Paper Presentation Abstracts

Paper Presentation Session 1A: Improving Crop Models to Capture Extreme Climate Responses		
Lead and Co-Authors	***Title***	***Abstract***
Kenneth J. Boote	Lessons Learned from Crop Model Intercomparisons	One of the goals of the Agricultural Model Intercomparison and Improvement Project (AgMIP) is to improve crop simulation models for various crops based on model intercomparison and comparison to data on response to carbon dioxide, temperature, water, and nitrogen (CTWN). Based on nearly 12 years of model evaluations, the following crop modeling issues have been revealed, some of which are currently being improved on by individual modeling teams. Experience with all teams, especially the crop water evapotranspiration teams is: 1) models do not adequately address surface residue effects on soil evaporation, 2) water tables are common but not often simulated, 3) capillary rise from deeper soil layers or water table is not well simulated, 4) partitioning of energy to transpiration vs. soil evaporation needs improvement, 5) termination of transpiration with maturity and senescence needs improvement. Experience with low input teams reveals the following: 1) rate of N mineralization from soil organic matter (SOM) is a major unknown for each new soil simulated 2) calibrating multiple pools of SOM is considerably “black-box”, 3) N response studies often lack a zero N treatment, 4) initial conditions for inorganic N are mostly missing in experiments (spin-up?), 5) uncertainties are related to N leaching, N volatilization, and N immobilization, 6) crop response to rainfall is less where N is limited. Teams evaluating crop response to CO2 find that: 1) response for C-3 crops is mostly understood and similar among C-3 species, 2) response for C-4 species is small but remains controversial (do not trust blanket statements of no response), 3) response to CO2 is much less under N limitation (models lacking true N balance miss this), 4) CO2 response can be less at high rainfall where excess rainfall leaches N and causes N limitation, 5) theoretically, CO2 response should be greater under water limitation, but evidence is controversial. For teams evaluating response to elevated temperature: 1) lack of response data creates uncertainty, 2) effect of elevated temperature on reproductive is more important than effect on photosynthesis, 3) effect of elevated temperature on reproductive is growth-stage specific, both pre- and post-flower, but less during grainfill, 4) foliage temperature is much lower than air under large vapor pressure deficits, but models use air temperature to drive. Crop model improvement efforts are ongoing, but are unfortunately diverted by pressure to apply the crop models for climate change and other scenario applications.
Bruce A Kimball	Simulation of Evapotranspiration and Soil Temperature under Maize: an Inter-comparison Among 41 (ET) and	Accurate simulation of crop water use (evapotranspiration, ET), as well as soil temperature, can help crop growth models assess the likely effects of climate change on future crop productivity, as well as being an aid for irrigation scheduling for today’s growers. To determine how well maize (Zea mays L.) growth models can simulate ET, an initial inter-comparison study was conducted in 2019 under the umbrella of AgMIP (Agricultural Model Inter-Comparison and Improvement Project). Here we present results of a second inter-comparison study of 41 maize models that was conducted using more comprehensive datasets from two additional sites - Mead, Nebraska, USA and Bushland, Texas, USA. There were 20 treatment-years with varying irrigation levels over multiple seasons at both sites. ET was measured using eddy covariance at Mead and using large weighing lysimeters at Bushland. A wide range in ET rates was simulated among the models, yet several generally were able to simulate ET rates adequately. The ensemble median values were

	33 (Soil T) Maize Models	generally close to the observations, but a few of the models sometimes performed better than the median. Many of the models that did well at simulating ET for the Mead site did poorly for drier, windy days at the Bushland site, suggesting they need to improve how they handle humidity and wind. Additional variability came from the approaches used to simulate soil water evaporation. Fortunately, several models were identified that did well at simulating soil water evaporation, canopy transpiration, biomass accumulation, and grain yield. These models were older and have been widely used, which suggests that a larger number of users have tested these models over a wider range of conditions leading to their improvement. The ET inter-comparison is largely finished, and now the effort has shifted to the ability of 33 models to simulate soil temperature using the same datasets as the standard for comparison. Several models and their approaches have been identified that do well at simulating soil temperature, whereas others were consistently too warm or very scattered. These revelations of the better approaches are leading to model improvements and more accurate simulations of ET and soil temperature.
Montse Salmeron	Intercomparison of soybean models for simulation of evapotranspiration and uncertainty under variable environmental conditions	Evapotranspiration (ET) is a critical component of crop-soil-atmosphere interactions, which can introduce uncertainty in crop model simulated yield and crop water use. We conducted the first multi-model evaluation of nine soybean models with 19 combinations of model and evapotranspiration (ET) methods for the simulation of soybean growth and ET using eddy flux measurements taken over five years at two locations (Mead, Nebraska and Ottawa, Canada). Observed crop growth, leaf area index (LAI), soil moisture, and ET data for model calibration were provided in stepwise approach to evaluate the effect of blind versus full observed input data on model performance. To identify sources of model variability in simulation of ET, we analyzed model performance during two periods: incomplete canopy (from emergence to the time to reach 2.5–3.0 m2 m−2 LAI), and during full canopy (30 days following the incomplete canopy period). We also evaluated the applicability of a multi-model ensemble to reduce model uncertainty. Lastly, we quantified model sensitivity to changes in temperature, solar radiation, wind speed, relative humidity, rainfall, and atmospheric carbon dioxide (CO_2).
Davide Cammarano	Response of crop models' sub-routines to changes in atmospheric CO_2	The aim of the AgMIP Wheat CO_2 is to conduct a detailed study on the way CO_2 responses are handled in crop simulation models. To complete such a task a questionnaire asking detailed information from each modeling group, including equations and algorithms, was sent. From this questionnaire, we implemented R code to compare changes in biomass gain, stomatal conductance, and transpiration rates in the atmospheric CO_2 range of 350 ppm to 1,000 ppm, isolating the CO_2 responses from the complete simulation models. Among the findings, we learned that the CO_2 factors modifying radiation use efficiency were different among crop models sharing the same way of accounting for CO_2 effects on biomass (Fig. 1). This difference was dramatically increased above 600 ppm. This same approach was used to compare the relative biomass, stomatal conductance, and transpiration responses to changes in atmospheric CO_2 concentration using algorithms extracted from models that have an explicit representation of these responses. An approach is being developed to prepare similar comparisons of models with more mechanistic approaches and not using explicit CO_2 factors. The next steps will be to investigate and map how crop models simulate genotypic response to CO_2 based on FACE data from Italy and Australia. In Italy, there are 3 genotypes with multiple planting times and no stresses. The Australia FACE data, part of which has been published, will have additional years for a total of 7, including 2 cultivars and different water and nitrogen treatments. An interesting feature is that both datasets share one common cultivar (Janz). Ultimately the aim is to answer the following questions: i) Can crop models simulate the CO_2 effects in different environments? ii) Do models that handle photosynthesis in different ways differ in their CO_2 response?; iii) Is there evidence that CO_2 response is cultivar-specific?

Paper Presentation Session 1B: Improving Crop Models to Capture Extreme Climate Responses		
Lead and Co-Authors	***Title***	***Abstract***
Soora Naresh Kumar	Quantification of uncertainty in impacts on crop yield due to the GCM and RCM scenarios and Crop simulation models in diverse environments	Global climate model (GCM) scenarios have significant bias in representing regional climates. On the other-hand regional climate scenarios, derived from GCMs data dynamically downscaled using regional climate models (RCMs), are expected to better represent regional climates. Further, using more than one crop model is expected to reduce the uncertainty in impact projections. A simulation analysis was done to quantify the uncertainty due to climate model scenarios and crop models on crop yield in two climatically different areas and seasons. GCMs bias corrected probabilistic ensemble scenarios (GCMen), developed in our lab, were compared with the bias uncorrected regional climate model (4 models) outputs for impacts on maize (grown during July-October, monsoon season) and wheat (grown during November-March) yield. Results indicated that the bias uncorrected RCMs have shown more impact on yield with significant variations among themselves for direction of impacts and climatic extreme year impacts on crop yield, particularly in locations with warmer climate. The uncertainty is more in monsoon season. Further, the climate model uncertainty increased with the time towards the end of the century. But, the bias corrected GCMen impacts were more consistent across locations and time scales. The uncertainty due to crop models (InfoCrop v2.1, APSIM and DSSAT) is relatively less as compared that arising from the uncertainty of climate models. Crop models tend to vary in the locations with warmer climate and monsoon season, and climate scenario. Thus, the results highlight the requirement of bias-correction and ensemble climate scenarios (from GCMs or RCMs) and at least three crop models to help reduce the uncertainty arising due to climate and crop models. However, it is also important to use the crop model (s) that could capture the response of crop(s) and variety(ies) to climatic stressors within the acceptable range of error for the region(s). It is cautioned that use of multiple models for the sake of it can lead to gross misinterpretations.
Rogério de S. Nóia Júnior	Improving DSSAT-Nwheat to extreme wet climate responses	Process-based crop models still miss the compound nature of many extreme climate, particularly wet weather-related events on crop growth and development. We reviewed the impacts of waterlogging on grain number per unit area, average grain size, and grain yield in different wheat phenological stages. Episodes of waterlogging from tillering to anthesis results in fewer, and during grain filling in lighter grains. To simulate these impacts, we implemented a waterlogging module in the wheat crop simulation model DSSAT-NWheat, affecting wheat root growth, carbohydrate accumulation and potential average grain size. The waterlogging module was tested in a controlled waterlogging experiment, presenting satisfactory wheat yield simulation. The improved DSSAT-NWheat was also able to simulate the wheat yield from field experiments in France, including the extreme year of 2016 when waterlogging, plant disease, heavy rainfall, and low solar radiation occurred together. The improved DSSAT-NWheat model better represents the impact of excess rainfall and wheat diseases on crop growth and yield, which may reduce modeling uncertainties.
Akinseye Folorunso, Madina Diancoumba *(Presenter)*	Finding adaptation options for smallholder farmers in West and Central Africa by improving the modeling of millet under climate risk	Smallholder farmers in the West African drylands need to continuously adapt to appropriate technologies and management practices that sustainably increase productivity and resilience to climate. Pearl millet (Pennisetum glaucum (L) R. Br.) is a staple food for 90m+ people in the Sahelian region of Africa and North-western India and the most important cereal crop for livelihoods mainly for household consumption in the region, particularly in Nigeria and Senegal. Pearl millet is a drought and heat-tolerant cereal crop that gives stable grain and Stover yields on poor, sandy soils under hot and dry environments where other cereals may fail to provide economic benefits. Very few studies have been conducted in the region to identify optimal agronomic and nutrient management options for high and stable yields. In this study, we investigated climate risk adaptation strategies including planting dates and soil fertility for pearl millet production in rainfed farming systems in Nigeria and Senegal under projected climate scenarios. We calibrated and tested the Agricultural Production Systems sIMulator (APSIM) millet model using a combination of experimental and farm-level yield data obtained from contrasting environments. Future climate change was estimated using five ensembles of bias-corrected climate model projection outputs under the RCP8.5 emissions scenario at the mid-century period, 2040-2069 against the baseline (1980-2009). In the simulation, two sowing regimes were applied to compare traditional farmers' practices and also 20 days after the

	scenarios using APSIM	onset of the rainy season while different fertilizer strategies included organic and inorganic fertilizers or a combination of both. The results show that the projected changes in temperature and precipitation have little to no impact on millet yield for the future time period, but a large impact was observed based on planting dates and soil nutrient changes. Increasing soil fertility from poor fertility to moderate, near-optimal, and optimal levels significantly showed higher positive yield change in both locations. However, the probability of a yield reduction appears to be greater in Senegal than in Nigeria which could be associated with an exacerbated sensitivity to temperature changes compared to rainfall changes. Thus, adaptation strategies such as improving soil fertility and sowing date changes had a much greater impact on millet yield than climatic change factors. These results provide actionable guidance on investments for agricultural inputs and climate advisory services for smallholder farming on effective climate change adaptation strategies for rainfed millet production in the region.
Sifang Feng	Interdependence among subregional crop production affects global crop failure risk	Synchronous crop failure among multiple breadbaskets worldwide, a typical spatially compound event, may amplify threats to the global food system and food security and has been a growing concern among the scientific community in recent years. While the risk of simultaneous crop loss across multiple breadbasket regions has been analyzed, to date, little is known about how interdependence among regional crop production affects aggregated crop failure at the global scale. Quantifying the impact of dependencies among breadbasket regions on global food production and assessing how the dynamic of spatially compounding crop failures is simulated by climate and crop models is essential for informing the modeling of global food security risk. In this study, focusing on different crop types, we quantify the influence of dependence between crop production of individual regions on global aggregated crop yield based on the Inter-Sectoral Impact Model Intercomparison Project (ISIMIP) dataset. We find that spatial dependence between regional crop yields may aggravate global crop deficits and identify a characteristic spatial scale beyond which the dependence between crop production in different regions vanishes. Furthermore, we assess the differences in the representation of the spatially compounding event across climate models and crop models. Overall, our results provide valuable information for designing risk strategies for food security at the suited scale.
Xuhui Wang	Extreme rainfall reduces one-twelfth of China's rice yield	Extreme climate events constitute a major risk to global food production. Among these, the extreme rainfall is often dismissed from historical analyses and future projections, whose impacts and mechanisms remain poorly understood. Here, we find that rice yield reductions due to extreme rainfall in China were comparable to those induced by extreme heat over the last two decades, reaching 7.6 ± 0.9% (one standard error) according to nationwide observations and 8.1 ± 1.1% according to the crop model incorporating the mechanisms revealed from manipulative experiments. Extreme rainfall reduces rice yield mainly by limiting nitrogen availability for tillering that lowers per-area effective panicles and by exerting physical disturbance on pollination that declines per-panicle filled grains. Considering these mechanisms, we projected ~8% additional yield reduction due to extreme rainfall under warmer climate by the end of the century. These findings demonstrate the critical importance to account for extreme rainfall in food security assessments, posing greater challenges to climate change adaptation.

Paper Presentation Session 2A: Regional Integrated Assessments		
Lead and Co-Authors	***Title***	***Abstract***
Babacar Faye	Can crop variety affect climate change impacts signal on major crop yields in Senegal?	Introduction Rising temperatures and higher variability of rainfall with inappropriate agricultural practices are the main drivers for yield losses in West Africa. In Senegal, most of the studies suggest yield losses for C4 crops due to shortened growth duration and yield gains for C3 crops due to CO2 fertilization effects under climate change. Nevertheless, few studies considered management options such as sowing date, crop variety etc. The main objective of this study is to assess climate change impacts on crop yields and how different crop varieties are affected by the climate signal for four arable crops in Senegal. Materials and Methods The Lintul5 process-based crop model in the SIMPLACE framework was used at a spatial resolution of 0.5° to simulate the crop growth. Simulations were performed for the near future 2030, the mid-term 2060 and for the long term 2100 relative to the baseline (1981-2010). The new generation of climate projections (CMIP6) was used with 9 GCMs under three Shared Socio-economic Pathways scenarios (SSPs). Soil data was derived from the HWSD global soil databases. Crop sowing dates and variety lengths were based on (Faye et al., 2018), assumed unchanged in the scenarios for crops. All simulations were conducted assuming nitrogen limitation and intensification case. Results and Discussion Consideration of crop variety on climate change impacts on yield differed by crop (Figure 1). The ensemble mean over Senegal, shows a positive changes in peanut yield; and this will become more positive when CO2 concentration increase. For pearl millet, relative yield changes were generally negative with increase of CO2 concentration. Yield changes were more variable across GCMs for peanut than for pearl millet, increasing with warmer SSPs. Yield gains were higher for the short variety Fleur11 (90 days) than for the long variety 73-33 (105 days) for peanut. While for pearl millet yield losses were higher for the short variety than for the long variety due to the shortening of the cycle length. Results for all 4 crops will be presented.
Wajid Nasim *(Virtual)*	Consortium on Climate Change, Sustainability & Conservation (CCSC): A Way Forward for Sustainable Food Security & Smart Policies to Address Global Food Systems	As our planet continues to warm, all countries will increasingly suffer losses and damage from climate beyond their capacity to adapt. This is a global crisis. It demands a global response. In Pakistan, there was mass damages due to floods in year 2022 due to heavy rainfall in Monsoon the have lot of loss on food security in the form of agricultural lands, damages in infrastructure, loss of lives and outbreak of diseases etc. Floods in 2010 and unusual spell of torrential rains in recent months, extraordinary melting of glaciers, severe heat waves, sea storms and cyclones, extinction of some species are clear signs of things to come. The importance of climate change can be recognized with recent visit of United Nations Secretary-General Antonio Guterres and he said, "I have never seen climate change on the scale of the floods here in Pakistan. The World Bank has anticipated the poverty rate in Pakistan at 39.3 percent, using the lower middle-income poverty rate of $3.2 per day. The rate for the upper-middle class stands at $5.5 per day for the fiscal year 2020-21. As a result of these factors, Pakistan is currently experiencing a dire economic crisis, and based on the Global Climate Risk Index, Pakistan ranks fifth globally. The IUB recently became a member of the FAO's Global Alliance for Climate Smart Agriculture (GACSA). Further, IUB established a consortium (https://ccsc.iub.edu.pk/) that brings together more than 80 universities, research organizations, private companies, and industries from across Pakistan (Azad & Jammu Kashmir, Gilgit Baltistan, ICT, KPK, Punjab, Sindh, Balochistan) to address climate change, agriculture, food security, sustainability, and other major challenges. Among all the universities of Punjab, IUB is officially recognized as the leading University on the theme "Theme-II: Climate Change, Environment & Pollution". For this consortium to be successful, it is critical to strengthen the INTERNATIONAL CENTER FOR CLIMATE CHANGE, FOOD SECURITY, AND SUSTAINABILITY (ICCFS). It is our aim to develop research projects, training workshops, seminars, conferences, and capacity-building initiatives that will benefit students, researchers, scientists, policymakers, farmers, industrialists, and the business community. We will also discuss the Islamia University of Bahawalpur's great initiatives (national and international) to explore even more opportunities and collaborations through AgMIP9. This Abstract will focus on following Themes of AgMIP9: 1. Deepening Collaborations for the Future of Food and Land 2. Enhancing Inclusion, Equity, and Justice in Food System Challenges 3. Synergizing Adaptation and Mitigation Along the Value Chain 4. Strengthening Science-Stakeholder-Policy Linkages for Future Systems

Sabine Homann-Kee Tui	Balancing co-benefits and trade-offs between climate change mitigation and adaptation under mixed crop-livestock systems in semi-arid Zimbabwe	Building Zimbabwe's national commitments to food systems transformation and climate resilience is of high priority. Integrated simulation-based research approaches developed under the Agricultural Model Intercomparison and Improvement Project (AgMIP) are an important source of evidence to guide policy decisions towards effective transformation. Through the identification of economically viable and environmentally sustainable development pathways, the analyses in this paper presents co-benefits and trade-offs between climate change adaptation and mitigation options for vulnerable smallholder crop-livestock holdings in semi-arid Zimbabwe. We explore how climate effects disrupt the livelihoods and food security for the diverse farm types, the extremely vulnerable and those better resource endowed facing high risks. In an iterative process with experts and stakeholders, we develop transformative development pathways. They include market-oriented adaptation and mitigation interventions and social protection mechanisms that would support the transition towards more diversified and better integrated crop livestock systems. We assess the trade-offs associated with interventions between strengthening incomes and food security on the one hand and increased GHG emissions on the other hand, for the different pathways and farm types. This informs the discussion on the drivers that can bring about sustainable change, and the extent to which welfare benefits could enhance the uptake of emission reducing technologies. Through this strategy we assess how to produce mitigation co-benefits, and what this would imply for policies that aim at transforming these food systems.
Valentin Pret	Don't put all your eggs in one basket: legumes diversification to improve resilience of rainfed cropping systems in sub-humid Zimbabwe	Climate variability is predicted to increase in sub-Saharan Africa. This will impact the food security of the populations who rely on rainfed cereal production. Sustainable intensification of cropping systems aims at increasing food production while adapting to future climate and mitigating environmental impacts. The opportunity to diversify cereal-based cropping systems with legumes to increase resilience has not been quantitively assessed so far. In this study, we explored the impact of interannual climate variability for a set of cropland allocations, going from maize only to various share and number of legume crops. We explored the hypotheses that maize and legumes inter-annual performances are not correlated, so that mixing the two crops will increase the resilience of the cropland allocation. We calibrated the STICS soil-crop model for maize, cowpea, groundnut and pigeon pea, with data from on-farm trials in Murehwa district in sub-humid Zimbabwe, conducted in the 2021-2022 and 2022-2023 growing seasons. Crop performance in terms of average yield and its variability was simulated with the calibrated crop model for the historical climate (1996-2016), on red-clay and granitic sandy soils, for more fertile homefields and less fertile outfields. Two planting dates (early-late) and three levels of fertilization (0-80-160 kg N/ha), brought by mineral fertiliser only, manure only, or by a combination of 30% manure and 70% mineral fertiliser, were investigated. The simulated crop performance was used to compute for each land allocation the agricultural productivity, the economic profitability and the environmental performance. From the on-going simulation results, we will draw critical insights on the complementarities between maize and legumes. More specifically, we expect smaller but more stable groundnut yield compared with fertilized maize, so that diversification with groundnut will increase production stability and food security in terms of proteins. With regard to crop management, we foresee that a mix of mineral and organic fertilization will limit nitrogen leaching compared with mineral fertilization only, the first strategy giving similar energy production but greater environmental performance and gross margin. Under favourable rainy seasons, early planting is expected to increase productivity of both cereals and legumes and thus land allocation resilience, while late planting might be more detrimental to the cereal. These results can help inform the current research agenda around the benefits of cereal-based systems integrating legumes and trade-offs between intensification and diversification of rainfed cropping systems in sub-Saharan Africa.

