Crop Modeling Gaps and Strengths within the CGIAR

Introduction

The Community of Practice on Crop Modeling was commissioned to conduct a **CGIAR wide gap analysis** to determine the **strengths, weaknesses, opportunities,** and **threats (SWOT)** of CGIAR centers in terms of modeling capacity, skills and expertize, and to determine how modeling can support other research and outreach activities at the CGIAR centers.

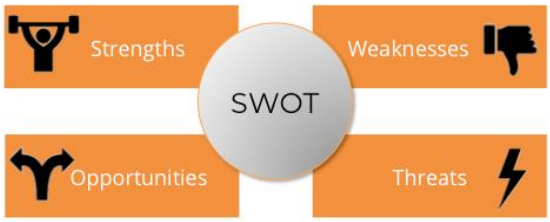


Figure 1. SWOT analysis

With this SWOT analysis, the Crop Modeling CoP aims to identify:

- Necessities (tools, methods, access to databases, funding, needs for infrastructural support…) to achieve desired goals
- Different **models, tools and databases** used for each center.
- Main **modeling goals** within each area
- Main **modeling inputs** in each area
- Collaboration opportunities

Methodology

During 2018 the CoP has been working in identifying the **strengths** and weaknesses or **gaps** in terms of modeling capacity within the CGIAR and collaborators. For doing this analysis, we extracted the information from the series of reviews that collect the modeling activities in CGIAR centers and external partners that is under preparation. We asked different CGIAR collaborators

from 7 different CGIAR centers (CIAT, CIMMYT, ICARDA, ICRISAT, IFPRI, CIP and IRRI) to send us a text that contained:

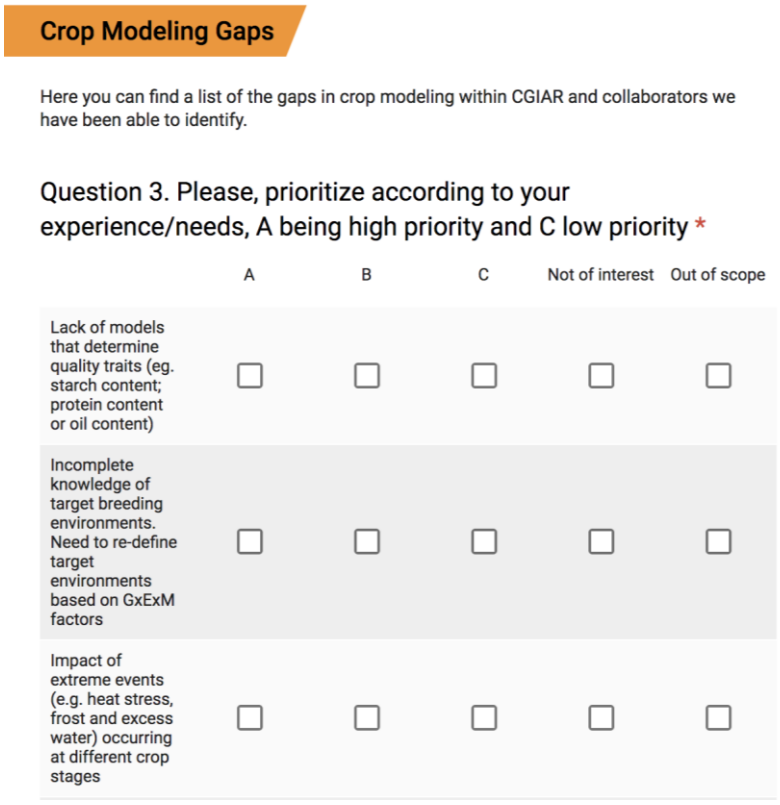
- A brief review of model outputs that included an overview of the modeling activities and goals of their centers, and examples of successful recommendations and outputs/impacts achieved through modeling, showing key data.
- A brief description of tools and methods used.
- A statement about near wins/impacts that could be achieved following on directly from your previous modeling work/proof of concept, with some modest additional investment.
- Big picture modeling goals that could have impact across research areas, cropping systems, rural communities, etc.
- Tools/methods required to achieve the above (that may be available and shared from other Centers, and/or requested in project proposals)

The information received was very diverse and not always complete, but we were able to identify some gaps and strengths among the respondents. With these results, we conducted an exercise during the Crop Modeling workshop that took place during the 2018 Big Data Platform convention in Kenya with the CoP members. The objective of the exercise was that the attendees had to prioritize some gaps and strengths detected in crop modeling according to their point of view and needs.

Figure 2. Workshop held for the CM CoP during the 2018 BDP Convention

Due to the good feedback obtained, the success in the exercise and to extend the participation among the whole community, a survey was designed and shared with over 370 CoP members. The

participants were able to prioritize the gaps from A to C, A being high priority and C being low priority. They could also select whether the gap was not of their interest or Out of the Scope (Figure 3).



Crop Modeling Gaps

Here you can find a list of the gaps in crop modeling within CGIAR and collaborators we have been able to identify.

