

Supplementary Material

Crop modelling: towards locally relevant and climate-informed adaptation

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Literature Search Methods

A combination of the following search strings were used to search for current place-based literature on climate change adaptation in Central America, using Web of Science advanced search criteria:

1. TI or TS= (agriculture OR farm* OR food NEAR production OR "food security" OR subsist*)
2. TS= ("climate change" OR adapt* OR vulnerability OR climate OR rain* OR drought OR temp*)
3. AD or TS= (belize OR "el Salvador" OR "Costa Rica" OR Guatemala OR Honduras OR Nicaragua OR Panama OR "Central America")
4. Year Published = 2000-2016
5. Language= 'English' or 'Spanish'

Criteria for exclusion and stage of review [Title, Abstract or Full-Article]	Information collected from included articles
Is the study (at least partly) within a Central American country [Title and Abstract]	Scale of the study
The study focus is relevant to a household or small-scale farming (self-defined or less than 5 ha) [Title and Abstract]	Adaptation strategies represented
The study discusses an agricultural practice that have been assessed, recommended or implemented to increase adaptation (resilience, or decrease vulnerability) to climate change and/or variability [Title, Abstract, and Full-Article]	Are outcomes or benefits of an adaptation measured? If so, is a control used for comparison (attribution) and what form is the outcome measured in (e.g. yield, economic, food security)?
The study uses data (physical or social) [Full-Article]	Use of climate data, climate projections, impacts models, type of data, type of model
	Were climate data used in an analysis of adaptation outcomes?
	Is more than one discipline used?

Table 1 Criteria for the inclusion of searched articles into the systematic review with stage of review denoted by square brackets, and the information collected from the resulting included studies during the review process

Adaptation Strategies References

Adaptation Strategy	Place-based References	Crop-modelling References
Crop diversification	7 [4, 17, 29, 34, 38, 5, 7]	0
Cultivar change	4 [4, 17, 33, 34, 37]	24 [3, 8, 13, 15, 18, 19, 20, 21, 22, 23, 25, 28, 31, 30, 32, 35, 36, 39, 41, 43, 44, 45, 46, 48]
Conservation agriculture (and soil conservation)	4 [4, 17, 34, 5]	0
Shade management (tree canopy)	4 [4, 17, 34, 5]	0
Fruit trees	3 [34, 38, 5]	0
Fence, windbreak	2 [34, 38]	0
Fertilizer	2 [34, 37]	3 [2, 40, 43]
Irrigation	2 [34, 4]	10 [6, 9, 10, 11, 16, 21, 24, 26, 42, 47]
Livelihood diversification	2 [29, 38]	0
Livestock	2 [34, 38]	0
Planting date	2 [37, 7]	22 [1, 3, 6, 11, 13, 14, 15, 18, 21, 23, 25, 27, 31, 35, 36, 39, 41, 43, 45, 46, 47, 48]
Seed (access and storage)	2 [5, 7]	0
Cropping area	1 [17]	1 [12]
Crop type	1 [4]	0
Crop insurance	1 [34]	0
Honey production	1 [34]	0
Water harvesting	1 [38]	0

Table 2 References from place-based and crop-modelling literature that address each of the adaptation strategies included within the analysis, bracketed numbers respond to included reference list

References

- [1] M. G. Abraha and M. J. Savage. Potential impacts of climate change on the grain yield of maize for the midlands of KwaZulu-Natal, South Africa. *Agriculture, Ecosystems and Environment*, 115(1-4):150–160, 2006.
- [2] P K Aggarwal and R K Mall. in Scenarios and Crop Models on Impact Assessment. *Climatic Change*, 52:331–343, 2002.
- [3] Vesselin Alexandrov. Vulnerability and adaptation of agronomic systems in Bulgaria. *Climate Research*, 12(2-3 SPEC. ISS. 6):161–173, 1999.
- [4] Maria Baca, Peter Laderach, Jeremy Haggard, Gotz Schroth, and Oriana Ovalle. An integrated framework for assessing vulnerability to climate change and developing adaptation strategies for coffee growing families in mesoamerica. *PLoS ONE*, 9(2), 2014.
- [5] Christopher M. Bacon, William a. Sundstrom, María Eugenia Flores Gómez, V. Ernesto Méndez, Rica Santos, Barbara Goldoftas, and Ian Dougherty. Explaining the ‘hungry farmer paradox’: Smallholders and fair trade cooperatives navigate seasonality and change in Nicaragua’s corn and coffee markets. *Global Environmental Change*, 25:133–149, 3 2014.
- [6] T. a. Butt, B. a. McCarl, J. Angerer, P. T. Dyke, and J. W. Stuth. The economic and food security implications of climate change in Mali. *Climatic Change*, 68(3):355–378, 2005.
- [7] Minerva Campos, Doribel Herrador, Carlos Manuel, and Michael K McCall. Adaptation Strategies To Climate Change in Two Rural Communities in Mexico and El Salvador. *Boletín De La Asociacion De Geografos Espanoles*, (61):433 – 436, 2013.