Paper Presentation Session 2B: Regional Integrated Assessments		
Lead Author	***Title***	***Abstract***
Benjamin Stuch	New land use change scenarios in the southwestern Amazon and the need of novel integrative approaches for assessing sustainable land use trajectories.	The global food security debate tends to focusses on key crops, which provide the largest share on macro and micro nutrition from cropland globally. However, food security and human well-being in the periphery of tropical regions often depends on "other crops and products", which are rarely investigated by international researchers nor put on the agenda of international policy making. One example of such "other products" are Non-Timber-Forest-Products (NTFPs), which regularly grow in natural or managed forest of high biodiversity. Since "other crops and products" are often underrepresented in available agricultural models (and national agricultural statistics), integrated assessments are at risk of being biased in some regions, i.e. the tropical peripheries. In this study, we describe a transdisciplinary and interdisciplinary research process, funded by the BMBF PRODIGY project. We develop participative, regional socio-economic scenarios on future land use in the southwestern Amazon. The global, dynamic and spatially explicit land use and land cover change model (LandSHIFT) is further developed to address modelling requirements for regional, integrated assessments in the tropical study region. The socio-economic scenarios are used to drive the land use and land cover change (LUCC) simulations at a high spatial resolution of 300 meters until year 2050. Our results show, that LUCC increases in all scenarios but particularly in the globalised, market oriented narrative, whereas LUCC remains at the lowest levels in the sustainability narrative. While the market oriented scenario emphasises globally traded key crops, the sustainability scenario emphasises "other crops and products" i.e. NTFPs such as Brazil Nut. Regionally, Brazil Nut is highly important from a cultural, economic and political perspective. The spatial distribution of this NTFP contributes remarkably to the conservation of natural forest ecosystems and thereby, influences the pattern of recent and expected future deforestation and respective agricultural expansion. We would like to share our ideas on the integration of NTFPs such as Brazil Nut into our modelling framework to reduce the earlier described bias in integrated assessment. At the end of our presentation, we would like to encourage an open discussion about the potential need of new modelling tools to enrich assessments on sustainable land use systems in tropical peripheries.
Elena V. Samokhvalova *(Virtual)*	Grain crop Simulation modelling in relation to agricultural land assessment in the Samara region (Russia)	Dynamic-statistical simulation modeling of plants production process was applied to assess agricultural land in the Samara region (Middle Volga region, Russia). Depending on factors of natural potential of the territory, normative yield of grain crops was calculated, its spatial variability was analyzed, and land appraisal was carried out in the context of administrative districts of the region. The model «Wheather – Crop Yield» (by All-Russian Research Institute of Agricultural Meteorology) was used in the work, which describes the process of plant productivity formation in dependence of solar radiation intensity, thermal and soil water regime. The model is implemented relative to the main grain crops: spring and winter wheat, spring barley; identification of their parameters was carried out based on field observations. A number of additions and changes were made to the original model, which provided consideration of mesoscale spatial variability and temporal structure of climate factors. Spatial analysis of the territory was carried out using the program complex AmITS (Agrometeorological informational territory system) for the Samara region. Calculation performed at nodes of spatial grid with a step of 10 km, using interpolation of climatic values according to the nearest weather stations. Using stochastic modeling of weather conditions in 400 year-cases, spatial distributions of both average value and time series characteristics of the yield (coefficient of variation and 75% quartile) were obtained. Based on a set of numerical experiments, setting the factors optimal or actual values, we obtained the spatial distributions of the moisture supply and overwintering conformity coefficients, showing a reclamation effectiveness. The results are the basis for the mesoclimatic zoning of the territory, recommended crop structure is determined, and suitability assessment in agriculture and cost. The use of the proposed system of indicators and the method of plant production process simulation provide a greater spatial detailing of natural agro-potential of the territory, taking into account probabilistic climate structure, in contrast to methods based on climate zoning. It also avoids the dependence of the results on the socio-economic conditions (agricultural technology level, capital supply, qualification of specialists), as is the case with the use of actual yields in agricultural enterprises and increases natural conditionality of the assessment. All that helps to increase the reliability and accuracy of

		land assessment for agricultural purposes (to justify land management design, work planning, production efficiency assessment) and for land management purposes.
Fasil M. Rettie	Regional-scale evaluation of uncertainty in the multi-model simulation of climate change impact on maize and wheat	Climate change is an urgent issue that that calls for developing adaptation strategies. However, quantifying the likely impact of climate change under a given scenario is difficult due to the many sources of uncertainty involved in the estimation process. To guide adaptation strategies and policymaking, it is crucial to quantify the impacts of climate change on a regional scale and disentangle the various sources of uncertainty. In this study, we calibrated and validated 3 process-based crop models in Ethiopia to examine the regional-scale impact of climate change on maize and wheat. The models were then driven by climate projections from nine global climate models (GCMs) under three emission scenarios at spatial resolution of at 10*10 km2 covering entire Ethiopia, considering the CO2 fertilization effects. Utilizing the best available soil data, we followed a bottom-up approach to project national-level estimates. Our large ensemble of model simulations allowed us to comprehensively quantify the uncertainties related to the estimated magnitude of the impact and provide better confidence to guide adaptation options. Under a high-emissions scenario, aggregated over the national level, the median projected impact was about -4% for wheat to +2.5%, while the 5th percentile yield is projected to decrease up to 18% for wheat and 4% for maize by the end of the century compared to the baseline (1983-2012) yield. The CO2 fertilization effects not only compensated for the impact but also improved the reliability of the projected results, particularly under high-emission scenarios. However, crop model spread followed by that of GCMs was identified as the largest contributor to overall uncertainty in the estimated yield changes. Our study provides critical insights into the regional-scale impact of climate change on crop yields in Ethiopia. It highlights the importance of improving crop models to further reduce overall uncertainty.
Priyanka Swami *(Virtual)*	Climate risk area identification and shock prediction for pearl millet production in North-West India	Climate change is affecting agriculture and food systems, and these impacts are expected to become more severe in the coming decades. It is altering temperature and precipitation patterns, which can affect crop yields, water availability, and pest and disease pressures. Rising temperatures and changing rainfall patterns can also lead to soil erosion, nutrient depletion, and reduced soil moisture, which can have serious consequences for agricultural productivity. The extreme weather events, such as droughts, floods, and heat waves, are becoming more frequent and severe due to climate change, leading to crop losses. Pearl millet is widely grown in the driest regions of India, mainly in the arid tropics. It grows well in semi-arid and dry soils, but responds very positively to slight improvements in growing conditions such as changes in temperature and additional irrigation. Pearl millet is considered a crop for the future due to its many desirable characteristics that make it suitable for cultivation in a changing climate. While pearl millet is a hardy crop with many advantages, it is still vulnerable to the impacts of climate change. Climate change is expected to increase temperature and rainfall variability, which could affect the growth and yield of pearl millet. As this crop is grown primarily under arid conditions, strategies must be developed to promote efficient water use, which can be achieved through field trials and/or crop modelling. The present study was carried out using Aquacrop model, a crop growth model developed by FAO's Land and Water Division to address food security and assess the effect of the environment and management on crop production. The water-driven AquaCrop model is used extensively for simulating crop growth and water use. A field experiment AquaCrop Model requires a minimal number of cropping parameters, aiming to balance simplicity, accuracy, robustness, and ease of use. In this study, we calibrate and validate his AquaCrop model under irrigated and rainfed conditions for an underutilized crop, pearl millet. The study was conducted using climate data from 1990 to 2022 and was calibrated using in-situ data collected from 3 research stations. The scope of study was extended to 10 agro-climatic zones. The study further propose methodology for assessment of area prone to production risk using weather and soil data. Furthermore artificial neural network models were developed to predict shock in production of pearl millet in north-west India.
Siwa Msangi	Capturing production technologies and field practices in regional	The question of how to better capture the adjustments in crop production technologies, practices, input levels and other adaptations that are required of agricultural production systems under future environmental stresses and policies – has been under active investigation by economic modelers interested in bringing more policy-relevant detail to regional economic assessments of global change and agriculture. A variety of approaches to capturing the production-level shifts in crop and livestock systems within an economic equilibrium framework exist – though often at a level of spatial and sectoral aggregation that doesn't allow for the explicit representation of production technologies that is required if biophysical process models of crop growth or livestock nutrition and

	economic models: the examples of REAP and USARM	performance are to be utilized. That level of detail typically exists in smaller-scale farm and ranch models, that are able to use micro-level data and field-level information that can be specific enough for capturing particular production practices and management strategies. But models at that scale, even if built around economic principles of profit maximization, optimal resource utilization and rational choice and expectations – are not able to capture economy-wide market dynamics. Therefore regional economic modeling approaches have been preferred, such that the farm-level behavior is captured by a representative farm(er) type that operates at a spatial level that can affect aggregate level supply, demand and trade . In this paper we contrast two different approaches to capturing agricultural production adjustments that have been used in US-focused, national-level modeling of agricultural supply, demand and exports within the Economic Research Service of the US Department of Agriculture – namely the Regional Environment and Agriculture Programming (REAP) model and the US Agricultural Resource Model (USARM). Both REAP and USARM disaggregate the US into distinct sub-regions and adopt a mathematical programming approach to capturing the choice of resource and technology usage in key agricultural sectors – but do so in ways that differentiate their ability to use the outputs of biophysical crop models to determine supply potential under agronomic constraints imposed by land characteristics and input availability. We use these two models and their simulated responses to environmental and policy shocks to illustrate key differences and important gaps that need to be considered by modelers when deciding up on the approach to use when trying to address how sector-level mitigation and adaptation responses can best be captured in regional economic models of agriculture and food.
Subash Nataraja Pillai	Science with participatory approach on assessment of climate change impact on farm production under Sustainable Agricultural Pathway	Around 85% of the Indian farming community belongs to marginal and small farmer categories that are resource poor. Indian farmers are heterogeneous and unorganized in nature. Climate change and variability are likely to aggravate future food security by putting pressure on agriculture affecting its sustainability. Excess use of inorganic fertilizer along with frequent use of pesticides adversely affected the soil health. In addition to this, climate change and climate variability threatens productivity, livelihoods and nutritional security of small and marginal farmers. Under this situation, there is a need to study the vulnerability of these small and marginal farms under projected climate change. Under ICAR-AgMIP Collaborative Project, we have studied the impact as well as vulnerability of agricultural farms in two districts (Meerut in Uttar Pradesh and Karnal in Haryana) using Climate-Crop-Economic modelling approach. Current farms exposed to climate changes could experience a decline in net farm returns of 4% to 14% and a decline in per capita income by 3.0% to 8.6%. Though the magnitude of decline in net farm returns and per capita income may seem small, these will adversely affect a large proportion of farms – nearly 49% to 74% of the population. Future rice-wheat production systems in 2050s are also vulnerable to climate change. Up to 51% of rice-wheat farm households could be vulnerable to climate change impacts under a sustainable pathway. In the future production system the adaptation strategy would result in 9% to 12% increase in net farm returns, about 6% to 9% increase in per capita income and 3% to 4% decline in poverty. Under sustainable pathways, about 53% to 60% of the farm population would adopt the adaptation. There is a lot of diversity in soil characteristics; hence, at least three to four major soil types and their characteristics should be included for simulation, so that more accurate and realistic assessment results can be drawn.
Shakeel Ahmad *(Virtual)*	Regional Integrated Assessment of Climate Change Impact on Cotton Production in a Semi-arid Environment	Climate change has a negative impact on the productivity of agricultural crops at local, regional and global levels. Foodstuff security and sustainable livelihood of cotton farmers in the core cotton growing region in Punjab, Pakistan is under threat because of decreased yield due to climate change. The quantification of the integrated impact assessment of climate change for developing adaptation approaches for cotton is vital for improving productivity at a regional level and improving food security at national level. Two crop models were evaluated with on-farm survey data of 165 farms employing stratified random sampling techniques. Representative agricultural pathways (RAPs) were developed for characterizing future cotton production. Global climate models (GCMs) depicted a rise of 3.6 and 4.3°C for maximum and minimum temperature, respectively, along with a decreased in rainfall of 600 mm under Representative Concentration Pathway (RCP) 8.5. The expected temperature rise for the hot-dry climate would cause a reduction in productivity of 35.3 and 39.2% by mid-century for RCP4.5 and RCP8.5, respectively, according to the Decision Support System for Agrotechnology Transfer (DSSAT) model by, while the Agricultural Production System Simulator (APSIM) showed a reduction of 51.1 and 59.6%, respectively. Increases under the current adaptation of a 15% increase in each of nitrogen and planting density ranged from 1.1 to 6.3% for DSSAT and 2.6 to 8.2% for APSIM. Climate-adapted cotton productivity was projected to rise from 18.7 to 35.9% for

		DSSAT and from 13.8 to 42% for APSIM for all GCMs. Results showed that current and future cotton systems are adversely impacted by climate change; however, climate-change-adapted management approaches could offset possible reductions in productivity. Sustained cotton productivity in core cotton zone requires capacity building amongst farmers, enabling them to improve their crop management in the face of seasonal climate variability and future climate change.

Paper Presentation Session 3: Global Assessments of Food Systems, Trade & Diets in a Changing World		
Lead Author	***Title***	***Abstract***
Julia M. Schneider	Modeling Global Cropland Expansion: Trade-Offs with Biodiversity, Carbon Emissions, and Food Security	Despite large potentials to close current yield gaps to increase agricultural production, cropland is still expanded to meet the rising demand for agricultural goods, mainly in Africa and South America. However, expansion into currently uncultivated areas it is associated with various issues, such as threatening biodiversity through the loss and fragmentation of natural habitat, or increasing carbon emissions due to deforestation. Investigating where cropland is under the highest risk to be expanded in the future contributes to identifying potential conflict areas and enables counteracting by policies. As part of the integrative land use change model iLANCE, we developed a coupled model approach to investigate cropland expansion. It is driven by biophysical conditions determining agricultural suitability, assumptions on crop management as well as socio-economic factors and dynamics, such as population growth, consumption preferences or policies. Based on simulations with the biophysical crop model PROMET and the computable general equilibrium model DART-BIO, the globally most productive and profitable areas for cropland expansion are integratively assessed. The expansion algorithm is integrated in the iterative coupling process within iLANCE, which allows for considering feedbacks of cropland expansion on regional crop prices, production quantities and trade patterns. As a result, we identify the globally most profitable areas for expansion (see figure), which we assume to be under the highest pressure of being transformed into cropland. To analyze potential trade-offs with biodiversity conservation and climate protection, we analyze the impacts of cropland expansion on biodiversity intactness and carbon emissions. This allows for identifying hot-spots in which cropland expansion is associated with a high loss of biodiversity and high GHG emissions. In the context of current political efforts to stop deforestation, mitigate climate change and protect life on land, we additionally simulated a conservation policy scenario.
Marco Springmann *(Virtual)*	Options for reforming agricultural subsidies from health, climate, and economic perspectives	Agricultural subsidies are an important factor for influencing food production and therefore part of a food system that is seen as neither healthy nor sustainable. Here we analyse options for reforming agricultural subsidies in line with health and climate-change objectives on one side, and economic objectives on the other. Using an integrated modelling framework including economic, environmental, and health assessments, we find that on a global scale several reform options could lead to reductions in greenhouse-gas emissions and improvements in population health without reductions in economic welfare. Those include a repurposing of up to half of agricultural subsidies to support the production of foods with beneficial health and environmental characteristics, including fruits, vegetables, and other horticultural products, and combining such repurposing with a more equal distribution of subsidy payments globally. The findings suggest that reforming agricultural subsidy schemes based on health and climate-change objectives can be economically feasible and contribute to transitions towards healthy and sustainable food systems.

Ruth Delzeit *(Virtual)*	Assessing impacts of climate change on agricultural markets taking uncertainties in global crop yield projections into account	The global impact of climate change on agricultural productivity is already being felt through various channels, primarily due to increasing average and extreme temperatures, changes in precipitation patterns and frequency of droughts, and rising levels of atmospheric carbon dioxide (IPCC 2019). At the same time, agricultural productivity has implications on the four dimensions of food security: availability, accessibility, utilization and stability (FAO 2020). Intercomparison projects using multiple climate and crop models have shown that on the one hand, different crops and countries are affected unevenly (e.g. Jägermeyr 2021), and the impacts of climate change on agricultural productivity are prone to different uncertainties (Müller et al. 2021). In this study, we analyze the impact of yield changes under different climate conditions (CMIP5 and CMIP6 projections) as well as changes in the inter-annual variability of yields by applying the integrative assessment approach iLANCE (integrative Land Allocation Sequencer). It links the global crop model PROMET with the global trade model DART-BIO, combing biophysical and socio-economic information (see modelling framework below). The computable general equilibrium model DART-BIO allows for an analysis of changing trading patterns, impacts on consumption, agricultural prices, as well as on producer incomes and gross domestic products of different countries.
Tony Carr	Addressing the Rising Food Demand in The Gambia: Can Climate-Smart Agriculture and Increased Crop Productivity Reduce Dependence on Imports?	The Gambia faces a range of food system challenges due to growing food demand, climate change, land degradation, low agricultural productivity, as well as a high dependence on food imports that leaves the country vulnerable to external shocks. To tackle these challenges, the country aims to increase domestic crop production and achieve greater self-sufficiency in food supply while also limiting deforestation. To evaluate the potential for reaching these goals, we use the food system model FABLE to test scenarios for increasing domestic crop production and reducing import dependence, taking into account climate change impacts on crops, climate-smart agriculture, and increased crop productivity. We have co-developed future scenarios for crop productivity in an iterative process with local stakeholders based on feedback on the feasibility and potential for intensifying agriculture as well as adopting climate-smart agricultural strategies. Our results suggest that the growing demand for food cannot be met by increasing crop production alone. If imports do not increase, or cropland is not expanded or reallocated towards more food crops, there will be a significant gap between demand and supply by 2050. However, investments in climate-smart agriculture and productivity-enhancing measures have the potential to halve this gap. Nevertheless, such investments would require a substantial increase in fertilizer and irrigation, and widespread investment in agriculture may not be feasible. To ensure food security and minimize the need for further cropland expansion, it is crucial to improve trade flows within the region. Our study underscores the urgent need for sustained investment and policy support to comprehensively scale up domestic crop production and regional trade flows to ensure sufficient and healthy food supplies amidst growing demand and climate change challenges. In addition, our study provides insights into modelling different adaptation scenarios for food and agriculture in data-scarce regions such as The Gambia. As adaptation strategies are highly context-specific, we relied on stakeholder feedback to develop a common understanding of the agricultural system in The Gambia and to improve the robustness of our model as well as the policy relevance and adoptability of our results.

Paper Presentation Session 4: Modeling Nutrition, Food Security and Crop Losses		
Lead Author	***Title***	***Abstract***
Gatien Falconnier	Increased mineral fertilizer use on maize can improve both household food security and regional food production in East Africa	Context Despite recent improvements in living standards, a substantial proportion of farm households in sub-Saharan Africa (SSA) is food insecure, and increasing crop productivity could help address this problem. Objective We estimated the effect of increasing maize yields with mineral fertilizer on household food security and on regional and national maize supply in two East African countries - Uganda and Tanzania. Methods We estimated maize yield response to nitrogen (N) fertilization with a machine learning model trained on 15 952 observations of maize responses to fertilizer across SSA. Together with spatial price data, we used this model to quantify the profit-maximizing N fertilizer input for a nationally-representative sample of 4188 agricultural households in the two countries. We computed a food availability indicator for all households. Results and conclusions The mean profit-maximizing N input was 82 kg ha-1 in Tanzania, but it was much lower in Uganda (24 kg ha-1) mostly because of less favorable prices. The profit-maximizing N input was above the reported N input for 95% of the households in Tanzania and for 43% of the households in Uganda. It was predicted to increase the food availability ratio of food insecure maize growers by 95% in Tanzania, and by 25% in Uganda. The administrative regions where maize supply could increase most were not the same as the regions where the increase in household-level food security was largest. With increased fertilization, food insecure maize growing households (35% in Tanzania and 42% in Uganda) could only contribute about 20% of the overall increase in maize supply, whereas the 20 to 30% food secure households that have a larger area planted with maize could contribute more than 60%. Significance Our study makes two key contributions: i) a substantial increase in national maize supply is more likely to come from already food secure households with relatively large farms, while food insecure households with small farms may nevertheless increase their household-level food security through maize intensification, and ii) high potential areas to increase maize domestic production do not necessarily match with areas where there is immediate scope to improve household-level food security
Jonas Jägermeyr	Climate change impacts on global crop productivity and its nutritional value	The emergence of the climate signal in global agriculture is expected to occur within the next decade, while current farm-level adaptation efforts are lagging behind the climate signal. Fundamental and wide-spread adaptation in the ag sector across all world regions is required, but it is particularly important in the Global South to reduce climate vulnerability. Here we present latest estimates of climate change impacts on the productivity and the nutritional value of the major crops globally based on multi-model ensemble projections from AgMIP's Global Gridded Crop Modeling Initiative. While there are dramatic regional differences in climate change impacts on crop yields, some regions can potentially realize productivity gains associated with elevated atmospheric CO_2 levels and moderate warming, especially in wheat producing systems at higher latitudes. However, the CO_2 fertilization effect also affects nitrogen uptake and thus the nutritional value of crops. As a result, the stimulating effect on crop and feed growth is moderated, leading to net negative protein and micro nutrient yields for some of the major food and feed crops in many regions. The model ensemble indicates that under a high-emission scenario, elevated atmospheric CO_2 substantially reduces protein content for wheat and rice by about 10-15% by the end of the century, while rising temperature on the other hand increases protein content in crops. Net changes in protein yield are expected to decline for most crops under high emissions scenarios, which increasingly becomes a concern for global nutrition and future food security. A transition towards higher shares of plant-based protein in our future diets is required to meet climate and environmental sustainability targets, but climate change puts additional constraints on the overall potential of plant-based protein sources.
Jyoti Singh	Improving the ozone damage parameterization in Community	Tropospheric ozone is phototoxic for plants due to its oxidizing nature. Ozone produces reactive oxygen species that can disrupt plant metabolism and physiological processes, including photosynthesis and stomatal conductance, affecting carbon assimilation mechanisms and the exchange of carbon dioxide and water between the biosphere and atmosphere. Community Land Model 5 (CLM5) considers integrated ozone flux and its effects on photosynthesis and plants' stomatal conductance. Ozone damage function in CLM5 by implementing using the relationship of photosynthesis and stomatal conductance with cumulative uptake of O_3 (CUO, which integrates