Question 3. Please, prioritize according to your experience/needs, A being high priority and C low priority *

	A	B	C	Not of interest	Out of scope
Lack of models that determine quality traits (eg. starch content; protein content or oil content)	☐	☐	☐	☐	☐
Incomplete knowledge of target breeding environments. Need to re-define target environments based on GxExM factors	☐	☐	☐	☐	☐
Impact of extreme events (e.g. heat stress, frost and excess water) occurring at different crop stages	☐	☐	☐	☐	☐

Figure 3. Screenshot of the Gaps and Strengths survey

From the 373 members that received the email, 48% opened the email (177 members), only a 9.4% clicked to the survey's link (35 members), and only a 7% replied to the survey (25 members). Therefore, we can not ensure that the results from the survey are representative of the whole Community, but it is a good starting point to start working and moving forward.

A summary with the results from the survey can be found in Annex 1.

Results and Discussion

During 2018, we have been focused in determining the "S" (strengths) and "W" (weaknesses) of the SWOT analysis in crop modeling within CGIAR and collaborators. The weaknesses or gaps and strengths from the community are very diverse; therefore our main goal was to detect common gaps, common needs and opportunities "O" in terms of modeling capacity to design a plan for sharing the crop modeling expertise and promote collaborations.

STRENGTHS ("S")

Crop Modeling activities within the CGIAR date from the late sixties and have been applied to a broad range of crops and environments. In the organisation, there is a wide range of expertise from soil scientists, agronomists, breeders, crop physiologists, crop modelers and systems modelers all working together. The benefit is that the necessary data can be collected with the highest quality and being used for crop modeling activities.

Some of the strengths detected are:

- High quality datasets and large amounts of data collected.
- Creation of GARDIAN for data discoverability and use.
- High crop modeling expertise (although not homogenously distributed). A team of modelers that can model rice, beans, cassava, sorghum, peanut, lentil, chickpeas, maize, wheat, and coffee and have the capacity to develop new or to modify existing models.
- Good data management expertise
- Successful and fruitful collaborations established with non-CGIAR crop modelers, such as the University of Florida, University of Queensland, CSIRO, Wageningen UR, University of Leeds, Standford University, Texas A&M AgriLife Research, University of Hohenheim, INRA, USDA, CIRAD, among others.

EVALUATION OF GAPS AND WEAKNESSES ("W")

In terms of gaps, needs and weaknesses within the crop modeling capacity and activities within CGIAR, we have detected the following:

Data and Datasets need to be more FAIR (Findable, Accessible, Interoperable, and Reusable)

One of the most common concerns within the CGIAR and collaborators is the accessibility, variability, interoperability, and quality of datasets for modeling activities. It is not only necessary that datasets are easily findable through search engines, but also that they are annotated with standard vocabularies in order they can easier be used for modeling purposes. Currently there are multiple data formats and many can not be used for modeling purposes because either they don't contain the sufficient information, they are not model-ready, or they are not properly shared. Data needs to be properly shared to avoid duplication of field work efforts. It is necessary to use tools to convert these data into formats useful to stakeholders (Porter et al., 2014), and it is important that these tools are available.

The Agricultural Model Intercomparison and Improvement Project (AgMIP) has been working in data standards and data collection protocols (Hoogenboom et al., 2012)(Boote et al., 2016)(Kersebaum et al., 2015) , and tools (Porter et al., 2014) to promote accessibility and Interoperability of data sets. However, according to the feedback received from various members, these protocols or tools have not been properly shared.

Maintenance, calibration and model update

- Lack of appropriate guidelines / tools for model calibration and use that explicitly take into account parametric and structural uncertainty
- Need of more –expensive- trials that verify models.

- Due to computational complexities (or simplifications), some centers have to over rely on calibration. Because of this, the calibrated parameters tend to be more site-specific and need to be recalibrated to be used in other areas of interest.
- Lack of appropriate documentation in certain models often makes it difficult to use them in science (though not in practice)
- Need of integrating and considering feedback of model performance into models.
- It can be useful to have a document that contain all the available models used within the CGIAR, with their strengths, applications, weaknesses and their availability. Several models have been created, but often remain in papers and are not properly shared.

Application of crop models for targeting breeding

Some advances have been done in using crop modeling for breeding purposes, however, still much needs to be done to effectively integrate crop models to assist in plan breeding decisions in most CGIAR centers. For achieving this it is necessary to do the characterization of target populations of environment to better target breeding decisions.

Capacity building

Crop Modeling capacities within the CGIAR need to be further improved and promoted via trainings, workshops, webinars, special sessions in conferences, and education activities. Some centers stress the lack of sufficient capacity to perform crop modeling activities. A lot of successful collaborations have been established with different universities and research centers, but still there is the need to facilitate and promote the crop modeling expertise between the CGIAR scientists. Some CGIAR centers (IITA, CIP, among others) do not promote crop modeling or do not have enough people or budget to carry out crop modeling activities.

