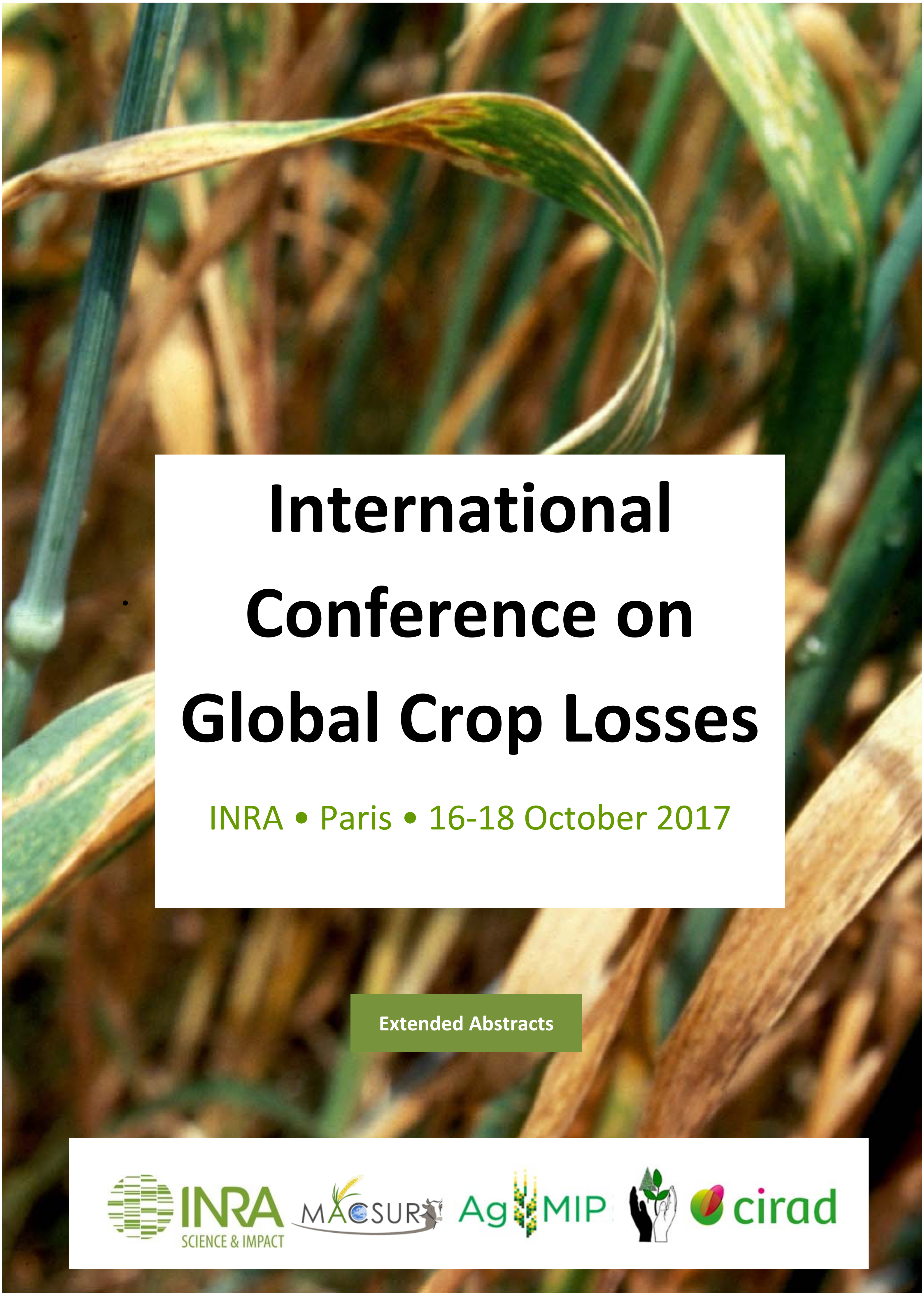

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Extended Abstracts

Impacts of Disease and Pest Crop Losses on Crop Yields and Agrosystem Performances

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The purpose of this paper is to describe the status and the potential of crop simulation models to account for crop yield losses attributed to diseases and various pests. All crop models have ability to predict yield responses to weather, soil characteristics, crop management, and to a limited extent genotypic variation. However, most crop models are generally lacking in ability to account for biotic pest damage effects on yield in farmers' fields, and those pests can cause serious yield losses where control practices are not implemented. Various strategies have been proposed for considering pest effects in crop models, at mechanistic levels by coupling pest models to crop models, or inputting scouted damage into the models, or with post-processing methods where model-simulated yield is reduced by a simple pest damage algorithm. Developing dynamic pest models that couple to crop models, while desirable, is limiting because there are so many different types of pests and the need to create good coupling points. On the other hand, the approach of inputting scouted pest damage in broad categories is more generic, but this works only where someone has already scouted the field and collected information.

