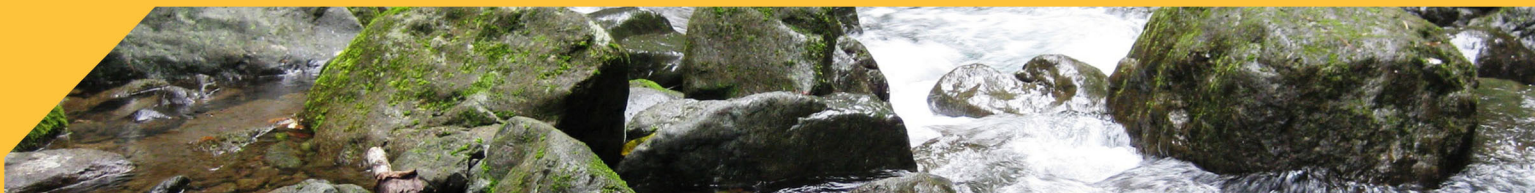


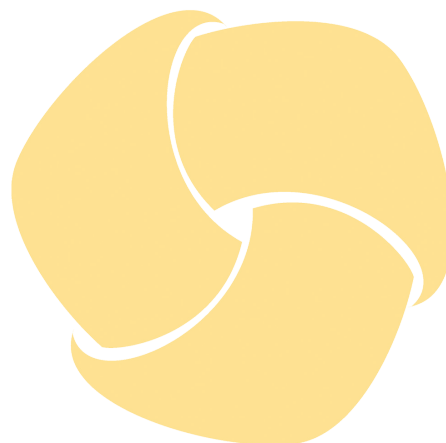


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The Climate, Disaster and Development (CDD) Journal aims to publish peer-reviewed, original research on all aspects and intersections of climate, disasters and development and their interaction. As policy makers, development workers and the general public become more keenly aware of the rising risks posed by climate hazards and disasters and their impacts on national development, the journal provides a forum for the presentation of recent research findings on these topics and their management implications. It is not only for researchers, but for anyone concerned with national development amidst climate risks and disasters.

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Toward developing a humanitarian crowdsourcing model: Enabling medical and disaster response through digital collaboration

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Abstract

Lately, the humanitarian community has been utilizing crowdsourcing to facilitate medical and disaster response. Grounded in Geiger et al.'s (2011) Crowdsourcing Information Systems (CIS) and Surowiecki's (2004) Wisdom of the Crowds (WC), this study content-analyzed 23 humanitarian crowdsourcing websites to find out how crowdsourcing has enabled medical and disaster response, as evident in global humanitarian movements from 2010 to 2014. Findings revealed that the digital volunteers that generate big data in humanitarian crowdsourcing websites are composed of an independent crowd with diverse opinions and a decentralized demography. The crisis-related inputs they contributed were community-based, infrastructure-based, information-based, and related to future threats. Emerging outputs resulted in three phases: 1) first degree material outputs (e.g., geographic crisis map, and/or text database/resource page); 2) non-material outputs (e.g., planning, strategizing, and operationalization via partner organizations); and 3) second degree material output (e.g., actual medical and disaster response). Results of the analysis suggest that the dynamic process of humanitarian crowdsourcing do not appear to be boxed into the CIS archetypes. Instead, the characteristic of the websites presented a merging of the four archetypes into two: 1) crowd creation and crowd solving; and 2) crowd rating and crowd processing. As an outcome of the study, a humanitarian crowdsourcing model is proposed.

Keywords: crowdsourcing · medical and disaster response · information system · wisdom of the crowds

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Introduction

One of the emerging concepts that has attracted the interest of the humanitarian community is the method of “harnessing the potential of a large crowd in generating solutions” (Howe, 2006) to crisis management. This phenomenon is called *crowdsourcing*. Crowdsourcing allows data and information related to medical crisis and disasters to be generated through the collaborative effort of *volunteers* who, in most cases, need not be physically present in the disaster zone (Starbird & Palen, 2011).

Information is a key element needed for an effective medical and disaster response. Due to crowdsourcing’s ability to rapidly generate vast information and to bring individuals to the loop of communication that aids in a large-scale problem-solving effort, it has been operationalized widely for disaster relief operations. Of noteworthy mention is Typhoon Haiyan (November 2013), where thousands of digital volunteers provided geographical information concerning the affected areas, which aided in search-and-rescue and relief operations in the Philippines (Butler, 2013). Another example is the search for the missing Malaysian Airlines MH370 aircraft (March 2014), where the online crowd—through the use of digital satellite images—helped find leads to the wreckage.

With the ongoing dialogue on crowdsourcing as an important function during emergency situations, a systematic perspective on how big data enables medical and disaster relief operations must be given foundation. Related questions that arise include: 1) What kinds of crisis-related information are produced in this method? 2) How are these large quantities of information transformed into an actual humanitarian action? and 3) How is this information being used?

Anchored on Geiger et al.’s (2011) Crowdsourcing Information Systems (CIS) and James Surowiecki’s (2004) *Wisdom of the Crowds* (WC), this study looked into the types of information (inputs) that are crowdsourced during medical and disaster crises, as well as the specific medical and disaster responses (outputs) that have emerged from crowdsourcing, to identify themes that may help elicit more information, as well as options, for a faster and more cost-effective humanitarian operations. Undertaking this analysis would generate a humanitarian crowdsourcing model based on the emerging crowdsourcing archetypes.

Crowdsourcing Information Systems

This study adopted the four models of CIS of Geiger et al. (2011) namely 1) crowd processing systems; 2) crowd rating systems; 3) crowd solving systems; and 4) crowd creation systems. Classifying the sampled crowdsourcing websites into these four archetypes relied on difference and value of contributions.

Difference of contributions (Geiger et. al, 2012) is the uniqueness of each input, which could either be a homogeneous contribution (i.e., crowdsourced information that adheres to predefined specifications and is processed quantitatively) or a heterogeneous contribution (i.e., contributions that are not limited to a single type of information). In Figure 1,

homogeneous contribution is represented by the identical shapes with the same color, while heterogeneous contribution is represented by the diverse shapes in various colors.

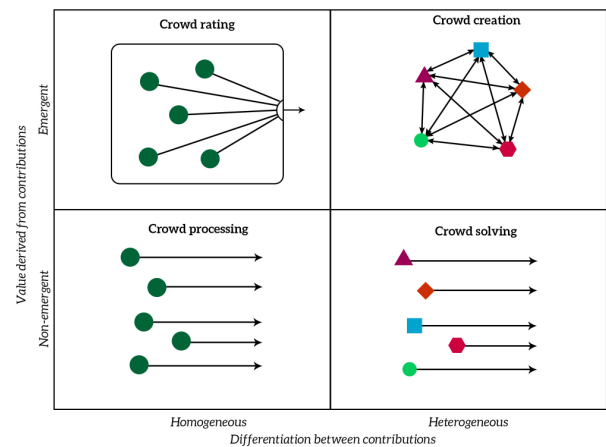


Figure 1. Geiger et al. (2011) sketched a diagram to differentiate the four archetypes based on the combination of *difference* and *value* of contributions.