Inter-disciplinary and trans-disciplinary approaches applied to addressing the full GxExMxS paradigm

There is still an incomplete knowledge of target breeding environments, and there is the need to re-define target environments based on GxExM (Genotype x Environment x Management) factors. The addition of Socio-Economic and Policy factors into the models is also important to help stakeholders and policy makers in taking decisions and to have access to more economic resources for crop modeling activities.

Application of crop models to other areas

Application of modeling to areas that have not been explored:

- Conservation Cropping systems
- Perennial crops (tree fruits, coco, mango, banana,…)
- Landscape and soil dynamics modeling
- Nutrient losses and the effect of crop residues
- Integrative modeling accounting for crop-livestock

Lack of investment for crop modeling activities

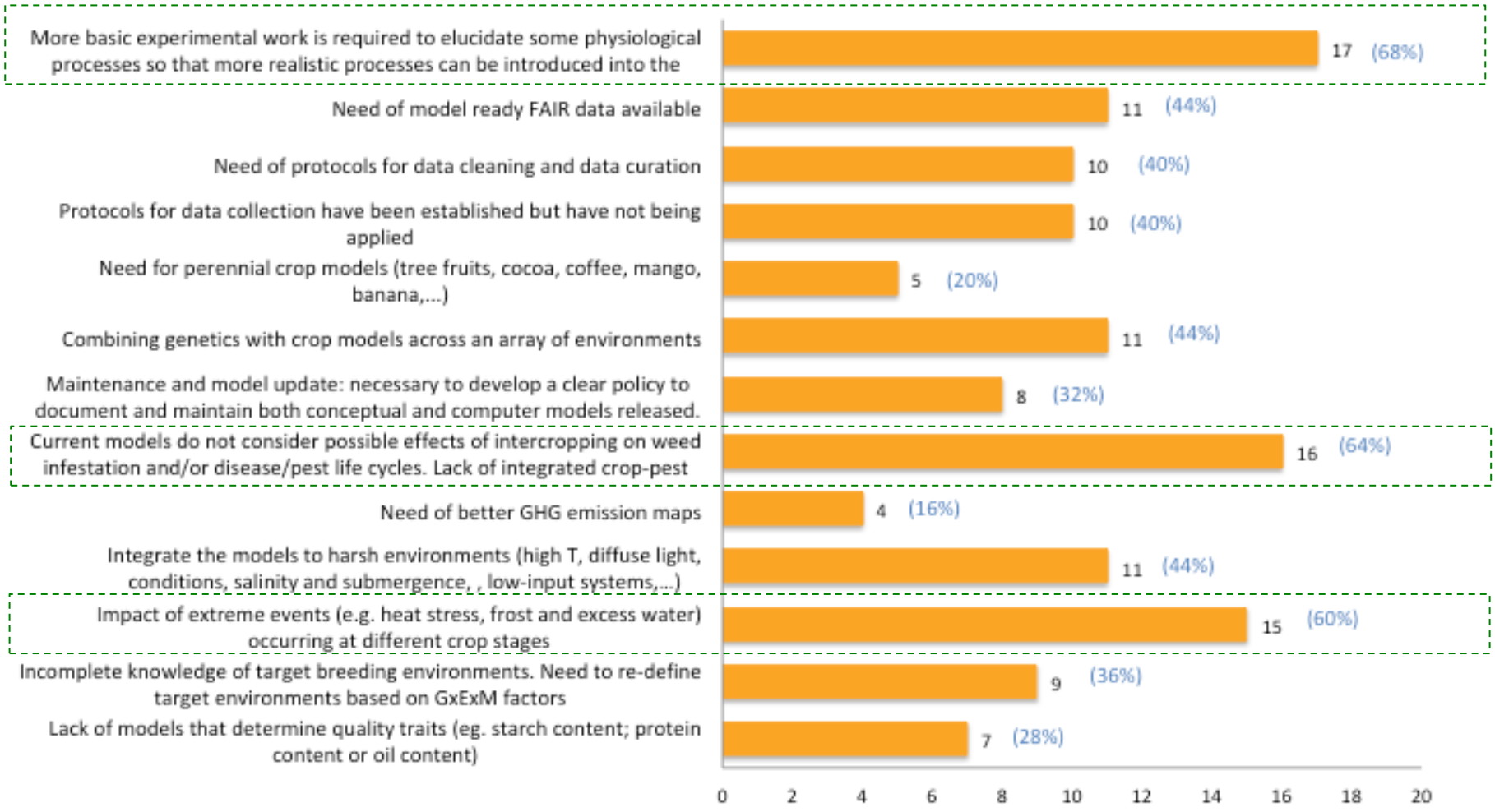
According to some CGIAR scientist, some crop modeling activities have not been finished or further explored due to resources limitations. To avoid that, it would be important to establish collaborations across CGIAR centers and external crop modelers to avoid the duplication of efforts, sharing the expertise, and do a better use of the resources available.

