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SUPPLEMENTARY INFORMATION

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A meta-analysis of crop yield under climate change and adaptation

Data collection and analysis methods

The AR4 dataset [3], which collated projections of the response of maize, wheat and rice to local warming, was extended and the entire dataset reanalysed using consistent methods. New information was added for a large number of entries on the projection period of the study. Adaptation was categorised according to whether planting date, irrigation, cultivar or “other agronomic” (e.g. referenced in the study as “technology change”) adjustments were simulated by the crop model. Multiple entries were made where many crops, regions, temperatures, projection periods or adaptations were used. Each entry in the dataset was designated as either a tropical or temperate system, according to the location and the crop studied. Where the classification was not clear through direct reference in the paper, some countries and regions were designated as tropical for all crops (Brazil, Central Africa, Central America , East Africa, Sahel, South Asia, Southeast Asia, West Africa, West Asia) and others as temperate (Europe, US, Andean region, Southern Africa). China was categorised as temperate, with the exception of rice, which was designated as tropical. Country-scale studies of Argentina were given neither a tropical nor temperate categorisation.

The procedure for adding to the dataset was similar to that of the original AR4 study, with the exception that we considered all published studies of crop yield response to climate change, whether from a process-based or statistical model; whereas AR4 included the former only. All the statistical models included in the meta-analysis use aggregated regional-scale data. Most studies (>75%) were climate impact studies, i.e. they used a climate model, but some were sensitivity studies and two, from the AR4 dataset, were field experiments. The literature search was broad and inclusive, with no preference given to any particular region and no assessment of the methods used in the studies. Instead, we devised a quality control procedure in order to remove datapoints that are not representative of global production.

Quality control consisted of first examining outliers in order to understand the reasons for the differences. All site-scale studies that produced changes of greater than 50%, in either direction, were examined in detail. Nine studies included reported yield changes of greater than +50% and ten studies were in the corresponding category for negative changes. This procedure resulted in the removals of 8 data points. Four studies produced high yields since they focused on high elevation areas and/or large increases in rainfall or CO_2. These studies were retained. In two cases, a single study contained a large number of data points in disagreement with consensus from the literature for the same crop in the same region. Those data points were removed in order to remove bias due to a single study. A final quality control procedure was conducted immediately prior to the use of the data in the first full draft of Chapter 7 of IPCC AR5, in order to remove any biases in the number of adaptation vs no-adaptation data points reported from within one study. This resulted in the removal of a further total of 44 datapoints, from two studies. All entries that passed the quality control procedures are treated equally in the meta-analysis. Appendix 1 provides a summary of the references used for each of the figures in this study.

Multiple entries from single studies are a potential source of bias, particularly given a number of regionally-differentiated global studies that have been published in recent years. These studies can have a large number of entries in the database, since projected crop yields were available by region or country in many cases, and for numerous crops. Therefore, a small number of studies could have a disproportionate impact on the meta-analysis. The frequency count of the number of entries per study (Supplementary Fig. 3) shows that the top six studies, which are the only studies that individually make up more than 5% of all entries, are a natural choice for testing this hypothesis. All analyses were repeated for these six studies [39-44] alone, and for the full dataset minus these six studies. Yield changes were generally lower in the top six studies alone (-7.9% on average) than in the full dataset (-4.5% on average). However, the underlying responses across climate variables were not significantly distinct between the two categories. This indicates that the emerging literature on global crop impacts is broadly consistent with regional studies.

A second potential source of bias in the meta-analysis is the geographical spread of data points. The regions where the major crops are grown are not necessarily the same regions that are studied in the literature. Supplementary Table 1 presents data on area harvested for 2011, together with the percentage of data points in the meta-analysis (by crop and region) that come from those countries. In all cases where the percentage of data points exceeds 20% the corresponding country is one of the top two producers globally. This suggests no significant skewing of results towards a particularly well-studied non-productive country. Conversely, with the exception of Russian wheat, the top two producing countries globally rank in the top two in terms of coverage in the meta-analysis. Thus the dataset is reasonably representative of the major global producers, although Brazilian maize and rice in Indonesia and Bangladesh are under-represented. Note that the rice production data is for paddy rice, whereas the meta-analysis included upland rice.

A more subtle question regarding the representativeness of the dataset is whether the spread of data differs between countries in a way that might bias results. Supplementary Fig. 4 presents the data from fig. 1 in the main text decomposed into the top five contributions from individual countries. The majority of the data do not show systematic differences between countries. Temperate rice is one exception, where China appears to have greater spread than the rest of the dataset, perhaps reflecting the large range of production environments in that country. There are also some single-country contributions in some cases at high (e.g. Cameroon in tropical maize) and low (e.g. East Africa in tropical maize) yield values. The paired analysis of adaptation also showed a good geographical coverage: Argentina, Australia, Austria, Bangladesh, Brazil, Bulgaria, Cameroon, Canada, India, China, East Africa, Egypt, Europe, France, Germany, Philippines, Indonesia, Japan, Kazakhstan, South Africa, Malaysia, Mali, Mexico, Moldova, Myanmar, Pakistan, Nepal, Paraguay, Poland, Romania, Russia, South Korea, Sri Lanka, Taiwan, Thailand, UK, Ukraine, United States, Uruguay.

Statistical regression models

Statistical analysis was implemented in the R package Regression Modelling Strategies (RMS) [45]. To control for non-independence, we calculated Robust Covariance Matrix Estimates (ROBCOV) of parameter standard errors using study (S) as a cluster variable [46,47]. The General Linear Models are described in the main paper. Interpretation of individual coefficients in the model requires some caution, given a small but statistically significant correlation between ΔT and ΔP ($r=0.30$; $P<0.001$) and ΔT and ΔCO_2 ($r=0.31$; $P<0.001$). That is, studies that consider larger temperature changes tend also to have higher CO_2 and more positive changes in rainfall, due to 1. the fundamental link between CO_2 and Global Mean Temperature (GMT) and 2. the increase in globally averaged rainfall with GMT, albeit with marked regional differences. Therefore, it is likely that the coefficient on ΔT (as well as bivariate plots such as Fig. 1) captures some of the positive effects of increased P and CO_2, and conversely that the coefficients on the ΔP and ΔCO_2 capture some temperature effects. Nonetheless, co-linearity is low enough that we do not view it as a serious concern for interpreting overall trends (see Supplementary Fig. 5).

In addition to the model presented in the main paper ('main') we fit a model which included all first order interactions between explanatory variables ('full'). The results are shown in Supplementary Table 2. Some of the interaction terms were significant including $P*\Delta CO_2$ (t=-2.57; P = 0.0102) and A*R (t=-2.10; P = 0.0362). This implies that the benefits of adaptation have been more clearly demonstrated for temperate compared with tropical regions; and that the positive effects of CO_2 are less clear under high precipitation (as also reported elsewhere [48]). The A*ΔP term is negative, and although the interaction falls short of statistical significance (P=0.0618), this result suggests that the positive effects of adaptation are less clear under high precipitation (c.f. Main Fig. 2, which shows a similar effect).

We calculated the marginal effects of both models for each of ΔCO2 , ΔP and ΔT. Increasing ΔCO2 by 1ppm caused a 0.06% increase in mean predicted ΔY in both the main and full models. Increasing ΔP by 1% caused a 0.53% increase in predicted mean ΔY in both the main and full models. Increasing ΔT by 1°C caused a 4.90% and 4.87 % reduction in mean ΔY in the main and full models, respectively. These marginal effects suggest there is little difference in mean model predictions between the main and full models. However, because the full model masked some of the significant main effects we chose to present a parsimonious model including only main effects in the paper. For both models, checking plots confirmed residuals were approximately normally distributed and homogenous among fitted values (Supplementary Figure 6).