Value of contributions (Geiger et al., 2012) is determined by the independence of the inputs which could either have an *emergent* value (i.e., contributions that are taken as part of the collection of information), as represented by the interlinked lines and arrows, or a *non-emergent* value (i.e., contributions that are viewed independently and may not necessarily need the entirety of crowdsourced contributions to come up with an outcome), as represented by the parallel lines and arrows in Figure 1.

Crowd processing systems seek homogeneous contributions with non-emergent value. This system collects similar types of contributions directly from the individual, instead of getting the sum or the entirety of the crowd’s inputs. The initiator posts only one type of task, and the crowd submits its ideas and outputs. From a pool of accomplished tasks, only one or a few get/s picked and rewarded by the initiator.

Crowd rating systems, or *crowd voting* (Howe, 2006), require large quantities of homogeneous contributions with emergent value. Identical inputs treated as “votes” are sourced from the crowd. It is the combination of all these votes that matters and results in an effective outcome of the crowdsourcing initiative.

Crowd solving systems seek heterogeneous contributions that have non-emergent value. Initiators introduce a problem, rather than a task, to a crowd of a diverse pool of knowledge, skills, and talents, who then offer different types of solutions. This system aims to get the best-fit solution to a single problem, through different approaches and ideas.

Crowd creation systems also require heterogeneous contributions but seek emergent value. The crowd in this system submits individual contributions that are valued as small parts of a collection of contributions. Each contribution therefore serves as building blocks that comprise the potential outcome of an initiative.

Wisdom of the Crowds

This study is also premised on the WC, which posits that effective outcome of a crowdsourcing initiative can only be achieved if all information that goes into the system comes from a wise crowd. Surowiecki (2004) identified three conditions that will enable a wise crowd, namely: 1) decentralization; 2) diversity of opinion; and 3) independence.

Decentralization refers to the diversity in the demography of the online crowd to allow for a more democratic forming of information.

Meanwhile, *independence* and *diversity of opinion* in an information system is vital to avoid “information cascade” (Easley & Kleinberg, 2010), which states that visibility of everyone’s opinion in a platform could result in an environment where the crowd could influence and imitate each other’s judgments. Social influence and peer pressure could lead to inaccuracy in the average of collected crowdsourced inputs.

Materials and Methods

This study adopted a quantitative content analysis design. Technical communication researchers use content analyses to reveal themes and relationships among different concepts, through comparison of existing contents (Thayer, 2007). This study specifically used web content analysis, as it focused on the content of crowdsourcing web platforms.

Identifying the Coders

Coding was done in two phases. For phase one, four coders were identified based on their knowledge and experience in crowdsourcing. Two coders (including the researcher) were BS Development Communication undergraduate students of the University of the Philippines Los Baños. The third coder was a member of a crowdsourcing website while the fourth coder was a Social Media Producer for Rappler, an internationally recognized crowdsourcing-advocate organization that handles Project Agos (one of the sampled websites). For phase two, four coders from various fields—computer science, engineering, biology, and communication—were tapped. The variety of fields is reflective of *diversity*, one of the WC criteria (Surowiecki, 2004).

Sampling

With the use of online databases, 23 crowdsourcing websites for humanitarianism were purposively sampled. Samples were selected based on these predetermined criteria:

1. Each website must contain recognizable content on a current and/or past crisis regardless of location.
2. Access to crowdsourcing activity page must adhere to any or all of the WC criteria:
 - a. Website is open to all countries and professions (decentralization);
 - b. Website does not provide contents that will preempt ideas of the users (diversity of opinion); and
 - c. Website allows users to work without being influenced by other’s opinions (independence).

3. Homepage of the website must explicitly announce the need for information from the users. Thus, there must be an “open call.”

To ensure reliability of analysis, coders were provided identical databases containing 255 screen shots taken from the sampled websites. The database included all relevant pages/sections, including the activity page, instruction page, about page, blog page, FAQ page, as well as important secondary sources.

Research Instrument

Two sets of codebooks were developed, one for each phase of coding. The first codebook looked into the websites’ input-output instances based on CIS. Meanwhile, the second codebook assessed the websites according to WC criteria.

Data Collection Procedure

For the first phase of coding, all crowdsourcing instances (e.g., type of task, input, and output) were identified using a specific coding scheme, and classified these instances according to their difference and value. Characteristics under difference and value were represented numerically as 0 (absence) and 1 (presence). Data under the variables “type of task,” “input,” and “output,” on the other hand, were coded as string variables in the first round of coding. For reliability analysis, they were then converted to a data file consisting of numeric codes.

For the second phase of coding, another set of independent raters qualitatively evaluated the adherence of the sampled crowdsourcing websites to WC criteria (see Table 1). These observations were then transformed to quantitative data through frequency counts of websites that were observed to employ the given set of characteristics.

Table 1. Guide questions and indicators used to evaluate WC criterion.

Criterion	Guide Question	Indicator
1. Decentralization	- Is the website open to all ages, genders, races, and professions? - Is it accessible by anyone from anywhere in the world?	Presence of sign-up/log-in options should not lead to domination of members with homogeneous characteristics.
2. Diversity of Opinion	- Does the website NOT provide contents that will preempt ideas of the users? - Does the website NOT pose any tendencies for users to “abandon their own information in favor of inferences based on earlier people’s actions?”	Actions and information from other users should not be visible in the main input/ activity page.
3. Independence	- Does the website allow for individual judgments? - Does the website allow users to work without being influenced by other users?	Elements displayed in the activity page should be limited to task-related options.

Intercoder Reliability

To test for internal consistency reliability, Krippendorff's alpha (α) or Kalpha was computed. Quantification of the agreement of the coders was computed using this formula:

$$\alpha = 1 - \frac{D_o}{D_e}$$

...where D_o is the observed disagreement and D_e is the expected disagreement. Kalpha ranges between 0 and 1, and is analyzed as follows:

Poor	K<0
Slight	0 to 0.20
Fair	0.21 to 0.40
Moderate	0.41 to 0.60
Near	0.61 to 0.80
Perfect	0.81 to 1.00

ReCal, an online reliability calculator, was used to countercheck the computation.

Results from the first Kalpha test revealed that four out of the twelve variables achieved only moderate agreement with a Kalpha of <0.55 (See Table 2). Adjustments to the codebook were then made and an additional round of coding for those four variables was conducted until a stronger level of reliability was achieved.

Table 2. Summary of the intercoder reliability tests.