- [8] a. J. Challinor, F. Ewert, S. Arnold, E. Simelton, and E. Fraser. Crops and climate change: progress, trends, and challenges in simulating impacts and informing adaptation. *Journal of Experimental Botany*, 60(10):2775–2789, 2009.
- [9] a. J. Challinor and T. R. Wheeler. Crop yield reduction in the tropics under climate change: Processes and uncertainties. *Agricultural and Forest Meteorology*, 148(3):343–356, 2008.
- [10] Andrew J Challinor, Elisabeth S Simelton, Evan D G Fraser, Debbie Hemming, and Mathew Collins. Increased crop failure due to climate change: assessing adaptation options using models and socio-economic data for wheat in China. *Environmental Research Letters*, 5(3):034012, 2010.
- [11] Netra B. Chhetri, William E. Easterling, Adam Terando, and Linda Mearns. Modeling Path Dependence in Agricultural Adaptation to Climate Variability and Change. *Annals of the Association of American Geographers*, 100(June 2009):894–907, 2010.
- [12] Avery S. Cohn, Leah K. VanWey, Stephanie A. Spera, and John F. Mustard. Cropping frequency and area response to climate variability can exceed yield response. *Nature Climate Change*, (March), 2016.
- [13] R Corobov. Estimations of climate change impacts on crop production in the Republic of Moldova. pages 125–131, 2003.
- [14] R. De Jong, K Li, A. Bootsma, T. Huffman, G Rohloff, and Gameda. Final Report for Climate Change Action Fund Project A080. Eastern Cereal and Oilseed Research Centre (ECORC). *Agriculture and Agri-Food Canada*, 2001.
- [15] D. Deryng, W. J. Sacks, C. C. Barford, and N. Ramankutty. Simulating the effects of climate and agricultural management practices on global crop yield. *Global Biogeochemical Cycles*, 25(2):1–18, 2011.
- [16] Peter Droogers. Adaptation to climate change to enhance food security and preserve environmental quality: Example for southern Sri Lanka. *Agricultural Water Management*, 66(1):15–33, 2004.
- [17] Hallie Eakin, Catherine M. Tucker, Edwin Castellanos, Rafael Diaz-Porras, Juan F. Barrera, and Helda Morales. Adaptation in a multi-stressor environment: Perceptions and responses to climatic and economic risks by coffee growers in Mesoamerica. *Environment, Development and Sustainability*, 16(1):123–139, 2014.
- [18] William E. Easterling, Netra Chhetri, and Xianzeng Niu. Improving the realism of modeling agronomic adaptation to climate change: Simulating technological substitution. *Climatic Change*, 60(1-2):149–173, 2003.
- [19] M El-Shaer, H, C Rosenzweig, A Iglesias, M.H Eid, and D Hille. Impact of climate change on possible scenarios for Egyptian agriculture in the future. *Mitigation and Adaptation Strategies for Global Change*, pages 233–250, 1997.
- [20] F. Ewert, M. D a Rounsevell, I. Reginster, M. J. Metzger, and R. Leemans. Future scenarios of European agricultural land use: I. Estimating changes in crop productivity. *Agriculture, Ecosystems and Environment*, 107(2-3):101–116, 2005.
- [21] G. a. Gbetibouo and R. M. Hassan. Measuring the economic impact of climate change on major South African field crops: A Ricardian approach. *Global and Planetary Change*, 47(2-4 SPEC. ISS.):143–152, 2005.
- [22] C. M L Hermans, I. R. Geijzenborffer, F. Ewert, M. J. Metzger, P. H. Vereijken, G. B. Woltjer, and a. Verhagen. Exploring the future of European crop production in a liberalised market, with specific consideration of climate change and the regional competitiveness. *Ecological Modelling*, 221(18):2177–2187, 2010.
- [23] S. M. Howden and R.N. Jones. Risk assessment of climate change impacts on Australia’s wheat industry. In *In: New directions for a diverse planet: Proceedings of the 4th International Crop Science Congress, Brisbane, Australia*, 2004.
- [24] M a Iqbal, J Eitzinger, H Formayer, a Hassan, and L K Heng. A simulation study for assessing yield optimization and potential for water reduction for summer-sown maize under different climate change scenarios. *The Journal of Agricultural Science*, 149(02):129–143, 2011.
- [25] M Kaiser, H. Global Environmental Change and Agriculture: Assessing the Impacts. chapter Assessing. Edward Elgar Publishing Ltd, 1999.
- [26] M. Lal, K. K. Singh, L. S. Rathore, G. Srinivasan, and S. a. Saseendran. Vulnerability of rice and wheat yields in NW India to future changes in climate. *Agricultural and Forest Meteorology*, 89(2):101–114, 1998.