	Land Model 5 (CLM5)	O3 flux into leaves through time) using data from peer-review literature till 2010 for three broad plant function types (PFTs; Broadleaf trees, needleleaf trees, and grasses). However, the correlation between photosynthesis and stomatal conductance CUO was weak, limiting the accuracy of the ozone damage function. To improve this, we explored other predictor variables using data from approximately 200 peer-reviewed articles published between 1970 and 2022. By doing so, we aim to develop a more comprehensive understanding of the impact of tropospheric ozone on plants and identify key drivers of response variables, leading to an improved ozone damage function. We will then implement this function in CLM5 for various plant function types, including wheat, soybean, and rice. This study will improve our understanding of the impact of tropospheric ozone on plants and enable more accurate modeling of its effects on ecosystem processes.
Mareike Köster	Effects of climate change and autonomous adaptation on spring barley production across 18 sites in Europe	Barley (Hordeum vulgare L.) is among the most important crops worldwide. In 2020 about 60% of global barley was produced in Europe, where diverse climate-induced production risks are prevalent across the different agro-ecological zones. In response to climate change risks, farmers are adapting their crop management practices autonomously. This study aims to assess potential climate change impacts and effects of likely autonomous adaptations on spring barley production, specifically changing cultivars and shifting sowing dates, across all its major cultivation environments in Europe, for baseline, near- and far-future climate. Using the Agricultural Production Systems sIMulator (APSIM), we simulated barley crop growth and grain yield at 18 representative sites across Europe. At each location, climate projections from six different General Circulation Models (GCMs), driven by emission scenarios SSP2-4.5 and SSP4-8.5, were downscaled for local impact assessments using the LARS- weather generator for two time slices: near-future (2050) and far-future (2080). Climate change scenarios showed an increase in growing season temperature by +1.1 to +4.7 °C and variable rainfall patterns across sites, scenarios and time slices. Throughout Europe, the APSIM model projected an overall reduction of grain yields by -5.6 and -6.9% for near- and far-future scenarios, respectively. However, yield changes deviated notably between sites, scenarios, and time slices. With an average yield penalty of -10%, the Mediterranean sites were the most affected, while continental sites by end-century showed yield increases under the high emission scenario, SSP4-8.5, corresponding to an enhanced atmospheric [CO2] level of 868 ppm. According to our simulations, the anticipated autonomous adaptations and elevated [CO2] reduced the potential yield decline moderately. Our findings emphasize the need for designing and planning site-specific adaptation strategies that combine new climate-resilient crop cultivars tailored to evolving climatic risk zones in conjunction with climate-smart management practices adjusted to local conditions.
Molly Brown, Walid Ouret *(Presenter)*	Enabling Anticipatory Action to Reduce Acute Malnutrition	According to UNICEF, in 2020 45.4 million children under 5 years of age were affected by acute malnutrition, which is a significant threat to child health and contributes to nearly half of all child deaths. Many countries have established early warning systems to alert humanitarian stakeholders to emerging nutrition-related emergencies. These systems, however, remain dependent on late indicators or proxies which emerge only after an emergency has begun. The responsible humanitarian stakeholders, including intergovernmental agencies, national governments, international and local non-governmental organizations, still respond only to declared emergencies, typically months or years after they have begun. We lack specific, timely, evidence-based, objective analysis of acute malnutrition risks that allows them to anticipate impending problems, make decisions, and act ahead of a crisis, with the goal of mitigating negative repercussions.Extending over a decade of research, we are focused on devising innovative, validated models for forecasting acute malnutrition in children under five and pregnant and lactating women. We believe predictive models that allow for early action and intervention would be transformative for the international community who are working to prevent excess mortality during emergencies. The models will create a rigorous, reliable means to anticipate where and when nutrition crises are most likely to occur, and at what scale of severity, as well as to illuminate risk factors and needed interventions. Successful deployment could: (1) bolster demand for predictive analyses of different scales, locations, and timing, (2) elevate the detection of at-risk situations and incipient crises that the humanitarian community could address, and (3) amplify visibility of situations liable to explode along political, social, and economic faultlines. The causes of acute malnutrition in children and pregnant and lactating women are complex, caused by a huge diversity of individual, household, region, national and international factors, enhanced by climatic, political, economic and geopolitical risks. Here we describe a modeling framework that can be used to identify patterns in complex and multilevel data over time to predict

		nutrition outcomes. The project involves collaborations with humanitarian organizations who are both generating data and responding to crises when they occur. This will allow us to operationally ingest data as it is created, validate our models and improve them in an operational context.
Sreeja Jaiswal *(Virtual)*	Projecting a food insecure world: Equity implications of land-based mitigation in IPCC modelled mitigation pathways	Least-cost global modelled mitigation pathways based on Integrated Assessment Models (IAMs) rely on the rapid deployment of land-based mitigation measures to meet temperature goals of 1.5 and 2 degree Celsius. These modelled pathways are a significant driving force behind global climate policy. However, what is poorly understood in their policy uptake is the unequal mitigation burden borne by the Global South to achieve the global climate targets. In this paper, we analyze projected outcomes related to food security for different world regions from 350 scenarios across five IAMs within the IPCC Sixth Assessment Report's scenario database. These scenarios were filtered from over 1000 scenarios in the database following the criteria that they limit warming to 1.5 and 2 degree Celsius and report results for 10 world regions. We find that the modelled mitigation pathways unequally distribute the burden of land-based measures perpetuating an unequal world. The analysis shows that the projected future food prices rise more for developing regions than for developed ones. The per capita food demand especially demand from livestock products in developing regions remains well below developed countries even at the end of the 21st century. To achieve temperature targets, the scenarios devote large amounts of land in developing regions for afforestation and bioenergy crops, thereby increasing competition for land and negatively impacting food prices. These mechanisms contribute to a world where millions of people are at risk of hunger, even in 2050 and 2100, with some modelling studies suggesting implementing food aid programs for alleviating the situation. While the IAM modelling community and the IPCC claim that the models do not make assumptions about equity and are not intended to deal with issues of distributive justice . However, projecting regional inequalities and food insecurity far into the future to achieve climate goals at the cost of human well-being is in fact a normative and value-laden choice with adverse distributional consequences for developing regions. This IAM-generated imagination of an inequitable world raises serious questions about their policy relevance and uptake. Alternative imaginations which consider the distributional effects of land-based mitigation measures on developing regions are essential to ensure that climate goals are achieved while prioritizing global equity and sustainability.
Rosita Endah epse Yocgo *(Virtual)*	Hotspots for Fall Army Worm in Africa under CMIP6 scenarios	Since its entry into Africa in 2016, Fall Armyworm (FAW) Spodoptera frugiperda has remained a threat to global food security. This is especially true in Africa, an agriculture-dependent continent. The importance of this pest is exacerbated by the fact that it attacks major staple crops such as maize that are cultivated by millions of small-holder farmers, thus impacting dietary needs and economic prosperity. Maize yield losses of about 21 million tons/year in 11 Africa countries have been reported, and linked to annual consumption demands of upto101 million people. Surprisingly, outbreaks across the continent are continuously received by alarms and unexpected losses, due in part to the lack of early preparedness strategies. The growth, development, and occurrence of FAW have nevertheless been linked to the climate. This can support the prediction of FAW's suitable habitats for better preparedness. While such studies are underway at a global scale, in Africa this is lagging. To close this knowledge gap and support better decision making, our study aimed at predicting the suitability of FAW in Africa, using the hypothesis that climate conditions in Africa will continue to influence FAW's suitability niches. Using 19 bioclimatic variables and FAW occurrence data we calibrated and evaluated the MaxEntropy (Maxent) model, before projecting the current distribution of FAW in Africa. Using this same model, the occurrence data set, four global circulation models (GCM) along with three shared socio-economic scenarios (SSP1-2.6, SSP3-7.0, and SSP5-8.5) from the recently released Coupled Model Intercomparison Project (CMIP 6), we predicted the future suitable habitats for FAW in the near-term (2021 – 2040), mid-term (2041-2060) and long-term (2061-2080). Our study showed that Maxent was able to project the current distribution of FAW, resulting in an area under the curve value of 0.924. Among the bioclimatic variables, isothermally, precipitation of the wettest quarter, precipitation of the warmest quarter, and annual precipitation had the greatest influence on its current distribution. New suitable habitats were also identified. Our study also showed that most of sub-Saharan Africa will continue to be suitable for FAW, with West Africa remaining the hottest spot throughout the study period as depicted by all four GCMs and warming scenarios. Therefore, this implies that even with the best climate mitigation action as depicted by SSP1-2.6, more is still required to limit warming well below

		the projected 1.8oC. Furthermore, more stringent farm management and policy actions are needed in general to irradiate FAW on the continent.

Paper Presentation Session 5: Seasonal Forecasting and Food Shocks		
Lead Author	***Title***	***Abstract***
Mariaelisa Polsinelli	Combining a Process Based Model with Machine Learning for Potato Yield Prediction in Prince Edward Island, Canada	Climate change is already affecting the Canadian climate with increases in air temperature, evapotranspiration rate and risk of rainstorms and drought. Potato, a major crop in Prince Edward Island (PEI), Canada, contributed 10.8% of the provinces GDP in 2018. However, potato yields are very sensitive to these changes in weather and an increase of 1–1.4°C could reduce yields by 18-32%. The ability to predict yield before harvest is invaluable information for both decision makers in charge of national food security strategies, and farmers who need to plan their on-farm actions to maximize yield under changing conditions. Process based models and machine learning (ML) are being increasingly applied for yield prediction. However, crop models can have a high data demand and their applications can be limited by data availability. One approach to overcome this is combining the outputs of crop models with training data for ML models in a 'hybrid approach'. This approach may outperform individual models by creating more flexible predictions which can better handle changing variables that are the result of climate change. The process based model STICS (Simulateur mulTIdisciplinaire pour les Cultures Standard) version 9.2 is tested to predict yield, total biomass, leaf area index, and total and plant nitrogen using multi-year data from research farms in Eastern Canada. The calibrated model will be tested to predict yield in a commercial farm with multiple field years in Prince County, PEI. The commercial farm data includes detailed management practices and gridded yield map data. This data set includes around 15000 data points and will be used to train an ML model for yield prediction in combination with the crop model output and without. We compare ML, the STICS model and the hybrid approach performance in predicting yield and provide some insight on the conditions in which each model performs reliably.
Marlene Palka	Assessing the performance of crop forecasts for in-season nitrogen management of winter wheat	Considering projected effects of climate change, crop production and cropping inputs are expected to suffer from increasing uncertainty. Therefore, crop forecasts have been promoted to facilitate targeted investments of agronomic inputs. Traditionally, such forecasts were based on crop models coupled with climatological records, generating projections of crop growth and development. Evidence that future growing conditions will deviate from historic averages and the continuous improvement of crop models and weather forecasts give reason to move from climatology-driven crop forecasts to forecasts that use weather forecasts of different lead time instead. The aim of our study was to translate state-of-the-art seasonal ensemble weather forecasts (SEAS5) into crop forecasts that provide timely decision support for in-season nitrogen (N-) management at field level, using the process-based crop model SSM-iCrop. SSM-iCrop was parameterised and evaluated for robustness and accuracy across a wide range of environmental and management conditions in the target region. SEAS5 is the latest generation of ECMWF's seasonal ensemble weather forecasting system, providing seasonal forecasts up to 215 days. Since N-management needs to consider crop demand for N and N supply from the soil, we created crop forecasts of different lengths (0-months, 1-month, full season) up to 7 months lead time, for phenological stages, biomass growth, and N uptake as well as plant available soil water and mineral N content throughout the season. To assess their performance, we used data from three winter wheat field experiments, conducted in Tulln, Austria from 2017 until 2020, and applied a comprehensive set of statistical measures, including root mean squared error (RMSE), mean absolute error, standard deviation, ranked probability score, and skill sores of these measures. Our results showed that –depending on season and variable- crop forecast performance was best at lead times of 0 to 2 months. RMSE of crop N uptake forecasts, for example, decreased from 1.74 to 0.36, 0.21 and 0.15 g m-2 at 5, 2, 1, and 0 months lead time, respectively (maximum and minimum values). Across all seasons, forecast lengths, and lead times, crop forecasts considering seasonal ensemble weather forecasts showed higher skill in 66.67% of the cases, compared

		to crop forecasts using climatological records -even at less than perfect performance- especially at stem elongation (73.34%) and booting (86.67%), when N is commonly applied. Thus, crop forecasts based on well-tested crop models and seasonal ensemble weather forecasts provide promising tools to inform in-season crop management in the face of increasing climate variability.
Rogerio de Souza Noia Junior	Implications of wheat supply disruptions for global food security	Extreme weather events, highly volatile commodity prices and geopolitical conflicts threaten global food security. Here, we studied the implications of national wheat supply disruptions in Brazil in 2006, in France in 2016, and in Ukraine in 2022. The disruption of the wheat supply in Brazil in 2006 was due to the lowest wheat production recorded in the last 20 years. Wheat production was 46% lower than the average from 2001 to 2020. This was caused by a combination of adverse weather and weak planting incentives due to a low wheat price. In 2016, France experienced the biggest wheat production failure since 1960. This was a consequence of an extended period of precipitation during the winter and spring, leading to the simultaneous occurrence of yield-reducing factors, including heavy rainfall, crop diseases, low solar radiation and waterlogging. The likelihood of these compound factors in France and in Brazil recurring under future climate change is estimated to change with a higher frequency of extremely low wheat yields. In addition to the poor weather and low price that affected the wheat production and supply from Brazil and France, geopolitical conflicts also have disastrous consequences for food security. In 2022, the war in Ukraine threatened to block 9% of global wheat exports, driving wheat prices to unprecedented heights. To compensate this shock, we estimate that a production increase would require extra half a million tons of nitrogen fertilizer, yet fertilizer prices are at record levels. Without stabilizing wheat supplies through judicious management of stocks and continuing yield improvements, food and national security are at risk across many nations in the world.
Ron Sands	Multi-Breadbasket Failures and Shocks to Food Systems: AgMIP Simulations	Modeling tools within the Agricultural Model Intercomparison and Improvement Project (AgMIP) are well-suited to support food shock analyses at regional, national, and global scales across a range of time horizons. A specific challenge is the potential for food shocks caused by simultaneous breadbasket failures in multiple locations across the globe to overwhelm food systems. However, impacts and effective responses will differ according to the type of multi-breadbasket failure that occurs. Key parts of the food system – i.e., production, supply chains, trade, and consumption -- will be affected differently, as will crop and livestock commodities owing in part to substitution effects and regional dynamics. For each type of multi-breadbasket failure, we utilize AgMIP outputs (particularly its ensemble of Global Gridded Crop Model Initiative (GGCMI) run over historical and projected future conditions) to provide information about the plausible mechanisms and changing probability of occurrence. A set of scenarios based on AgMIP biophysical results drives two global economic models to provide perspectives on food system responses to multi-breadbasket failure types. An initial set of scenarios defines uniform global productivity deficits of 5%, 10%, and 15% for four major field crops. A second set of scenarios varies the distribution of the global productivity shock to be concentrated in major breadbaskets, including the United Sates and Eastern Europe. Results from the first set of scenarios confirm previous analysis by the AgMIP global economics group: economic adjustments to harvested area, realized crop yield, and crop prices limit the impact on consumers. The second set of scenarios expands the role of international trade as an adaptation mechanism to regional shocks. We use two global economic models: the IMPACT model from the International Food Policy Research Institute, and the Future Agricultural Resources Model (FARM) from USDA's Economic Research Service. Economic adjustments include (1) substitution of other inputs (fertilizer, labor, capital) for land; (2) cropland expansion; (3) international trade patterns; and (4) dietary change. The pattern of economic adjustment differs between economic models: this helps identify stress points in the chain of economic adjustment and identify areas for model improvement. We discuss the challenge of representing output from a biophysical crop model in an economic model of agriculture. Are the mechanisms to substitute other inputs for land in an economic model feasible from a biophysical perspective? If not, how can economic models be parameterized for greater consistency with crop models?

Paper Presentation Session 6: Data Assimilation and Remote Sensing		
Lead Author	***Title***	***Abstract***
Hossein Zare	Exploring the role of model structure and input uncertainty in data assimilation-based crop yield prediction: a comparative study of three crop models and their ensemble	Forecasting regional crop yields in real-time is essential for food security. Many studies have explored the potential of data assimilation (DA) techniques, which integrate satellite remote sensing data into crop models, to improve yield predictions. However, the impact of uncertain inputs on crop models and the role of model structure in DA has not been well understood. To address these issues, we used a particle filtering algorithm to assimilate remotely-sensed leaf area index (LAI) data into three standalone crop models implemented in the agro-ecosystem modeling framework Expert-N (CERES, GECROS, and SPASS) and their multi-model ensemble (MME). To account for input uncertainty, we considered nitrogen fertilization, sowing date, soil hydraulic parameters, and weather data as random variables. We then applied this setup to six winter wheat sites in southwest Germany. All models were calibrated and validated using in-situ measured data from an independent multi-site, multi-year dataset before DA. The results showed that input uncertainty had a considerable impact on the prediction accuracy and precision of all models. It caused high bias in the predictions of GECROS and SPASS. However, DA substantially improved LAI simulation in all models and enhanced grain yield prediction by GECROS, SPASS, and by MME. For example, the bias in yield prediction decreased from 25% to 15% in the case of GECROS, from 26% to 15% in SPASS, and from 19% to 7% in the MME. Conversely, DA had no significant effect on yield prediction with CERES, which had an error of less than 5% even without DA. Furthermore, we found that correlation analysis between the error of LAI (assimilation variable) and yield error is crucial in selecting a crop model for DA. In the absence of such an analysis, the MME approach has proven promising for data assimilation. Further research is necessary to evaluate the impact of MME size and the involved model weighting scheme on the results of DA.
Luke Monhollon	LAI Integration to Reconcile Cultivar and Soil Inaccuracies in DSSAT-Maize	Data inaccuracies and gaps are a major obstacle for large-scale agricultural models, even in highly observed areas like Iowa. The integration of remote sensing information may compensate for uncertainty in model inputs; for example, constraining biomass production from drifting over the course of a growing season. The integration of these data also requires a firm understanding of model responses to perturbations caused by assimilation to avoid inducing further error. This study assimilates leaf area index (LAI) into a high performing CERES-Maize crop model, beginning with a field experiment site in Perry, Iowa. Simulations compare remotely-sensed LAI against modeled LAI, exploring the potential use of remote sensing data to constrain and adjust imprecise cultivar and soil information. In each scenario, 14 assimilation schedules were used to identify phenological stages in which LAI assimilation as the largest potential benefit. Adjustments within the flowering period proved most beneficial, with assimilation mass imbalances small compared to benefits from constraining LAI. On broader scales across a high-resolution (30m) configuration across the entire state of Iowa, assimilation of remotely-sensed LAI improves overall performance under imprecise configurations. Results support the need for accurate, field specific inputs, such as cultivar and planting date; however, when only generic data is available, remote sensing improves accuracy. In addition, this approach captures crop conditions not directly simulated by the model, including the 2020 Iowa Derecho and delayed planting due to water logging. This approach is appealing in applications spanning wider areas with prediction time pressure where more complex assimilation methods or recalibration of crop model parameters is not practical.
Luleka Dlamini	Coupling WOFOST with Sentinel-2 data to estimate maize yields under rainfed small-scale	Accurately estimating crop yield at a field scale is critical for making informed agricultural decisions and improving the food security of rainfed small-scale farmers in South Africa. There have been increasing efforts to benefit from remote sensing data access combined with crop models' simulation capacity to improve crop growth accuracy and yield estimations. Remote sensing observations, especially leaf area index (LAI) can account for the combined effect of growth environment and management when estimating crop yield within the crop model. To improve the accuracy of crop yield estimates in data-limited areas of South Africa, this study proposed an approach to estimate maize yield at a field scale for rainfed small-scale farming systems in the Eastern Cape Province by assimilating the retrieved time-series LAI data from high-resolution Sentinel-2 into the WOrld FOod STudies (WOFOST) model. The yield gap and life span of leaves growing (SPAN) were selected as the parameters needed to be optimized by minimizing the cost function with the simplex algorithm, and then the optimized parameters were used input into the WOFOST model (at water-limited mode) for improved maize

	farming systems in the Eastern Cape, South Africa	yield estimation. The estimation accuracy of maize yield was validated using field-estimated yields collected during 2019, 2020, and 2021 growing seasons. Our preliminary results indicate that assimilating remotely sensed LAI into WOFOST achieves better maize yield estimates compared to one without assimilating remotely sensed LAI. These results show that assimilating LAI from high spatiotemporal resolution Sentinel-2 into WOFOST data has a huge potential to provide improved reference maize yield estimation for small-scale farming systems at a field scale. The finding of this study can provide useful insights to policy and decision-makers who need to provide appropriate and accurate yield estimations in data-limited areas.
Raphael Linker	Combining model-based optimization and data assimilation: The next generation of decision support systems?	In previous works we have developed a number of model-based optimization frameworks for irrigation scheduling, and shown that the impact of imperfect weather forecasts can be mitigated by repeating the optimization and updating the irrigation schedule several times throughout the season, using either deterministic or stochastic approaches. As model-based approaches inherently affected by the imperfectness of the model on which they are based, we have also developed a framework in which data assimilation and partial re-parametrization of the model are performed before each optimization in order to improve the model and, more importantly, the decisions based on the model. This framework includes performing sensitivity analysis before each data assimilation in order to ensure that only influential parameters are adjusted. This framework was tested with the model DSSAT-CROPGRO for a processing tomato crop both via simulations and in an experimental trial. We also conducted separate work on assimilation of information extracted from multi-spectral images acquired by a small unmanned aerial vehicle (UAV) into DSSAT-CROPGRO. Finally, we are currently working on coupling DSSAT-CROPGRO with the radiative transfer&energy balance mode SCOPE (Soil Canopy Observation of Photochemistry and Energy) that predicts, among other outputs, canopy reflectance and fluorescence. This coupling will enable direct use of remote sensing data (e.g. reflectance or sun-induced fluorescence) for calibrating or validating DSSAT-CROPGRO. In my talk I will present insights gained from these various studies and discuss the role of within-season measurements in the general framework of model-based decision making.
Xiangming Xiao	Satellite-based modeling of sugarcane photosynthesis and transpiration at the field scale	Sugarcane biomass is an important feedstock for sugar and ethanol production, and thus plays a key role in food and bioenergy industries. Photosynthesis and transpiration of sugarcane plants are affected by many factors, including weather, soil, fertilizers, irrigation, and diseases, which will affect aboveground and belowground biomass of sugarcane plants. In this presentation, we introduce satellite-based Vegetation Photosynthesis Model (VPM) and Vegetation Transpiration Model (VTM), These models use satellite images and climate data to estimate gross primary production (GPP), transpiration (TR), ecosystem respiration (ER), and net ecosystem production (NEP) at the field scale (as small as 0.025 acre, or 0.01 ha). Cumulative GPP data are used to estimate the temporal dynamics of aboveground biomass of sugarcane fields. We evaluate the results from these models at a sugarcane field in Louisiana, USA, where it is equipped with an eddy flux tower system that measures carbon, water, and energy fluxes between the sugarcane field and the atmosphere. Our work shows the potential of these models for providing accurate and timely data that could be used to support sustainable production of sugarcane ecosystems and sugarcane-based sugar and bioenergy industries.