Variable	Intercoder Reliability	
	Test 1	Test 2
WC Criteria		
• <i>Decentralization</i>	1.00	1.00
• <i>Diversity of opinion</i>	0.54	0.85
• <i>Independence</i>	0.46	0.88
Types of task	0.52	0.79
Crowdsourced inputs	0.85	0.88
Medical and disaster responses		
• <i>First degree output</i>	0.52	-
• <i>Geographic Crisis Map</i>	-	0.91
• <i>Text database/ resource page</i>	-	1.00
• <i>Second degree output</i>	0.89	0.89
Difference and value		
• <i>Homogeneous</i>	0.85	0.85
• <i>Heterogeneous</i>	0.85	0.85
• <i>Emergent</i>	1.00	1.00
• <i>Non-emergent</i>	1.00	1.00

Observations of the initial results also suggested that variables for first degree output must be further subdivided into two: 1) geographic crisis map; and 2) text database/ resource page. This resulted to the absence of values in the first degree output row (Table 2), and the addition of two different Kalpha values under this variable in the second run of Kalpha.

After the second run of Kalpha, all of the variables achieved a substantial to near perfect level of reliability with >0.70. Four of these variables achieved a perfect reliability (1.0). This indicates that data produced in this study is statistically significant and can be replicated with the same technique, materials, and samples.

Data Analysis

Correspondence analysis of values coded under difference and value was employed using the XLSTAT software. Data were plotted on an asymmetric graph where, difference and value of contributions (Geiger et al., 2011) served as the x-axis (emergent vs. non-emergent) and y-axis (homogeneous vs. heterogeneous), respectively. Results of this analysis served as the basis in classifying each website into the four crowdsourcing archetypes (Geiger et al., 2011), and in describing the characteristics of each one.

Descriptive data analysis (i.e., frequency and percentage distribution) was done to provide a summary of the collected information.

Results and Discussion

Results are discussed in the following order: 1) website's adherence to WC criteria; 2) types of crowdsourced inputs; 3) medical and disaster responses (outputs); 4) weight of significance of contribution; and 5) classification of humanitarian crowdsourcing websites according to the four CIS archetypes. It then discusses the proposed humanitarian crowdsourcing model based on the themes that surfaced.

Websites' Adherence to WC Criteria

Generally, the digital volunteers of the humanitarian crowdsourcing websites satisfied Surowiecki's (2005) WC criteria.

All websites were accessible by anyone on the web—regardless of age, gender, race, and profession. Majority of the websites (65.22%) allowed users to contribute anonymously without specific conditions. Only eight websites (34.78%) required users to sign up for an account. These suggest that the sampled websites encourage forming a decentralized crowd in humanitarian crowdsourcing systems.

Meanwhile, 21 websites (91.30%) were found to exhibit a system that values "private information," and therefore allows diversity of opinion. Similarly, independence was observed in 21 (91.30%) sampled websites.

However, it is important to mention that the nature of observed crisis information was different from the types of information in other fields. Crisis information in humanitarian crowdsourcing websites largely constituted reports that could not be easily emulated by others, or would not matter if emulated. For instance, re-posting reports on a missing person would not devalue the system, as compared with emulating product opinions in a crowd-solving business-initiated system (which is the basis for crowdsourcing studies such as that of Geiger et al).

Crowdsourced Inputs

The types of crowdsourced information (inputs) generated in a crowdsourcing humanitarian website could be differentiated into: 1) *type of task*; and 2) *type of crisis-related information*.

Type of task. Five types of tasks were identified, namely: 1) text/image data submission; 2) object tagging; 3) text/image sorting; 4) donation/crowdfunding; and 5) text/image mapping (Figure 2).

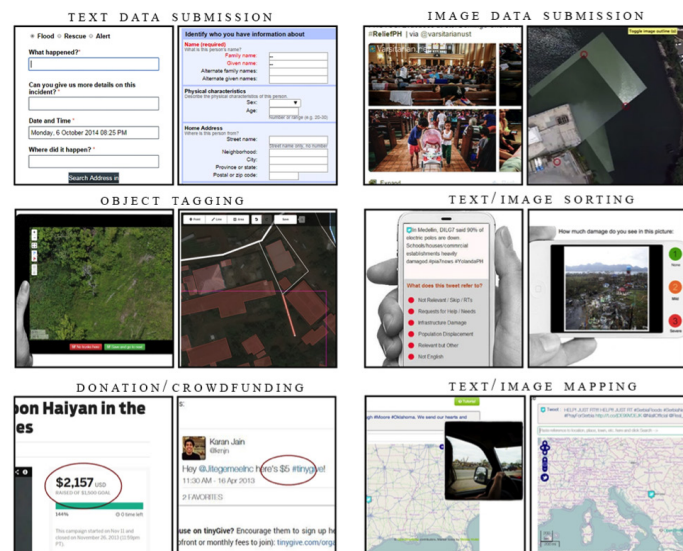


Figure 2. Screen captures of types of task found in the sampled websites.

Text data submission, as observed in 39.13% of the samples, allowed digital volunteers to submit incident reports and details relevant to the current crisis. Observed text data submission websites like Project Agos and Ushahidi provided a text form in the “Report” page, which allowed users to freely contribute crisis-related information, such as flood, rescue, and relief alerts. As the most basic form of crowdsourcing task, text data submission also provided outcomes that lead to operationalization of some of the other types of tasks (i.e., text sorting, text mapping, and crowdfunding). For instance, information collected from social networking sites (SNS) hashtag scheme is further processed and filtered through Micromappers, a text sorting and text mapping web platform. Crowdfunding websites like Indiegogo and TheSparkProject, on the other hand, is powered by individual campaigns created through text data submission.

Image data submission, as observed in the image uploading feature of SNS platforms, such as Twitter and Facebook, allowed the uploading and managing of photos of various scenes of the disaster. This task, which can be closely linked to citizen crisis photography, allowed authorities and responders to analyze current situations in specific locations in real time. In some cases, websites like Mapkitter asked users to either upload their own aerial photographs, or to simply manage and “knit” aerial photographs (uploaded by other users) into an accurate and updated crisis map.

Object tagging, as observed in 21.74% of the sampled websites, posed the virtual act of locating and tagging objects (damaged roads and infrastructure, injured humans, etc.) in a given map or satellite images provided by an external source, such as Google Earth and Digital Globe.

Image sorting, the classification of images according to predefined choices, was observed in 17.39% of the sampled websites. In this type of task, a series of images (provided by an external source, such as Twitter and YouTube) flashed on the screen; users then rated each image as “severe,” “mild,” or “none”, as observed in ImageClicker and VideoClicker apps of Micromappers. In some websites, users are only asked to identify if the image is useful or not, such as the cases of Veri.ly and MapMill.

Text sorting, the least observed employed type of task among sampled websites, entailed the classification of text (usually tweets) according to predefined choices, depending on the situation being solved. The Text Clicker app of Micromappers helped classified tweets relevant to Typhoon Yolanda by asking users to choose from a given set of categories, which included requests for help/needs; infrastructure damage; population displacement; not relevant/skip/RTs; and not English. Categorized tweets from this task are then processed either via a different type task or through an automated system.

Donation/crowdfunding, as observed in 13.04% of the sampled websites, allowed digital volunteers to collectively give financial assistance (often converted to in-kind gifts) via online money transfer systems. It was found that this task always comes after text data submission, where users post an open call for the crowd to send financial inputs.