According to this analysis and some suggestions, we elaborated a list with some **gaps** identified for a prioritization exercise:

1. Lack of models that determine quality traits (eg. starch content; protein content or oil content)

2. Incomplete knowledge of target breeding environments. Need to re-define target environments based on GxExM factors
3. Impact of extreme events (e.g. heat stress, frost and excess water) occurring at different crop stages
4. Integrate the models to harsh environments (high T, diffuse light, conditions, salinity and submergence, , low-input systems,…)
5. Need of better GHG emission maps
6. Current models do not consider possible effects of intercropping on weed infestation and/or disease/pest life cycles. Lack of integrated crop-pest models for most crops
7. Maintenance and model update: necessary to develop a clear policy to document and maintain both conceptual and computer models released.
8. Combining genetics with crop models across an array of environments
9. Need for perennial crop models (tree fruits, cocoa, coffee, mango, banana,...)
10. Protocols for data collection have been established but have not being applied
11. Need of protocols for data cleaning and data curation
12. Need of model ready FAIR data available
13. More basic experimental work is required to elucidate some physiological processes so that more realistic processes can be introduced into the models (nutrients uptake and their relation with root growth and soil properties, plant growth regulator responses, maintenance respiration, sink-source relationships, key adaptive processes, long term effects of elevated CO_2 on stomatal conductance).

The main outcomes from the gap survey can be seen in Figure 4.


More basic experimental work is required to elucidate some physiological processes so that more realistic processes can be introduced into the
17 (68%)
Need of model ready FAIR data available
11 (44%)
Need of protocols for data cleaning and data curation
10 (40%)
Protocols for data collection have been established but have not being applied
10 (40%)
Need for perennial crop models (tree fruits, cocoa, coffee, mango, banana,...)
5 (20%)
Combining genetics with crop models across an array of environments
11 (44%)
Maintenance and model update: necessary to develop a clear policy to document and maintain both conceptual and computer models released.
8 (32%)
Current models do not consider possible effects of intercropping on weed infestation and/or disease/pest life cycles. Lack of integrated crop-pest
16 (64%)
Need of better GHG emission maps
4 (16%)
Integrate the models to harsh environments (high T, diffuse light, conditions, salinity and submergence, , low-input systems,...)
11 (44%)
Impact of extreme events (e.g. heat stress, frost and excess water) occurring at different crop stages
15 (60%)
Incomplete knowledge of target breeding environments. Need to re-define target environments based on GxExM factors
9 (36%)
Lack of models that determine quality traits (eg. starch content; protein content or oil content)
7 (28%)
0 2 4 6 8 10 12 14 16 18 20

With the results from this analysis we have identified areas where some capacity building is needed, some knowledge needs to be shared, and some actions need to take place. Based in these results, we have elaborated a plan for sharing the crop modeling expertise during 2019 that consists in different actions and channels.

To fill the gap related to make datasets more FAIR, the CoP on Crop Modeling will carry out two webinars during 2019:

- **Webinar #1:** **GARDIAN and GEMS: Platforms for discovering, sharing and storing datasets and tools**
- **Webinar #2:** **Minimum Data requirements for Crop Modeling purposes** (in collaboration with AgMIP and the UF**)**

More activities will be performed to share the knowledge via scientific publications, newsletters and blogposts to inform the community about interesting news, publications, datasets, tools and other interesting technologies.

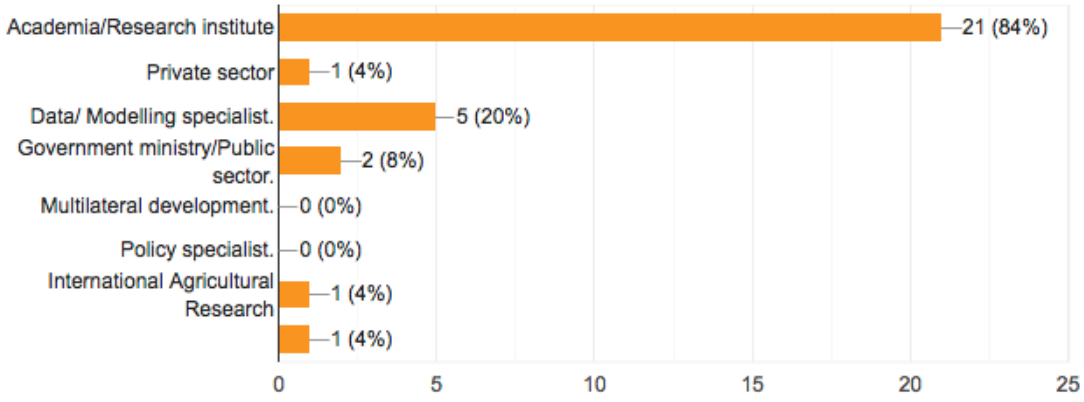
However, some of the gaps detected need to be discussed more deeply with the community in order to establish a broader strategy to address them. This will take place during 2020.