There are various coupling points for connecting pest damage to crop models that consider the C and N flow processes and the crop state variables (e.g., leaf area, seed mass, etc.). Boote et al. (1983) defined eight categories for types of pest damage: assimilate sapper, tissue consumer, stand reducer, leaf photosynthesis rate reducer, leaf senescence enhancer, light stealer, water and nutrient stealer, and turgor reducer. For example, assimilate sappers include aphids, nematodes, and pathogens that use assimilate before the plant gets to use it. Other pests such as insect larvae and some pathogens are consumers of tissue, for example feeding on leaves or sending compounds ahead to destroy leaf tissue. Viruses and some pathogens reduce the electron transport capacity of photosynthesis, thus affecting a rate process. Leafspot disease of peanut accelerates leaf senescence/abscission. Weeds are light, water, and nutrient stealers. In addition, some pests can be in multiple categories.

The DSSAT crop models, especially CROPGRO models, have generic pest coupling points, whereby scouted pest damage such as percent leaf area loss or leafspot necrosis can be entered into the model (Batchelor et al., 1993). The pest coupling subroutine interpolates between scouting observation dates and connects to the right process or state variables of the model, such that daily pest damage effects are entered into the crop model. Then the crop model simulates the season, with the reduced leaf area index and/or the reduced leaf rate, thus less assimilate is produced and available for growth of crop and seed tissues. In this respect the crop yield loss is mechanistically simulated, but also with consideration of the weather and soil in the particular season. Model simulation with, and without, the disease input gives the yield loss incurred. This approach has been used with good success over the past 20 years to account for peanut yield losses from leafspot disease or soybean insect defoliation, but with the caveat that scouting data is needed. Examples of the coupling points and outcomes will be presented to show how percent leaf area lost or percent necrosis act at two different model coupling points. Recent work demonstrated how leafspot necrosis (percent necrosis on remaining leaf area) could be input at leaf-level, to reduce single leaf photosynthesis. Single leaf photosynthesis is reduced with increased percent necrosis at leaf level, with beta factor ranging from 3.6 to 4.6 for two different peanut cultivars. This approach has been used several times to predict yield loss from leafspot disease on peanut cultivars under unsprayed and fungicide treated conditions in Ghana, with dis-aggregation of ICRISAT disease score into percent leaf area loss and percent necrosis.

There is future need and on-going work by new groups within the AgMIP crop modeling community that is aimed at coupling simple simulators of various disease pests directly to the crop models, with daily step connection. Direct coupling would improve the feedback effects and communication between the crop model and simple pest models. Such a system would minimize the need for scouting data, and could be used for future climate scenario cases. This approach requires critical research knowledge on infection processes, latent period, lesion expansion, and sporulation for polycyclic diseases, including weather effects on the disease processes and crop genotypic resistance traits to influence the various disease processes. Research on relatively generic pest simulators is needed, and data for model evaluation and improvement are needed. The AgMIP crop modeling community can serve that need, by defining protocols, aggregating data sets on pest damage and crop yield loss, and by promoting development of the pest simulators and their linkage to crop models. To predict region-wide yield and economic losses from different disease and insect pests especially under future climate scenarios, we need generic simple models applicable for many different pests, linked to gridded-type crop models that realistically predict crop growth and yield.

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Overview of approaches to quantify and model disease and pest losses

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Plant diseases and pests affect global crop production in many different ways. A key effect is a reduction of crop yield, but many other impacts need consideration: on the physico-chemical characteristics of produce; on the shelf-life, organoleptic, or appearance of products; and also on the nutritional value of food as a result of toxin accumulation. Recent analysis actually indicates that these impacts affect the multiple components of food security as defined by the United Nations: food availability (primary production, stockpiles), access to food (physical and economic), stability of food supply, as well as the nutritional value and safety of food. These multiple impacts are related to two main elements: first, the entire diversity of all crops in the world is exposed to pests and diseases – whether annual or perennial, or whether staple crops, or much-traded food/feed crops, or again crops with key trade importance. And, second, the biological diversity of crop pathogens and pests is tremendous, including nematodes, arthropods, fungi, oomycetes, bacteria and viruses, as well as many other groups of organisms. Considering the nature of crop losses at a global scale implies looking at a very large Crop x Harmful Organism matrix.

Yet, we wish to ask questions such as: what is the current state of affairs – how much is lost to diseases and pests today? Which are the most important pests and diseases? On which crop? Are the losses they cause worth enhancing disease and pest management? How to assess available, existing, or potential tools for disease and pest management in terms of losses avoided (i.e., of gains from management)? And, starting from the first question of this list: will climate change increase, or decrease, the losses to pests and diseases? Or, will global changes (world population, shifts in diets, trade agreements, technology shifts), and the on-going changes in agroecosystems and their management lead to decreased or increased losses to diseases or pests?

The quick answer to the above first question is: Yes, diseases and pests do cause massive reductions in the performances of global agroecosystems, and much more, if one includes weed infestation. However, while the available data is extraordinarily patchy (across crops and ecosystems, and over time), what is known indicates very large variability, depending on the crop, on the diseases, pests, and weeds considered, and on the environmental contexts of agriculture.