Text mapping (8.70%) and *image mapping* (8.70%) both required users to identify and enter location of the source of the tweet (TextGeoClicker), and the perceived site where the scene in the images can be possibly found (ImageGeoClicker). Through this, the information coming from the same locations were mapped and analyzed accordingly.

Type of input. There were 17 distinct types of crisis-related information produced in a humanitarian crowdsourcing system. These were further subdivided into four: 1) community-based; 2) infrastructure-based; 3) information-based; and 4) future threats. Table 3 enumerates the specific types of inputs found.

Table 3. Distribution of inputs by category of crowdsourced information.

Category	Input
Community-based	• Relief needs
	• Missing persons
	• Relief operation sites
	• Rescue alerts
	• Emergencies/urgent needs
	• Medical emergency (number of death cases and patients)
	• Population displacement/ community-wide evacuation

Table 3. *Continued...*

Category	Input
Infrastructure-based	• Infrastructure damages (non-passable roads and bridges) • Approximate location of damages and emergencies • Severity of damage • Faulty telecommunication lines
Information-based	• Crucial announcements (Call for volunteers, class suspensions, important hotlines) • Relevance to disaster information • Translation needs • Photographs of crisis geographical locations
Future threats	• Natural hazards (flood reports, weather updates) • Other security threats

Medical and Disaster Response (Outputs)

Analysis showed three phases of transforming crowdsourced crisis information into an actual humanitarian action: (Phase 1) first degree material outputs; (Phase 2) non-material outputs; and (Phase 3) second degree material outputs.

Phase 1. *First degree material outputs* are the immediate results of computer-mediated activities. These were, generally, the visual representations of the summarized crowdsourced information delivered to the responders.

First degree material outputs do not provide direct aid to the affected communities, as there is no intervention from the responders and the authorities at this stage yet. They may come in the form of any or both of the following: 1) geographic crisis map; and 2) text database/resource page (as shown in Figure 3).

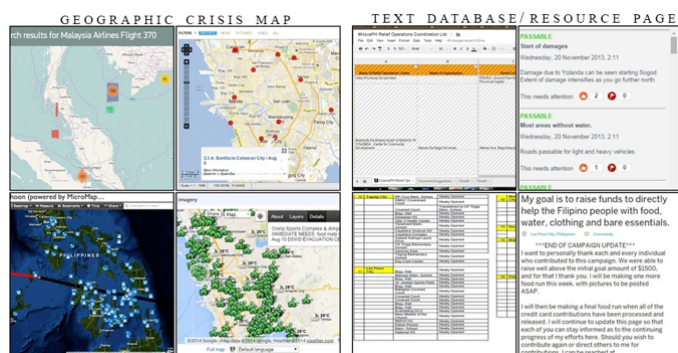


Figure 3. Screen captures of (1) geographic crisis maps and (2) text databases found in the sampled websites.

Phase 2. Humanitarian crowdsourcing platforms also produced *non-material outputs* (e.g. ideation, planning, and strategizing of the partner organizations). Each website has at least one external partner organization—from medical and disaster response groups to national and local government agencies—that directly receives information processed by the website. Some of these partner organizations include: Red Cross International, the World Health Organization, the United States Agency for International Development, the Office for the Coordination of Humanitarian Affairs of

the United Nations, the Federal Emergency Management Agency, Médecins Sans Frontières, and the Cooperative for Assistance and Relief Everywhere. These partner organizations served as the main agents in transforming inputs into non-material outputs, such as: 1) ideation; 2) planning; 3) strategizing; and 4) other intangible outputs significant to transform crowdsourced information into an actual medical and disaster response.

Phase 3. *Second degree material outputs* constitute actual medical and disaster response. These are indirect outputs generated through crowdsourcing websites that lead to a direct impact on an affected community. Observed second degree material outputs include road, bridges, and infrastructure repair; search and rescue operations; power restoration; re-establishment of communication lines; relief operations; financial assistance; evacuation operations; medical assistance; and deployment of volunteers.

Weight of Significance of Contributions

The *weight of significance* of contributions is determined based on difference and value.

Difference of contributions. The type of task posed by a crowdsourcing platform determined the difference of contributions. This is because the type of task, as given in the instruction and activity pages of the website, indicates whether the user is allowed to submit information without restrictions (i.e., heterogeneous), or to just simply choose between/among options (i.e., homogeneous).

A contribution is heterogeneous if the task posed is/are: 1) text/image data submission; and/or 2) donation/crowdfunding. This is because both of these types of tasks seek data that do not need to adhere to a limited type and amount of information.

Meanwhile, a contribution is considered homogeneous if the type of task posed is/are: 1) object tagging; 2) text/image sorting, or 3) text/image mapping, which limits users to a specific type of information.

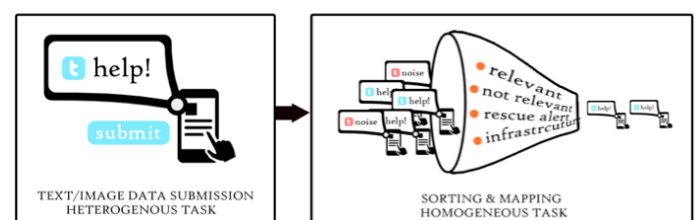


Figure 4. In some cases, homogeneous and heterogeneous tasks co-existed in a single crowdsourcing information system where heterogeneous tasks acted as a strategy to collect “raw” crisis information while homogeneous tasks served as the “filter” mechanism.

Value of contributions. As opposed to the theoretical expectation that a crowdsourcing information system may either have an emergent or non-emergent value, each website possesses **both** emergent and non-emergent values throughout the different phases of a crowdsourcing initiative (Figure 5).

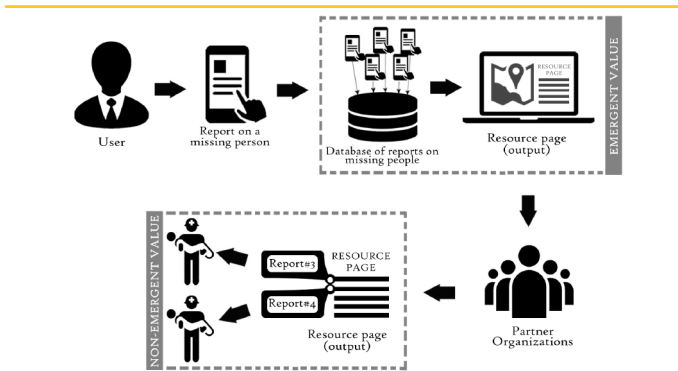


Figure 5. Each input that goes into the system initially has an *emergent* value, as it is taken to be a part of the collection of information and is presented as a *geographic crisis map* and/or a *text database/resource page*. Such information, once received by the responders and the community, loses its *emergent* value and gains *non-emergent* value because, at this point, the reports are processed individually.