Comparison of results with historical data

Ongoing evaluation of crop model skill using experimental data (e.g. refs 49, 50) is a critical part of building confidence in the predictions made by models. Observed changes are becoming an increasing resource for evaluating model results. Whilst there is evidence that some of the processes that are predicted to be important under climate change are starting to be observed across large regions (e.g. ref. 51), it can be difficult to assess the ability of models to reproduce observations (c.f. refs 52, 53). Nonetheless, evaluation of crop model skill using experimental data, which has been carried out for all of the models used in this meta-analysis, is an important underpinning element of confidence in the results generated by this study.

Whilst the wealth of work on model evaluation is important, it leaves unanswered the question of how consistent the meta-analysis is with current understanding of crop responses to climate change. Historical data from crop science experiments and regional scale analyses can be used to assess the results of this study. Both types of comparison have associated challenges. Direct comparison of the meta-analysis presented here with experimental data is impossible, since the knowledge generated on the response of crops to climate by field and controlled environment experiments is inherently different to that generated from modelling. Temperature response curves developed from the meta-analysis include associated changes in other meteorological variables, making direct comparison to controlled environments impossible. Also, much of the experimental data is itself used, or even designed [54], to develop model parameterisations – so the two sources of data are not independent. Given these limitations, a comparison of crop science experiments with the central tendencies derived in this study is not warranted. However, the full range of yield responses provided by the meta-analysis would be expected to be consistent with experimental data. This is indeed the case, although the large range of reported yield sensitivities, even within one study, means that this comparison is of limited use. For example, refs 55, 56 show sensitivities of winter wheat seed yield of around 5-10%, whilst ref. 57 reports values ranging from a few percent up to around 50%, depending on the season analysed. Each of these estimates of yield sensitivity is itself subject to the uncertainty in measuring the response of yield at each temperature. The ranges are not dissimilar in character to those found in this study.

In contrast to experimental data, regional data can be compared to the central tendencies derived from the meta-analysis. Using country-scale data from 1980 to 2008, ref. 58 observed a global-scale yield loss of approximately 5% per degree of warming for wheat and maize. Values for individual countries ranged between 2 and 12%. Rice showed a less clear response to warming, with temperature sensitivities showing some dependency on the method chosen. Central tendencies in the meta-analysis show yield changes of less than 5% per degree for temperate maize and wheat, and values within the range 5-12% for tropical maize and wheat. As with ref. 58, rice showed a less clear response to warming. Given the range of temperature sensitivities reported by ref. 58 we find our results to be broadly consistent with theirs; although the lower temperature sensitivities in temperate regions (main Fig. 1) are worthy of note. The statistical analysis presented here shows no significant difference between temperate and tropical crops, however, which suggests that the comparison of global values is the most robust.

Comparison with AR4

In order to understand the value of the model data generated since AR4, a bootstrap analysis of data (including simulations with and without adaptation) was conducted using i. the full dataset and ii. only those data from the AR4 dataset. Supplementary Fig. 7 shows the results. The additional data have resulted in more constrained bootstraps in some cases (e.g. tropical maize and wheat at low temperature changes). This indicates that the additional datapoints have decreased the uncertainty in estimation of aggregated yields. However, the increased spread of data in the new dataset means that there are also regions of the plots where this is not the case, and uncertainty has not changed. For some parts of some curves the results from the two datasets are clearly separated. In particular the results highlight the potential, visible in the full dataset, for yield loss in all three temperate crops at low temperature change. This results contrasts with AR4, where gains were observed at low temperatures.

The increase in the spread of datapoints between AR4 and the current analysis may in part be due to changes in methodology. Of the top six studies (see Supplementary Fig. 3), five are post-AR4. Four of these use global or near-global gridded crop models [39-42], whilst just one focusses on sampling uncertainty over a more limited spatial domain [44]. This suggests that the increased spatial sampling associated with gridded models may be the cause of the increase in spread. Another possible reason is differences in the structure of gridded models, compared to the more traditional point-based models; however, it is difficult to postulate a cause for such a systematic difference.

The AR4 dataset included only process-based crop models. In order to understand the impact of inclusion of statistical models, analyses for all the figures were repeated using only process-based models. This removed 127 datapoints, taken from four studies. The only case where results were not virtually identical to the full dataset is the projection figure. Supplementary Fig. 8 presents the projection results for process-based models only (see Appendix for details of references). The principal discernible difference between this figure and Main Fig. 1, where the full dataset is presented, is that for the 2020s (the period over which most of the statistical models are applied) the full dataset shows less consensus on yield decreases and more consensus on yield increases than the subset. Thus the statistical models predict a greater (negative) impact of climate on crop yields for the near future.

Differentiating tropical and temperate regions

The tropical vs temperate distinction as used in this study, and outlined at the start of this document, contains some classifications that are less universally agreed than others. In order to test the influence of our chosen classification on the results, we repeated the statistical regression, omitting the less clear-cut classifications, namely any data from China or the Andean region. The results are presented in Supplementary Table 3. The results are very similar to those presented in the main paper (Table 1). The only difference in the statistical significance of the GLM is that the CO2 term has gained greater significance (P=0.0003, as opposed to 0.0022).

The effectiveness of different adaptation strategies

Of the adaptation strategies distinguished in the study (planting date, fertiliser, irrigation, cultivar or “other agronomic”), only two categories have more than 20 entries in the paired adaptation studies: planting date plus cultivar adjustment (with n=151, mostly from ref. 40), and cultivar adjustment alone (n=56). Conclusions regarding which adaptation strategy is best are therefore difficult. Supplementary Fig. 9 summarises the results from the paired adaptation studies. The clearest benefit of adaptation is seen in simulations that adjust the cultivar (which are also the categories with the largest sample sizes). Irrigation and planting date adjustment also show some benefit, although in these cases the standard error crosses the zero line. Low sample size is likely an issue.

Widening the analysis to include all simulations where adaptation was simulated provides more data, although it precludes paired comparisons with the non-adapted case. Supplementary Table 4 shows that of the four categories (for this analysis fertiliser was included with “other”) only irrigation and “other”, on average, increase yields from baselines values. Of the four categories, irrigation is the one that is most likely to systematically increase yields, since planting date and cultivar changes can reduce yields. Modelling studies do not always distinguish between proven beneficial adaptations and adaptations that attempt to minimise or reverse yield loss, but in practice may fail. Thus the high ranking of irrigation as an adaptation option in this analysis in part reflects the fact that irrigation is unlikely to be a maladaptation; but also in part reflects the modelling methods used. In all four cases the standard deviation of yield change is larger than the average result, indicating that caution is required when interpreting the results.

Limitations of the analysis

The inclusivity of the literature search conducted for this analysis has resulted in a large sample size. Whilst this is beneficial in statistical terms, important limitations also result from taking such a broad sweep of the literature. The numerous yield projection data are from studies that not only use different methods, but also are for a range of crops and regions. Some of the resulting limitations have been at least partially addressed above (e.g. the biases introduced by the random geographical sample provided by the literature; the implications of decisions regarding whether a system is tropical or temperate). Perhaps the most notable limitation – and also the most difficult to assess – is that the assumptions in the underlying studies affect the robustness of the analysis. A partial assessment of this limitation has already been made with respect to the inclusion of both statistical and process-based models. However, within each of these categories, particularly the latter, there is significant variation in the modelling methods used.