Methodology helps addressing this type of questions because of the size of the Crop x Harmful Organism matrix. But methodology is necessary because these questions need to be handled in a multidisciplinary, international, and networked manner, and therefore, with shared and transparent approaches and tools. Most of the methodology has concerned the quantitative aspect of crop losses, that is to say, yield losses.

First in line is a series of concepts, many of which have been established over several decades: (1) a production situation enables documenting the environmental context (ecological, economic, social) of agriculture; (2) the attainable yield is the performance of the uninjured crop in a production situation; (3) the potential, attainable, and actual crop yield levels enable tracking the yield-determining, yield-limiting, and yield-reducing effects of environmental factors on crop performances; (4) the yield-reducing effects of diseases, pests, and weeds are characterized by their injuries; and (5) the concept of yield loss is operationalized by the difference between the (uninjured) attainable yield and the actual (harvested) yield.

Crop loss research is first experimental. Many trials, where different levels of (disease, pest, weed) injuries are established, including a level where the attainable yield (no injury) can be measured, have been conducted to quantify yield losses. Ways to implement (to vary and manipulate) the levels of injuries must be devised, for instance, by (1) introducing the harmful organism(s) in a crop stand at different dose or crop development stage, or (2) generating differences in levels of injuries through minute genetic differences in the host crop (e.g., isogenic lines), or (3) establishing different levels of (chemical) plant protection. The ability to measure injuries is critical. Methods have been developed to quantify injuries by nematodes, fungi, viruses, or weed, for instance, and on different plant organs or whole plants. The physical sizes of experimental plots, as well as the proper sampling techniques, are also critical in enabling reliable, replicable measurement of yield losses. And a wide array of statistical methods has been developed to analyse crop loss - experimental data.

Another area concerns the representativeness of crop loss data. Most crop loss experiments are conducted under “research station” conditions, and commonly address one or a few yield-reducers. Surveys in farmers’ fields enable upscaling information to the entire agrosystem. First, surveys in farmers’ fields lead to quantification of actual, realistic, levels of injuries. And second, the approach enables defining the existing farmers’ production situations. As a result, surveys in farmers’ fields enable inferences (if not measurements) with respect to attainable yields – the key to the upscaling of crop loss data.

These approaches, experiment- and survey-based, enable addressing present losses to diseases, pests, and weeds, within a set of existing production situations. Together with a body of statistical approaches, they provide the data required for quantification – for the quantitative description of ongoing losses. Many of the questions we ask, however, go beyond this. We also wish to ask “what if” questions: “what if an emerging disease establishes?”; “what if production situations evolve?”; “what if climate changes?” That is, we wish to know the impact of yield reducers in a yet-to-exist context. Addressing questions of the “what if” type requires (1) understanding processes and (2) integration. Process-based simulation provides these elements. Process-based models have applications to both the dynamics of injuries and their crop loss consequences. Published results suggest that shareable, transparent simulation models constitute a main avenue to collectively address these questions.

Economic implications of disease and pest losses – modelling and analytical approaches

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There is no question of the economic, environmental and social importance of disease and pest losses (DPL), as documented by many prior studies as well as presentations in this conference. But the scientific and institutional challenges in making progress in this domain are also daunting - as other presenters here observe, the scientific challenges explain the limited capability of most crop models to incorporate diseases and pests in a rigorous manner. Due in part to the lack of scientific capability to understand, predict and manage diseases and pests, the agro-chemical industry continues to grow, developing and promoting the use of pesticides as well as pesticide tolerant and pest resistant crop varieties, along with globally expanding networks of input distributors and pest management advisory services. Despite decades of research on rational pest management, high levels of pesticide use and pesticide resistant diseases and pests continue to be major problems in the world's industrial agricultures. At the same time, DPL in regions such as Africa are largely uncontrolled, dangerous chemicals are being aggressively promoted to semi-subsistence farmers who lack the capability to use them safely or effectively, and major pest outbreaks such as the fall armyworm wreak havoc on Africa.

How then to establish some order out of this complex and chaotic situation?