CIS Archetypes

Correspondence analysis was used to determine the association between difference and value of the sampled websites in relation to the variables' positions in the perceptual map.

Here, the four quadrants formed by the intersection of the x- (*difference*) and y- (*value*) axes represent *crowd rating* (Quadrant 1), *crowd creation* (Quadrant 2), *crowd solving* (Quadrant 3), and *crowd processing* (Quadrant 4) (see Figure 6). Through this, the emerging CIS archetypes of the humanitarian crowdsourcing websites may be determined.

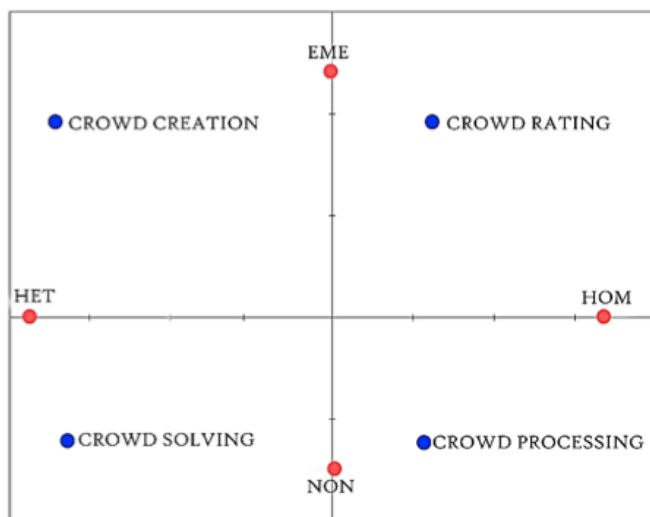


Figure 6. Expected position of CIS archetypes based on value and difference of contributions.

However, results from the correspondence analysis showed a deviation from the expected CIS plot. Since all sampled websites were observed to produce information with both emergent (observed in phase 1 of output) and non-emergent (observed in phase 2 of output) values, the websites formed only two

clusters—across the difference (HET and HOM) axis—instead of four.

Since the clustering of websites landed on the same difference axis, and were only differentiated by type (HET and HOM), the graph presents merging of crowd creation and crowd solving (Quadrants 2 and 3), as well as crowd rating and crowd processing (Quadrants 1 and 4).

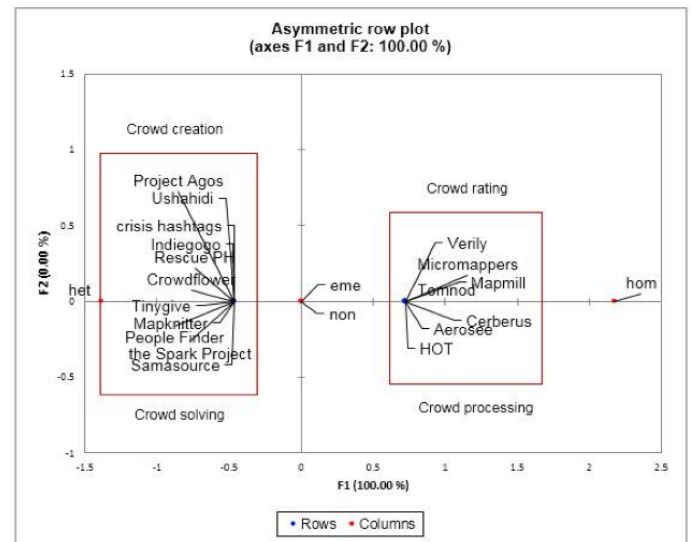


Figure 7. Asymmetric row plot representing the clustering of the websites according to the emerging archetypes.

This merging could be interpreted as the transformation of archetypes from emergent to non-emergent.

From crowd creation to crowd solving archetypes. In general, Quadrants 2 and 3 merged due to the kind of information flow observed on the sampled websites: Crowd creation websites collect heterogeneous contributions and “create” comprehensive databases of texts and maps. These websites then become a crowd solving system as some of the heterogeneous reports are taken among the list and are used to “solve” or respond to a crisis.

From crowd rating to crowd processing archetypes. The merging of Quadrants 1 and 4, on the other hand, could be explained by the phases by which “rates” transform to “processed” information: Crowd rating websites “rate” information according to: 1) relevance and usability (e.g., Micromappers, Mapmill, Verily); or 2) the likelihood of presence of a crisis situation in specific locations (e.g., Tomnod, HOT, Cerberus, aeroSee). These homogeneous “ratings” are then used to produce crisis maps and text databases. As rates turn to filtered information, the websites act as crowd processing systems because they “process” and filter huge amount of raw data.

The dynamic process of humanitarian crowdsourcing does not appear to be boxed into the CIS archetypes. Though the difference and value of contributions were important to determine the characteristics of each system, resulting data did not end up strictly adhering to Geiger et al.,’s (2011) four

CIS archetypes, which arose from analyzing business-oriented websites. Unlike most business crowdsourcing systems where the role of the websites ends online, humanitarian initiatives are expected to conclude with an actual humanitarian response.

Proposed Humanitarian Crowdsourcing Model

Integrating the weightiest findings discussed in this paper, a humanitarian crowdsourcing model (Figure 8) is proposed.

Enabling medical and disaster response through crowdsourcing starts from the aggregated information collected from a wise crowd. Eliciting crisis-related information from a large group of digital volunteers would only be effective if the crowd is composed of individuals with a decentralized demography who willingly contribute their private information and private judgment.

This crowd tosses its information through the different types of tasks posed by humanitarian crowdsourcing websites. The amount and significance of an individual's contribution depend on these tasks, as they limit the kind of input that one can contribute to the system. The types of tasks include: 1) text/image data submission; 2) text/image sorting; 3) text/image mapping; 4) object tagging; and 5) donation/crowdfunding. Through these tasks, crisis-related information is crowdsourced and used to solve real-life crisis situations. The types of information are: 1) community-based; 2) infrastructure-based; 3) information-based; and 4) future threats.

To translate crowdsourced information into actual medical and disaster response, information undergoes processes that result in three types of outputs: 1) first degree material outputs; 2) non-material outputs; and 3) second degree material outputs.