It is impossible to fully assess the implications of the numerous assumptions made by the numerous models and methods used across the studies; indeed, even for single studies this is a difficult task. However, given that most crop models share similar assumptions, some general comments can be made. Models have limitations in simulating all types of adaptation, since in each case there are parameter and/or input data sensitivities that cannot be fully evaluated. For example, skilful simulation of crop yield using a given cultivar parameter set in a given environment does not in itself imply skill in another environment. In short, capturing G x E x M is challenging for crop models, and this has implications for the fidelity of adaptation simulations. Changes in planting date are subject to similar limitations, since crop models can show high sensitivity to the timing of rainfall [59]. This leads some authors to use planting date as a metric of uncertainty, rather than an adaptation measure [41]. Perhaps the most notable limitation, however, is the fact that all adaptations simulated are incremental. These relatively small adjustments contrast to more systemic changes such as changed crop species or grazing integration, or more transformational options such as crop relocation or complete change in the farming system, such as moving from irrigated to dryland systems [10]. For these reasons the assessment of adaptation options presented in this study should be clearly understood as being model-centric and inherently limited.

A key implication of the inclusivity of the literature search is the large spread of projected yields; larger than that of the AR4 analysis. Similar results have been found elsewhere: ref. 60 found that their simulations "display a wider range of uncertainty compared to the AR4 results, reflecting the much fuller geographical coverage and diversity of crop models represented in the current study." In contrast, climate model uncertainty (as expressed by ranges in meteorological variables) has not changed significantly between AR4 and AR5 [61, 62]. This contrast is perhaps not surprising, since i. analyses of climate models tend to focus on a relatively small number of variables (temperature, precipitation etc), and ii. the systems analysed lack the biological and social diversity that lead to the multiplicity of crops, locations and yields analysed in this paper.

The analysis above (“Comparison with AR4”) shows that the increased spread between AR4 and AR5 analyses of yield projections need not result in significantly greater uncertainty in estimating central tendencies. Further, there is some suggestion that this spread may in part be due to greater spatial sampling. The diverse nature of the literature available does mean that the central tendencies derived should not be taken in isolation. Broadly speaking the central tendencies derived here are consistent with other estimates of yield response to climate change (see “Comparison of results with historical data” above).

Country	Area (MHa)	% datapoints
Wheat		
India	29	55
Russian Federation	25	3.4
China	24	15
United States of America	18	17
Rice		
India	44	67
China	30	61
Indonesia	13	0
Bangladesh	12	2.8
Maize		
United States of America	34	35
China	34	38
Brazil	13	3.5
India	7	13.3

Supplementary Table 1. Data from FAOSTAT showing the area harvested for the top four producers of maize, wheat and rice in 2011. The second column shows the percentage of datapoints in the respective meta-analysis category (e.g. temperate maize) that come from that country.

Term	Coefficient	S.E.	t	P
Intercept	-12.6140	5.6392	-2.24	0.0256 *
A ('no'=0; 'yes'=1)	14.0560	6.3581	2.21	0.0273 *
R ('temperate'=0; 'tropical'=1)	4.9728	6.7468	0.73	0.4613
M ('c3'=0; 'c4'=1)	2.9265	4.4719	0.65	0.5130
ΔT	-4.1575	2.2038	-1.89	0.0595
ΔP	1.4597	0.3124	4.67	<0.0001 ***
ΔCO_2	0.0748	0.0446	1.67	0.0946
A*R	-11.1276	5.3029	-2.10	0.0362 *
A*M	-7.007	3.2938	-1.70	0.0755
A*ΔT	-0.3494	1.8446	-0.19	0.8498
A*ΔP	-0.3514	0.1879	-1.87	0.0618
A*ΔCO_2	0.0375	0.0234	1.60	0.1105
R*M	-2.8040	5.7509	-0.43	0.6235
R*ΔT	-0.1199	2.7886	-0.04	0.9657
R*ΔP	-0.065	0.2737	-0.24	0.8110
R*ΔCO_2	-0.023	0.0222	-1.02	0.3061
M*ΔT	0.6118	1.8544	0.32	0.7415
M*ΔP	-0.3451	0.2060	-1.68	0.0942
M*ΔCO_2	0.0017	0.0184	0.09	0.9264
dT*ΔP	-0.0952	0.0792	-1.20	0.2293
dT*ΔCO_2	-0.0013	0.0087	-0.14	0.8860
dP * ΔCO_2	-0.0023	0.001	-2.57	0.0102 *

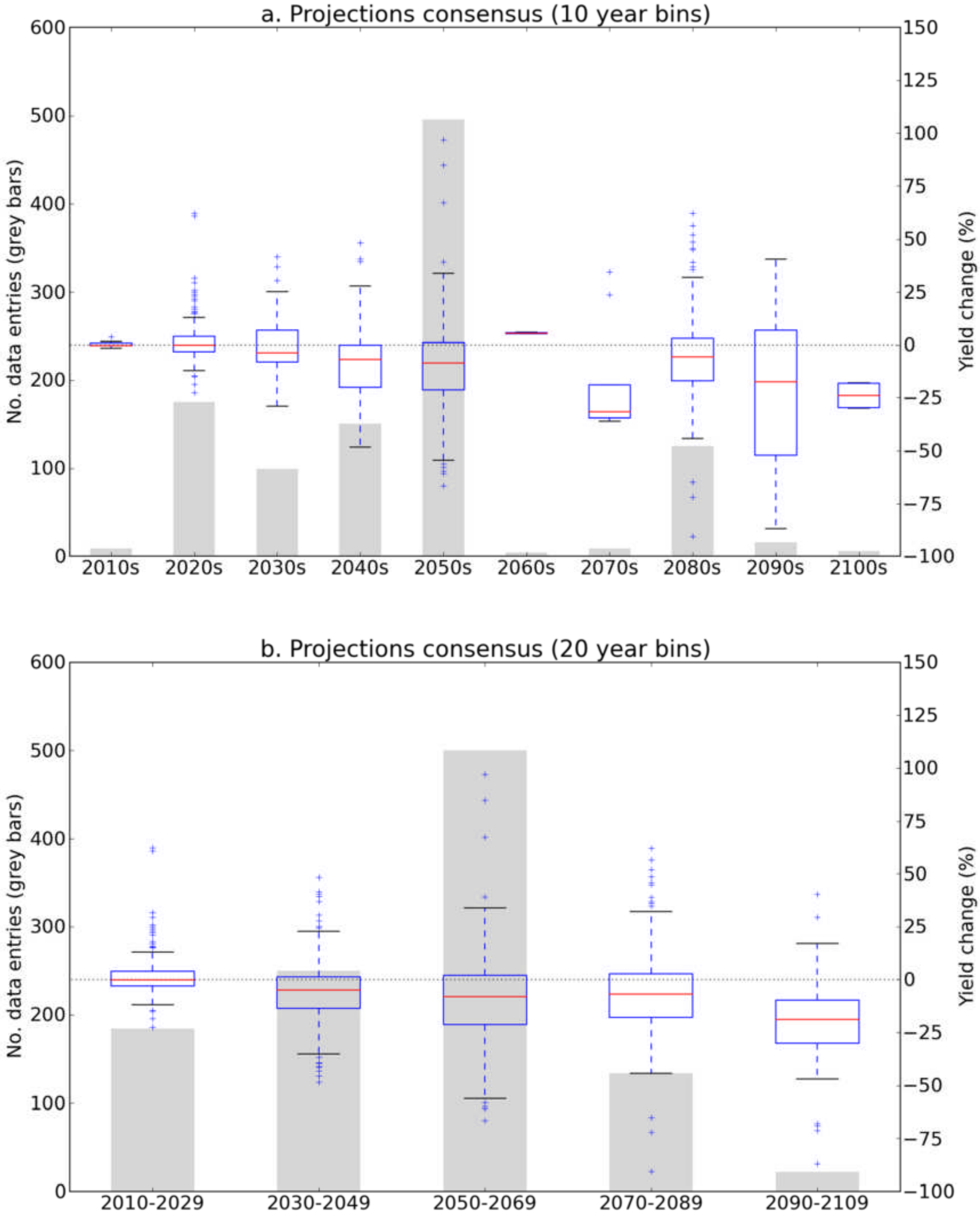
Supplementary Table 2. Results of a General Linear Model including all first order interactions, applied to all studies with reported values for changes in yield (ΔY), temperature (ΔT), CO_2 (ΔCO_2) and precipitation (ΔP), as well as three categorical variables describing treatment of adaptation (“yes” or “no”), region (“temperate” or “tropical”), and crop metabolism (“C_3” or “C_4”). (n = 860). Significance Levels: *P<0.05, **P<0.01, ***P<0.001