Paper Presentation Session 7: Data and Information Technologies Advances for Ag Modeling

Lead Author	***Title***	***Abstract***
Adama Faye, Walter Baethgen *(Presenter)*	Climate information's translation into agricultural and	Managing climate-related risks is one of the key components of enhancing resilience and productivity in agriculture under an increasingly variable climate. In West Africa, there is an increasing need for appropriate tools and management practices that sustainably increase productivity and resilience to climate. In this study, a decision support tool, SIMAGRI, previously developed in Uruguay is adapted to West African conditions to translate climate information into agricultural and economic terms that can support strategic and tactical decisions in crop production e.g., crop choices, agricultural management practices, among others in Senegal. The

	economic terms to support strategic decisions in crop production: the case of SIMAGRI in Senegal	SIMAGRI helps users to run crop simulation models for three target crops (peanut, sorghum and millet) with representative management options, based on historical climate data and probabilistic seasonal climate forecasts. The user-friendly interface of SIMAGRI allows users to compare results of several management practices (e.g., planting dates, crops and cultivars, fertilizer/irrigation application, etc.) given a climate condition, and thus help identify appropriate mixes of production options, which can increase (reduce) positive (negative) impacts of current and future climatic conditions. The SIMAGRI can be used for different purposes (e.g., initial assessment or operational use for generating crop yield outlook, etc.). It can enhance better communications with stakeholders, and for identifying their needs.
Endalkachew Kebede	A global open-source dataset of monthly irrigated and rainfed cropped areas (MIRCA-OS) for the 21st century	Irrigated areas contribute disproportionately to the global food supply, accounting for 40% of food production while occupying only 24% of croplands. Irrigated agriculture is the chief water consumer globally – accounting for approximately 90% of humanity's water footprint and, in many places, contributing to the depletion of aquifers and surface water bodies. Given the critical role that irrigation plays in meeting food demand and its dominance in dictating water use and scarcity, it is essential to understand how spatial patterns of global irrigation have recently evolved and which crops have contributed most to these changes. Yet existing global datasets lack the spatial resolution, temporal coverage, or crop disaggregation to quantify crop-specific irrigation changes since the start of the century. Here we combine a new data library of subnational crop-specific irrigated and rainfed harvested area statistics with global gridded land cover products to develop annual global gridded (5-arcminute) crop-specific maps for the years 2000 to 2015 for 26 crop classes. Globally, we find that irrigated area has expanded by 11% while rainfed area has expanded by 18%. Our new dataset also enabled us to examine spatially detailed crop- and country-specific changes. For example, we find that the area of irrigated and rainfed rice in India increased by 25% and 14%, respectively. The harvested area of irrigated maize in Argentina increased by 8%. In other places, we observe overall declines in the crop-specific irrigated area for certain crops. For instance, in the United States, the harvested area of irrigated wheat decreased by 18%. These global maps provide a much-needed understanding of fine-scale patterns of irrigated and rainfed cropland change and contribute directly to informing food security, water sustainability, and climate adaptation efforts.
Kwang soo kim	COMPASS: An ensemble modeling platform based on containerized crop models	Uncertainty in crop growth simulations can undermine the effectiveness of the decisions using the crop growth simulations. Multi-model ensembles that have been used to minimize the uncertainty often require considerable effort and expertise. The objectives of this study were to develop and evaluate that crop model platform that supports multi model ensemble, which was referred to as the COntainerized Model Platform for Agricultural SimulationS (COMPASS). The COMPASS was designed to perform multi-model ensembles through an application programming interface (API) for crop models. It consists of subsystems for management of crop models, input and output (IO) data, storage and administration. In particular, open source tools were used to facilitate operation of crop models, preparation of input data and processing of output data. As a case study, five models were used to estimate the heading dates of rice at five sites. COMPASS had a web based interface where input data were submitted and outputs of the individual crop models were listed after running crop growth simulations using multiple crop models. This platform would support a wide use of multi model ensemble simulations for decision making on crop management practices as well as climate change impact assessments.
Kwang soo kim	GLUEOS: A high performance computing system based on the orchestration of containers for the GLUE	The cultivar parameters of crop growth models are typically estimated through calibration procedures based on a global optimization method such as Generalized Likelihood Uncertainty Estimation (GLUE). A system that supports parallel processing would accelerate the calibration of cultivar parameters using GLUE, which requires a large amount of computation. In the present study, a framework for a distributed computing system was proposed to aid calibration of model parameters, which was referred to as Generalized Likelihood Uncertainty Estimation Orchestration System (GLUEOS). GLUEOS was designed to manage multiple containers in a distributed computing system and to provide a simple web-based interface. In a case study, the cultivar parameters of the CERES-Rice model were calibrated for a rice cultivar Shindongjin using GLUEOS. The calibration procedures were repeated 100 times to take into account the uncertainties of parameter estimates. The elapsed wall time for the parameter calibration process was compared between two computing systems including low end single board (LESB) and high end desktop (HEDT) computers. It was found that GLUEOS

	parameter calibration of a crop growth model	completed with less wall time for HEDT than LESB. However, the absolute time difference between these systems was considerably small on average, e.g., 22 s, when 32 containers were used for a single round of calibration procedure. The computing efficiency of GLUEOS was affected by the configurations for the containers, e.g., the number of containers per node. The mean value of calibrated parameter sets resulted in reliable estimate of heading dates for both calibration and validation datasets. These results suggested that GLUEOS would allow for calibration of cultivar parameters with less wall time for computation and minimum expertise required for distributed computing. Utilizing GLUEOS with other crop models would facilitate a wider range of studies for any research that requires parameter calibration.
Mohamed Jabloun, Mike Rivington *(Presenter)*	MySmartFarm: A crop growth monitoring and decision support system for Scottish farmers	We present a new two-way data exchange and simulation modelling research platform, MySmartFarm, serving as a bridge between farmers and scientists to help resolve the challenge of increasing crop production while reducing agriculture's environmental impact. Meeting multiple production and environmental objectives requires a better understanding of key factors limiting crop yield and quantification of the within-field spatial variation. Much of this spatial variability in production results from variation in plant population and soil properties, either naturally occurring or induced by management (e.g., compaction, organic matter depletion) that in turn regulate soil water holding capacity and nutrient supply. A better understanding of this within-field spatial variation can, therefore, lead to improvements in the precision and effectiveness of field-level crop and soil managements with potentially substantial yield benefits. A constraint however is the availability of field level data for use in process-based crop growth models that simulate the complex relationship between soil properties, weather conditions, cultivar choice and agricultural practices and have been widely used to understand the factors that limit crop yield and cause spatial yield variability. Such models have the potential to provide crop intelligence and decision support to address within-field yield variability. However, their utilization raises many challenges regarding driving data, model calibration and validation and usually, their usage is intended for researchers and experimented users. The latest advances in earth observation (EO) technologies also enable the monitoring of crop status and growth and spatial and temporal variability of the main factors driving crop productivity at a national scale. However, the interpretation of the large data sets produced by EO, and its application to crop management requires the collection of field observations (field operations, sowing, phenology, crop yield) to help build the empirical models relating data to variables of interest to farmers. To overcome this, MySmartFarm establishes a two-way relationship between scientists (who develop the platform and interpret earth observation data) and farmers (who provide the field-scale data). The new tool provides a state-of-the-art research platform that is also a DSS, crop growth monitoring and a data management system allowing farmers to upload their own field operations and observations, utilize multiple spatial data (field topography, satellite multispectral vegetation indices) and crop model outputs to enable improved data-driven decision making. Therefore, combining the use of EO data, crop models and farmer supplied field observations in MySmartFarm creates an improved synergistic relationship between scientists and practitioners.
Pierre Martre	Crop2ML: a framework for crop model component exchange and reuse to increase model reproducibility and accelerate model improvement	The increasing impact of climate change and variability on food security and agriculture, and the need for an agroecological transition require improving the performance of crop simulation models and to model new biophysical processes that tackle new challenges. Recently, the Agricultural Model Exchange Initiative (AMEI) proposed Crop2ML, an open-source modeling framework for exchanging and reusing crop model components between modeling platforms. This framework provides a unified description of model components based on shared concepts, removing the constraints of modeling platforms through an automatic system that transforms models into platform-compliant components. Crop2ML uses a reverse engineering approach to automatically extract and transform meta-information and algorithms of existing crop model processes into a platform-independent model component. A search algorithm using Crop2ML concepts, and a many-to-one transformation system is used to produce components that follow the specifications of specific modeling platforms. To demonstrate the capabilities of Crop2ML, we exchanged height soil temperature models between the modeling platforms BioMA, DSSAT, OpenAlea, SIMPLACE, SiriusQuality, and STICS and analyzed the uncertainty of simulated soil temperature in multiple platforms. Crop2ML is a significant contribution towards the interoperability of crop modeling platforms and the reuse of crop model components beyond programming languages. In conclusion, we demonstrated the possibility to automatic transform a model component from a modeling platform in a common language and to translate it automatically in other languages and simulation

		platforms. Crop2ML gives modelers the freedom of choice of a modeling platform and the capacity to minimize the efforts required in software development for the reuse or improvement of model components. The Crop2ML framework is intended to be a benchmark for evaluating the performance of model components in different crop models and simulation platforms. Future work will develop of a semantic representations of model component composition and will extend Crop2ML with more modeling platforms.

Paper Presentation Session 8: Livestock, Grasslands and Multi-Cropping

Lead Author	***Title***	***Abstract***
Fabiani Denise Bender *(Virtual)*	ECOSMOS-Forage model for simulating palisadegrass	Agriculture covers nearly 44% of the Cerrado biome, where approximately 70% is covered by pasture (MapBiomas, 2019) and a significant fraction of those lands is under some level of degradation (MapBiomas, 2021). Biophysical models are useful tools to understand gaps in knowledge and technological adoption to improve pasture-bases livestocks production systems. Thus, the present study aimed to develop and parameterize a Forage submodel in the Ecosystem Model Simulator (ECOSMOS), hereafter referred to ECOSMOS-Forage, to simulate carbon and water fluxes, and growth of Marandu palisadegrass [Brachiaria brizantha (A. Rich.) Stapf syn. Urochloa brizantha (Hochst. ex A. Rich.) R.Webster]. The calibration was performed with experimental eddy covariance data conducted throughout February 2019 and January 2022, in a rainfed area with extensive livestock farming system, located in Pirassununga, Central-East of São Paulo state, Brazil (21°58’44.92’’ S; 47°26’25.53’’ W, 630 m altitude). The soil texture is sandy loam, and the regions is characterized as Cwa type in the Köppen’s climate classification, with a cool and dry winter (Apr-Set) and another warm and wet season (Apr-Set) (Alvares et al., 2013). The impact of grazing over the forage was considered by prescribing the daily amount of forage mass consumed by the animals. Preliminary results showed that the ECOSMOS-Forage consistently simulates CO2 and water fluxes over the years in the grazed forage simulated system. Particular attention was given to capture the seasonal variability of Marandu palisadegrass growth, in response to seasonal rainfall and temperature variability. Simulated and field-observations of gross primary production (GPP) and evapotranspiration (ET) were generally well reproduced by ECOSMOS-Forage (Figure 1). Although seasonal trends are well represented, the accumulated GPP was overestimated by the model, mainly due to slower declines in CO2 assimilation compared to observed values (overestimated values of leaf biomass; not shown) in the beginning of dry season, which could be associated with the increase of leaves senescence rate, and requires further investigations. At the beginning of the rainy season, the fast increase in observed GPP is reasonably well represented. While accumulated ET simulated by the model was greater than observed values, with a tendency of overestimated values at the beginning and end of the rainy reason, in general, the amplitude and water fluxes seasonal cycle is consistently simulated by the model. Although further improvements are in progress, with additional calibration and evaluation in distint environments and management conditions, ECOSMOS-Forage is showing a promising performance for simulating tropical forage growth.
Gatien Falconnier	Sustainable intensification of cereal-based cropping systems in semi-arid sub-	Sustainable intensification of cereal cropping systems can contribute to reduce food insecurity while mitigating biodiversity losses in sub-Saharan Africa thanks to land sparing. Yet, intensification of crop production often leads to greater sensitivity to climate hazards and greater yield inter-annual variability. An understanding of how different options for sustainable intensification interact, and how they could help achieve greater and more stable yields is missing for key cereal cropping systems of sub-Saharan Africa. Here we use a calibrated soil-crop model to explore the move towards sustainable intensification through three strategies, namely i) the integration of legumes, intercropped with cereals or as sole crop within the cropping system, ii) improved varieties with high harvest index and greater nitrogen use efficiency, and iii) the use of more mineral fertilizer . We did this for a case study of sorghum-based cropping systems of semi-arid southern Mali, using a historical weather series for the period 1980-2010. We found that the incremental

	Saharan Africa: intercropping or combining cereal and legume sole crops?	combinations of two or three of the strategies helped increase productivity in terms of energy and protein. However, greater productivity went hand in hand with greater inter-annual variability. Intercropping sorghum with cowpea helped to reduce the inter-annual variability of productivity, but only when mineral fertilizer was not added. With mineral fertilizer input, sorghum contributed the largest share of the intercrop productivity, and its yield was more variable than that of cowpea. Overall productivity of intercropping sorghum with cowpea was always greater than having the two sole crops on separate plots. This was possible thanks to facilitation for light, water and N acquisition by the two crops in the intercropping, regardless of the specificities of the growing season with regard to water and nitrogen stress. However, the cultivation of the two sole crops on separate plot had lower inter-annual variability of productivity . We discuss the implication of these findings in light of the current research agenda for sustainable intensification of cropping systems in sub-Saharan Africa.
Greg Kiker	Global Rangeland Modeling Highlights Zones of Challenge and Opportunity for Livestock Production Areas Under Future Climate Change Conditions	The pressing issue of feeding a growing and changing population while mitigating carbon emissions is exacerbated by projected climate change dynamics that will impact resource-limited agricultural areas differently. The G-Range Global Rangeland Model was configured globally at a 0.5-degree (50 km^2) grid resolution to simulate weekly from 1950 through 2070. G-Range provides over 100 different outputs varying from vegetative components (grass, shrub and tree biomass and cover) to soil fertility metrics (moisture, C and N) under a wide variety of General Circulation Model (GCM) climate and CO_2 inputs. Rangeland management dynamics were also simulated to compare both current and climate-smart practices on seasonal, annual and decadal metrics. These rangelands results are linked with global trade models to estimate potential changes in national productivity and trade deficits/surpluses. G-Range simulations reveal significant effects on livestock production, particularly in western and eastern Africa, with implications for grazing quality and national productivity. The study underscores the importance of sustainable food production in vulnerable regions and its link to climate-induced resource stress and conflict. These global rangeland models offer a tool for stress-testing potential mitigation policies in problematic areas.
Katharina Waha	Land use modelling needs to better account for multiple cropping to inform pathways for sustainable agricultural transitions	Multiple cropping, the cultivation of several crops in space or time in situ, is practised in many crop production systems globally. Multiple cropping is an essential part of intensifying and diversifying agriculture and influences soil erosion, albedo, soil nutrients, pest infestation and the carbon sequestration potential of agricultural ecosystems. Multiple cropping is, however, rarely, or poorly accounted for in assessments of global food production, sustainability and climate change research. These are often supported by using Earth System, agricultural or land use models. Such modelling studies are of growing relevance in decision- and policy-making but are still largely confined to representing combinations of mono-cropping systems with bare soil outside the single growing season, and neglecting any carryover effects between different crops and seasons. Not accounting for multiple cropping may limit the application of modelling studies and their conclusions for baseline assessments while neglecting a substantial portion of the option space for sustainable intensification, the potential of nature-based solutions in foresight studies, and the resulting land-atmosphere feedback. Herein, we highlight five broad observations about the state of research in modelling different types of multiple cropping systems. While we consider multiple spatial scales and models from crop models to Earth System models and agro-economic models, we place particular emphasis on the relevance of multiple cropping in large-scale – regional, national, global – analyses. Our observations outline research that already made progress considering multiple cropping, and key challenges. Our observations also identify persisting limitations in data and process understanding and point to short- and long-term options for better representing such systems in modelling studies.
Mariana Rufino	Advancing modelling tools to analyse	The need Animal products are important for food security and livelihoods, especially in low-to-middle-income countries (LMICs) although their production causes widespread environmental concerns. Livestock systems have to adapt to climate change (CC) while reducing air and water pollution, improving resource use efficiency in high income countries (HIC) and LMICs. Avoiding trade-offs and

	livestock-grassland-cropland interactions	enhancing synergies across prospective interventions requires simultaneous consideration of multiple attributes and scales. Science and models are needed to find strategies to increase overall livestock systems' resilience to climate extremes. The gaps There is no analytical tool or livestock system model (encompassing primary production and the animals) with robust representations of productivity, animal health and welfare, greenhouse gas (GHG) and nitrogen (N) emissions, vegetation productivity, and the interactions between these dimensions. Individual models represent some of these processes in isolation. Most livestock system models have been developed from experimental data from a limited diversity of livestock systems and fail to capture important aspects of low input, and extensive systems. For example, the strong seasonality affecting rangeland and pastures productivity throughout the world has significant impact on environmental metrics. The options available There is a need to capitalize on the existing body of models and empirical data, exploiting the new opportunities offered by developments in sensor technology and data capture platforms. An example is the study of heat stress on livestock. Simple models can be calibrated with empirical relations derived from big data collected through producers, capturing diverse environments, animal and plant genetics, for which the most important gaps have to be identified to prioritise data collection. There is an urgent need to: (i) develop better models for LMIC; (ii) coherently integrate model (outputs) to provide evidence relating to grand challenges on resilient livestock systems compatible with climate neutrality. The future Livestock system analysis is progressively adopting data-science approaches linked to sensors and artificial intelligence. Data collection through crowd-sourcing offers great potential to gather field-animal performance data, filling some important gaps. Investments to understand better grazing ruminant and low-input livestock systems are needed. Grassland models can be integrated with earth observation data, and data gathered in real-time, encouraging collaboration between livestock systems modellers. Comparing livestock systems models presents a challenge, and requires an effort to consensually select simple frameworks to answer key system questions. Coupling of relevant models within integrated frameworks could answer these questions, and identify key knowledge gaps that could be addressed using cutting-edge data science.
Weldemichael Tesfuhuney *(Virtual)*	Innovative knowledge of rainwater harvesting techniques in semi-arid ecosystems: Maize-bean intercrop productivity and resources use efficiency	This innovative study was designed to support the rural communities in the semi-arid areas of South Africa by promoting knowledge uptake to increase productivity through the engagement of smallholder farmers, extension, & researchers to enhance the adoption of alternative farming techniques. Among many alternative techniques available to smallholders in the semi-arid areas, are the integration of in-field rainwater harvesting (IRWH) & inter-cropping practices, seen as complementary with inherent sustainability to increase household nutritional security. In this study, two tillage systems [conventional (CON) and IRWH] as the main plot and three cropping systems as sub-treatment, (sole-maize and beans, & intercropping) were used to measure water use and radiation use parameters. In addition, a systematic engagement strategy was used to identify contextual factors that prevent farmers from accepting the IRWH technique. The purpose of the qualitative study is to assess farmers' knowledge and attitudes about the technique, as well as their adoption & perceptions thereof. The water use in IRWH was higher by 15.1%, 8.3%, & 10.1% over the CON for sole maize and beans & intercropping, respectively. Similarly, the intercropping system showed the water use advantages over the solely growing crops by 5% & 8% for maize & by 16% & 12% for beans under IRWH and CON tillages, respectively. Maximum RUE was found for solely grown maize & beans under IRWH and higher by 13% & 55% than the CON tillage, respectively. The results also show that less than a third (27%) made an informed choice while 89.6% had a positive attitude. The overall reflection of excellent knowledge (75%) about the technique was high among farmers aged 41 & over and amounted to 55.6%. Farmers' narratives about anticipated interventions, such as intercropping training & timely drought warning services, should increase their adoption. To further improve water & radiation use efficiency in maze-bean intercrop under IRWH, there is a need to optimize plant population & sowing dates relative to water availability and on-set of rainfall. This study focuses on farmers' specific technology adoption needs, offering another perspective on how achieving the sustainable development goals (SDGs) of zero hunger and climate action necessitates a decentralized approach. Keywords: water and radiation use, Smallholder farmers, informed choice, Knowledge transfer, Farmers' adoption.