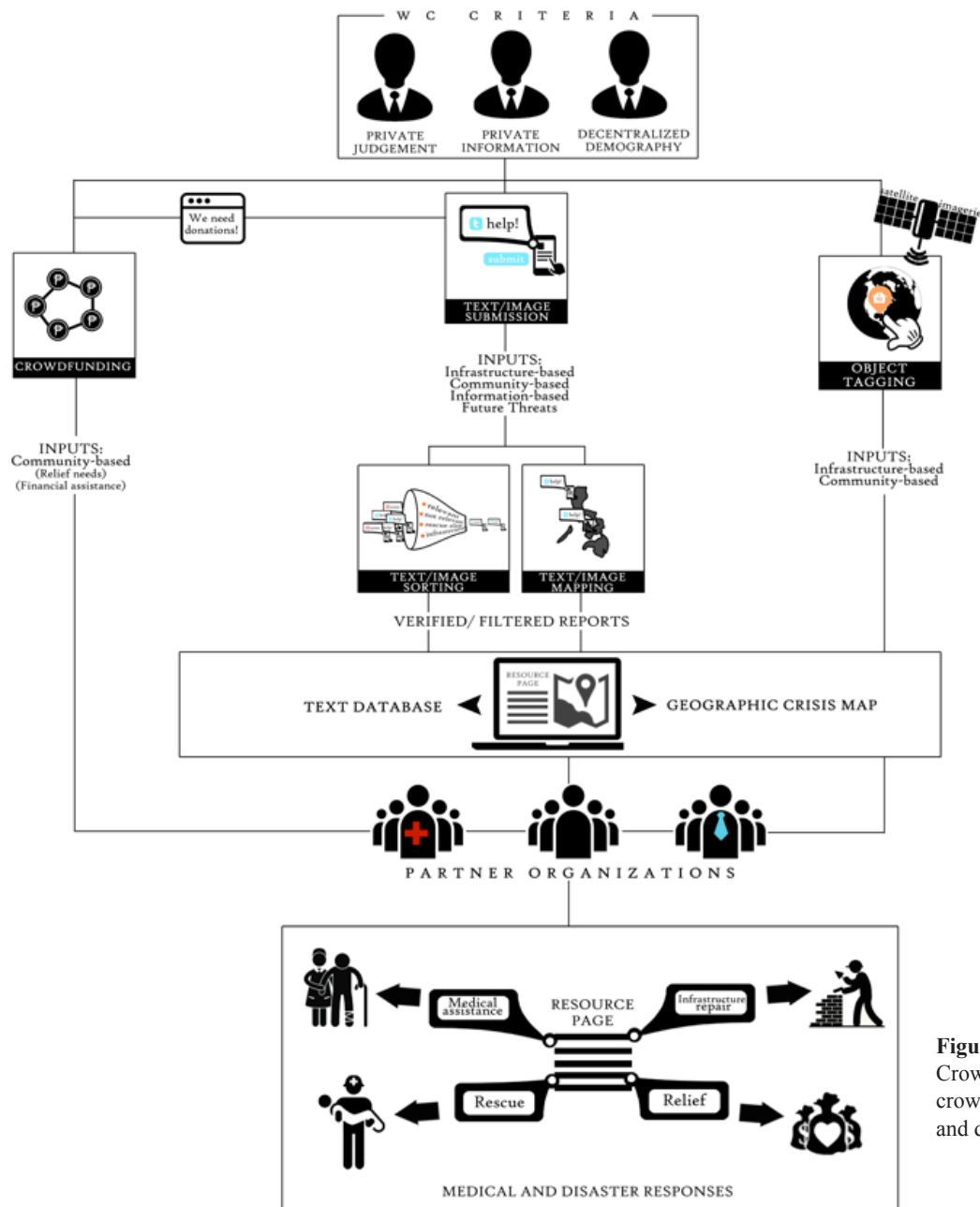


Figure 8. Proposed Humanitarian Crowdsourcing Model illustrating how crowdsourcing platforms enable medical and disaster response.

During the initial phase of transforming information to its desired output, crowdsourced information is presented as a comprehensive geographic crisis map and/or text database/resource page (first degree material output). These outputs are delivered directly to partner organizations (e.g., medical and disaster response groups, local and national authorities, non-government organizations or NGOs), which facilitate the planning, strategizing, and operationalization (non-material output) of the suggested actions.

As the partner organizations act on information that has been crowdsourced, the final phase of humanitarian crowdsourcing is achieved and the actual medical and disaster response (second degree material output) is enacted/delivered to the affected communities.

Conclusion

Enabling medical and disaster response through crowdsourcing consists of integrated elements and processes that co-dependently work as a system.

This study affirms that digital volunteers must be composed of an independent and decentralized crowd with diverse opinions to produce significant outcomes. However, based on content analyzed and results that surfaced, it appears that the nature of the digital volunteers who work for humanitarianism is different from the nature of the online crowd (sometimes paid microworkers) that makes contributions for business purposes (as is the basis of most studies on WC). While Surowiecki's (2005) WC suggests that social influence could lead to emulation of information, some features of a humanitarian crowdsourcing initiative may not necessarily be devaluated if there is repetition of submitted information, especially if it is in the form of raw inputs on critical reports and announcements.

There are two aspects significant in determining the kinds of humanitarian information generated through crowdsourcing: a) type of task; and b) type of crisis-related information. While the types of crisis-related information are more relevant during the actual crisis situation (practical), the types of task prove more useful in describing the nature of the websites (theoretical).

There are two types of material outputs produced in a humanitarian crowdsourcing initiative: a) first degree or the immediate outcomes of a website; and b) second degree or the actual medical and disaster response. A CIS's partner organization enables first degree outputs to be transformed to second degree outputs. This is because it can facilitate non-material outputs (i.e., planning, ideation, and strategizing). Unless the humanitarian crowdsourcing website works with a partner organization, the information crowdsourced on the website would not be acted upon.

The weight of significance of digital volunteers' contributions varies by the difference of the types of tasks and the value they have, to realize actual medical and disaster response. While the homogeneity and heterogeneity of the websites can be easily distinguished through identifying the types of task, this

study concludes that the emergence and non-emergence of the websites must both exist in each humanitarian CIS.

The study's findings conclude that the fundamental dimensions (difference and value of contributions) of Geiger et al.'s (2011) CIS could aid in classifying crowdsourcing systems, but humanitarian crowdsourcing websites did not end up boxed into the four archetypes (i.e., crowd creation, crowd solving, crowd processing, and crowd rating). Instead, humanitarian crowdsourcing websites could be divided based on the types of tasks (e.g., text/image data submission, text/image sorting, text/image mapping, object tagging, and donation/crowdfunding), where homogeneous (filter mechanisms) and heterogeneous (raw inputs) features of the system are given more emphasis.

Recommendation

This study recommends to the humanitarian community and the digital volunteers in the Philippines that they collaborate with web experts in developing a comprehensive humanitarian CIS that would aid in the coordination of various local and national government units, NGOs, local and international humanitarian groups, and digital volunteers during crises. It also recommends to the humanitarian groups, especially to the communication and web experts, to integrate the different types of tasks, types of crisis-related information, and types of outputs in the development of a comprehensive system to optimize the application of crowdsourcing as a method for humanitarian movements in the Philippines. Lastly, this study recommends to further harness the power of social media to attract attention from the public, so that more organizations and individuals would participate and contribute significant information to humanitarian movements in times of disasters.

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Calibration, validation and application of CERES-Maize model for climate change impact assessment in Abuan Watershed, Isabela, Philippines

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Abstract

Recently, corn farmers in Abuan Watershed and Isabela Province are experiencing declining crop yields caused by insufficient amount of rainfall. To increase crop yields and reduce production risks, research on better use of available rainfall and better understanding on effects of climate variability, and soil and field management on crop production is imperative. Simulation models, driven by daily climatic data, can be used to predict the impact of long-term climate variability on the probability of success of a range of crop, and water and soil management strategies.