Annex 1: Summary of the Gaps and Strengths survey

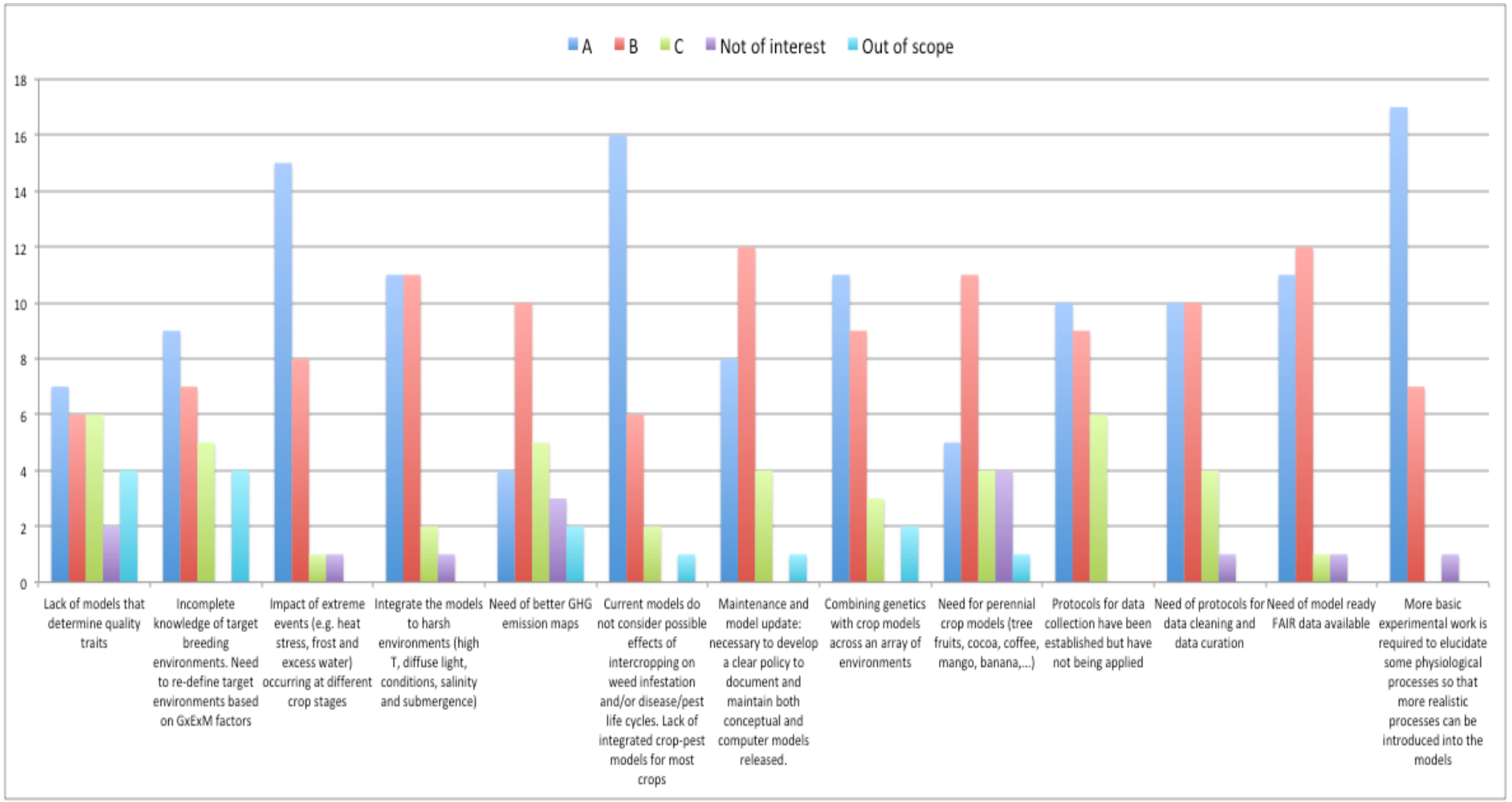
***Question 1**. Please provide your name, organization, and area of expertise. Your response will provide background information for analytic purposes only, but your answers to the following questions will remain confidential.*

Variety of CGIAR centers (CIAT, CIMMYT, IITA, ICRISAT, Biodiversity International) and non-CGIAR research institutions, as well as academic institutions represented (INRA, UF, IRD, Michigan State University, University of Sri Lanka, CAB International, Crop Science Chinese Academy of Science, USDA-ARS, University of Arizona, University of Southern Queensland).

***Question 2**. Which best describes your occupation?*



***Question 3**. Please, prioritize the gaps according to your experience/needs, A being high priority and C low priority*



Please add any comment if needed:

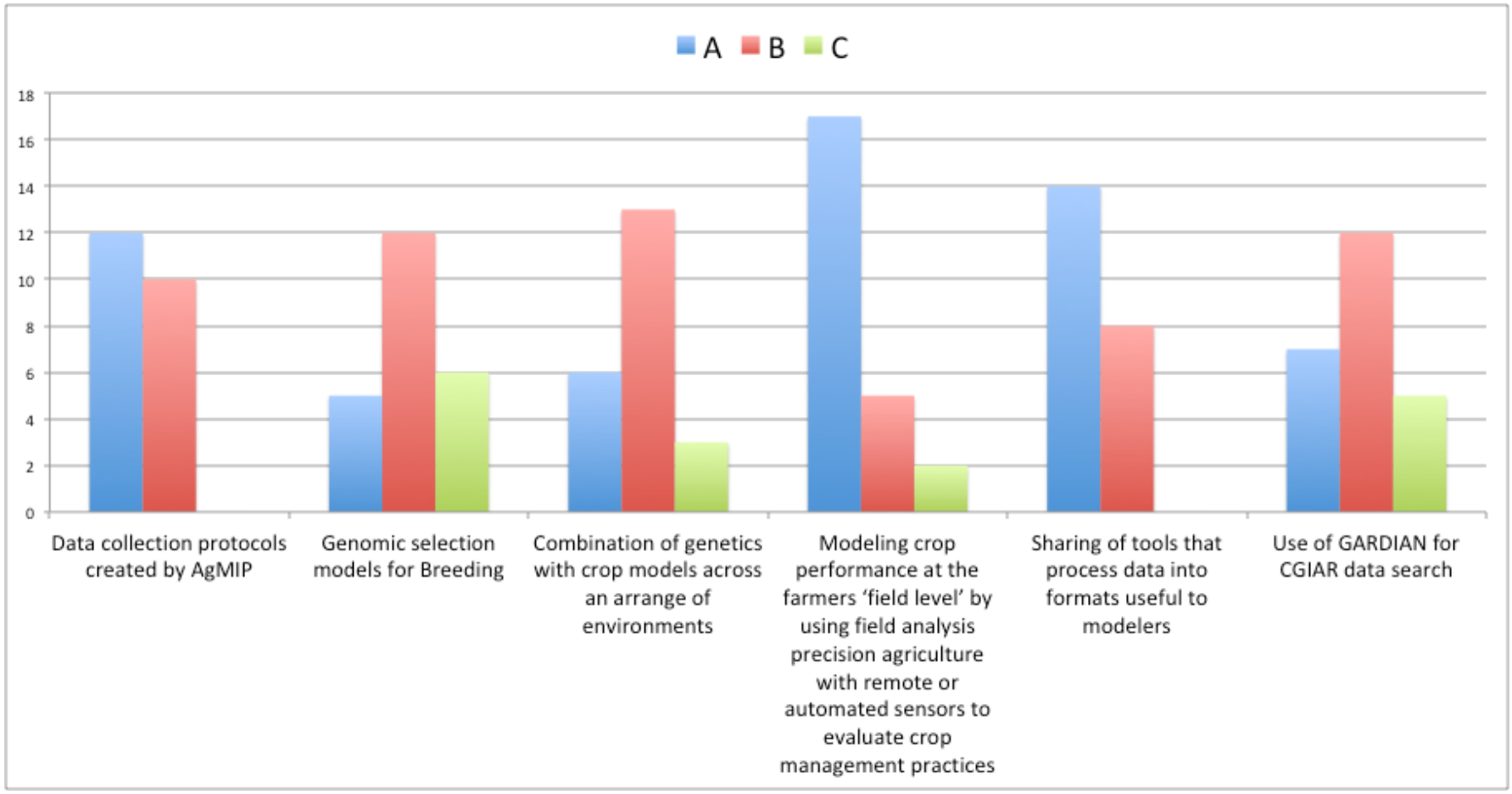
- Where models exist, focus needs to be laid on improving existing models. We have several models but often remain in papers or labs and not applied
- The focus of this list is insufficiently on model application
- Integrate crop modeling and plant breeding and their impact

***Question 4**. Are there other important gaps not listened here that you consider of high priority for your research activities /organization?*

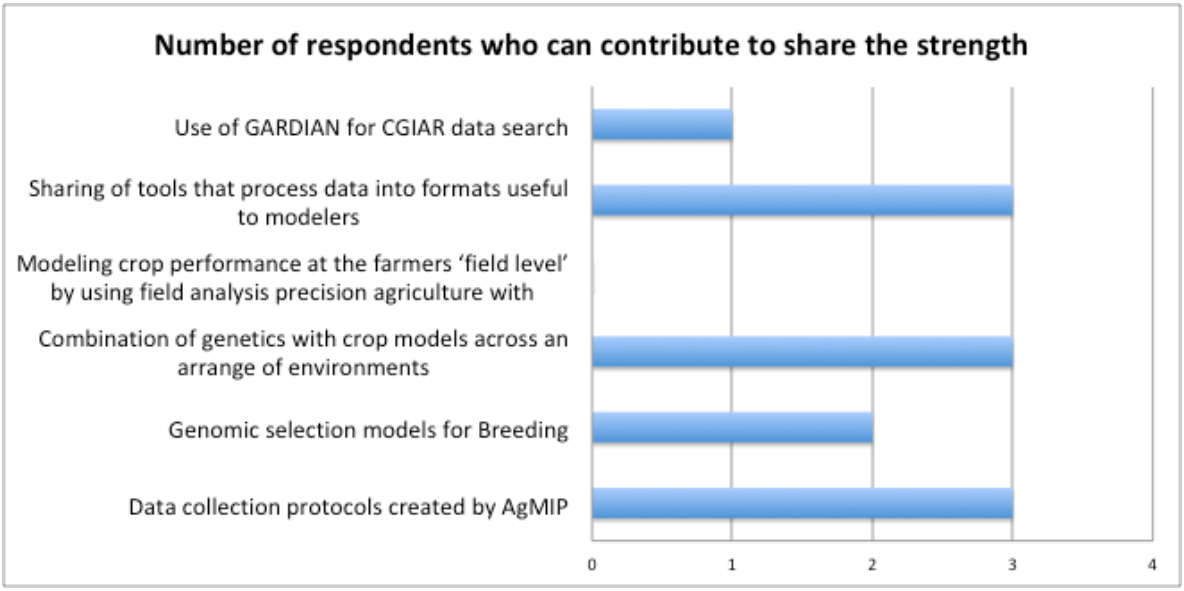
- No
- No
- Effects of crop residues on biogeochemical cycles
- Climate effects
- Lack of financial support for crop model improvement
- Model useability, modularity, interoperability
- Need to determine whether an energy balance is required to adequately simulate crop responses especially in drier or stress conditions.
- Calibration is equally an important part in crop modelling, in order to get the realistic simulation outputs. However, despite the advancements in simulation based optimisation computational techniques, effective calibration is still missing in most of the crop models/modelling works.
- Would be interesting to take stock of the available models in our field or work with their potentials, strengths and weaknesses and their availability to mention. A link to such a document could be made available to users and could act as a starting point for some body interested in working with models.
- Relay or double cropping in crop models
- N/A
- Systematizing of participatory feedback on model performance should be another gap
- Integrating models with GIS