Paper Presentation Session 9: Crop Model Products in Practical Application		
Lead Author	***Title***	***Abstract***
Anthony Whitbread	Innovating and scaling risk-reducing measures for farmers and livestock keepers in the drylands	In the drylands, low and variable rainfall patterns often leave poor communities, dependent on rain-fed pastoral and agropastoral production, highly vulnerable. Risk-reducing measures in the form of innovative insurance schemes for livestock producers, or climate risk tools for tactical agronomic management for farmers, have been piloted by the CGIAR and its partners in many dryland geographies. At their core is the use of crop and pasture models, spatial data from remotely sensed imagery, and historical time series-weather and vegetation indices datasets which, when linked to expert knowledge of the system, are used together to develop triggers for decision-making or action. For example, for pastoralists in Kenya, Ethiopia and Somalia, the index-based livestock insurance (IBLI) products linked to fodder availability (biomass), have been scaled to the regional level as de-risking instruments. In crop-based systems, a decision support tool called 'iSAT' defines a process to create context-specific climate-informed agro-advisories for use in tactical agronomic decisions making at the farm level. For livestock keepers in mixed crop-livestock systems, the decisions which are linked to climate throughout the life cycle of fodder and animal components are used to develop actionable management strategies. In these examples, models have been used in a participatory mode to develop scenarios that farmers face in their day-to-day management. When linked to medium-range and seasonal climate forecasts, future climate change predictions, and bioeconomic analysis for example, the scenarios can be communicated to decision-makers in a: (i) strategic mode to design more resilient farming systems; or (ii) in a tactical mode as the prevailing season unfolds leading to more informed climate risk management. Low-cost internet, affordable smartphones, mobile network penetration, open access satellite data, cloud computing, and novel communication methods (e.g. SMS and IVR), increasingly offer unprecedented opportunities for the dissemination of information to farmers through digital channels and to re-imagine agriculture advisory. Digital technologies also enable innovative and affordable methods of acquiring and sharing high-frequency data, ground truthing, and user feedback, especially in data-sparse and complex environments.
Anupam Bhar, Balaji Pokuri *(Presenter)*	Optimization of small farm holder profit using the MISSION framework's model-predictive in-season irrigation or nitrogen fertilizer scheduling	Agriculture farm profit depends on application time and amount of fertilizer and irrigation inputs. Profit is non-linear with input cost. On one end, a low application can cause reduced yield; on the other, excess input can cause wastage and environmental pollution without increasing yield. Irrigation and rainfall affect fertilizer and water use efficiency. Less water prevents fertilizer from reaching the crop roots, whereas high water application leaches or runoff valuable fertilizer. Farmers use their experience, heuristics, and general guidelines to decide the amounts and times of irrigation and fertilizer applications, which often need to be more precise and optimum. Irrigation is scheduled, so that plant available soil water never falls below a threshold and stresses the plant. A model-predictive real-time in-season decision-making framework is proposed here considering (i) current plant and soil conditions and (ii) past weather and its future forecast. To maximize farm profit, the framework prescribes irrigation and fertilizer applications which are revised daily (accounting for the latest update on weather, field and plant conditions). While considering profit, the number of trips made to apply inputs and associated costs are also considered apart from the cost of inputs. The recommended amounts are determined by efficiently running a forward simulation of a field-calibrated RZWQM agriculture model daily, under different combination scenarios of irrigation and fertilization amounts, and weather forecast from GFS (Global Forecast System) model obtained as grib data files. We implemented the framework on field scenarios in Greeley, Colorado. We give simulation results for (i) a real-time in-season scenario, factoring the practical uncertainty in knowing the future weather, versus (ii) an "after-the-fact" scenario as a thought experiment when the entire season weather is known. Also, results are compared with contemporary expert knowledge based (without the aid of a computer) applications in the same experimental field. The "After-the-fact" scenario achieved a profit of approximately $2100/Ha compared to $1361/Ha from the traditional knowledge-based application. The real-time in-season scenario gave around $1900/Ha profit which is just 10% less profit than the "after-the-fact" scenario, nevertheless much better (around 40%) than traditional expert knowledge-based application.

Mara Gabbrielli	Development of an integrated system that combines a cropping system model and a tool for the optimisation of manure redistribution	Increasing intensification of crop and livestock production and the consequent farming specialisation and high livestock density raises growing difficulties in the achievement of an optimum balance between economical profitability and environmental sustainability. An integrated system was developed to support stakeholders in the identification of viable solutions to maintain crop productivity and reduce environmental impact at a local or regional scale. A regional database, containing farms data about livestock load, manure-N, and crop nitrogen requirements, was employed to perform long term simulations of the prevalent cropping systems with the ARMOSA process-based model that simulates crop growth and development, water and nitrogen dynamics under different pedoclimatic conditions and crop management practices. A software tool was developed to assess the opportunity of moving manure from farms with excess manure (surplus-farms) to farms where manure is lacking according to the crop N requirement that is fulfilled mainly with mineral fertilizers (deficit-farms). The tool ran at a regional scale and it was applied in two case studies, i.e., Lombardy (Northern Italy) and Denmark. The opportunity of manure moving was estimated with the integration of optimization algorithms that consider the distance between surplus-farms and deficit-farms, the costs and CO2 emissions associated with manure transport and the mineral fertilizers purchased in the deficit-farms. The outcome of the tool is the list of deficit-farms that take the advantage, in terms of costs and CO2 emissions, of receiving manure and reducing the purchase and application of mineral fertilizer. In these farms, ARMOSA is applied to assess the crop productivity, soil organic carbon stock, crop N recovery, and N losses (NO3 leaching, N2O and NH4 emissions) before and after receiving manure. Additional assessments were performed in deficit-farms after manure redistribution optimization, to evaluate the environmental benefits of alternative management practices aimed at reducing N losses. This integrated system can be applied to data available Europe-wide thus allowing the a priori evaluation, at a regional scale, of the impact of moving manure on N use efficiency and soil carbon stock evolution, in a wide range of pedoclimatic conditions and cropping systems.
Siyabusa Mkuhlani, Meklit Chernet *(Virtual)*	AgWise: A Collaborative Analytical Framework for Tailored Fertilizer Recommendations	—
Soora Naresh Kumar	Simulation modelling assisted climatic risk adaptation in small-holder farms in India	With information and communication technology helping seamless outreach to enable farmers with information and decision support, use of simulation models for farm management has become more relevant then earlier. Although, use of models for managing green-houses and large and homogenous farms is widely adopted, their use for highly diverse small holder farms is not well explored. InfoCrop v2.1, a crop simulation model based DSS, is used to first simulate the crop yields small holder farms in six villages (four in Jhansi district, Uttar Pradesh and two in Niwari District, Madhya Pradesh) with current management and with climatic risks. Then, yield gaps and gains due to adaptation technologies are simulated. These were tested in the farmer's fields. Adaptation gains due to technological interventions in about 1000 small holder farms for three years during Kharif (July-October, monsoon), Rabi (November-March) and summer (April-June) crop seasons were quantified. Crop yields in farms, where the technological interventions were made, increased up to 33% and 37% respectively in green gram and black gram during Kharif season. While yield gains were up to 53% and 60% respectively in wheat and chick pea, as compared to their respective local varieties and farmers practice of crop management. These yield gains were attributed to introduction of improved varieties and agronomic practices such as timely and line sowing, nitrogen and irrigation management. In addition, summer moong was introduced in some farms as sustainable intensification option. Due to adoption of adaptation technologies, an estimated increase in income was about 5.32 crore Indian rupees ( ), equivalent of 625,882 US$, for the direct intervention farmers during the project period. Farmers', who are not directly part of the project

		interventions but got technological dissemination (including seed), gained an estimated income increase of over 21.72 crore (eq. 2,555,294 US$) during the project period. Hence overall benefit to farming community in six villages is estimated at 3,81,176 US$.

Paper Presentation Session 10A: Projections of Future Crop Productivity		
Lead Author	***Title***	***Abstract***
Alex Ruane	Initial climate change impacts on crop yields may misinform stakeholders	We utilize a global warming level (GWL) lens to evaluate global and regional patterns of agricultural impacts as the world warms. The GWL perspective sheds important light on the experience of stakeholders with continued warming in the 21st century. We analyze crop productivity outputs from 10 crop models simulating 5 climate models under 3 emissions scenarios across 4 crops within the AgMIP / ISIMIP Phase 3 ensemble. We categorize regional results (without adaptation) into 9 characteristic response patterns, identifying consistent increases and decreases as well as non-linear (peak or dip) responses indicative of inflection points reversing trends as GWLs increase. Many maize regions and pockets of wheat, rice and soybean show peak decrease patterns where initial increases may lull stakeholders into complacency or maladaptation before productivity shifts to losses at higher GWLs. Although the GWL perspective has proven useful in connecting diverse climate models and emissions scenarios, we identify multiple pitfalls that recommend proceeding with caution when applying this approach to climate impacts. Chief among these is that CO2 concentrations at any GWL depend on a climate model's transient climate response (TCR). This leads to more pessimistic agricultural projections for so-called 'hot' models and can skew multi-model ensemble results as these models with high TCR are disproportionately likely to reach higher GWLs. While there are strong connections and pathway independence between many climatic impact-drivers and GWLs, the vulnerability and exposure components of risk assessment have strong temporal dimensions that will affect food system risk depending on development pathways.
Christoph Müller	Don't mind the yield: central lessons from a decade of AgMIP	Over the last twelve years, AgMIP has facilitated and conducted a very broad set of different model intercomparison efforts. Among many other findings, these have shown that crop models perform decently well, if compared to historical records at site, national or global level. Unfortunately, we cannot take comfort in this finding, as we find tremendous differences in future yield projections across crop models. I will illustrate that this is particularly evident in global yield projections for the 21st century, where models are applied to a very broad range of conditions, but also prominent at site-scale and across different crops. Several AgMIP activities have contributed to shedding light on the problem, but we have failed to comprehensively address the problem – not to mention fixing it. Model development is an imperfect process and models have been developed for a broad range of applications. Even though crop models simulate a cornucopia of variables of the soil-plant-atmosphere-management system, the main and often only focus is on crop yields. However, crop yield is the result of the interaction of many complex mechanisms, of which only a fraction is implemented in models. I will present evidence from observations and from modeling exercises that models tend to be right – but for the wrong reasons. While it is the objective of models to reduce complexity, the process of reducing complexity is not objective but subject to model purpose, model history (i.e. choices made previously), data availability, knowledge, resources, and values. That is fine in principle, but users of models (or of data generated with these) need guidance in model selection and interpretation. And, equally important, model developers need guidance in how to improve their models. Consequently, the next decade of AgMIP research needs to work with new principles of model evaluation. I will present ideas on process-based model testing that can help to get models right for the right reasons and to derive model fingerprints – a meta-description of models that allows for better selection of models fit for particular

		purposes. The whole AgMIP community needs to contribute to make this happen. With the power of AgMIP, we can make crop models better. Let's start at AgMIP9!
Mikhail Semenov *(Virtual)*	Estimating global genetic yield gap by designing crop ideotypes	The greatest challenge facing humankind is maintaining global food security, which will require food production to be increased substantially in the coming decades in the face of a changing climate and scarcity of land and fresh water. The closure of existing genetic yield gap Yig by genetic improvement could increase crop yield potential and global production. In this study, we estimated global wheat Yig, covering all wheat growing environments and major producers, by designing wheat ideotypes based on the current local cultivars and available genetic variation using Sirius, a state-of-the-art wheat simulation model. Crop idiotype is defined as an ideally adapted cultivar which would deliver maximum yield by utilizing optimal combination of cultivar traits in a target environment. The cultivars based on an ideotype design would capture natural resources more efficiently and utilize the local environment better to deliver the highest yield. We estimated mean global Yig for wheat as 51%, implying that global wheat production could be, potentially, doubled by closing the untapped genetic yield gap through the use of optimal cultivar designs, utilization of the vast variation available in wheat genetic resources and application of advanced breeding tools.
Oleksandr Mialyk	Historical look at crop water productivity: the results of global crop modelling	Crop water productivity (CWP) – the amount of crop produced per unit of water – is one of the key metrics in global food production. Understanding its temporal and spatial dynamics is important for food security, particularly in regions with limited water resources. One way to study CWP is by looking at actual field measurements. However, this analysis is generally limited in temporal and/or spatial coverage. Remote sensing can address this issue but it often focuses on cropland as a whole, making crop-specific analysis challenging. Another approach is to utilise global gridded crop models (GGCM). They can simulate crop production and water use at high special resolution while considering numerous bio-physical processes that affect CWP, such as changes in CO2 concentration and response to heat and water stresses. In this two-part presentation, we first discuss the main outcomes of our recent global study on green and blue CWP of 175 crops during 1990-2019 simulated with ACEA – a gridded version of FAO's AquaCrop model. Among the covered topics are: i) CWP trends across all crop groups and their main drivers, ii) differences between rainfed and irrigated production systems, and iii) key challenges and opportunities in CWP. In the second part, we expand historical CWP analysis to the 1901-2019 period using recent simulations by AgMIP's Global Gridded Crop Model Intercomparison initiative. These simulations comprise several GGCMs, including ACEA. Hence, it is possible to substantiate the findings of the previous part as well as evaluate differences in simulated CWPs among the models. To conclude, we provide a preliminary analysis of the long-term climatic signal in CWP and suggest topics for further research.
Pierre Martre	Is crop intensification necessary to increase the yield potential of wheat under climate change?	Wheat is the main stapple food in many regions of the world, providing over 20% of calories and proteins in the human diet, and with 221 million ha harvested in 2021 wheat is the most grown food crop globally. Innovations in plant breeding and agronomy have supported a linear increase in wheat yield potential since the 1960's, which has significantly contributed to global food security. However, in many regions of the world, the translation of genetic yield progress into farmers' fields is increasingly constrained by a yield gap, which in most regions is caused by low soil N availability. In a new AgMIP study, we analyzed improvements in grain yield that can be expected from promising new yield traits. We also quantified the amount of N that would be needed to translate an increased yield potential from these traits to higher yields in framers' fields. First, we evaluated a multi-model ensemble (MME) of 12 wheat models at five global high-yielding field sites. We found that the ensemble captured well both the interannual yield variability and yield response to sowing date and sowing density. The MME also simulated well the yield response to new sink-source traits observed in the field at several contrasting sites. We then used our tested wheat model ensemble to quantify the yield response of improved wheat cultivars with high-yielding traits under current and climate change scenarios across 60 representative global sites and quantify yield increase with present N application rates and the amount of N-fertilizer needed to achieve full yield potential with the improve traits. Our simulations show that wheat yield could be increased with the new traits by 16% with current N fertilizer applications under both current climate and mid-century climate change scenarios. To achieve the full yield potential from the new traits, a 52% increase in global average yield under a mid-century RCP8.5 climate scenario, and simultaneously maintain grain protein concentration at the value required for bread making, N fertilizer applications would need to increase fourfold over current rates. Such increase in N fertilizer application would unavoidably lead to higher environmental impact from wheat production. New sources of N and novel solutions to

		improve N management reducing N fertilizer losses for high-yielding wheat crops are thus urgently needed, especially in regions where yield is already strongly limited by nutrients and where the access to fertilizer is most difficult.
Yean-Uk Kim	Methodologies to assess changing climate risks on agroecosystems	Extreme weather events (EWE), such as heatwaves, droughts, and excess rains, cause crop failures. As their intensity and frequency are expected to increase in the future, assessing their impacts on agroecosystems is becoming more critical. However, the methodologies to assess changing risks due to EWE are rarely discussed compared to those for mean climate change impacts. This study aims to explore methodologies to assess changing climate risks on agroecosystems regarding driving climate data and risk visualization methods. First, two driving climate data were compared: a large ensemble from global climate models versus a stochastic weather generator. After that, the number of realization years required to reproduce the impact of the EWE at a given return period is analyzed. Lastly, different methodologies to present the changing climate risks are discussed. The methodologies were applied to the case of grain maize production in Brandenburg. The results indicated that both driving climate data could be used to reproduce a historical yield variability. The number of realization years required to reproduce the impact of the EWE at a given return period increased as the return period increased. A risk curve (i.e., yield loss plotted against return period) or yield distribution can be used to visually compare the present and future climate risks. Relative distribution can quantify differences in the entire yield distribution between the present and future. Meanwhile, copula functions are particularly useful for assessing tradeoffs among different indicators such as crop yield, carbon sequestration, and nitrogen loss. This study highlights the importance of driving climate data and visualization methods for making robust estimates of changing climate risks and communicating holistic results, respectively. In the future, the methodologies will be tested at a regional level across several nations to assess the suitability of the methods under different topographies, climates, and cropping systems.

Paper Presentation Session 10B: Projections of Future Crop Productivity

Lead Author	***Title***	***Abstract***
Davide Cammarano	Impact of projected climate on processing tomato production	Most climate change impact studies using crop growth models have mainly concentrated on wheat, maize, rice, and soybean, while fruits and vegetable have not received enough attention. Tomato is among the most important vegetables and ranks second only to potatoes by acreage, production, yield, commercial use, and consumption. There are two types of cultivated tomato, the one for fresh consumption and the one used for industrial transformation (processing) which is cultivated under field conditions. Processing tomatoes are used for tomato paste, tomato sauce, ketchup and other tomato-based products. Their production is concentrated in ten major “tomato baskets” around world and three of those (USA, Italy and China) account for 65% of the global production. A current scientific gap is the lack of an up-to-date biophysical assessment of the potential impact of climate change in these three countries using the latest climate projections (CMIP6) and a protocol that makes the results comparable with the results from other global efforts (e.g. AgMIP, MACSUR). The crop model used to simulate field-grown processing tomato is Cropping System Model (CSM)-CROPGRO-Tomato available in the DSSAT, V4.7. The model has been calibrated for tomato genotypes in different environments using published scientific literature and validated at regional level using the data from the World Processing Tomato Industry for the period 2005-2019. Three Shared Socioeconomic Pathway and Representative Concentration Pathway (SSP-RCP) scenarios were used: low (SSP1-2.6), high (SSP3-7.0), and very high (SSP5-8.5) greenhouse emissions and related socio-economic conditions and atmospheric carbon dioxide concentrations. Simulation results showed that processing tomato production in the three main producing countries decrease by 2050 under the ensemble of projected climate scenarios, with minor changes for SSP1-2.6 (+0.2 to -9.9%) and more severe losses under SSP3-7.0 (+8.6 to -8.6%) and SSP5-8.5 (+6.5 to -15.2%). The amount of water required for irrigation increased by 5 to 50%, depending on the region. In China the projected water requirements is projected to be lower

		comparted to California and Italy, suggesting that China has a potential to become one of the important regions for processing tomato production by 2050 to become one of the main processing tomato production hubs. Future work includes additional political and socio-economic information to be integrated in similar studies to assess changes in the whole system to evaluate shifts in the value chain including processing plants and transportation lines that may be anticipated.
Leonard Borchert	Change of negative year-to-year agricultural yield extremes under global warming	Studies on projected agricultural yields predominantly focus on end-of-century scenarios. Simulations from the Global Gridded Crop Model Intercomparison (GGCMI) Project phase 3b show conflicting results for global and regional changes of different crops by the end of the century. Here, we interrogate the same simulations, focusing on year-to-year variations of agricultural yields in the important staple crops maize, rice, soybean and wheat. An ensemble of GGCMI models shows that year-to-year variations of projected crop yield largely become more pronounced over time, especially so for negative crop yield anomalies. As a result, the frequency of negative global crop yield extremes increases with global warming. We show that these negative yield extremes may occur for individual or multiple crops at the same time, and may originate from individual or multiple regions. North America dominates global maize and soybean yield extremes, and South East Asia and South Asia are important for rice extremes, while regional results are inconclusive for wheat. Multi-crop extremes occur most commonly for the combination of maize and soybean, and are dominated by the North America region. Based on these findings, we show that depending on the region and crop, persistent spring or summer drought, cold or heat can be associated with years of global and regional negative agricultural yield extremes. Our results show how specific climatic boundary conditions can lead to negative year-to-year extremes in important staple crops, highlighting the potential to anticipate such events in the future.
Meijian Yang	Projecting Maize Yield in the US Corn Belt and Ethiopia Using Process-Based Model and Machine Learning Models	The changing climate poses increasing challenges to agriculture, particularly in highly productive regions such as the US Corn Belt and food-insecure countries such as Ethiopia. The objective of this study is to project maize yield changes, identify environmental stressors on maize yield, and support potential climate adaptation and mitigation strategies in the agricultural sector. Based on experiments using a process-based model (DSSAT) driven with statistically downscaled and bias-corrected historical and future climate data from multiple GCMs and RCMs, we assess how maize yield responds to projected climate changes in the Corn Belt and Ethiopia. Maize yield is projected to decrease in both regions, but for different reasons. In the Corn Belt (a region where historically water stress is the primary limiting factor for crop yield), the primary cause for the projected yield loss is an increase of heat stress after midcentury, leading to a northward shift of the most productive zone; earlier planting is found to partially compensate for the projected yield loss. In Ethiopia, the projected yield reduction is primarily attributed to the increasing water stress during the critical growth stage(s); the currently most productive regions would suffer the most from climate change, while some less productive regions may become more suitable in the future, leading to a spatial shift of the most productive zone. In addition to DSSAT, we also apply machine learning (ML) models to future yield projections, and compare the ML-based projection with DSSAT projections. Our ML models were found to outperform DSSAT in modeling the historical yield variability and extremes; for this reason, the ML-based projections may be considered more reliable.
Paulina Ansaa Asante	Climate change impacts on cocoa production in the major producing countries of West	Climate change is expected to negatively impact cocoa production in West and Central Africa, where over 70% of cocoa is grown. However, effects of temperature, rainfall and atmospheric carbon dioxide concentration [CO2] on cocoa tree physiology and productivity are poorly understood. Consequently, possible implications of climate change for cocoa productivity and adaptations have not been adequately considered. Our objective was to improve understanding of potential cocoa productivity responses to climate change projected by general circulation models (GCMs) by mid-century (2060). We simulated potential water-limited yields (Yw) using a crop model to evaluate effects of warming and changes in precipitation based on five plausible future climate scenarios projected by GCMs, with and without elevated CO2 effects. We examined the extent to which variation in current and projected

	and Central Africa by mid-century	future yields was associated with variation in individual climate variables using mixed-effects models. We then quantified how much cocoa could be produced in the future without expanding the current cocoa plantation area under low-input business-as-usual and high-input scenarios. With some notable exceptions, model predictions showed that, under future climate, increases in Yw and in area suitable for growing cocoa were expected particularly when assuming full effects of elevated [CO2] and under wetter climate-change scenarios. Impacts followed a (south) east - west gradient with projected yield increases being most positive in Cameroon and Nigeria (~39-60%) then Ghana and Côte d'Ivoire (~30-45%). On the other hand, larger yield reductions were expected in Côte d'Ivoire and Ghana (~12%) followed by Nigeria (~10%) and Cameroon (~2%). In terms of area suitable for cocoa, larger increases were expected in Nigeria (~17-20Mha), followed by Cameroon (~11-12Mha) and Ghana (~2Mha) whilst reductions (~6-11Mha) were expected for Côte d'Ivoire by 2060. In areas with increasing yields, inter-annual yield variability was expected to decrease, but increased variability was predicted in areas with low yields, especially in north-west Côte d'Ivoire. Simulations based on one climate-change scenario showed that current country-level production to be maintained within current cocoa growing areas of Côte d'Ivoire and Ghana by mid-century. Predicted increases in Yw were mostly associated with projected increases in dry season precipitation whilst projected shortening of the dry season reduced yield variability. These modelling results indicate that, despite the increases in temperature and changes in rainfall distribution as projected by the selected GCMs, many areas where cocoa is currently grown will either maintain or increase in productivity, particularly if full effects of elevated [CO2] are assumed.
Sam Rabin *(Virtual)*	Observation-based sowing dates and cultivars significantly affect yield and irrigation for some crops in the Community Land Model (CLM5)	Farmers around the world time the planting of their crops to optimize growing season conditions and choose varieties that grow slowly enough to take advantage of the entire growing season while minimizing the risk of late-season kill. As climate changes, these strategies will be an important component of agricultural adaptation. Thus, it is critical that the global models used to project crop productivity under future conditions are able to realistically simulate growing season timing. This is especially important for climate- and hydrosphere-coupled crop models, where the intra-annual timing of crop growth and management affects regional weather and water availability. We have improved the crop module of the Community Land Model (CLM) to allow the use of externally-specified crop planting dates and maturity requirements. In this way, CLM can use alternative algorithms for future crop calendars that are potentially more accurate and/or flexible than the built-in methods. It also enables CLM to participate in AgMIP's Global Gridded Crop Model Intercomparison (GGCMI). Finally, it provides an opportunity for evaluation: How good is CLM at reproducing observed growing seasons, and what can we learn about CLM when forcing with observations? Here, we use planting and maturity inputs derived from GGCMI-provided crop calendars to perform such an evaluation. Using observation-derived planting and maturity inputs reduces bias in the mean simulated global yield of sugarcane and cotton but increases bias for corn, wheat, and especially rice. These inputs also reduce simulated global irrigation demand by 15%, much of which is associated with particular regions of maize and rice cultivation. We discuss how our results suggest areas for improvement in CLM and, potentially, similar crop models.