Term	Coefficient	S.E.	t	P
Intercept	-6.00	6.70	-0.90	0.37
A ('no'=0; 'yes'=1)	7.69	3.29	2.34	0.020*
R ('temperate'=0; 'tropical'=1)	-2.14	4.01	-0.53	0.59
M= 'c3'=0; 'c4'=1	0.21	3.33	0.66	0.95
ΔP	0.52	0.18	2.87	0.0042 **
ΔT	-5.33	1.26	-4.23	<0.0001 ***
ΔCO_2	0.06	0.02	3.63	0.0003 ***

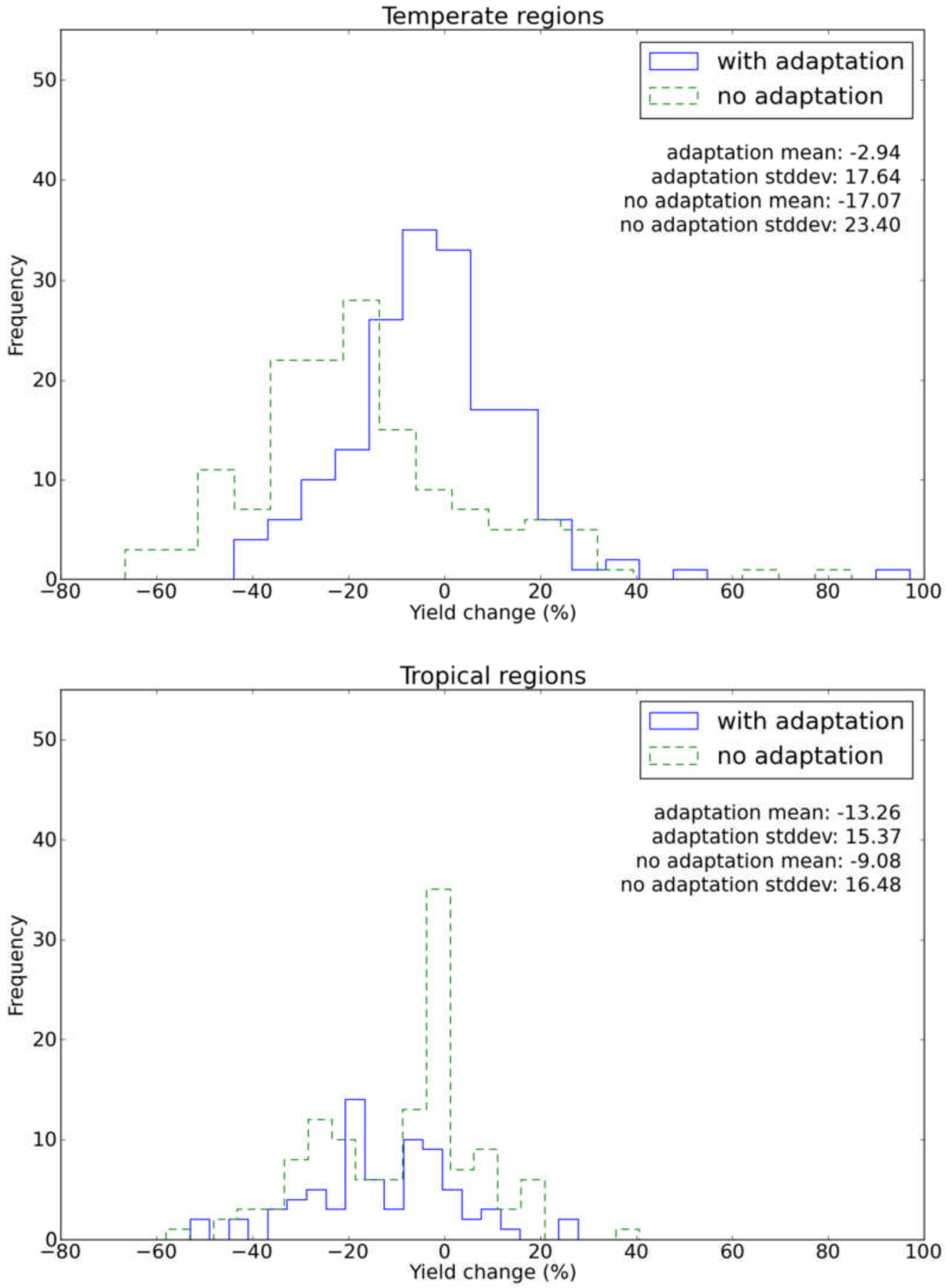
Supplementary Table 3. Summary of crop yield responses to climate change and adaptation with unambiguous tropical / temperate distinction. Results of a General Linear Model applied to all studies with reported values for changes in yield (ΔY), temperature (ΔT), CO_2 (ΔCO_2) and precipitation (ΔP), as well as three categorical variables describing treatment of adaptation (A: “yes” or “no”), region (R: “temperate” or “tropical”), and crop metabolism (M: “C_3” or “C_4”). (n=794). Significance Levels: *P<0.05, **P<0.01, ***P<0.001

	Mean	**St. Dev.**	**N**
Cultivar	-0.4	19.4	405
Irrigation	3.6	10.7	68
Planting	-5.0	16.9	414
Other	0.9	18	43