Calibration of the model was based on field data from Cagayan Valley Research Center at Ilagan, Isabela during two growing seasons in 2013-2015. Model validation of phenology, yield and biomass was undertaken on-station and at farmer fields. Results showed acceptable accuracy between actual and simulated data. Specifically, the model yields high efficiency of 0.86 in predicting yield of participating farmers. It also demonstrated the possibility of simulating production of other hybrid varieties.

Projected yield as affected by temperature and rainfall changes indicated a sharp reduction by up to 44% in 2020 and 35% in 2050. The model can be used as important input in developing decision support system by the Department of Agriculture and local government units.

Keywords: CERES-Maize Model · calibration · validation · Abuan Watershed

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Introduction

It is well accepted in the scientific community that our climate is changing due to rising anthropogenic greenhouse gas emission. According to Intergovernmental Panel on Climate Change (IPCC), the future degradation of soil and water resources will be a major challenge facing global agriculture (IPCC, 2001).

Climate change poses serious threats to Abuan Watershed's ecological services and to livelihoods of farmers (Tongson, 2014). The increasing frequency of inter-annual anomalies from both typhoons and drought in recent years foretell the impacts from global warming. In the early half of 2010, prolonged dry spells caused wilting of rice and corn crops. Yield reductions of corn were recorded at 66% from normal yield. With climate change, anomalies occurring the same year are becoming more common and are likely to get worse. According to PAGASA (2011), the 2050 scenario for Isabela will result in a 1.9 to 2.1 °C increase in temperature, a 29% decrease in mean rainfall for dry months, and a 1.7 to 25.1% increase in rainfall during wet months. This rise in temperature will increase atmospheric demand for water through evaporation and transpiration. The redistribution of rainfall will translate to frequent and more intense flooding during wet months and prolonged dry spells during summer.

In recent years, several dynamic crop simulation models have been developed as information technology tools to support strategic decision-making in research, crop production and land planning (Hoogenboom et al., 1992; Penning de Vries et al., 1993; Hoogenboom et al., 2004). These crop models can be used to evaluate agricultural production risk as a function of climatic variability, to assess regional crop yield potential across a wide range of environmental conditions and to determine suitable planting dates and other management factors for increasing crop yield (Egli & Bruening, 1992; Meinke et al., 1993; Aggarwal & Kalra, 1994; Meinke & Hammer, 1995; Hunt et al., 1996; Chapman et al., 2000).

Crop simulation models would help in investigating climate change impacts on crops. It will help in identifying and prioritizing the management options for adapting to and mitigating climate change effects. It will assess variability in yield or effects of water deficits. Bridging yield gaps and attaining potential yield will inspire farmers to achieve best results in spite of climate change effects.

This study aims to develop a localized Decision Support System for Agrotechnology Transfer - Crop Environment Resource Synthesis (DSSAT-CERES) Maize model using field data and assess future corn production under climate change scenarios. It is intended to support the government initiatives to mitigate climate change impacts to corn production and build resilient corn farms in the province of Isabela.

Methodology

Study Site

Located in the province of Isabela, the Northern Sierra Madre Natural Park hosts the last remaining old-growth dipterocarp

forests in the country. In its western buffer zone lies in the Abuan Watershed, a 63,754 hectare ecosystem that supports the livelihoods of some 2,900 farming households. The higher catchment comprises 44,000 hectares (69%) of the Northern Sierra Madre Natural Park.

The lower sub-catchments consist of farm lands, residual forests and brush lands with an area of 19,000 hectares (31%) of the watershed area. The watershed is named after the Abuan River, which, together with the smaller Bintacan River, drains into the Pinacanauan de Ilagan River, before merging with the Cagayan River. Most of the rice and corn areas are planted at the lowest sub-catchment of the watershed. Rice areas in the watershed are 133 hectares while corn areas constitute 2,779.5 hectares (Figure 1).

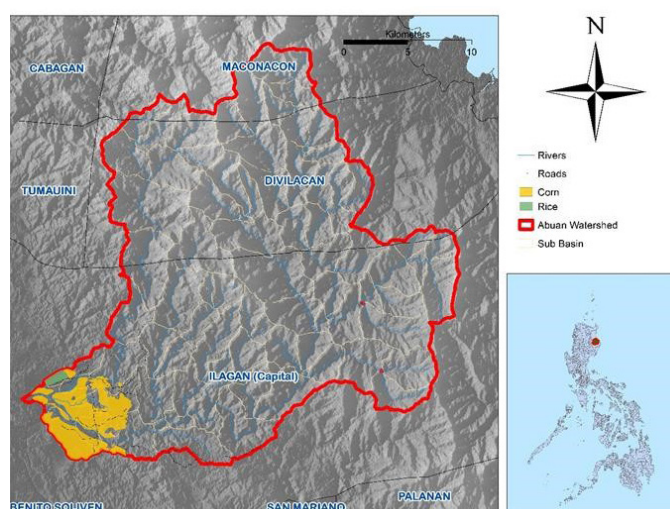


Figure 1. Rice and corn areas in Abuan Watershed

Weather

A 26-year weather data (1988-2014) from the Cagayan Valley Research Center (CVRC) was used for the study area. Average annual rainfall is 2,176 mm and rainy season starts in the month of May and ends in December. Highest rainfall occurs in the month of November with 319.16 mm and lowest during the month of March with 56.99 mm. The hottest month was observed in June with an extreme value of 35.64 °C while coldest month is January with a minimum value of 19.88 °C. Sunshine duration is highest in the months of April, May and June with 6.9, 7.0 and 6.7 hours, respectively.

Soil Characteristics of Experimental Areas

The soil at CVRC site is characterized as alluvial plain with slope of more or less 1%, a soil depth is 100 cm and silty clay loam texture of surface and subsoil. Cabisera 10 is also located in alluvial plain with slope of more or less 1%. Soil depth is more than 100 cm and soil texture of surface soil and subsoil is loam. At Villa Imelda site, the area is situated in rolling terrain with slopes ranging from 8 to 18%. Soil depth is more than 100 cm and soil texture of surface

soil and subsoil is clay. Sindon Bayabo is a hilly area with slope ranges from 18 to 30%. Soil depth is 65 cm and soil texture of surface soil is sandy clay loam, while subsoil is clay.

Table 1 shows some physical and soil characterization of the study areas. Agro-zone is classified based on percent slope. Information on soil characteristics includes soil depth, texture and some chemical properties. As shown, typical corn soil in the watershed are acidic with low contents of organic matter, phosphorus and potassium.