- Need more - expensive - trials that verify models. Modeling is liked by funders since relatively cheap but too often not sufficient trials conducted to verify modeling results. Model verification with trial data should be part of every model project
- Modernization of the ExMxS component
- Need of better models for cane juice quality estimation
- NO
- Efficiency of integrating crop modelling and plant breeding compare with conventional practice of plant breeding
- Soil dynamics and functions not sufficiently modeled.
- Capacity building of model users/developers especially in the South.
- Lack of appropriate guidelines / tools for model calibration and use that explicitly take into account parametric and structural uncertainty
- Yield prediction model
- Integrative modelling accounting for livestock and the diversification like rice-fish

Question 5. *Please, prioritize the strengths according to your needs, A being "high priority, there is the need to promote this" and C "it is not so relevant/necessary".*



Number of people who can contribute to share the strength:



Please add any comment if needed

- Linking plant nutrition to genomics
- Another clear strength is the capacity to develop new or to modify existing models –this clearly needs to be promoted widely if we are to better understand model capabilities and be able to tailor models to specific needs.

***Question 6**. According to your experience in Crop Modeling, could you highlight some other strengths and weaknesses within your center/organization?*

- Weakness: improvement of C-N-P-Water cycles to support plant production / estimate GHG emissions, nutrient losses and the effect of crop residues.
- The University of Florida has one of the strongest crop modeling teams across the world and will be glad to contribute to the CoP
- Remote sensing, landscape ecology, land use change, physiology
- Strengths: high quality datasets. Discipline expertise. Data management expertise.

- Strength: i found it more useful to optimise the resource use, track the growth, outputs in absolute terms (rather than in relative terms). Weakness: Due to computational complexities (or simplifications), we have to over rely on calibration. Because of this, the calibrated parameters are more site specific (couldn't generalise it, to some extent).
- Weakness: Capacities for crop modeling need improvement
- Education and training
- We do not have sufficient capacity in crop modelling
- Lack of interest in modeling at IITA. Limited internal expertise in modeling in the Institute
- Crop modeling has made good progress, in various areas. But in order to be useful to set priorities in a breeding program, prediction ranges still too wide. Genetic variation among elite lines in range of 5 - 10 % so models that are not more precise are not very helpful.
- Inter-disciplinary and trans-disciplinary approaches applied to addressing ExExMxS.
- Lack of basic informations.
- Working on PRISE project developing Crop models. Still in learning phase
- Use of crop modelling in applied agricultural research need more attention.
- Plant stress physiology and modeling with use of experimental and longterm data. Conservation Cropping systems should be modeled.
- In the organisation, there is a wide range of expertise from soil scientists, agronomists, breeders, crop physiologists, crop modellers and systems modellers all working together. The benefit is that the necessary data can be collected with the highest quality. The weakness is that there seems to be little focus on modeling per se in recent years.
- A clear weakness is the lack of expertise and tools to link genetics and crop models; lack of appropriate documentation in certain models often makes it difficult to use them in science (though not in practice). Strengths include [1] a team of modelers that can ably model rice, beans, cassava, maize, and coffee; [2] capacity to develop models in fortran, especially within the DSSAT suite; [3] strong statistical background in the team; and [4] strong links with the bean and forage breeding programs.
- Strengths: large amount of data collected Weakness: ability to solve breeding and genetics questions; explaining biological meanings of big data