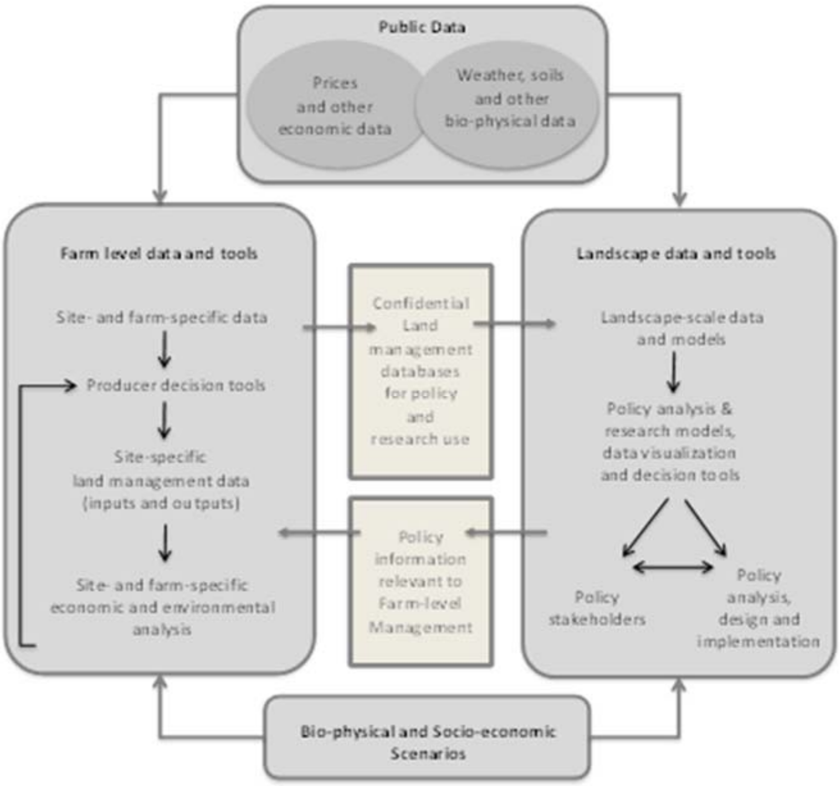
In my presentation I will first briefly describe a conceptual framework that can be used to to set priorities and establish a research agenda, through a collaboration between scientists and private and public stakeholders, to address DPL. This framework involves the identification of the principal economic, environmental and social (human health) outcomes associated with major agricultural systems, and the evaluation of the tradeoffs among those outcomes. Once these key outcomes have been identified for major production systems, the research community can assess what data and analytical tools are needed to evaluate these outcomes and their inter-relationships (tradeoffs) associated with the status quo as well as possible technology and policy interventions. We have various data and modeling tools that can be utilized and further developed, but the complexity of these problems means that this process of prioritization is needed to accelerate progress.

While a variety of data and analytical tools have been developed specifically for analysis of agricultural systems and for DPL, there are many new data and analytical methods and tools that could be utilized from outside the agricultural sciences. Other presentations in this conference discuss new we-based data acquisition methods, and new approaches to analysis and prediction, such as machine learning, could be investigated and utilized. Moreover, there is a large and growing private sector in the business of disease and pest management.

Together with the need for advances in data and analytical tools and methods in this area, there is a need to develop a collaborative approach to meet the needs of the various stakeholders that include farmers, agribusiness, consumers, public research organizations and government agencies and politicians. Antle, Jones and Rosenzweig (2017) discuss the need for a strategy to develop “Next Generation” agricultural systems data, models and knowledge products, and propose a framework that parallels developments in the pharmaceutical industry, wherein a “pre-competitive space” for collaborative, public-goods research is linked to a “competitive space” for development of new products.

Advances in information technology and computational power create the opportunity for a transition to a “computational agricultural science” that would exploit advances in information technology, data science and artificial intelligence. A major challenge to exploiting this potential is the lack of a set of data standards or a common data “ontology.” This issue was recognized decades ago in the first coordinated crop modeling consortium (ICASA), and the recent work by AgMIP to develop translators from various crop models into a common input database took advantage of that early work. This problem is even more apparent in the technology impact assessment field that utilizes farm survey data. Virtually every farm survey utilizes a case-specific set of variables and definitions – even the World Bank’s Living Standards Measurement Surveys differ over time and across countries. Moreover, these surveys typically lack basic agronomic information needed by crop modelers such as planting dates. The information on pest management is often completely lacking, or limited to qualitative questions about disease or pest problems. Pest management information is often limited to basic qualitative information about types of pests of concern. Except for some special-purpose surveys, almost no surveys obtain the kind of detailed data on pest occurrence or quantities and timing of pest management actions that are needed to reliably model damage functions or management decision processes. These shortcomings reflect the difficulties associated with farm survey data collection largely based on farmer recall and manual collection of data by enumerators.

Accordingly, in addition to the priority setting process described above, an essential first step towards advancing improved analysis, prediction and management of DPL is the development of a data ontology and generic data structure for agricultural systems with sufficient detail in the area of DPL and pest management. This should be based on a private-public collaboration to work towards a system that links private and proprietary on-farm, real-time management data and tools to a cloud-based, open-source data repository for research, and public policy analysis and policy decision making. A prototype of this type of system is illustrated below. Existing private and public data could be linked to this system through data translators, following the approach that AgMIP has developed for crop model databases.