Paper Presentation Session 11: Land and Climate Modeling		
Lead Author	***Title***	***Abstract***
Audrey Brouillet	Attribution and impacts of excessive rainfall and drought on maize yields in low-inputs systems using crop models	AgMIP low-inputs smallholder systems crop simulations show that maize yield was affected by more precipitation in sub-Saharan Africa. Although the amplitude of this effect was both site and model dependent, yield losses were attributed to N leaching and were greater when N was limiting in simulations (no fertilizer input). Moreover, there has been a clear increase in high rainfall events during the last decades in West Africa, attributed to global warming. This intensification have resulted in 5 to 20% yields losses depending on crops and locations. In the future, more rainfall is expected under climate change scenarios in most of the eastern part of West Africa, whereas models project drying trends within the western part. As both wet and dry events can result in large impacts on yields, it is of a major importance to better quantify those impacts using crop model simulations at diverse sites across sub-Saharan Africa. Specific input climate simulations also allow to determine whether those events and their impacts on crops are attributed to the global warming. In this context, we propose a new AgMIP exercise to study the attribution of excessive rainfall and drought and their effects on maize yields in low-inputs smallholder systems in sub-Saharan Africa. Our protocol aims to: (i) compare crop model responses to excessive rainfall and drought for varying geographic and soil conditions in low-inputs systems in Africa (5 sites); (ii) characterize the specific contribution of wet and dry events on yield losses in a warming climate; (iii) attribute those events to human-induced global warming using factual (current) and non-warming counterfactual (without human activities) climate simulations from the MRI-AGCM3.2 climate model. Preliminary results show higher temperatures in factual than counterfactual simulations for all of the 5 sites (Mali, Benin, Ghana, Rwanda, Ethiopia) as expected. For precipitation, Mali and Benin are characterized by a dryer climate in factual simulations. However for the three other sites, rainfall indicators are not consistent and do not exhibit a clear dry or wet climate change influence (e.g. more annual rainfall in Rwanda but more dry days). We expect to obtain corresponding crop multi-model simulations by July 2023 in order to emphasize rainfall events influence in crop yields and if possible crop loss/gain can be attributed to climate change in such low-input systems in sub-Saharan Africa.
David Helman	Detecting wheat response to drought under elevated CO2 using remote sensing metrics	The spectral-based photochemical reflectance index (PRI) and thermal imaging-derived leaf surface temperature (Tleaf) derived from thermal imaging are important metrics of plant functioning. The relationship between PRI and radiation use efficiency (RUE) and Tleaf and leaf transpiration could be used to monitor crop photosynthesis and water use. We conducted an [CO2] enrichment experiment in which three wheat genotypes were grown at ambient (400 ppm) and elevated (550 ppm) [CO2] under well-watered and drought conditions in two replicate glasshouses. Leaf transpiration (Tr) and latent heat flux (LE) were derived to assess evaporative cooling, and RUE was calculated from assimilation and radiation measurements on several days during the season. Simultaneous hyperspectral and thermal images were taken at 1.5 meters from the plants to derive PRI and the temperature difference between the leaf and its surrounding air (ΔTleaf-air). A PRI-RUE decoupling was observed under drought at ambient [CO2] but not at elevated [CO2], likely due to changes in photorespiration. For a LE range of 350 W m-2, the ΔTleaf-air range was 10°C at ambient [CO2] and only 4°C under elevated [CO2]. Thicker leaves in plants grown at elevated [CO2] suggest higher leaf water content and, consequently, more efficient thermoregulation at high [CO2] conditions. PRI, RUE, ΔTleaf-air, and Tr decreased linearly with canopy depth, displaying a single PRI-RUE and ΔTleaf-air – Tr model through the canopy layers. Our study demonstrates the utility of these sensing metrics for detecting wheat responses to future climate and environmental changes.
Kaela Lucke	Land Surface Model Sensitivities and Its Impacts on Land Cover Change in the	The Great Plains (Montana, Wyoming, Colorado, North/South Dakota and Nebraska) has 9% of the total farms in the United States (US) but has a quarter of all US cropland. The Northern Great Plains (North/South Dakota and Minnesota) is considered to have some of the world's richest soils in the Red River Valley. In the Northern Great Plains there has also been a transition from grains to leafier crops due to a warming climate, genetically modified hybrids, and the economy. From 2006 to 2011 in North Dakota, soybean and corn acres increased by almost 700,000 acres (about the size of Rhode Island) and the trend continues. The expansion of this crop belt plays an important role in the localized weather and climate through evapotranspiration. It is also plausible that severe weather

	Northern Great Plains	parameters like CAPE could also be impacted by crops. For this project it is important to fully understand the land surface model (LSM) of the regional climate model first. This study will investigate the sensitivity of LSM selection in regional climate simulations using the Weather Research and Forecasting (WRF) model. Spin-up, microphysics and cumulus scheme tests will be run to determine what schemes and spin-up time returns the most accurate results compared to observations. Next, different Leaf Area Index (LAI) predictors within the LSM will be used to see how slight land surface changes in agricultural regions affect the boundary layer parameters over the course of a decade (2009-2018). The Noah-MP LSM will be used and will evaluate three different LAI predictors (dveg 4, 5, and 9). Dveg 4 uses a look-up table, dveg 5 calculates a vegetation fraction and dveg 9 uses data modified from the Moderate Resolution Imaging Spectroradiometer (MODIS) sensor satellite. A dynamic vegetation crop model (Noah-MP-Crop) will also be used and tuned to the region. To tune Noah-MP-Crop satellite derived LAI from the (MODIS) sensor is used and collocated with the Cropland Data Layer (CDL). Comparing parameters from different LAI predictors should start to show the impacts of a changing land surface on the atmosphere. Lastly, the LSM model will be tuned to create an alternative past simulating a time when the region was mostly wheat and grasslands. This should produce more distinctive results from the land surface changes and show that leafier crops could reduce maximum temperatures, increase water vapor, increase humidity, and increase localized severe weather. This raises the question can crops hurt themselves?
Ligalem Agegn Asres *(Virtual)*	Effect of Historical Climate Data on Reference Evapotranspiration and Crop Water Requirement for Maize Crop	The demand for crop water and agricultural output are negatively impacted by climate change, a significant global environmental concern. Researchers exploited past climate data in several research projects even though it is periodically updated. The purpose of this study is to investigate the major impact of historical climatic data on reference evapotranspiration (ETo) and crop water requirement. The demonstration farm land at Arba Minch University served as the study site for this investigation. For the purpose of studying the influence, the 31-year (1987–2018) historical climatic data were gathered. Climate data for three months (July, August, and September 2021) were gathered and utilized as a baseline to investigate the effect. A Penman-Monteith method was used to determine reference evapotranspiration using CROPWAT8.0 model. Based on the crop coefficient and reference evapotranspiration, the amount of water required by the crop was calculated. For the use of current and historical climate data, 290.9 mm and 363.69 mm of ETo, as well as 277.56 mm and 337.71 mm of ETc, were obtained respectively. Thus, the estimated ETo and ETc from historical climate data were higher for the maize crop than the current climate data by 20% and 17.8%, respectively. This suggests that there is water loss, which is the crop root zone impacted by waterlogging or water ponding. Also, the actual outcome is not observed in the study of irrigation water management (deficient irrigation).
Wenfeng Liu *(Virtual)*	Safeguarding China's climate spaces for crop production	Climate change has had significant impacts on crop production globally and poses a challenge to global food security. It is crucial to mitigate these impacts to meet the future food needs of a growing population. The concept of a safe climate space (SCS), which is similar to the idea of planetary boundaries, relies on biotemperature, precipitation, and aridity as indicators to identify hotspot regions where crops need protection from climate change. However, it remains unclear how to safeguard crop production within the SCS under future climate change. To address this issue, we investigated the proportion of China's crop yields within the SCS during the period of 2036-2065 for four major crops: maize, rice, soybean, and wheat. Our findings suggest that, under the SSP126 scenario, about 11% (with a range of 7-27%) of China's crop production will transgress the SCS. However, this fraction would increase to 23% (with a range of 15-39%) under the SSP585 scenario, highlighting the significant challenges to ensuring future crop production. To tackle these challenges, we optimized crop planting distribution and climate adaptation strategies. With these optimizations, the proportions of crop production within the SCS would increase to 99% under both the SSP126 and SSP585 scenarios. This study underscores the impacts of future climate change on China's crop production and proposes an essential pathway to safeguard food security in the country.

Paper Presentation Session 12: Water Resources		
Lead Author	***Title***	***Abstract***
Christopher Jung	A land use change model to simulate the global development of irrigated cropland areas	Irrigation plays an important role in global agricultural production today and is likely to become even more important in the coming decades. On global average, irrigated cropping systems achieve two to three times higher yields per hectare than non-irrigated systems, enabling higher production volumes for a growing world population with its increasing demand for food, fiber and bioenergy. Moreover, they are more resistant to expected climatic changes such as heat waves and droughts. Therefore, irrigation agriculture is and will remain a keystone of global food security policies. In order to end hunger, as it is the aim of Sustainable Development Goal 2, an expansion of irrigated cropland areas will be indispensable. However, Irrigation agriculture it is by far the largest water use sector, responsible for 70 percent of global freshwater withdrawals and more than 90 percent of global consumptive water use. Hence, an expansion of irrigation agriculture can easily come into conflict with Sustainable Development Goal 6 (sustainable withdrawals and supply of freshwater) as well as with Sustainable Development Goal 15 (sustainable use of terrestrial ecosystems). In order to avoid or at least to minimize these conflicts, to achieve global food security on the one hand and a sustainable supply of freshwater on the other hand, reliable and accurate estimations of the future extent of irrigated cropland areas are needed. Although there are several approaches and models that are in principle capable of simulating the future extent of irrigated areas, in most cases they are too simple and/or too coarse in spatial resolution. In order to close this gap, we developed an integrated, spatially and temporally explicit land use model within the modeling framework of LandSHIFT that allows to allocate current and future irrigated crop production and resulting area on global land use grid maps with a cell size of 5 arc-minutes. The model uses (irrigation-specific) socioeconomic and biophysical input data to perform a suitability assessment and allocates irrigated crop production and resulting areas separately from rainfed crops using a specific algorithm. Comparison of results of historical runs with current state of the art irrigation maps is promising. The model results can provide crucial input for other global models and studies related to water use, food production or climate change. It can be a useful tool for politics of large-scale and long-term planning.
Meijian Yang	Coupling high-resolution DSSAT crop model into NASA Land Information System	Crops play a vital role in the land-hydrology system, particularly in agriculturally intensive regions such as the Midwestern United States, and improved information on this complex system helps both farmers and water managers. Accurate simulations of crop growth and development can provide insights into the land surface energy and water balance, crop productivity, and crop water use efficiency. Understanding these facets of sustainability are critical for managing land and water resources, as well as supporting decision-making in food security. In this study, we use NASA supercomputers to couple a 30m high-resolution version of the Decision Support System for Agrotechnology Transfer (DSSAT) spatial crop model into the NASA Land Information System (LIS). The goal of this coupling is to improve the accuracy of the LIS model's simulations of agricultural productivity and water use by integrating a detailed crop growth and development model. The coupling process involves including DSSAT as a sub-model in LIS, allowing for the exchange of input and output data between the two models, and integrating satellite crop phenology information for data assimilation. The coupled model was then tested for maize and soybean crops over a period of two decades in Iowa, and the results were compared to those of the standalone LIS model. The coupled model demonstrated improved accuracy in predicting crop yields, soil moisture, and evapotranspiration. Initial comparisons also underscore continuing gaps in high-quality management and cultivar information needed to configure this system. This high-performance computational setup also identifies several DSSAT model development opportunities that would set the stage for improved assimilation of remote sensing data.
Shichao Chen	Spatial and temporal variability in global irrigation	Irrigation is the single largest component of human freshwater use and helps maintain 40% of food production globally, in water-scarce regions to even higher degrees. It is a common hypothesis that irrigation water requirements (IWR) will increase under climate change, but process-based simulations at global level across major crops are very scarce and it remains unclear to what degree unabated climate change effects water requirements in agriculture. A climate-driven increase in irrigation water requirement would pose additional pressures on water and food security. While higher temperatures and changes in precipitation patterns will lead to higher

	water demand under climate change	water demands to avoid water stress in various world regions, two climate change-related crop growth processes can offset these increases. Moderate warming leads to hasted phenological development, leading to shorter crop growing seasons length and thus reduced total water requirements. Moreover, elevated atmospheric CO2 concentrations can increase the water-use efficiency of various crops, leading to lower irrigation requirements. Here we use latest results from AgMIP's Global Gridded Crop Modeling Initiative to evaluate multi-model ensemble responses to future irrigation water requirements for the major crops maize, wheat, soybean, and rice. Identifying trends in IWR in different regions can guide decision-making for water usage and adaptation planning.
Yi Yao	The irrigation impact model intercomparison project (IRRMIP)	Irrigated agriculture, which covers only ~20% of the world's cropland, plays a crucial role in ensuring food security by contributing ~40% of the global food production. The use of water from rivers, lakes, or reservoirs by farmers for irrigating fields accounts for about 90% of the world's freshwater consumption. This has resulted in substantial environmental changes at both global and regional scales. The extent of irrigation experienced a substantial increase during the 20th century, from less than 100 mha before 1950 to about 300 mha around the year 2000. To advance the scientific understanding of the irrigation-expansion-induced impacts during the last century, we launched a model-intercomparison project (MIP), through which we intend to discover its effects on different sectors, i.e. water, climate, and agriculture, with Earth system models. In the protocol, two experiments are designed, i) simulation with transient irrigation extent and ii) simulation with the irrigation extent fixed at the level of the year 1901. For every experiment, three ensemble members are required to reduce the uncertainty. Currently, the analysis of outputs will be focused on climate extremes, the water cycle, vegetation-carbon interactions and some social implications. In the next phase of IRRMIP, we plan to combine the Earth system model community with both the hydrological model and crop model communities.

Paper Presentation Session 13A: Modeling Mitigation and Adaptation

Lead Author	***Title***	***Abstract***
Gerald (Jerry) Nelson	The limits to adaptation in agriculture: Physics, the chemistry of biology, and human behavior	Climate change impacts on food systems are already well documented and expected to get substantially worse as GHG concentrations climb and increase warming. Food production is a complex system of chemical interactions that are mediated by temperature. Human interventions can change the nature of these interactions (plant and animal breeding), alter the locations at which food is produced, change the inputs into food production (e.g., provide more shade and other forms of cooling, switch from manual labor to mechanization) and alter demands for agricultural products (e.g., promote dietary changes). A series of papers have been produced for a special issue of Global Change Biology over the past two years using the CMIP6 data to look at aspects of the adaptation options as well as the limits to adaptation in different parts of the food system (annual and perennial crops, farmed and wild caught marine fish production, livestock, impacts on humans productivity in agricultural work, and elements of the role of policy in facilitating or hindering this adaptation). This paper provides an overview of key results from this series of papers, providing the most up-to-date and comprehensive view of the status of climate change impacts on food systems available.
Huey-Lin Lee *(Virtual)*	Spatial reallocation helps to reduce methane emissions from	In most Asian countries, rice is highly regarded as a symbolic staple crop of food security. The governments tend to make significant policy efforts, such as producer support, rice stock maintenance and price stabilization, to secure self-sufficiency in this important staple crop. However, rice cultivation is rather intensive in CH4 emissions. To mitigate climate change in the next few decades, countries are urged to take action towards the "Net-Zero Emissions" target. The CH4-intensive rice sector is certainly in the spotlight. Relocation of the cultivated areas could help the country cut rice CH4 emissions without slashing rice production. In this study, we applied the concept of mathematic programming to explore the CH4 mitigation potential of area relocation in rice cultivation. We

	paddy rice cultivation.	conducted an ex post analysis for the 2017 crop by setting up a relocation model for rice cultivation in Taiwan, in which national CH4 emissions from rice paddies are minimized, with the aggregate rice output unaffected. Key parameters that determine the CH4-minimizing relocation of rice cultivation areas include per-hectare output and per-hectare CH4 emissions. We first measured per-hectare CH4 emissions of both spring and summer rice crops at 16 sites of rice paddies located across 8 counties in Taiwan, where crop management varies to local weather conditions and soil characteristics. The per-hectare CH4 emissions measurement information is next coupled with the county-specific per-hectare rice yield, as surveyed by the agriculture ministry. Based on the county-specific parameters of CH4 emissions per tonne of rice output at the two cropping seasons, we relocated rice cultivation areas in the year 2017 among the two cropping seasons in the 18 counties of Taiwan. This CH4-minimizing relocation would be able to cut rice CH4 emissions by 1948.98 kilo-tonnes CO2 equivalent, which is a 17.38% reduction from the 2017 emissions of 11,212.24 kilo-tonnes CO2 equivalent. This rice CH4 abatement potential through relocation of cultivation areas is around 9% of the carbon sequestered by Taiwan's 2,160,898 hectares of forest (21,961.27 kilo-tonnes CO2-eq in 2017). Our results indicate that area relocation of rice cultivation is a cost-effective way to cut greenhouse gases emissions. Our study also offers policy insights in the pursuit of net-zero emissions particularly for Asian countries, where rice cultivation is both economically and politically indispensable.
Mike Rivington	Assessing risks and opportunities for land use transformations to achieve multiple social and ecological benefits considering climate change impacts	The wide range of potential site-specific and national-scale climate change impacts on people and nature presents challenges on how to assess risks and opportunities and provide information that enables practitioners to best respond, adapt and plan strategically. This becomes a greater challenge when we consider the need for integrated policy coherence for strategic spatial and infrastructure planning for land use transformations to achieve multiple objectives from land for economic viability, net zero emissions and food and nutrition security whilst enhancing Natural Capital to ensure delivery of ecosystem services. We present a combination of approaches to address biophysical and socio-ecological challenges. A key initial step to resolve these complex and contested issues is to better understand what climate change means in terms of impacts on biophysical properties that influence land capability for multiple uses and capacity for alternative uses. We present a range of integrated high spatial and temporal resolution research approaches that provide an improved understanding of risks and opportunities: the Land Capability research platform; agrometeorological indicators; crop and ecosystem modelling; and impacts assessments on Natural Capital. These are applied at a high spatial resolution (1km or finer unique soil-climate combinations) in Scotland. These tools utilise high resolution observed and future climate projection data to map changes and impacts to explore options for land use transformations. Outputs include time series animations of maps and spatial analyses providing an improved understanding of how climate change will affect land uses, ecological process and use of Natural Capital's potential for Nature Based Solutions for climate mitigation. A further dimension considers the issues of policy coherence in achieving multiple objectives for land use allowing for potential climate impacts. This requires generating a holistic understanding across systems, as these challenges are wicked problems, rather than simplifying or narrowing analyses to make them more tractable, which means grappling with the complexity, uncertainty and trade-offs inherent in large scale, closely coupled, social-ecological systems functioning at national and international scales. This aspect utilisers Quantitative Story Telling (QST) based research conducted through co-construction with national or regional policy actors to define the scope of analysis and interpretation of the outcomes. We use the Shared Socio-economic Pathways (SSP1 and SSP3) narratives adapted to the UK and Scotland levels. This approach enables us as researchers to develop the 'science of foresight' to better inform decision making (at specific locations) and policy formulation to improve the resilience of land-based planning and management.
Mohammad Ibrahim Khalil	Using Whole Farm Modelling to Inform Land Use Planning for Greenhouse Gas Emissions	The agriculture sector contributes approximately 12% of global greenhouse gas (GHG) emissions, although the specific amount at regional or farm levels depends on soil, climate, and management practices. Mitigation approaches associated with alternative land use and management practices are constrained by limited information on activity data and the accurate quantification of GHG emissions/removals, and nutrient losses at a farm/landscape level. Given the continuing uncertainties associated with labour-intensive field measurements and monitoring, modelling is one of the best approaches to address these challenges. Most of the existing whole farm/landscape models have limitations in the methodologies that are required for a systems-based quantification of GHG emissions and nutrient losses, covering extensive areas and/or long-time scales. To explore this further, we tested the Whole Farm Canadian