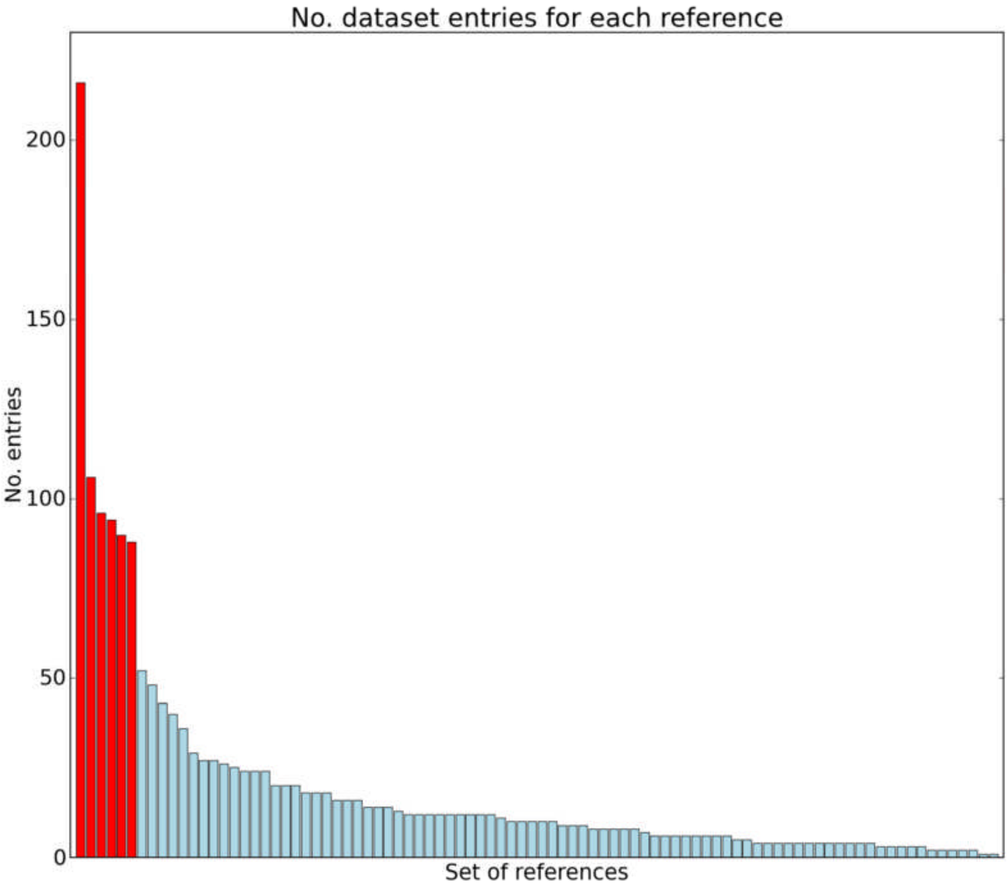
Supplementary Table 4. Percentage change in yield, from the baseline, for the four categories of adaptation. The mean and standard deviation across all N studies are shown. Where two adaptations were used results appear under both categories.



Supplementary Figure 1. Boxplot of the projected yield changes for all crops and regions, by **(a)**, decade and **(b)**, 20-year periods. Boxes show median and Inter-Quartile Range (IQR). n=1130 from 44 studies. Whiskers show the extent of data within 1.5 x IQR, and remaining data are shown as data points. Grey bars show the number of data points used for each box and whiskers. Data are plotted according the decade in which the centre point of the projection period falls.



Supplementary Figure 2: Distribution of yield changes with (solid line) and without (dashed line) adaptation for projection periods centred during the 2040s and 2050s. N=517 from 19 studies.