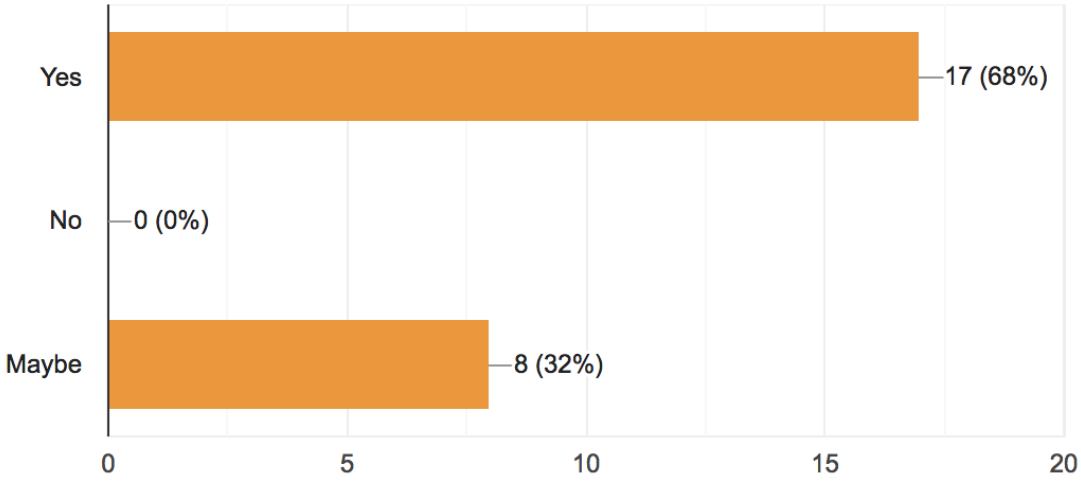
- We are very skilled in point field level modelling and there is a need to consider landscape modelling

Question 7. *Can you think about some effective ways of sharing Crop Modeling expertise?*

- Service/business units close to the research units
- Training stewards from the several CoPs
- An update on the basics aiming young scientists and undergraduate students. Crop modeling is a very complex subject and maybe an updated book making all points very clear all the way. I mean, a book that you could give to undergrad and they would have everything, from collecting data to basic modeling development. This book should be free and simple models coded in python or R (a scientific language) could be provided. In this way courses could be all levered to high crop modeling standards and professors and lectures would have excellent material. For example the book 'Understanding Options for Agricultural Production' cost more than 260 euros! That way too expensive for anyone. In this way the basics are 'solved across world' and expertises can be improved and shared easily if everyone is in the same page.
- Continuous capacity building and training
- Hackathons, visiting scientists
- Problem-oriented hands-on workshops with extensive pre-workshop sharing of datasets.
- Recently, crop modelling is accelerating in all fronts, thus, it is essential to share the advancements with relevant stakeholders. Still crop modeling group is relatively small, but, expanding. Sharing the crop modeling expertise to experienced researchers can be relatively easier than newbies (whom we cannot ignore). combination of workshops/webinars/special sessions in conferences/summer schools/ etc, will help in this regard. Now crop modelling is reached a level where it can be included as a separate course at graduate/post-graduate level programmes.
- Workshops and trainings
- Crop model developers forum (may be arranged annually)
- Intensive workshops and postdoctoral research associate funding opportunities

- through workshops offered at Universities
- sharing organising data, across center workshops and writing papers with multiple authors from different centers
- bundle resources to do collaborative research across disciplines
- Replicating the developed crop models across geography to test the effectiveness of the developed models.
- Arranging Training/ workshop in collaboration with international experts in different countries and advice to take the responsibility/ownership
- Networking- webinar- conference and meta-analysis. Linking model results to impact pathways.
- Regular meetings and sharing via a mailing list application of these models
- Exchange visits that respond to specific needs in a given center or partner and joint projects that capitalize expertise from different CoP members.
- Forum; easy-to-use tools
- Conference with specific application to the CG interest, Forum, webinar

***Question 8**. Are you willing to participate in the Crop Modeling CoP Workshop that will take place by the end of 2019?*



***Question 9**. Do you have any additional comments or recommendations for your CoP and the Big Data Platform?*

- All CoP activities should support the overall mission of the Big Data Platform.
- 1. Rather than striving for some "near perfect" data management strategy, we need compelling case studies/test applications that show the value of merging models and big data.

  2. If you look at AgMIP exercises, the truth is that the datasets were appallingly weak. For example, the multi-location dataset provided by CIMMYT for wheat heat stress lacked irrigation and nitrogen management information, yet agronomists familiar with the regions would tell you that crops are often allowed to suffer N and water deficits as the crop approaches maturity as a means of reducing lodging. This would be a good time to establish some coordinated trials of say 15 locations x 4 genotypes for different crops and ensure that soils, management and weather data are properly recorded.
- You guys are doing great work in terms of collaboration and bring best expertise in the domain to tackle the CoP
- Just need creating awareness and show the benefits and work closely with the local experts, create platform/ network in the country level
- Agroecology and sustainability models are needed.
- Create a One stop modelling platform i.e. bring AgMIP and Big Data together
- N/A
- More regular and advance communication, use of the CGIAR website and assuring each center has focal resource person to interact with their existing teams and partners.