reduced (g/cm^3)/(g/cm^3)	0.3	0.3	0.3
SL	Optimal specific leaf nitrogen of canopy (g/m^2)	3.2	3.2	3.2
T1	Base temperature for emergence (^oC)	3	3	3
T2	Base temperature for stem extension (^oC)	4	4	4
T3	Base temperature for booting (^oC)	4	4	4
T4	Base temperature for anthesis (^oC)	2	2	2
T5	Base temperature for maturity – phase 1 (^oC)	8	8	8
T6	Base temperature for maturity – phase 2 (^oC),	8	8	8
O1	Optimum temperature for emergence (^oC)	33	33	33
O2	Optimum temperature for stem extension (^oC)	33	33	33
O3	Optimum temperature for booting (^oC)	33	33	33
O4	Optimum temperature for anthesis (^oC)	33	33	33
O5	Optimum temperature for maturity – phase 1 (^oC)	40	40	40
Z1	Maximum temperature for emergence (^oC)	40	40	40
D1	Base daylength for booting photothermal time (h)	0	0	0
D2	Base daylength for anthesis photothermal time (h),	6	6	6
TE	Thermal time for emergence (^oCd)	78	78	78
TA	Thermal time for stem extension (^oCd)	385	385	385
PB	Photothermal time for booting (^oCdh)	5300	5300	5300
PA	Photothermal time for anthesis (^oCdh)	7000	7000	7000
M1	Thermal time for maturity phase 1 (^oCd)	500	500	500
M2	Thermal time for maturity phase 2 (^oCd)	500	500	500
FT	Frost threshold temperature (^oC)	0	0	0
FD	Frost damage to grain number (%)	7.2	7.2	7.2
HT	Heat threshold temperature (^oC)	32	32	32
HD	Heat damage to grain number (%)	0.96	0.96	0.96
G1	Grain number coefficient ($\#/m^2$)	800	800	800
G2	Grain number coefficient ($\#/m^2$)	108	108	108
GR	Maximum grain growth rate (g/d)	2.9	2.9	2.9
GS	Maximum grain size (mg)	50	50	50
GN	Target maturity grain N concentration (g/g)	0.0155	0.0152	0.0150
GT	Duration of grain N transfer to grain (^oCd)	425	425	425
PR	Maximum pre-anthesis biomass transfer to grain – proportion of biomass at anthesis (g/g)	0.25	0.25	0.25

Table S5. Variable ranges and means for AGFACE treatments from ambient [CO_2] (a[CO_2]) and elevated [CO_2] (e[CO_2]). SD = standard deviation of the mean. Level of statistical differences between paired a[CO_2] and e[CO_2] treatment are indicated: * *P* < 0.001; ns non-significant *P* < 0.05**

Variable	Range	Mean ± SD	
Grain yield (kg/ha)			
a[CO_2]	895 – 7,427	3,516 ± 1,733	n=165
e[CO_2]	1,026 – 9,149	4,181 ± 2,079	***
Grain protein concentration (%)			
a[CO_2]	7.5 – 19.1	12.8 ± 2.7	n=165
e[CO_2]	6.7 – 17.4	12.0 ± 2.5	***
Test weight (kg/hl)			
a[CO_2]	76 - 88	82 ± 3	n=104
e[CO_2]	72 - 88	82 ± 3	ns

Table S6. Difference in gross value of wheat produced in Observed (100,000 t) and either Victoria Scaled-e[CO_2] scenario (117,900 t) or Mallee NRM region Climate change (56,678 t) scenarios with a range of base prices for APW1 and three scenarios for price spread for different wheat grades. Differences are expressed in $ million and percentage relative to Observed

	Victoria Scaled-e[CO_2]			Mallee Climate change		
APW1 Base price	"-50%" Spread	Standard	"+50%" spread	"-50%" Spread	Standard	"+50%" spread
$187/t	$3.16	$2.98	$2.80	-$8.01	-$7.92	-$7.84
	17.3%	16.6%	15.9%	-43.7%	-44.1%	-44.5%
$237/t	$4.06	$3.87	$3.69	-$10.18	-$10.09	-$10.00
	17.4%	16.9%	16.4%	-43.6%	-43.9%	-44.2%
$287/t	$4.95	$4.77	$4.59	-$12.34	-$12.26	-$12.17
	17.5%	17.1%	16.6%	-43.6%	-43.8%	-44.0%
$337/t	$5.85	$5.66	$5.48	-$14.51	-$14.42	-$14.33
	17.6%	17.2%	16.8%	-43.5%	-43.7%	-43.9%
$387/t	$6.74	$6.56	$6.38	-$16.68	-$16.59	-$16.50
	17.6%	17.3%	17.0%	-43.5%	-43.7%	-43.9%