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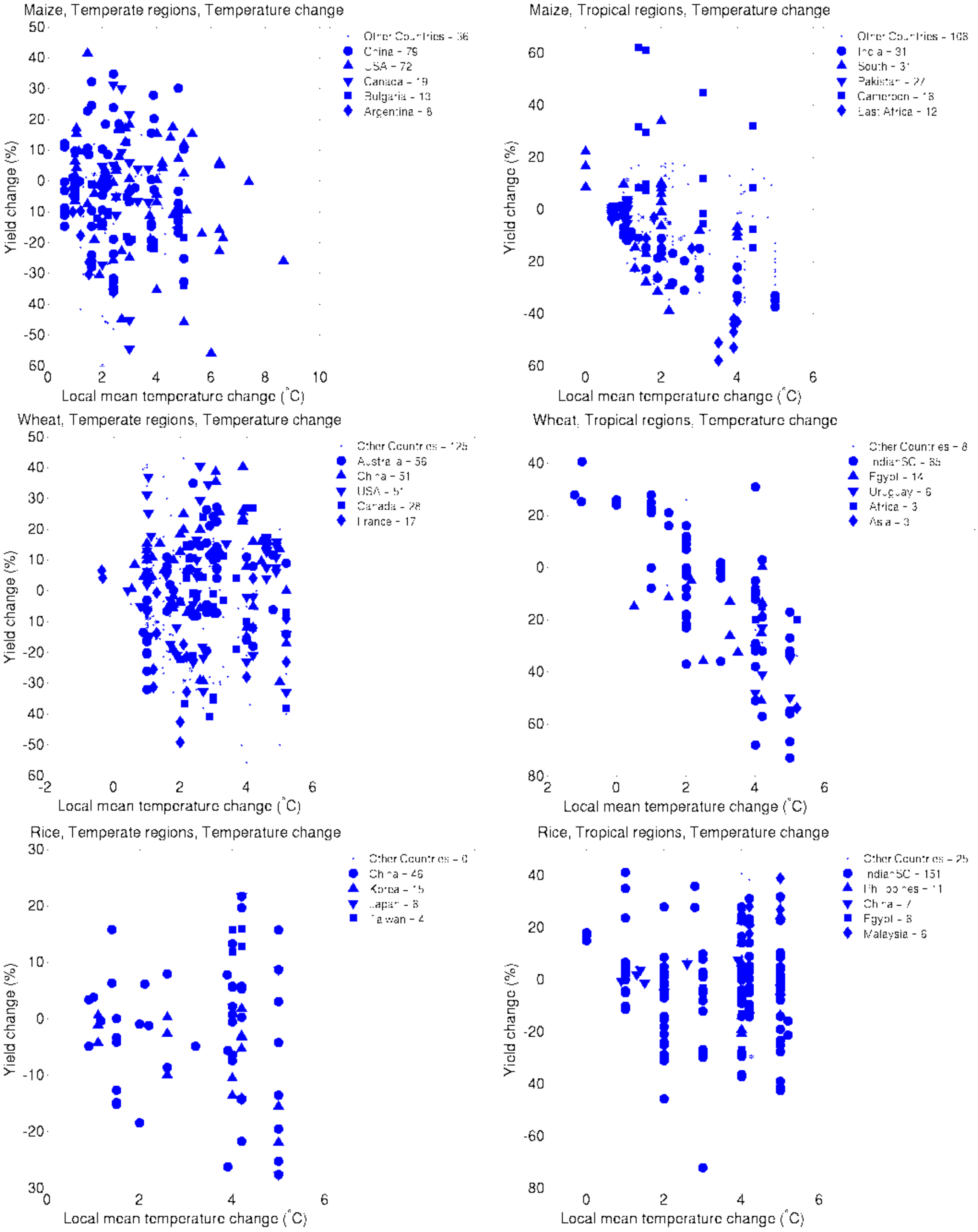
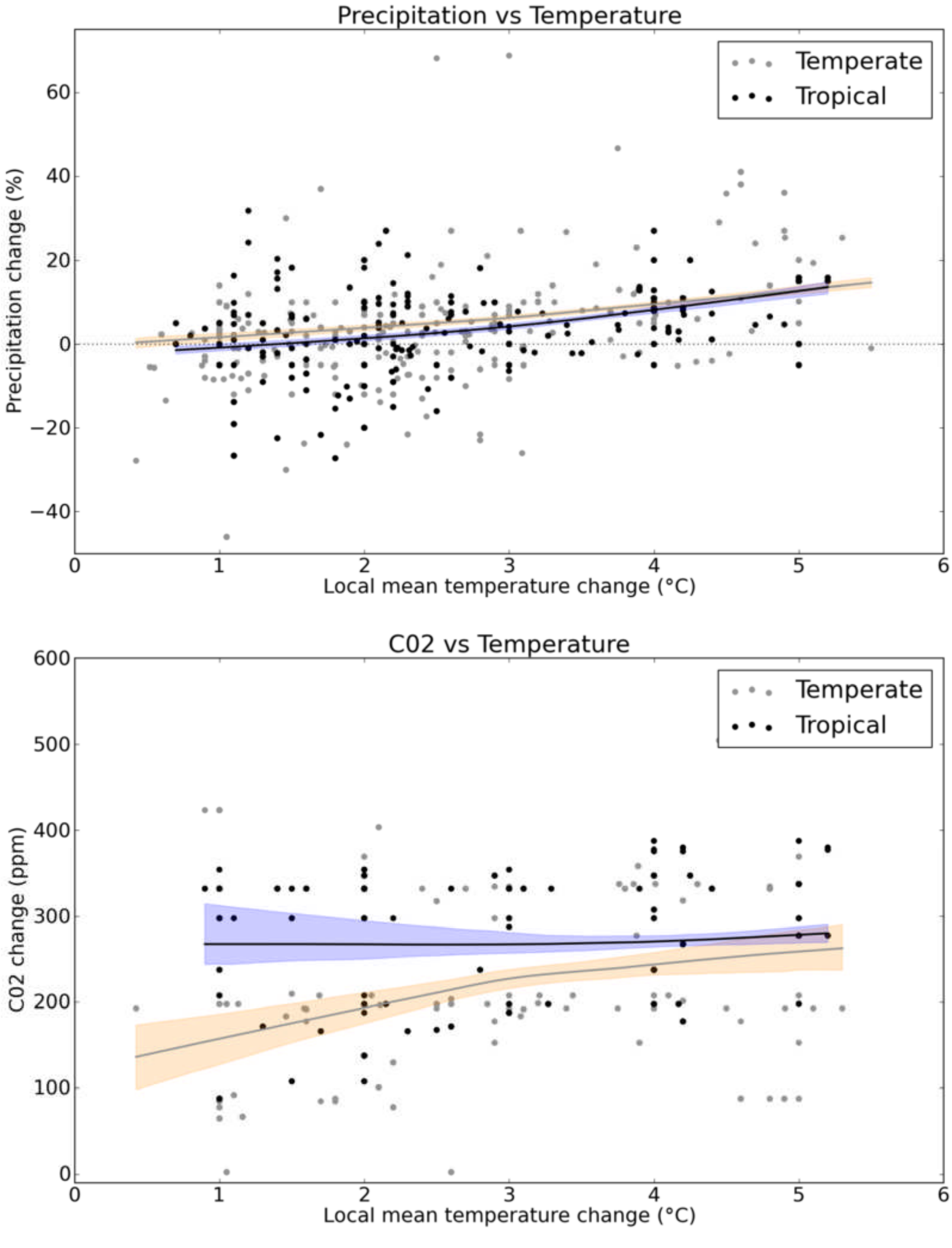
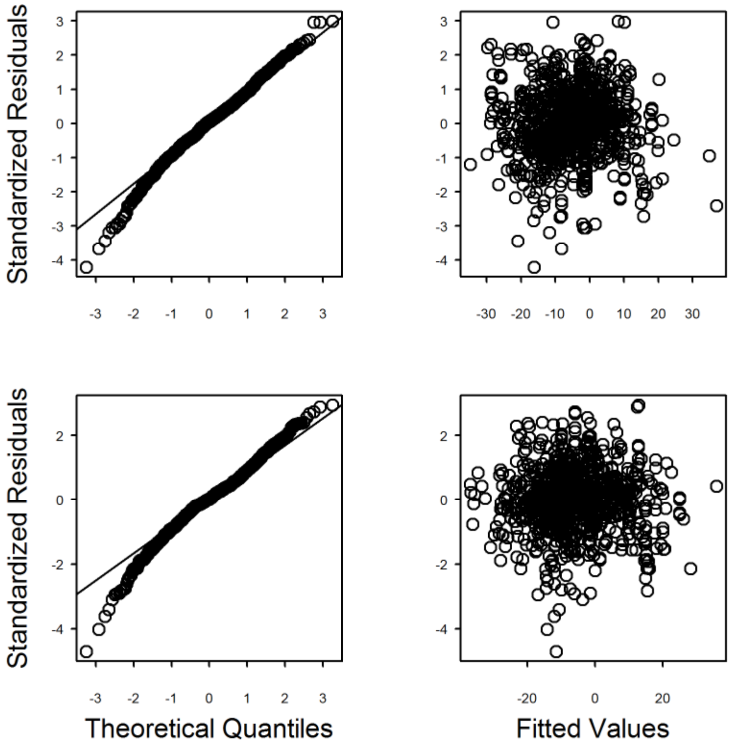
299 **Supplementary Figure 3.** Frequency count of the number of yield entries per study. The top six
300 studies [39-44] are highlighted in red.



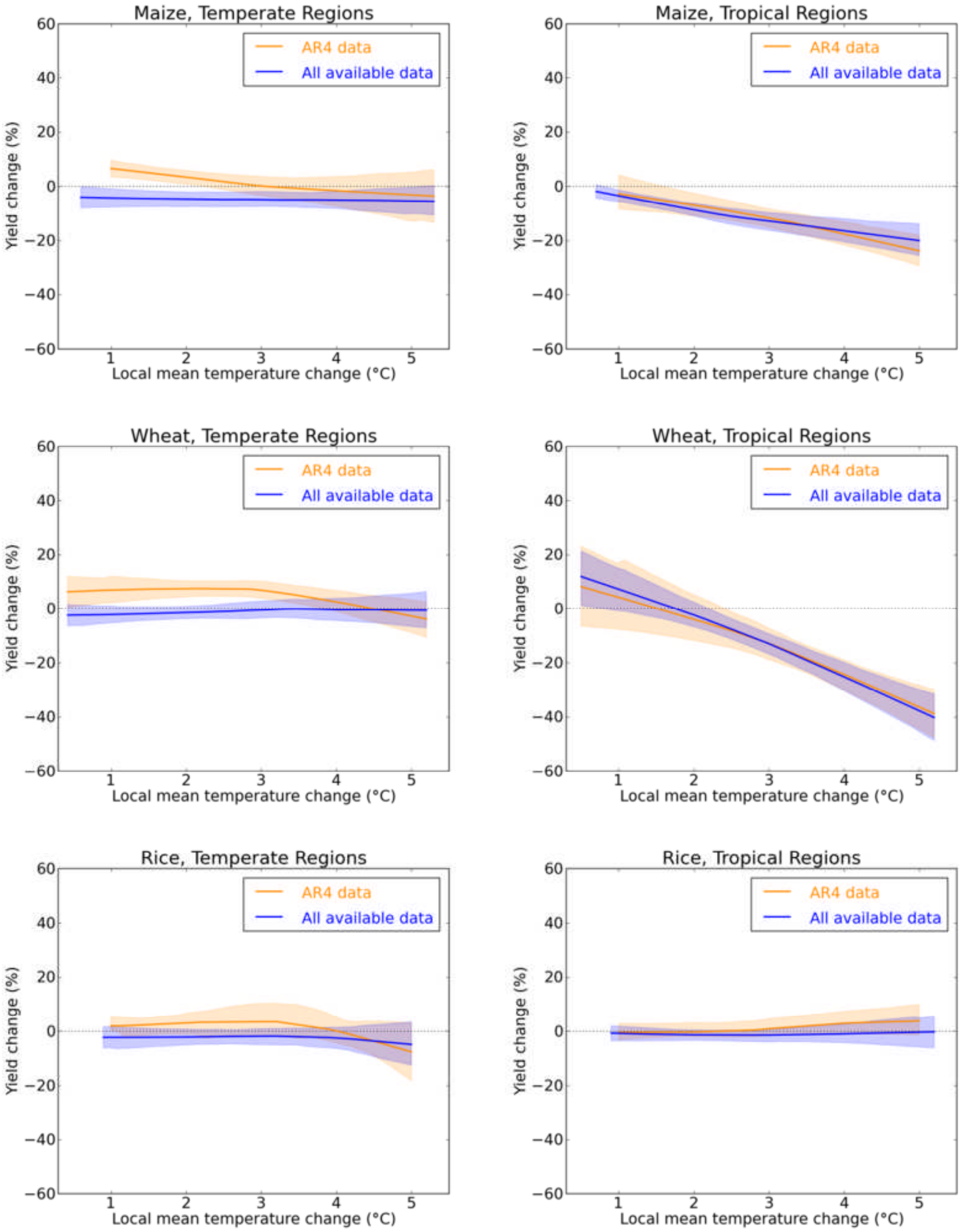
Supplementary Figure 4. Percentage yield change as a function of temperature for the three major crops and for temperate and tropical regions (n=1083 from 68 studies), highlighting the country composition of the dataset. The top 5 contributions from individual countries are marked for each panel.