	Mitigation and Offsetting	Model 'HOLOS' on a 45-ha farm consisting of 2/3 pasture and 1/3 silage with 176 livestock units. The model estimated the overall GHG balance/budget at a farm scale and found that the response of GHG emissions to soil variables depended on the ratio functions used. The primary drivers of GHG emissions were N fertilizer and temperature, and a 30% reduction in these variables decreased the total on-farm GHG emissions by 9% and 18%, respectively. The majority of the 865 Mg CO2-equivalent emissions came from enteric-CH4 (51%), direct-N2O emissions (22%), and manure-CH4 (17%). We also assessed different land use combinations and found that a reduction in dairy cattle by 10-20% decreased emissions by 10-20%. When combined with silage production, the land use that showed the highest carbon sink, the emissions decreased by 86-90%. Arable land with or without forestry also showed lower emissions compared to pasture or pasture and silage with 100% dairy cattle (837-845 Mg CO2-equivalent). These results suggest that shifting from a single land use to a mixed farming system. consisting of arable, pasture, silage, and forestry has the potential for reducing on-farm GHG emissions. However, to achieve carbon neutrality, a reduction in livestock and inorganic fertilizers application combined with more afforestation, would be necessary. This research was conducted under the EU-ERA-Net ReLIVE project, which was supported by the partners of the Joint Call of the Cofund ERA-Nets SusCrop (Grant N° 771134), FACCE ERA-GAS (Grant N° 696356), ICT-AGRI-FOOD (Grant N° 862665) and SusAn (Grant N° 696231) and by the EU Commission Recovery and Resilience Facility under the Science Foundation Ireland (SFI) Future Digital Challenge Grant Number 22/NCF/FD/10947.
Shelby C. McClelland	Climate 'penalty' on the efficacy of cropland soil mitigation strategies	Improved soil management can reduce emissions of carbon dioxide (CO2) and nitrous oxide (N2O) to the atmosphere. The IPCC estimates that adoption of agricultural soil mitigation measures could reduce more than 3 Gt CO2-eq yr-1 by 2030. These estimates do not account for impacts of climate change (CC) on the efficacy of mitigation. There is mounting evidence for a positive feedback between cropland soil biogeochemical cycles and CC. We examined this possible climate 'penalty' by quantifying greenhouse gas (GHG) emissions from adopting soil mitigation options at the global scale in croplands. Cropland carbon and nitrogen dynamics were simulated at 0.5° resolution with DayCent under three climates: no climate change, SSP1-2.6, and SSP3-7.0. We modeled five soil mitigation scenarios holding land use and nitrogen inputs constant from 2016-2100: typical management, residue retention, no-tillage, and cover cropping (grass, legume). When not accounting for CC, no-tillage was the only mitigation scenario at the global-scale that led to annual soil organic carbon sequestration across the simulation period; all other mitigation scenarios reduced CO2 emissions but did not result in net CO2 uptake relative to the typical management scenario baseline. This dynamic varied considerably across climate regions and cropping systems. However, when soil mitigation scenarios were simulated together with CC, we observed a climate 'penalty' for all mitigation scenarios with some scenarios leading to higher annual soil CO2 emissions than baseline (i.e., grass cover crop, residue retention). At mid-century, we observed reduced soil CO2 emissions for legume cover cropping (~ 0.01 Mg CO2-eq ha-1 yr-1) and no-tillage (~ 0.20 Mg CO2-eq ha-1 yr-1), but by end-of-century annual soil CO2 emissions were higher by upwards of 0.02 Mg CO2-eq ha-1 yr-1 (i.e., 28% relative change). Annual global soil N2O emissions - almost twice as high as CO2 emissions - increased as much as 30% under the scenarios relative to the baseline, but were driven more by practices rather than CC except for no-tillage. Combined annual soil GHG emissions were higher than baseline at mid- and end-of-century, and only no-tillage reduced, but still did not offset GHG emissions. These results suggest: (1) the carbon sequestration potential for soils is not only lowered when CC is accounted for, (2) but mitigation practices increased soil N2O emissions and, thus, positive annual soil GHG emissions. Given CC, improved soils management should be viewed as an opportunity for GHG emissions reductions rather than GHG offsetting.

Paper Presentation Session 13B: Modeling Mitigation and Adaptation		
Lead Author	***Title***	***Abstract***
Florian Zabel	Modeling global integrative land-use adaptation	The consideration of human adaptation to climate change in global agriculture is challenging, due to the manifold opportunities for action at different scales. Crop models are able to represent management adaptation measures on the field, such as shifting sowing dates, planting different crops and/or switching to more adapted varieties. Besides field measures, the agricultural system offers many additional opportunities for adaptation along the supply chain, such as global trade patterns and land-use change. A major question in this context is by how much land-use change could contribute to agricultural adaptation to mitigate climate change related impacts. Here we investigate adaptation potentials of land-use change by using the integrative assessment approach iLANCE (integrative Land Allocation Sequencer). It links the global crop model PROMET with the CGE model DART-Bio and thus allows for optimizing land-use patterns at regional scale to maximize profitability based on global agricultural markets and local environmental conditions. Thus, feedbacks on trade patterns, prices and agricultural productivity are assessed and discussed.
Lorenzo Villani *(Virtual)*	Hydrologic and agricultural impacts of climate change and management practices in a Mediterranean catchment	Crop-growth models have been largely used to assess climate change impacts on agriculture and the effectiveness of agronomic adaptation strategies, focusing mainly on crop yields but also on other indicators such as water footprint. Likewise, many studies evaluated the impacts of climate change on the water cycle. However, the effects of adaptation strategies on water balance components at the catchment scale have been mostly neglected. With this study, we aim to conduct a comprehensive assessment of the climate change adaptation capacity of agricultural systems in a catchment in Central Italy. We estimate how adaptation strategies will impact crop yield, water footprint and some water balance components, such as evaporation and soil moisture, comparing the changes with the ones caused by climate change. We calibrate and validate the SWAT+ agro-hydrological model of the Ombrone catchment for crop yields of durum wheat, sunflower and maize. The impacts of climate change are then assessed by forcing the model with five bias-corrected climate models. Afterwards, six agronomic adaptation strategies are simulated, individually and in combinations, and their effects on crop yield, water footprint and water balance components are quantified. Results show unclear and negative impacts on crop yields under RCPs 4.5 and 8.5, respectively, while water footprints have consistent opposite trends. The adaptive capacity of agricultural systems in the Ombrone catchment is high, even more when combinations of adaptation strategies are considered. For the three crops considered, the most effective strategy considering crop yield and water footprint is the use of longer crop cycle varieties. For wheat, earlier sowing is also beneficial, while in specific climate scenarios supplemental irrigation and cover crops are effective for wheat and sunflower. The impacts of adaptation strategies on water balance components at the catchment scale are generally low. Instead, considering only cropland and not the whole catchment, the effects are considerable. We conclude that management changes can have significant and non-negligible impacts on some water balance components in agricultural catchments, sometimes higher than those caused by climate change. Future assessment of adaptation strategies should not be limited to considering only crop yield and water footprint, but they should be as integrated and comprehensive as possible and evaluate also the impacts at the catchment scale.
Sonali Shukla McDermid	Co-benefits and tradeoffs of agricultural mitigation and adaptation in rice based cropping systems	There is rising interest in reducing agricultural GHG emissions while simultaneously facilitating agricultural systems' adaptation to climate change. Much of the research on combined agricultural mitigation and adaptation centers on managing soil carbon and nutrient cycling processes, and for rice-based farming systems in particular, water management. We present preliminary results from a recently launched AgMIP effort - Mitigation and Adaptation Co-Benefits in Agriculture (MAC-B) - to evaluate agricultural soil-water-crop interactions and discuss implications for climate mitigation and/or adaptation. MAC-B projects leverage the AgMIP integrated assessment protocols to link climate, crop and agricultural economic models with soil models that also resolve GHG fluxes and soil carbon dynamics for regional-scale mitigation and adaptation assessments, inclusive of socioeconomic trade-offs and co-benefits. We present preliminary results from this newly-adapted MAC-B modeling framework that focus on rice-based cropping systems in Bangladesh, Vietnam, and India. These results suggest that specific combinations of management options, inclusive of alternate

		wetting and drying and at some sites earlier transplanting and altered nutrient management, can provide mitigation and adaptation benefits under current and future climate change. Furthermore, there are a host of important co-benefits, trade-offs and uncertainties that must be considered in factor productivity, as well as between environmental and socioeconomic outcomes. We will review these in the context of our current regions of focus, and then zoom out to consider ways the AgMIP MAC-B approaches may be applied to other cropping systems and areas.
Sotirios Archontoulis	Predicting the Inputs	Crop model predictions of future grain yields come with uncertainties regarding future climate scenarios and assumptions regarding the input cultivar parameter values and management practices. In most cases, cultivar parameters and management practices are held constant. Here we attempt to address this deficiency. We first synthesize experimental findings from a comprehensive Genotype x Management x Environment study in which we collected 50 plant traits from maize hybrids released from 1980 to 2020. These datasets together with literature provided a 40-year temporal baseline in plant traits which was extrapolated into future to develop cultivar parameter values. Similarly, we sourced datasets on the optimum N-fertilizer for maize and plant density and developed future scenarios for these inputs. Finally, we run APSIM maize using the pSIMS framework for Iowa, Illinois, and Indiana and estimate future crop yields under a range of GxExM scenarios. The results will be presented and discussed at the meeting (work in progress).
Vellingiri Geethalakshmi	Simulating climate-smart rice production system in south India: DSSAT model improvement	A study was undertaken to develop a modified CERES-Rice model for simulating the growth and yield of rice under System of Rice Intensification (SRI). The data were collected from the field experiments conducted at Tamil Nadu agricultural university, Coimbatore, India during summer and samba season to assess the effect of SRI practices on the growth and yield of rice and improve the CERES-Rice model. The CERES-Rice model was modified to incorporate the effects of SRI practices into the existing model and the performance of the modified-model was evaluated against the experimental data. In the improved CERES-Rice model, a new genetic coefficient named TISRI was added as user input in the cultivar file and used to calibrate the tillering behaviour in the model for SRI. Cono weeding was added using tillage operations module and necessary additions were made in the root growth module to simulate increased root growth for SRI. The cono-weeding effect was implemented for seven days starting from the third day after the cono-weeding operation. Radiation Use Efficiency (RUE) assumption was calibrated for SRI for simulating increased carbohydrate assimilation and increased growth. The model's grain growth rate factor was determined to be low for SRI and was changed to improve simulation accuracy. The factor is inversely proportional to the rate of grain filling. A master switch named "ISSRI" was added to control all the modifications. The improved model showed good accuracy with a percent deviation of 6.8 percent from the observed yield of SRI treatments. The improved model (CERES-SRI) was found to be well-suited for simulating growth and yield of rice under SRI. The improved model could be used to study the impacts of various management operations and climate on rice growth and yield under SRI. Further improvements by modifying the driving processes will make this model more efficient in simulating SRI in varied climates and different management practices.
Wei Ren	Quantifying Biogeochemical Footprints of Conservation Tillage at Multiple Scales: Perspectives from Climate-Smart Agriculture	Conservation tillage has been considered a climate-smart agricultural (CSA) practice that aims to improve food security and enhance agroecosystem resilience to climate change. However, its benefits for crop yield, soil health, and greenhouse gas emission reductions vary significantly among studies, depending on many factors, such as soil type, climate conditions, and other management practices. Our meta-analysis results show that no-tillage (NT) can reduce CO2 and CH4 emissions but increase N2O emissions. The yield benefit of NT is more pronounced in dry climate conditions than in dry climate conditions. Then we applied an improved agroecosystem model to investigate NT impacts at multiple scales. The model results at a long-term site suggest that NT led to an increase in SOC mainly through reducing CO2 emissions compared to conventional tillage; however, NT alone is insufficient to benefit soil C sequestration under climate change. The state-level simulations show NT can reduce CO2 and N2O emissions in Kentucky corn and soybean cropping systems. Our modeling results at the Ohio River Basin indicate that NT can enhance crop water productivity at the basin scale due to the reduction in evaporation. However, there is the potential for an increase in subsurface drainage under NT. Our findings provide insights into how conservation tillage can enhance production stability and support climate change mitigation. We, therefore, call for further efforts that consider specific environmental and management conditions to identify suitable CSA practices at local and regional scales.

Paper Presentation Session 14: Machine Learning for Agricultural Applications		
Lead Author	***Title***	***Abstract***
Andres Castellano	Machine learning emulators and empirical models combining climate and global crop models for seasonal agricultural production	We present results from several connected efforts to apply machine learning methods to estimates of seasonal agricultural production anomalies around the world. First, we explore a selection of tree based algorithms such as the Extreme Gradient Boosting (XGBoost) algorithm to fit seasonal-oriented emulators that mimic global crop models participating in the AgMIP Global Gridded Crop Model Intercomparison (GGCMI). These emulators use 8 climate variables split across 5 sub-seasonal representations of the growing season for each ½ degree grid cell around the world for maize, wheat, rice and soybeans. Emulators are useful for estimating conditions that have not already been simulated by GGCMI (e.g., in a seasonal prediction model). Once an appropriate emulator had been trained, we used an interpretability protocol known as SHAP based on game theory. The SHAP protocol allowed us to explore the importance of individual climate variables in emulating crop model simulations and also to diagnose model differences and capabilities. For example, emulators of the pDSSAT maize model tend to be more reliant on mean temperatures than the LPJmL model, and few models have strong responses to cold extremes. Areas where simple emulators do not perform well also point us toward regions and systems likely to have compound or sequential risks. Second, we use a similar tree based approach to fit a machine learning model for national production data for the top 20 producing countries according to the United Nations Food and Agricultural Organization (FAO). Models select a subset of 5 predictor features from climate observations (8 metrics x 5 sub-seasonal periods) and the GGCM models, resulting in skillful models for many (but not all) top producing-countries. The high use of GGCM outputs as a primary feature underscores their utility, and the broader patterns of climate and crop model features selected indicate regions and systems that are better or worse simulated by the GGCMs. For example, information on excessive rainfall (flooding) and cold extreme (frost) predictors are often combined with GGCM output predictors to provide sensitivity that models may underrepresent.
Guiling Wang	Deep Learning Models for Crop Yield Prediction and Comparison with a Process-Based Model	Accurate prediction of crop response to climate variability and change is critical for short-term management and long-term adaptation planning purposes. Process-based models of crop yield such as DSSAT are subject to uncertainties related to a large number of variety-specific physiological parameters at the spatial scale consistent with model applications. Machine learning offers an alternative approach to accelerating crop yield modeling and prediction, but suffers from performance drop when applied to an extreme scenario that significantly differs from the training climate. In this study, using maize as an example, we trained and tested multiple machine learning (ML) models to predict crop yield based on meteorological variables and soil properties using the leaving-one-year-out approach, and compared their performance with DSSAT performance. Among the traditional ML approaches tested (including Random Forest, Cross Gradient Boosting, and multiple variants of Long Short-Term Memory (LSTM)), our proposed LSTM with attention (LSTM_att) performs the best, explaining 73% of the spatiotemporal variance of the observed maize yield in the Corn Belt; in contrast, DSSAT explains 16%. The magnitude of yield prediction errors in LSTM_att is about one-third of that in DSSAT. When applied to the extreme drought year 2012 that has no counterpart in the training data, both the LSTM_att and DSSAT performance drop slightly, but LSTM_att still shows advantage over DSSAT. In addition to traditional ML models, we also tested multiple variants of Transformer-based models. The vanilla version of Transformer does not perform as well as LSTM_att; the version with the newly proposed Customized Positional Encoding with an additional layer for attention (CPE_att) outperforms LSTM_att, although the improvement is relatively minor. Interestingly, the ML model skills in Ethiopia are much lower than in the U.S. Corn Belt, likely due to both the inferior data quality (for crop yield and meteorological forcing) and greater uncertainties in human factors such as seed quality, resource input, and planting time (that influence crop yield but are not included in the feature data). In regions with sufficient amount of good quality data to train the ML models, both LSTM_att and the CPE_att are suitable tools for predicting crop yield, with great potential for application to yield projections in future climates.

Jingye Han	Knowledge-guided machine learning for modeling crop growth dynamics	Even though process-based crop models are widely used to simulate crop growth, the challenge of parameter calibration and model improvement makes it difficult to use them in practice. Data-driven methods have shown superior performance in various disciplines, but the application of purely data-driven methods is restricted by the lack of data. To address these issues, we propose a family of knowledge-guided machine learning (KGML) models to learn crop growth patterns from both process-based model and real world. The models could simulate the time-series development stage, plant area index, biomass of leaf/stem/storage organ, above-ground biomass, and yield. Three model architectures were designed with/without knowledge of crop growth to investigate the effect of knowledge-guided structure (KGS). A synthetic dataset generated by a process-based model was used to pre-train a machine learning model to implement the knowledge-guided initialization (KGI). A real dataset from a two-year experiment of rice was then used to finetune and evaluate the KGML model. Results showed that the KGML model can perform equally or better than the well-calibrated process-based model. Furthermore, the discussion about KGI and KGS indicated: 1) KGI enabled the model to learn the correct and long dependence between inputs and outputs; 2) the simulated time series crop states were more in line with the real crop growth law by using KGI; 3) KGS improved the overall model performance but may cause a decrease in the simulation accuracy of part variables (e.g., plant index, leaf biomass); 4) removing/separating non-causal inputs variables could improve simulation accuracy for the corresponding variables. In addition, the experiment also provided suggestions about generating a synthetic dataset: 1) identifying effective driving variables could help the model better learn the relationship between input and output; 2) calibration of the processed-based model was necessary before generating a synthetic dataset because it could improve the accuracy of KGML model. There are some limitations in this study: 1) the interpretability about how the model improved by KGS was discussed insufficiently; 2) the KGS was implemented manually (by designing structure according to the knowledge of process-based model) but not automatically established; 3) fundamental principles (e.g., mass conservation) are not embedded in the structure or loss function. Therefore, a better structure embedded with fundamental principles and interpretation should also be further investigated in the future.
Lily-belle Sweet	Using interpretable machine learning to identify meteorological drivers of crop yield failure	Agricultural yields are vulnerable to extreme weather events, such as droughts, floods or heatwaves, but the relationships between growing-season climate conditions and harvested yields are complex and nonlinear. Consequently, extreme crop yield failure may be caused by a combination of weather events that would not individually be considered extreme. For example, co-occurring hot and dry weather conditions can impact crop yields simultaneously. A more complex temporally-compounding example is the phenomenon of ‘false spring’, which causes damage to crops when all of three conditions are met: abnormally warm temperatures in early spring, sufficient above-freezing days for the plant to enter a vulnerable stage of development, and finally a subsequent frost. Machine learning techniques are capable of learning such nonlinear relationships from data, and such models have been used in recent studies to explore the influence of monthly- or seasonally-aggregated weather data and/or hand-picked extreme climate indicators on crop yields. However, as yields may be impacted by climatic events on different temporal scales, it is desirable to identify machine learning methods that are able to extract relevant features from higher-resolution time-series data. We aim to use interpretable machine learning to identify meteorological drivers of yield failure from simulated crop model output data, compare the identified drivers between crop models, and explore the interactions learned by the model between the selected meteorological drivers. Ultimately, our goal is to present a robust method for the identification of compound meteorological drivers of crop yield failure that is capable of ingesting data with high temporal resolution.
Oumnia Ennaji	Application of Machine learning in crop yield prediction	Developing effective agricultural systems and policies to ensure food security depends on accurately predicting crop yields. Recently, many methods have emerged to address the complexity of crop yield prediction. These include the use of machine learning methods to identify the factors of spatial and temporal yield variability. Integrating these methods with field data from multiple sources can contribute to a deeper understanding of soil-level dynamics and nutrient management. In this study, indicators such as SOM, nitrogen input, phosphorus input, temperature, and precipitation were used to develop a machine learning approach (Extreme Gradient Boosting, XGBoost) for predicting corn yields. The main objectives were to identify the optimal features that affect yield production, the accuracy of corn yield prediction using machine learning, and to determine the spatial robustness and adaptability of the proposed

		framework. Our approach included feature development and selection, training and hyper-tuning of the XGBoost model, and visualization of the results. Model performance was evaluated on a dataset with over 1700 pairs of corn yield data. The study found that XGBOOST provided more accurate estimates (RMSE= 0.38, R2=0.85, MAE =0.27). The study also found that weather improved the accuracy of yield estimates. Finally, combining machine learning algorithms with data from multiple sources demonstrated their ability to handle spatial heterogeneity. Overall, this study provides valuable insights into the use of machine learning to guide the management of agricultural systems and provides a reliable reference for future research projects.