Linkages between data and decision tools at farm and landscape scales
(Capalbo, Antle and Seavert, *Ag Systems* 2017)

Plant diseases in a changing climate – approaches to assess and estimate future crop risks

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Although climate variation has reached a historically low level in the last 8,000 years, slight shifts have remained a continuous phenomenon. In the last century, weather records indicate an increase in mean surface temperature in Germany of +1.0°C, an increase in precipitation by ~20% and an extended length of growth period by 22 days. This is orchestrated by an increase in atmospheric CO2 levels from 300 to 395 ppm (Pretzsch et al., 2014). As a consequence, a significant global gain in terrestrial net primary productivity has been recorded for managed and unmanaged vegetation since the 1960s (Tiedemann, 2016). This raises the question, whether and how such climatic shifts may indirectly affect crop productivity and potential losses via altered risks of plant diseases.

The potential climate change impact on crop diseases implies three key questions, namely, is climate change …

… creating novel pathogens/pathotypes/races,

… driving the emergence of diseases in new areas and/or

… modulating the severity of pre-existing diseases?

Although there have been 140 reports of disease outbreaks in new crops or geographic regions from 2010 to 2015 (Bebber, 2015), very few of them can be considered truly novel pathogens. Good examples of recently emerging new pathotypes are the UG99 races of stem rust spreading in Africa and Western Central Asia and the new races of stripe rust invading Europe and North Africa since 2015. A chief driver of this type of pathogen evolution is the cropping system, particularly the selective force exhibited by cultivars harboring specific resistance genes.

The emergence of pathogens in new regions of cultivation due to invasion from other parts of the world is an often found phenomenon for which several historic examples exist such as the introduction of downy and powdery mildew into European vineyards, the spread of coffee rust in SE Asia or of potato late blight in Europe. More recent examples are the spread of ramularia leaf spots in barley in Europe, of Asian soybean rust in the Americas or of Verticillium in rapeseed in Europe and Canada.

For all these diseases, compelling evidence exists indicating that the main drivers of dissemination have been introduction by trade and traffic, crop area expansion and altered agrotechnology while climatic variation has played no significant role (Anderson et al., 2004; Bebber, 2015).

However, alterations in climatic conditions may affect the damage potential of yet existing pests and pathogens. Methodological approaches to investigate this question include meta-analyses, empirical studies in climate controlled conditions and by linking disease and phenological forecasting models to regional climate models (Juroszek & Tiedemann, 2013a, 2013b & 2015).

Experimental approaches generate exact data however they may be constricted by artificial conditions not reflecting the field situation. Field–based simulation facilities may mitigate these constraints (Siebold & Tiedemann, 2012 & 2013). Moreover, the main factor usually considered in such studies to simulate climate scenarios is temperature.

Linking disease models with climate models appears a more holistic approach, however, again constricted by the large uncertainties in climate predictions. Using this approach revealed potential shifts in the prevalence of diseases due to expanded crop growth periods and to more or less conducive conditions for disease development. In oilseed rape and winter wheat, a pronounced change in the prevalence of major pathogens may occur without an overall aggravation of threats to these crops. Diseases in maize and sugar beet may be increased in general potentially requiring stronger efforts in crop protection.

Shifts in pathogen range and prevalence within crops and the evolution of new pathogens or pathotypes will continue to occur but the main driver will be the cropping system determined by agrotechnical progress and market conditions. Therefore the focus in yield loss and crop risk estimation must be put on crop conditions as determined by the cropping system rather than long-term climatic shifts which are not likely to have a significant direct and/or dominant impact on future crop losses.

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Pests and diseases data in the context of yield gaps – the Global Yield Gap Atlas

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Global Yield Gap Atlas – why and how

It is generally agreed that global food production will have to increase substantially to meet increased demands due to population growth, changing diets and an emerging biobased economy. While a global increase of 60% in monetary value of the production between 2005/7 and 2050 (as estimated by the FAO) is often quoted, this number will be highly differentiated across the different regions in the world due to enormous differences in population growth, anticipated changes in diets and current productivity levels of crops. It is thus highly relevant to know where and how much crop yields can still increase on existing land through a process of so-called sustainable intensification. To this end yield gaps are a helpful indicator. They are defined as the difference between potential yield and actual farm yield in a given location. Potential yields can be estimated for both irrigated and rainfed conditions, the latter is often called the water-limited potential yield. Spatially explicit and robust estimates of yield gaps and thus possible opportunities to expand agricultural production on existing agricultural land require agronomic rigour. This in turn demands local information on weather, soils and agronomic practices, and simulations that are evaluated with empirical data from the region. These are all key features of the Global Yield Gap Atlas, that was initiated in 2012 and aims to map yield gaps of key food crops in all food producing countries of the world. Currently, over 50 countries have been mapped with a global protocol (Grassini et al., 2015; Van Bussel et al. 2015), in close collaboration with one or more national experts for each of the countries to ensure local rigour (www.yieldgap.org). Together with the mapping of the yield gaps at three spatial scales, i.e. representative weather stations of climate zones, climate zones and countries, underlying data (weather, soil and agronomic data) are posted on the website under open source conditions. This is resulting in a unique and powerful database.