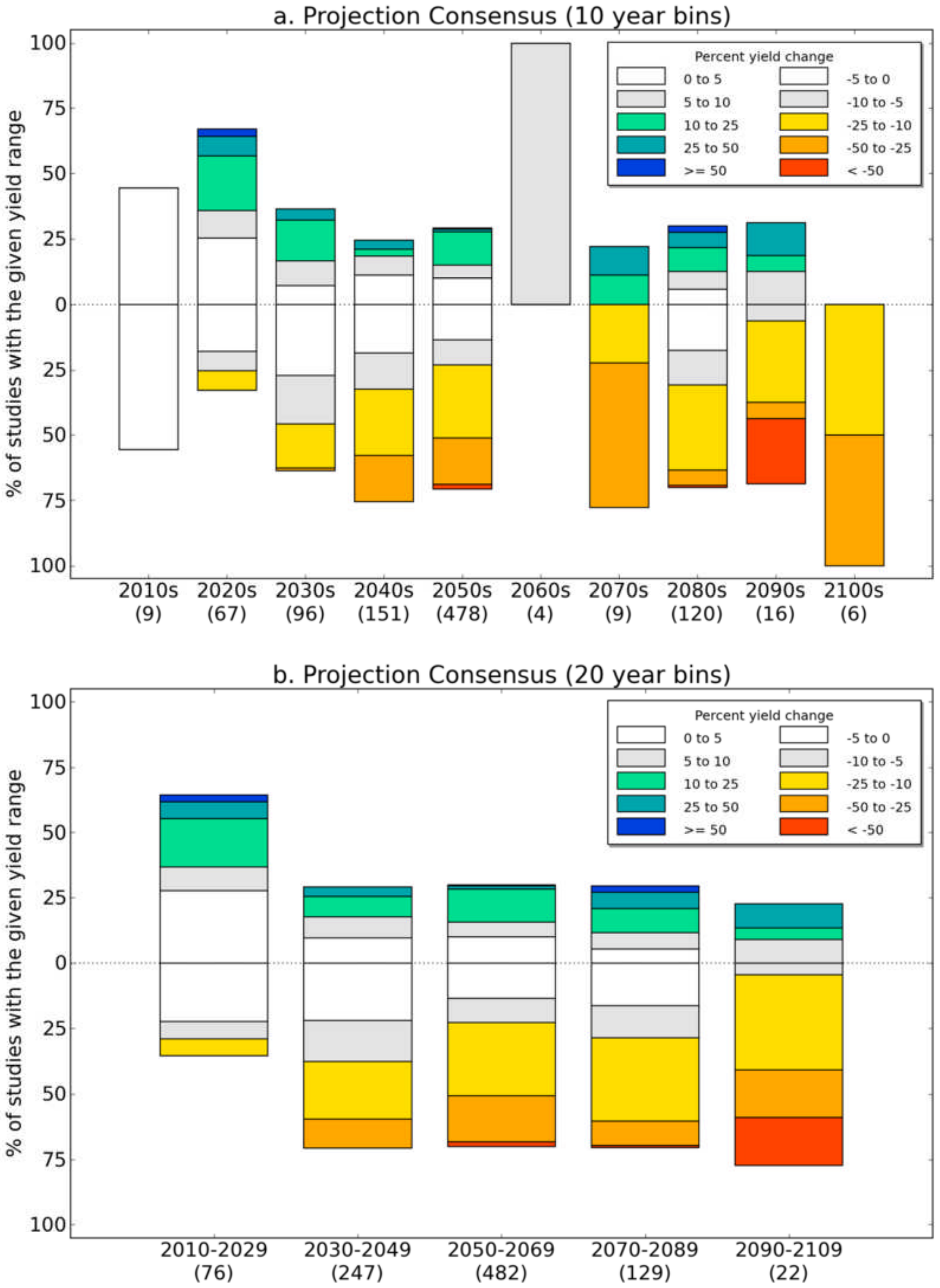
Supplementary Figure 5. Change in precipitation (top panel) and CO_2 (bottom panel) vs change in local mean temperature for the yield impact studies (n= 1173 in top panel, n=633 bottom panel; from 73 studies). Shading indicates the range of regressions consistent with the data, assessed using the same bootstrapping method as in the main paper. To avoid error due to small sample size, the eleven data points with warming greater than 6^{o}C are excluded from the regressions. Four data points are also excluded due to very high (194%) precipitation change.