- [27] Xiang Li, Taro Takahashi, Nobuhiro Suzuki, and Harry M. Kaiser. The impact of climate change on maize yields in the United States and China. *Agricultural Systems*, 104(4):348–353, 2011.
- [28] Robin Matthews and Reiner Wassmann. Modelling the impacts of climate change and methane emission reductions on rice production: A review. *European Journal of Agronomy*, 19(4):573–598, 2003.
- [29] Andrea Milan and Sergio Ruano. Rainfall variability , food insecurity and migration in Cabricán, Guatemala. *Climate and Development*, 6(1):61–68, 2014.
- [30] T B Moya, L H Ziska, O S Namuco, and D Olszyk. Growth dynamics and genotypic variation in tropical, field-grown paddy rice (*Oryza sativa* L.) in response to increasing carbon dioxide and temperature. *Global change biology*, 4(6):645–656, 8 1998.
- [31] C. Muller, A. Bondeau, A. Popp, K. Waha, and M Fadar. Development and climate change. Technical report, 2010.
- [32] Tom Osborne, Gillian Rose, and Tim Wheeler. Variation in the global-scale impacts of climate change on crop productivity due to climate model uncertainty and adaptation. *Agricultural and Forest Meteorology*, 170:183–194, 2013.
- [33] Timothy G Porch, Richard Bernsten, J C Rosas, and M. Jahn. Climate change and the potential economic benefits of heat-tolerant bean varieties for farmers in Atlántida , Honduras 1 , 2. *Journal of Agricultural University PR*, 91(3-4):133–148, 2007.
- [34] Eric Rahn, Peter Lederach, Maria Baca, Charlotte Cressy, Gotz Schroth, Daniella Malin, Henk van Rikxoort, and Jefferson Shriver. Climate change adaptation, mitigation and livelihood benefits in coffee production: where are the synergies? *Mitigation and Adaptation Strategies for Global Change*, 19(8):1119–1137, 2014.
- [35] P. J. Reyenga, S. M. Howden, H. Meinke, and G. M. McKeon. Modelling global change impacts on wheat cropping in south-east Queensland, Australia. *Environmental Modelling and Software*, 14(4):297–306, 1999.
- [36] C Rosenzweig. Potential impact of climate change on world food supply. *Nature*, 367:133–138, 1994.
- [37] Alex C. Ruane, L. DeWayne Cecil, Radley M. Horton, Román Gordón, Raymond McCollum, Douglas Brown, Brian Killough, Richard Goldberg, Adam P. Greeley, and Cynthia Rosenzweig. Climate change impact uncertainties for maize in Panama: Farm information, climate projections, and yield sensitivities. *Agricultural and Forest Meteorology*, 170:132–145, 2013.
- [38] Axel Schmidt, Anton Eitzinger, Kai Sonder, and Gustavo Sain. Tortillas on the Roaster (T O R) Full Technical Report Central American Maize -Bean Systems and the Changing Climate. (October), 2012.
- [39] Jane Southworth, J.C. Randolph, M. Habeck, O.C. Doering, R.a. Pfeifer, D.G. Rao, and J.J. Johnston. Consequences of future climate change and changing climate variability on maize yields in the midwestern United States. *Agriculture, Ecosystems & Environment*, 82(1-3):139–158, 2000.
- [40] Zhengxi Tan, Larry L. Tieszen, Shuguang Liu, and Emmanuel Tachie-Obeng. Modeling to evaluate the response of savanna-derived cropland to warming-drying stress and nitrogen fertilizers. *Climatic Change*, 100(3):703–715, 2010.
- [41] Fulu Tao and Zhao Zhang. Adaptation of maize production to climate change in North China Plain: Quantify the relative contributions of adaptation options. *European Journal of Agronomy*, 33(2):103–116, 2010.
- [42] Fulu Tao and Zhao Zhang. Impacts of climate change as a function of global mean temperature: Maize productivity and water use in China. *Climatic Change*, 105(3-4):409–432, 2011.
- [43] Philip K. Thornton, Peter G. Jones, Gopal Alagarswamy, and Jeff Andresen. Spatial variation of crop yield response to climate change in East Africa. *Global Environmental Change*, 19(1):54–65, 2009.
- [44] Munang Tingem and Mike Rivington. Adaptation for crop agriculture to climate change in Cameroon: Turning on the heat. *Mitigation and Adaptation Strategies for Global Change*, 14(2):153–168, 2009.
- [45] Francesco N. Tubiello, Marcello Donatelli, C. Rosenzweig, and Claudio O. Stockle. Effects of climate change and elevated CO₂ on cropping systems: Model predictions at two Italian locations. *European Journal of Agronomy*, 13(2-3):179–189, 2000.
- [46] Paul Winters, Rinku Murgai, Elisabeth Sadoulet, Alain D E Janvry, and George Frisvold. Economic and Welfare Impacts of Climate Change on Developing Countries. *Environmental and Resource Economics*, 12:1–24, 1998.

- [47] Guoju Xiao, Weixiang Liu, Qiang Xu, Zhaojun Sun, and Jing Wang. Effects of temperature increase and elevated CO₂ concentration, with supplemental irrigation, on the yield of rain-fed spring wheat in a semiarid region of China. *Agricultural Water Management*, 74(3):243–255, 2005.
- [48] D N Yates and K M Strzepek. An Assessment of Integrated Climate Change Impacts on the Agricultural Economy of Egypt. *Climatic Change*, 38(3):261–287, 1998.