Applications of the Atlas

The yield gaps, the spatial framework and underlying data are now increasingly used for different purposes. First, they are used for scenario analyses of future food production and self-sufficiency analyses (Van Ittersum et al., 2016). Second, the spatial framework assists in identifying regions where response to crop and soil management technologies and cropping system performance are similar. The framework has potential to amplify return on investments in agricultural research and development, contribute to research prioritization and ex-ante impact assessment of R&D investments. Third, we aim to develop the Atlas into a dynamic database that can be used for ex-post impact assessment purposes of R&D investments. Fourth, the Atlas and its yield gap estimates are used as a starting point for explaining and mitigating yield gaps. In a couple of recent publications it has been shown how yield gaps can be decomposed in various components (gaps due to inefficiency, lack of inputs, economic constraints and lack of technology) (Silva et al., 2017; Van Dijk et al., 2017). This leads to insight in the causes of yield gaps and also allows to link such causes to appropriate techniques, incentives and policies to narrow yield gaps.

Linkage to yield reducing factors: weeds, pests and diseases

From a crop management point of view, yields gaps are explained by yield limiting factors (nutrients under irrigated conditions and water and nutrients under rainfed conditions), and yield reducing factors (weeds, pests and diseases). The Atlas currently already provides information on water limitation and water productivity, both under actual and potential conditions. We are currently also working on adding nutrient (uptake and input) gaps for a number of countries in sub-Saharan Africa. Addition of quantitative information on yield reduction due to weeds, pests and diseases would largely complete the list of biophysical factors that explain yield gaps from a biophysical perspective. This contribution to the Crop Loss Conference aims to present the Atlas as an example of the development of a global database and its use, as well as to discuss opportunities of developing a database on weeds, pests and diseases to explain yield gaps and to identify opportunities for sustainably increasing yields on existing agricultural land.

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Linking crops with pest and diseases

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Global food demand was estimated to increase by 100–110% from 2005 to 2050 (Tilman et al. 2011) - due to a growing world population in combination with the growing per-capita consumption as a function of rising incomes in many countries. To double food production by 2050, average annual growth rates in crop production of 2.4% (non-compounding rate) would be required (Ray et al. 2013). However, there are actually substantial deviations between potentially achievable crop yields and actual farmer´s yields, named as yield gaps, in many regions of the world. A significant contribution of these yield gaps are estimated to be caused by crop loss through pest and diseases. Closing the yield gap is one option to increase worldwide food production. For the assessment of crop limitations dynamic, process-oriented crop growth models have been widely used. While the estimation of water or nutrient limited crop production is relatively well established, the consideration of either weather extremes or pest and diseases is still not well developed.

So far, the quantification of crop yield loss from pest and diseases is highly uncertain since it is either based on expert assessments or on yield loss observations. Therefore, global or regional estimates are differing dependent on the method of estimation. Additionally, these methods are retrospective and don´t allow to assess future development under changing boundary conditions, e.g. climate change. Model based estimation of crop loss would provide opportunities to better assess impacts of future climate projections not only on long-term developments and strategic decisions regarding adaptation. Moreover, models could be also beneficial for short-term tactical decisions in order to assess consequences of different plant protection opportunities on crop loss and finally on the cost-benefit of measures since the decision of applying a pesticide also requires information on the potential damage caused by the pathogen and the corresponding estimate of the expected economic impact,. This would improve the chances for an integrated pest management and smart applications to enhance sustainability and reduce environmental risks associated with pesticides. However, the impact of pest and diseases has not been well implemented in most crop models so far.

Simulation models of plant growth and development are available at different levels of complexity, depending on their purpose and type of plant. They exist either as single-plant models or as generic models that use different parameter sets for different plants. Their applications range from assessments of inter-annual weather variability to the impact of management and climate change scenarios on the performance of various crops and cropping systems. In parallel a number of different modelling structures have been developed to address the modelling of epidemics in different pathosystems. These models are mainly used to describe the development of the pathogen depending on environmental conditions. Their practical purpose is to support early-alert systems that would enable applying real-time plant protection measures based on empirically derived critical thresholds of injury severity.

Early attempts to consider losses from pest and diseases in plant models have been presented already in the 1980ies. Plant models have been linked to pest and disease models to estimate crop losses and to determine critical pressure of pathogens. However, this often requires a higher resolution of weather variables compared to the time step of one day usually requested for crop models since pest inoculation may occur during shorter periods, when conditions are favourable. Often microclimate estimation, e.g. leaf wetness estimation is required.

The effects of disease and pest injuries on physiological processes and their effect on yield loss of crops are defined according to damage mechanisms. The typology of injuries according to damage mechanisms is supported by large series of different studies, especially for plant pathogens and insects. The unifying concept of the damage mechanism is the basis of the coupling of plant models with pest and disease models or with pest and disease driving functions. However, recent efforts to implement defined damage mechanisms into different crop models showed that the estimated crop loss showed significant differences depending on the structure and parametrization of the crop models.