Paper Presentation Session 15: Modeling Soils and Carbon

Lead Author	***Title***	***Abstract***
Elnaz Ebrahimi	Modeling maize yield affected by underground Pipeline installation and tillage practices	Subsoil compaction is one of the major concerns for maize producers following the installation of underground pipelines in Right-of-Way (ROW) areas. This study aimed to simulate maize yield on highly disturbed (subsurface pipeline installation) and adjacent undisturbed (control) land areas. We used the Agricultural Production Systems sIMulator (APSIM) to assess the impact of soil disturbance on maize yield in conventional and no-tillage systems. Field observations and simulation results depicted the negative impacts on soil physical, chemical, and hydrological properties. Yield (26%) and aboveground biomass (23%) losses were observed in the pipeline disturbed area, where the soil profile had lower soil water holding capacity than the undisturbed soil. APSIM was parameterized using two years (2019 and 2020) of in-season crop growth observations. Simulations of yield production were further evaluated against independent data from 2017-2019. Maize water use efficiency decreased in response to disturbance and tillage practices. To minimize yield loss, it is important to concurrently evaluate maize production in the highly disturbed area.
Margarita Garcia-Vila *(Virtual)*	Representing waterlogging and its effects in crop models: Where are we now and where do we need to go?	Waterlogging represents a significant constraint to global cereal production and is expected to increase in the next years. Compared to drought stress, the impacts of waterlogging on crop production have received less scientific attention, despite comparable yield losses. Crop simulation models (CSMs), built based on experimental evidence, play an essential role in assessing impacts of waterlogging. However, their accuracy is reduced due to our limited understanding on the issue and a lack of adequate and representative experimental data. We reviewed the recent experimental research on waterlogging impacts on wheat and identified the need for further research into the effects on phenology, root development, and water and nutrient uptake, as well as their interactions with atmospheric CO2 concentration, temperature and other biotic/abiotic stresses, particularly under undisturbed field conditions with continuous monitoring of soil moisture. To identify pathways for improving CSMs' ability to capture waterlogging effects, we conducted an in-depth survey to characterize how current wheat CSMs (19 CSMs participated) simulate waterlogging conditions and their impacts. The proper generation of waterlogging conditions is the first difficulty faced by CSMs, with only 37% of them covering the water table dynamics, being a frequent cause of waterlogging. Other processes leading to waterlogging are also covered to a limited extent by the surveyed CSMs, such as subsurface water lateral flow (considered by 28% of CSMs), water ponding (53%), melting (53%) and thawing (16%). Regarding the trigger of waterlogging stress, six of the CSMs do not respond to a water excess different from that caused by a shallow water table, and most (56%) do not consider a delay in the plant response to excess water induced water stress, as reported in many studies. The complexity and the lack of experimental data on the waterlogging effects are especially reflected in the fact that the majority of the CSMs do not simulate the impacts on soil, specifically on the nitrogen cycle and movement, as well as the salt movement and CH4 emissions, or completely neglect the soil compactability. The crop processes and/or variables directly and indirectly affected by waterlogging vary broadly among CSMs, with crop transpiration reduction being the main driver. This wide variety in the CSM approaches for simulating waterlogging conditions and resulting plant stress responses calls for

		future studies focussing on model intercomparison to help identify the key improvements in waterlogging algorithms and experimental studies to support effective model improvements.
Mohammad Mamunur Rasid Sarker *(Virtual)*	Assessing the long-term impact of conservation agriculture on rice-maize systems in Bangladesh under climate change using the APSIM model	Conservation Agriculture (CA) has been researched and promoted across the globe as a way of maintaining high soil organic carbon (SOC) and high yields simultaneously. However, there has to date been no research on the efficacy of CA practices for coping with the effects of climate change on rice-maize systems in Bangladesh. In the present paper, a cropping system modelling technique is used to examine the potential of CA to adapt rice-maize systems in Bangladesh to climate change. Agricultural Production Systems simulator (APSIM) was driven by 29 Global Climate Models (GCMs) to forecast the effect of tillage on rice-maize productivity and soil C-sequestration in conventional tillage (CT) vs. CA systems. The study periods considered were the baseline (1980–2009), mid century (2040-2069) and end century (2070–2099) under two Representative Concentration Pathways (RCPs; RCP4.5 and RCP8.5). Five climate models capture a representative subset of temperature and precipitation changes in the CMIP5 ensemble. CA emerged as more effective than CT in enhancing soil organic carbon and grain yield across all time periods and RCPs, with yields consistently higher under CA conditions. By mid-century, SOC was projected to increase 9 to 14% under RCP4.5 and 8 to 12% under RCP8.5. By end-century, SOC was projected to increase 12 to 17% under RCP4.5 and 9 to 15% under RCP8.5. SOC increases were due to excess organic matter being left on the soil. By mid-century, the rice yield was projected to increase by 10 to 14% under RCP4.5 and by 13 to 17% under RCP8.5. By end-century, the rice yield was projected to increase by 10 to 15% under RCP4.5 scenario, and by 9 to 16% under RCP8.5. Rice yields consistently increased due to CO_2 fertilisation. During mid-century, the maize yield was projected to decrease by 1 to 4% under RCP4.5, and by 1 to 7% under RCP8.5. By end-century, maize yield was projected to decrease by 3 to 5% under RCP4.5 scenario, and by 9 to 16% under RCP8.5. Maize yields decreased due to increased temperatures, leading to a shortened growing season. Without adaptation to climate change, maize yields are projected to decrease, showing the need for further understanding of possible adaptation strategies. These results show that CA has the potential for improving food production and enhancing SOC in the region. Farmers should be given incentives to adopt CA technologies for long-term sustainability that contributes to the achievement of the SDGs.
Prakriti Bista *(Virtual)*	Simulating the Long-term Impact of Cover Crops on Soil organic Carbon on Semi-Arid Southwestern USA	Many cultivated lands, including those in the arid and semi-arid Southwestern USA, now contain less than 50% of soil organic carbon (SOC) compared to their undisturbed natural counterparts. Crop-fallow, a common cropping system in this region, often hinders biomass production and soil organic carbon (SOC) accumulation due to low precipitation and low cropping intensity. Increasing weather variability, decreasing precipitation, and declining water resources have further challenged crop production and led to the rapid transition of croplands from irrigated to limited irrigation or dryland cropping in many areas. Cover cropping can reduce the fallow period, increase residue returned to the soil and increase SOC. This study aimed to calibrate and validate the DayCent ecosystem model for croplands transitioning to limited irrigation and predict long-term soil organic carbon (SOC) changes with cover cropping, a strategy to minimize soil degradation. We estimated SOC sequestration in no-till winter wheat (Triticum aestivum L.)-sorghum (Sorghum bicolor L. Moench)-fallow rotations with and without cover cropping. The cover crops considered were pea (Pisum sativum L.) and oat (Avena sativa L.). DayCent was verified with five years of observations and achieved R^2 values of 0.81 and 0.24 for wheat and sorghum total yield (grain + biomass), respectively. Observed cover crop biomass was highly variable (R^2 = 0.11), but DayCent captured the observed trend and treatment difference. The model predicted that three decades of cover cropping and no-tillage has the potential to sequester ~ 39 % to 43 % more SOC compared to no-tillage fallow alone despite the limited irrigation management in this agroecosystem. Cover cropping could improve soil health and sustainability of limited irrigation cropping systems while maintaining crop production.

Paper Presentation Session 16: New Crop Species Models		
Lead Author	***Title***	***Abstract***
Ashifur Rahman Shawon	Assessing the Climate Change Impacts on Rye Production in Europe and Canada	Process-based crop models are increasingly important tools for studying genotype × environment × management interactions in agriculture. However, climate change (CC) threatens global food security by creating more frequent and prolonged droughts, high temperatures, and changed precipitation patterns. In response to the challenges posed by CC on food security, crop modelling has emerged as a vital tool for investigating viable adaptation measures. In this study, we adapt the DSSAT-CERES model for rye and utilize it for studying rye production under present and future climatic conditions in important rye-growing regions of the northern hemisphere. Rye has promising potential in temperate regions due to its high resource use efficiency, relatively low input requirements, and adaptability under drought and frost conditions. To adapt CERES for rye, we first calibrated it for wheat and then modified it for rye based on a vast experimental dataset. The data comprised plant variety trial data from multiple sites and years plus data from two experiments, which investigated nitrogen and water availability effects including extensive in-season phenotypic data. The calibration of CERES-wheat exhibited high accuracy in simulating various parameters, with RMSE% of 12.7% for BBCH stages, 24.2% for tiller density, 36.1% for grain density, 17.9% for unit seed weight, and 18.9% for grain yield (N= 61 experiments). The CERES-rye model successfully simulated various parameters with acceptable accuracy. For instance, the model achieved RMSE of 20.2% for BBCH stages, 28.8% for grain density, 11.5% for unit grain weight, and 25.74% for grain yield (N= 194 experiments). We then used climate projection data of two RCPs (4.5 & 8.5) and two climate models (GISS-E2-R-CC and HadGEM2-ES) to analyze the potential effect of CC on future rye production in the selected sites in Austria, Canada, Estonia, Finland, Germany, and Poland. Projected changes in crop yields under different representative concentration pathways (RCPs) were evaluated for selected sites. Results indicated that, by mid-century, RCP4.5 was expected to produce a yield increase ranging from 8% to 48%, while RCP8.5 was projected to have a larger yield increase ranging from 38% to 87%. Similarly, by end-century, RCP4.5 was expected to result in a yield increase ranging from 14% to 60%, while RCP8.5 was projected to produce a yield increase ranging from 43% to 93%. The newly adapted CERES-rye model offers new opportunities to assess rye production potential in various environments, including the evaluation of different crop management strategies and its inclusion in different crop rotations.
Louise Busschaert	FAO crop growth model AquaCrop v7.0 for regional simulations: new advances and opportunities	Version 7 of the AquaCrop crop model has been released and the code of the official version has been made open-source for the first time. AquaCrop v7.0 now includes (1) the standard graphical user interface for single field applications, (2) Linux, Windows, and MacOS stand-alone executables for plugin into regional or climate simulations, and (3) the open-source code on GitHub (https://www.fao.org/aquacrop/en/). Additionally, AquaCrop v7.0 has been integrated as the first crop model into NASA's Land Information System (LIS) to support regional modeling and satellite data assimilation (DA). These tools offer new opportunities for various applications from the field to the regional scale. This presentation outlines recent work using regional AquaCrop modeling. First, regional AquaCrop simulations have been evaluated over Europe in terms of soil moisture by using satellite retrievals from the NASA Soil Moisture Active Passive (SMAP), ESA Soil Moisture Ocean Salinity (SMOS), and Sentinel-1 missions. In addition, the biomass has been evaluated with the optical-derived vegetation product of Dry Matter Productivity from the Copernicus Global Service, and irrigation estimates have been evaluated against sparse in situ data. At different resolutions (0.01° and 0.50°) and with different meteorological forcings, the regional simulations showed a reasonable performance. Next, the simulations were improved by assimilating different satellite products. Two DA systems have been setup using a one-dimensional ensemble Kalman filter. The SMAP Level-2 surface soil moisture retrieval product was assimilated on a 0.25° resolution grid over Europe to explore the potential of soil moisture updating and its impact on biomass estimation. In a second DA experiment, soil moisture and vegetation were simultaneously updated by assimilating 1-km Sentinel-1 backscatter observations into the model. Both DA experiments show improvements in the (coarse- and fine-scale) surface soil moisture and an impact on biomass estimates. Finally, regional AquaCrop simulations also offer the opportunity to assess future trends under climate change. We estimated future irrigation water

		requirements over Europe. Under a very high emission scenario (SSP5-8.5), results show that the net irrigation requirement for a general C3 crop during the summer months will increase by 35% on average by the end of the century compared to present-day conditions.
Monique Pires Gravina de Oliveira *(Virtual)*	Hierarchical calibration of a crop growth model of intermediate complexity	In crop models, parameters have a dual role in model structure: to give flexibility to the relationships represented and accommodate uncertainties derived from measurements, as well as to represent behaviors associated with crop species and genetic variability into the same species. There are several examples of studies aiming to improve existing methods to determine parameters' values, from Bayesian and frequentist ones to inverse modeling and hybrid approaches based on post-processing. Additionally, some studies focus not on the statistical methods, but on how the overall procedure relates to plant development and growth and to plants' response to environmental conditions, discussing represented processes' order of adjustment or which variables should be used at each step. Our study's goal was the calibration of one crop growth model of intermediate complexity, named AgS, for maize and soybean. We explored a hierarchical approach that subsets the different sources of data and target variables that would better inform the calibration process. We grouped the parameters, isolating as much as possible each crop process, and sequentially determined their values. Species parameters were selected in five steps: cardinal temperatures for phenological development, followed by maximum gross photosynthesis and optimal temperature ranges for photosynthesis, reference crop evapotranspiration coefficients, and water stress sensitivity effect on canopy and on growth, in this order. We then determined parameters associated with photoassimilate partitioning between different organs for each cultivar. In this first approach, the optimization method chosen was trial and error of hundreds of random samples, which also allowed us to better understand parameters' ranges as well as their sensitivities, by inspecting their effect on the range of models' outcomes. Values for parameters were sampled from a uniform distribution in pre-defined ranges, generating what we called "artificial cultivars". The artificial cultivar with the lowest error metric in the selected dataset for the pre-defined target variables was selected for the following step. Model evaluation used subsets of the datasets ascribed to each step to determine which artificial cultivar led to the lowest error, which allowed for comparison in performance and parameter values. Optimization led to improvement when compared to the manual process and automation made it possible to calibrate a new specie or cultivars in a faster way. For maize, the average RMSE for yield was of 1,040 kg ha-1, and for soybean, of 583 kg ha-1, in the calibration set. The manual reference led to 1,615 kg ha-1 and 909 kg ha-1, respectively.
Ruoling Tang	How to develop vegetable versions based on originally-designed-for-cereals models? Take WOFOST-Chili as an example	Most existing crop modelling studies are mainly addressing cereal crops. Chili pepper (Capsicum annuum L.), as one of the most agro-economically important, and nutrient-rich vegetables, received less attention on yield and nutrient-uptake predictions. To improve nutrient use efficiency in open-field chili systems with shallower roots, shorter lifespan, and higher nutrient requirements, we adapted the WOrld FOod STudies (WOFOST) crop growth simulation model for chili pepper (WOFOST-Chili) to support better fertilizer management under various climate and soil conditions. We conducted field experiments with six different fertilizer strategies, including a control treatment without applying any fertilizer (CK) and denitrification fertilizer products (DMPP) in southwestern China from 2019 to 2021. In WOFOST we used DMPP data for potential simulations while CK data for nutrient-limited simulations. In total about 20 parameters relevant to physiological development, dry matter accumulation, photosynthesis, and nutrient uptake were measured and used in model adaptation. Our study shows that it is possible to use WOFOST to simulate chili pepper without changing much from the generic model structure. We provide solutions by adapting user-defined developmental stages to mimic the growth from transplanting to fruiting and subsequently ripeness. Overall, the developed WOFOST-Chili model shows good simulations of chili growth dynamics in response to nitrogen (N) fertilization, both on biomass assimilation (rRMSE = 0.07 for total aboveground yield; rRMSE = 0.06 for fruit dry weight) and nutrient uptake (rRMSE = 0.46 for leaf N amount; rRMSE = 0.29 for fruit N amount). In addition, a sensitivity analysis of around 10 high-impact parameters (crop initial and climatic-susceptible parameters) shows an increased model robustness with wider acceptable intervals covering more observations. Reduced performance on leaf area index (LAI, rRMSE = 0.76) is ascribed to practical measurement limitation. Model validation confirms good predictions under potential simulation while performance under nutrient-limited simulation is weaker. These findings improve our understanding of yield-nutrient interactions of chili pepper, provide insights on expanding originally-designed-for-cereals models to apply to vegetables too. They also call for a

		refined dynamic nutrient simulation flow within soil module to evaluate mitigation effect of expanded fertilizer strategies such as using new fertilizer products (etc., organic fertilizer, denitrification products, and slow-control-release fertilizers), which is the objective of future work. Keywords: Chili pepper, WOFOST, fertilizer response, nutrient uptake, yield, sensitivity analysis
Zhe Zhang	Modeling food-water system in high-resolution convection-permitting regional climate models	To enable the investigation of the complex climate-agriculture-hydrology nexus, we developed a two-way coupled atmosphere and crop modeling system within the Weather Research and Forecasting model (WRF-Crop). We will present this coupled modeling framework, focusing especially on the crop and agriculture management (irrigation and tile drainage) models and evaluation of these agriculture models. To improve our understanding of the food-water-climate system and make effective decisions in agricultural and water management, high-resolution convection-permitting WRF simulations results are used to assess complicated interaction and feedback. We first use the high-resolution, long-term WRF output to drive the uncoupled Noah-MP-Crop model and examine the interannual variability in simulated crop yield with climate variations. Our results demonstrate substantial improvement in simulated crop yield, both in spatial distribution and temporal variability, due to the accurate representation of summer precipitation and temperature in WRF. Next, we use the coupled WRF-Noah-MP-Crop model to study the feedback of crop growth dynamics to temperature and precipitation in the US Corn Belt. The dynamic Noah-MP-Crop model provides a realistic representation of crop growth in leaf area index and turbulent fluxes, resulting in evident responses in precipitation and temperature in summers. Finally, studying the two-way coupling of the food-water system highlights the benefit of convection-permitting modeling and allows us to advance our knowledge in these complex processes under changing climate.

Paper Presentation Session 17: Calibration and Crop Model Improvement		
Lead Author	***Title***	***Abstract***
Balaji Sesha Srikanth Pokuri	Cloud-Hosting of Agricultural Crop Simulator and Optimizer for Calibration and Management Decision Support Systems	Agriculture models have primarily been designed for windows desktop computers. In contrast, the cloud-based tools improve their accessibility across any device with browser support, lowering individual compute requirements, enabling results transparency, and easing collaboration. In this work, we report the first cloud-hosting of a popular agriculture model RZWQM (Root Zone Water Quality Model) on MyGeoHub cyber-infrastructure to benefit the agriculture community by making the tool easily accessible to farmers, researchers, stakeholders, and decision/policy-makers. Agriculture models like RZWQM have hundreds of parameters that make the model sensitive to the soil, hydrological, agrochemical, atmospheric, and genomic properties. Calibrating the model to the farm conditions is quintessential to making meaningful predictions of crop health, crop yield, and environmental impacts. Optimizers for model calibration are also useful in model-predictive decision-making to improve profitability and the environmental impact of farm-management practices. Therefore, in this work, we also built a cloud-based tool for model calibration and optimizing irrigation and fertilization applications for the best crop yield with minimum human intervention, using evolutionary algorithms. Simulations show that our calibration tool finds the best fit more efficiently than the PEST calibration tool shipped with RZWQM. The use of cloud resources helps accelerate search in parameter space by lower resource and skills requirements of end users, job parallelization, and transparency and ease of sharing results with producers, policy-makers, and the research community.
Daniel Wallach	How to calibrate crop models?	Multiple studies have shown that there is large uncertainty in crop model predictions. For given inputs, this uncertainty arises from two sources; uncertainty in model structure (i.e. the model equations) and uncertainty in the parameter values. A recent study has shown that for crop phenology models, if one correctly accounts for parameter uncertainty, then that uncertainty is by far the larger contribution to total uncertainty. This implies that improving parameter values is a major path, perhaps the most important path, to model improvement. The goals of the AgMIP calibration activity are to document current calibration practices, propose improved practices and help modeling teams apply those improved practices. A first series of studies concerned modeling just crop phenology. An original protocol was proposed and tested by 19 modeling teams, which had all previously used their usual calibration approach with the same data. Compared to usual calibration, calibration following the new protocol reduced the variability between modeling teams by 22% and significantly reduced prediction error. Building on that experience, a new protocol for calibration of crop models, using multiple data types, was proposed and tested on artificial data. The protocol addresses three major hurdles of crop model calibration; how to combine results from multiple types of variables, how to decide which parameters to estimate and how to efficiently explore the parameter space. In this talk we will describe the protocol, its evaluation using synthetic data and the next phase of the project, which is to test the protocol on field data for multiple different model structures.
Seyedreza Amiri *(Virtual)*	Optimizing agronomic practices for closing chickpea yield gaps in rainfed agroecosystems	Understanding yield potential, yield gap and the priority of management factors for reducing the yield gap in current rainfed chickpea agroecosystems is essential for meeting future food demand with the limited resources. In this study, the SSM-Legume model was used to simulate chickpea rainfed potential production, rainfed potential production of chickpea with actual sowing date (YRS), plant density (YRD) and nitrogen fertilizer (YRN), practiced by farmers as well as yield gaps due to improper sowing date (YGS), plant density (YGD), nitrogen limitation (YGN), and yield gap due to other limiting and reducing factors (YGO) at 12 chickpea producing locations of Iran. Our results showed that at national scale, the mean total yield gap (YG) was 67%, indicating chickpea grain yield achieved by farmers was only 33% of attainable yields (YA) during the past 3 decades. Furthermore, the YG was 23% higher for the mid-maturity cultivar (ILC482) than for the early maturity cultivar. Nationally, across two cultivars, the most significant share of YG belonged to YGO (44.4%), followed by YGS (37.2%), YGD (9.2%), and YGN (9%). However, the share of each YGO, YGS, YGD, and YGN in YG varied based on region. The highest YG was related to YGO (67%) in all studied regions (except west). Furthermore, the greatest share of YG

		belonged to YGS (75%) in western regions. The mean YGD was lower than 5% in all regions (except in the south and the west).There was a small yield gap due to farmers' lack of starter nitrogen fertilizer, which varied from 1% in the south to 15% in the west. . Overall, our results approved that there was the low agronomic efficiency of chickpea cultivation despite resource accessibility in these regions. In other words, the replacement of the early maturity cultivars (Beavanij as check cultivar) with the mid maturity cultivar (ILC482) would increase attainable yield by 20%. However, we can argue that chickpea yield in studied locations is limited mainly by other limiting and reducing factors (YGO) and not the genetics of the current cultivars or sowing date, plant density, and nitrogen.