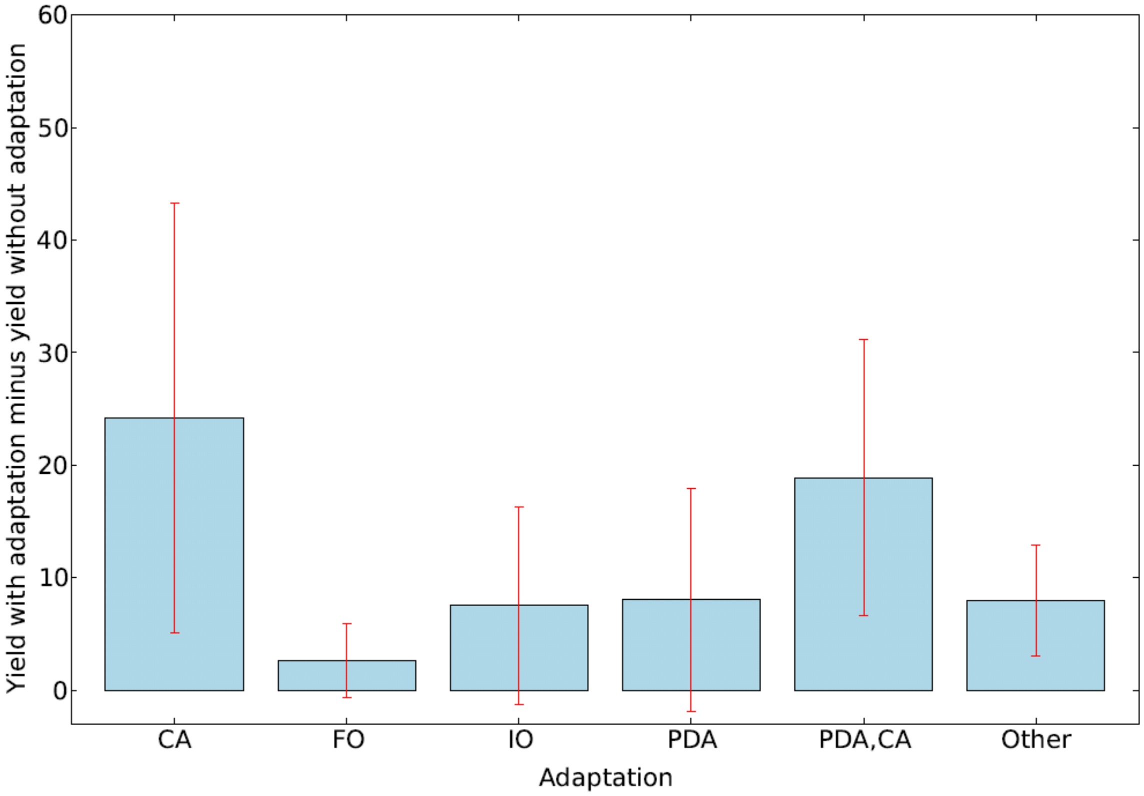
Supplementary Figure 6. Model checking plots for main (top panels) and full (bottom panels) models. For both models it can be seen that residuals are approximately normally distributed (left panels) and variance homogenous (right panels) among fitted values.



Supplementary Figure 7. Percentage yield change as a function of temperature for the three major crops and for temperate and tropical regions for local mean temperature changes up to 5.5 degrees. Shaded bands indicate the 95% confidence interval of regressions consistent with the data based on 500 bootstrap samples, which indicate use of the full dataset (blue) or the subset of data used in AR4 (orange).



Supplementary Figure 8. Projected changes in crop yield as a function of time for all crops and regions as projected by process-based models (n=956 from 33 studies). The vertical axis indicates degree of consensus and the colours denote percentage change in crop yield. Data are plotted according to (a) decade or (b) 20-year periods in which the centre point of a study’s projection period falls. The number of datapoints for each bin is shown in brackets.



Supplementary Figure 9. The benefit (percentage change, from the baseline, in yield with adaptation minus that without adaptation) for the crop management adaptation employed in the 32 paired adaptation studies: CA – cultivar adjustment (n=56); FO – fertiliser optimisation (n=10); IO – irrigation optimisation or adjustment (n=17); PDA – planting date adjustment (n=19); and other(n=9). The PDA, CA category has n=151, the vast majority of which come from ref. 40. The bars indicate standard error.

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Appendix 1: References used in the meta-analysis

Reference	Figs 1 & S4	Fig 2	Figs 3 & S1	Fig S2	Fig S5	Fig S7
Abou-Hadid, 2006	*					
Abraha & Savage, 2006	*	*	*		*	*
Aggarwal & Mall, 2002	*	*			*	
Alexandrov, 1999	*	*			*	
Alexandrov & Hoogenboom, 2000	*		*	*	*	*
Alexandrov et al., 2002	*	*			*	
Arndt et al., 2011	*		*	*	*	*
Berg et al., 2013			*		*	*
Brassard & Singh, 2008	*		*	*	*	*
Brassard & Singh, 2007	*		*	*	*	*
Butt et al., 2005	*	*	*		*	*
Byjesh et al., 2010	*					
Calzadilla et al., 2009			*			*
Challinor & Wheeler, 2008						
Challinor et al., 2009		*			*	
Challinor et al., 2010						
Chhetri et al., 2010	*		*	*	*	*
Chipanshi et al., 2003	*				*	
Ciscar et al., 2011			*		*	*
Corobov, 2002	*	*			*	
Izaurralde et al., 2001	*				*	
Das et al., 2007						
DeJong et al., 2001	*	*			*	
Deryng et al., 2011	*	*	*	*	*	*
Droogers, 2004	*	*			*	
Easterling et al., 2003	*	*			*	
El Maayar et al., 2009	*				*	
El-Shaher et al., 1997	*	*			*	
Ewert et al., 2005	*	*			*	
Gbetibouo & Hassan, 2005	*	*			*	
Giannakopoulos et al., 2009			*			*
Hermans et al., 2010			*	*		*
Howden & Jones, 2004	*	*			*	
Iqbal et al., 2011	*		*	*	*	*
Izaurralde et al, 2005	*		*	*	*	*
Jones & Thornton, 2003	*				*	
Kaiser, 1999	*	*			*	
Kapetanaki & Rosenweig, 1997	*				*	
Karim et al., 1996	*	*			*	
Kim et al., 2010			*		*	*
Krishnan et al., 2007	*				*	
Lal, 2011	*	*	*	*	*	*
Lal et al., 1998	*	*			*	
Lashkari et al., 2011						
Li et al., 2011	*		*		*	*

Erda et al., 2005	*	*			*	
Liu et al., 2010	*				*	
Lobell & Burke, 2010						
Lobell & Ortiz-Monasterio, 2007	*				*	
Lobell et al., 2008			*			
Luo et al., 2003	*				*	
Matthews & Wasmann, 2003	*	*			*	
Moriondo et al., 2010			*			*
Moya et al., 1998	*	*			*	
Muller et al., 2010		*	*			*
Osborne et al., 2013	*		*	*	*	*
Peltonen-Sainio et al., 2011			*			
Piao et al., 2010	*		*	*	*	*
Porter & Semenov, 2005	*					
Reyenga et al., 1999	*	*			*	
Ringler et al., 2010			*	*		*
Rosenzweig et al., 1994	*	*			*	
Rowhani et al., 2011			*			
Sands & Edmond, 2005	*				*	
Schlenker & Lobell, 2010					*	
Schlenker & Roberts, 2009	*		*		*	
Shuang-He et al., 2011	*		*		*	*
Southworth et al., 2000	*	*	*	*	*	*
Srivastava et al., 2010						
Tan et al., 2010	*		*		*	*
Tao & Zhang, 2010	*		*	*	*	*
Tao & Zhang, 2011	*	*	*		*	*
Tao et al., 2009			*	*		*
Tubiello et al., 2000	*	*			*	
Thomson et al., 2005	*				*	
Thornton et al., 2009	*		*			*
Thornton et al., 2011	*		*			*
Thornton et al., 2010	*	*	*	*	*	*
Tingem & Rivington, 2009	*	*	*		*	*
Tingem et al., 2008	*		*		*	*
Walker & Schulze, 2008	*		*		*	*
Wang et al., 2011			*		*	*
Winters et al., 1998	*				*	
Xiao et al., 2005	*	*			*	
Xiong et al., 2009			*		*	*
Xiong et al., 2007	*		*	*	*	*
Yates & Strzepek, 1998	*	*			*	
Zhang & Liu, 2005	*	*			*	
Zhao et al., 2005	*				*	

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