Applicability of models in agricultural practice requires a balance between a minimum complexity to avoid structural errors, on the one hand, and adequate data requirements and robustness to keep parameter errors at a feasible level and ensure real-time data flow. Therefore, only a few models have been applied in real time to support farmer's decisions in crop management, mainly for irrigation scheduling and fertilization. Interactions between crops and pests/diseases as well as between pest and predators are very complex. Therefore, observed injuries are often used for the retrospective or real-time assessment of crop loss. This requires reasonably accurate data on injury levels, which are mainly based on subjective appraisals. With respect to this Willocquet et al. 2008 mainly identified a lack of standardised methods for measuring injuries in farmer´s fields; an over-specialisation of the information gathered, which would often consider only one or a few pests, but very rarely all of them; and poor information related to production situations, including cropping practices, plant protection practice and choice of varieties. Therefore, further development is required to assimilate real-time observations of canopy conditions and injury situations in crop models to be applicable in practice for decision support. Data availability and costs to detect required inputs real-time and in a sufficient spatial-temporal resolution are among the main causes hampering the use of models in practice. The use of remote sensing techniques is considered capable of ensuring the required data flow to feed models for decision making. Moreover, they integrate observations over entire fields to provide representative information for site specific decisions.

For the impact assessment under climate change the link between crop and pest and disease models is indispensable since empirical relations might be invalid under different boundary conditions. A worldwide data base to improve models with respect to the complex interactions of crops, pest and diseases under various climatic and management conditions is required. However, data requirements need to be carefully defined to support both crop as well as P&D modelling.

Past and ongoing experiences in developing open source online scientific data bases

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Data has been described as the fuel of the future and the next big global commodity. A data revolution has been heralded by the United Nations (UN) as being essential to drive economic growth but also to benchmark and track progress towards the UN Sustainable Development Goals (SDGs), including those related to life on land, hunger, water and poverty reduction. This growth in digital data has led to rapid improvements in the availability and quality of data related to agriculture and in turn crop health, but gaps still remain.

The growth in available data related to agriculture has been driven by several factors.

- One is an increase in the number of international collaboration networks. These networks support global, multi-disciplinary research programs that require and often take the lead in developing and opening up such data. Some of these networks, such as GODAN (Global Open Data for Agriculture & Nutrition) and the CGIAR Platform for Big Data in Agriculture have clear aims to make agriculturally relevant data more available, more accessible, and more usable. Others such as the Global Yield Gap and Water Productivity Atlas (GYGA) use Creative Commons licences to make many of their results accessible while the Agricultural Model Intercomparison and Improvement Project (AgMIP) is both a user and generator of data (AgMIP Data Interchange) and the tools to use that data (AgMIP Toolshed).
- Technological advances mean that we can collect, process and distribute more data than ever before. One example is the growth in remotely sensed data that provides regular, global information on water, land and atmospheric conditions at a wide range of spatial, temporal and spectral resolutions. The rapid increase in high spatial resolution data from fleets of small, low-cost “cubesats” and unmanned aerial vehicles (UAVs) in particular is driving novel research applications in crop management and production characterisation.
- Easy-to-use data tools and platforms are increasingly becoming available, such as: data generation (e.g., crowdsourcing through ubiquitous mobile devices); data sharing (e.g., cloud-based platforms); data discovery (e.g., searching through open data repositories); collective review (e.g., online collaboration platforms), and; tracking of usage (e.g., data citations), as well as licensing terms (e.g., Creative Commons).
- As the importance of data has increased (helped by the high visibility of “Big Data” and “machine learning”), so has the interest and willingness of donors to fund efforts to create, improve and release datasets as global public goods.

- Finally, there have been some carrot and stick incentives for developing open datasets. Donor insistence on making their funded research outputs open-access has certainly helped. Some journals and data repositories have started to publish and recognise datasets in a similar way to peer reviewed articles. There is also evidence that publications that contain new datasets tend to be highly cited (WorldClim is a classic example).

As a result, there are now many databases that have direct relevance to crop health which include data across the value-chain. This includes: crops and livestock such as production, area, trial data, suitability, farming systems and research investments; environmental factors such as climate, weather, vegetation and soils; management factors such as irrigation facilities, machineries, crop protection technologies, crop calendars and nutrients; socioeconomic factors such as population, nutritional information, access to markets/facilities for processing and storage, land ownership and farm size. In the past, a researcher may have despaired at the lack of data, now they may feel similar emotions when trying to keep up with new developments or deciding which datasets to use.

Here we focus discussion on the datasets or open data initiatives related to agriculture that are global in scope, meaning that they are either global in terms of their coverage, or global because their content is globally relevant (the data would be of use anywhere). We base this on a number of examples of past and current open data efforts and provide insights into their inception, development, sustainability/community and measures of their success or failure. We also caution that not all datasets are created equally. Some are generated (interpolated/extrapolated, modelled/simulated, gap-filled by fusing other secondary datasets or based on expert assessments), while some are purely measured. Global datasets may not guarantee their local relevance beyond certain spatiotemporal resolution.

We end the talk with three questions to the audience: (i) what are the key information gaps on crop health; (ii) how can this information be generated and maintained, and; (iii) who should do this?

Importance of disease and pest losses on key world crops – priorities

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What are the key world crops?
Key world crops can be characterized according to a number of criteria: the land which is used to grow a crop, crop production, value of traded commodity, nutritional value, feed use, or non-food or non-feed use (e.g. energy source, fibre).

In this paper, we propose to focus on food security. Rice, wheat and maize are the main staple food crops in the world. Other crops of overall importance globally include soybean (food and feed, trade), potato (food), coffee (trade), sugarcane (production, food and energy use), tomato and citrus (source of vitamins), palm oil (trade), and cotton (lint). Other food crops of great importance regionally – on which regional food security critically depends - include: plantains, cassava, sorghum, or pearl millet. In this respect, there is value in considering world's agricultural hotspots, where the importance of different crops may vary, as well as the patterns of crop health.

What is the importance of disease and pest losses on key world crops?
The diseases, pests, and weeds which develop in any given field during a crop cycle translate into direct impacts, but also have consequences beyond the limits of a cultivated field (socio-economic impacts at the farm scale and at larger scales) and beyond the crop cycle (over successive years). Quantification of these negative impacts is often fragmented and/or based on very rough estimates. We discuss below five examples of crop loss estimates made at large geographical scales.

1. Example 1 [1]: Global and regional estimates of actual and potential yield losses for major crops (rice, wheat, potato, soybean and cotton) caused by animal pests, pathogens, viruses, and weeds in 2001-2003 were based on experiments and literature reviews. According to these estimates, the ranking of importance and total losses depend on crops and world regions, and total actual and potential losses ranged between [26-40%] and [50-82%], respectively.

2. Example 2 [2]: A global survey on crop losses caused by diseases and insect pests for rice, wheat, soybean, potato and maize was conducted online in 2016, eliciting inputs from crop health experts. The results indicate that crop loss profiles depend on crops and world regions: the number and importance of diseases and pests reported vary greatly according to both factors.

3. Example 3 [3]: Estimates of yield losses caused by diseases, insect pests, and weeds on rice in tropical Asia in 1987-1998 and 2009-2011 were based on surveys in farmers' fields, crop loss experiments, and yield loss modelling. Both individual components of injury profiles and injury profiles varied according to production situations. The resulting yield losses associated with injury

profiles ranged from 20 to 40 %, with weeds, diseases, and insect pests, in decreasing order, contributing to these losses.

4. Example 4 [4]: Fusarium head blight has emerged as an important problem for the production of small grain cereals over the last 30 years, particularly because the associated pathogens can produce toxins on the infected ears that can affect human health. Yield losses, quality losses, and economic losses have been estimated in the USA based on data collected at the county scale. Because of the acute nature of epidemics, high variation in losses are observed across years and geographic locations. Economic losses for the period 1998-2000 were estimated at 733 million USD.

5. Example 5 [5]: Since 2008, a series of coffee rust epidemics have affected Central America. These epidemics have resulted into a reduction in coffee production by 17% between 2011 and 2014. This reduction amounted in a loss equivalent to 616 million USD. This example illustrates that a non-food, export-oriented crop may be affected in its role towards food security by plant disease.

Interestingly, surveys in the scientific community, specifically of plant pathologists, generate a ranking of importance of diseases which only partially matches ranking made according to crop losses. Plant pathologists view point is in general more focused on pathogens, their molecular interactions with the host, or their ecology, than on their impact on crop loss.

It is important to note that there is a dearth of quantitative analyses on crop loss under scenarios of future global and climate changes.

What priorities according to the importance of disease and pest losses on key world crops?
Priorities are set according to criteria. A first criterion to consider is the importance of the crop, as discussed above. A second criterion is the level of crop or economic losses which are incurred.

Other criteria are linked to patterns, and allow an ex-ante appraisal according to current knowledge of the processes that determine crop losses, as follows:

(1) The spatial and temporal variation of loss, which can be captured by chronic vs acute categorization. Chronic and acute losses have different socio-economic impacts, the former regularly hampering crop performance, the latter potentially causing market destabilization, economic disturbance, and social upheavals;

(2) The potential loss, i.e., the maximum crop loss that can occur in a farmer's field, which is determined by the ecology and damage mechanisms of the disease or pest. For example, potential losses caused by many viral diseases can be expected to be very high;

(3) The availability and efficiency of management tools, which depend on the life history and biology of the pathogen or pest (damage mechanism; evolutionary capacity; spatial spread; survival).

What avenues for disease and pest loss appraisal?
Avenues to improve our appraisal on crop loss are proposed. They can be structured according to data and information: (1) how to improve ground data collection and availability? (2) how to foster remote data collection, analysis, and use? (3) how to derive virtual data e.g., from linking epidemiological and yield loss models? (4) how to mobilize current knowledge and technologies to develop robust scenario analyses for the future?

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