Table 1. Physical and soil characteristic of the study areas

Location	CVRC	Cabisera 10	Villa Imelda	Sindon Bayabo
Corn Farmer	Research Center	Charlito Servilla	Eulalio Paredes	Amado Bolda
Agro-zone	Flood plain	Flood plain	Rolling	Hilly
Slope (%)	≥ 1	≥ 1	8-18	18-30
Soil depth (cm)	>100	>100	>100	65
Texture	Silty clay loam	Loam	Clay	Sandy clay loam over clay
Soil reaction (pH)	5.60 (medium acid)	4.84 (very strongly acidic)	4.66 (very strongly acidic)	5.00 (very strongly acidic)
Organic matter (%)	0.41 (very low)	0.16 (very low)	0.59 (very low)	0.05 (very low)
Phosphorus (mg/kg)	8.30 (low)	6.99 (low)	15.96 (medium)	0.40 (very low)
Potassium (cmol/kg)	0.18 (very low)	0.24 (low)	0.30 (low)	0.36 (low)

Crop Management

In the CVRC site, planting is usually done in the months of December or January with a spacing of 0.75 m by 0.20 m and fertilizer application followed the package of technology for corn. In Cabisera 10, Villa Imelda and Sindon Bayabo, farmers wait when soil moisture is wet enough to commence land preparation and planting. As practiced, planting usually takes place during the months of October and November. Plant population is approximately 60,000 per hectare and fertilizer application rates largely depend on the financial capability of farmers.

Field Experimental Data

Field experiments were conducted for two cropping season under various agro-ecological zones namely: floodplains, rolling

and hilly croplands. Figure 2 shows the locations of these field sites as follows:

1. Villa Imelda - rolling terrain, farmers field, rainfed
2. Sindon Bayabo - hilly terrain, farmers field, rainfed
3. Cabisera 10 - flood plain, farmers field, rainfed
4. CVRC - formerly Cagayan Valley Integrated Agricultural Research Center (CVIARC), flood plain, rainfed and irrigated

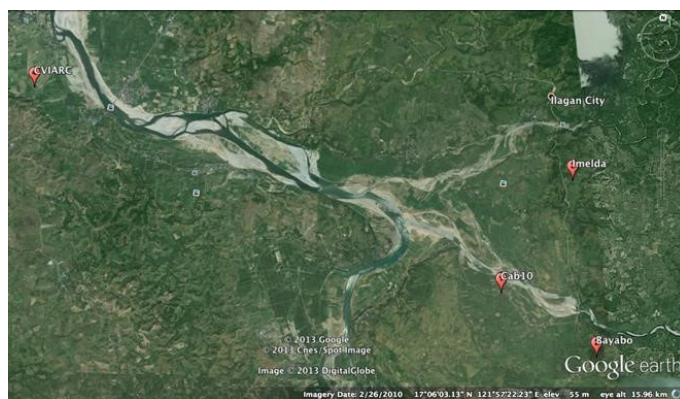


Figure 2. Location of field sites

Maize hybrid, Dekalb 9132, a long season hybrid yellow corn was selected being the preferred choice of most farmers in the Abuan Watershed. Local daily climate data and soil information from each site were gathered and monitored. Phenological events were recorded in reference to date of planting. Biomass data were gathered after every 10 days from emergence to harvest through destructive sampling. Ten plants are chosen in random as samples and were oven dried for 48 hours at 70°C. A harvest area of 5 m by 3 m was designated in the middle of each plot for yield data collection.

Model Description

Advance crop production management support systems need appropriate process-based crop simulation model which utilizes site specific parameters such as weather, physical and chemical properties of soil, water management, and agronomic practices (Penning de Vries et al., 1989). O' Toole and Stockle (1987) described the potential of simulation models in assessing trait benefits of winter cereals and their capacity to survive and reproduce in stress-prone environment. Crop growth models have been used in plant breeding to simulate the effects of changes in the morphological and physiological characteristics of crops which aid in identifying ideotypes for different environments (Hunt, 1993; Kropff et al., 1995).

A process-oriented Cropping System Model (CSM) - Ceres-Maize Model has been developed to simulate vegetative and reproductive development, growth and yield as a function of crop characteristics, climatic factors, soil characteristics and crop management. These models are part of suite of crop growth models that encompass DSSAT (Hoogenboom et al., 2004).

The CERES-Maize model was first introduced by Jones and Kiniry (1990). Over the years, the model has been improved and included as a module in the software package (Ritchie et al., 1989; Hoogenboom et al., 2003; Jones et al., 2003). CSM-CERES-Maize simulates corn growth on a daily basis in response to weather, soil, and environmental conditions, fertilizer rates, and other field management strategies. It simulates plant phenological development, biomass accumulation and partitioning, and final yield production. The CSM-CERES-Maize model can provide a prompt assessment to support decisions in crop production systems that involve risk (Jagtap et al., 1999). Modeled processes include phenological development, i.e., duration of growth stages, growth of vegetative and reproductive plant parts, extension growth of leaves and stems, senescence of leaves, biomass production and partitioning among plant parts, and root system dynamics.

DSSAT software integrates the effects of soil, crop phenotype, weather, and management options. It allows users to ask “what if” questions and simulate results by conducting, in minutes on a desktop computer, experiments which would consume a significant part of an agronomist’s career. It also provides for validation of crop model outputs; thus allowing users to compare simulated outcomes with observed results. Crop model validation is accomplished by inputting the user’s minimum data, running the model, and comparing outputs. By simulating probable outcomes of crop management strategies, DSSAT offers users information with which to rapidly appraise new crops, products, and practices for adoption. The DSSAT package incorporates models of 27 different crops with new tools that facilitate the creation and management of experimental, soil, and weather data files. DSSAT v4.5 includes improved application programs for seasonal and sequence analyses that assess the economic risks and environmental impacts associated with irrigation, fertilizer and nutrient management, climate change, soil carbon sequestration, climate variability and precision management.

In the Philippines, Lansigan et al. (2004) used CERES-Maize in the analysis of corn yield gaps in major corn growing areas where crop genetic coefficients specific for the local corn variety IPB 911 was derived.

The localized model input data was taken from the first cropping experimental set up for all the five sites. Model calibration was undertaken using DSSAT utility program called Generalized Likelihood Uncertainty Estimation (GLUE). The GLUE program was used to estimate genotype-specific coefficients for the local crop model using data from the field experiments i.e., biomass and yield. Information for cultivar specific genetic coefficients is normally not readily available for certain local cultivars. In the first step, a model calibration was conducted to determine the cultivar coefficients for cultivar of corn that is normally grown in the Abuan Watershed.

Using the set of actual data inputs, the GLUE uses an inverse engineering technique to calculate the six coefficients for corn. GLUE iterates the simulation until it determines the coefficients that will give the best goodness of fit between the actual and simulated biomass, phenological events and yield. The derived genetic coefficients will then be copied to the DSSAT database which can be properly named and used to validate the model (Figure 3). The uncertainty of the coefficients is reflected as statistical indicators which are also a measure of the accuracy of the model.

Model Validation

Simulation models are thought to be an indispensable tool for supporting scientific research, crop management, and policy analysis (Fischer et al., 1999; Hammer et al., 2002; Hansen, 2002). However, validation of such models needs to be conducted because these are developed under very specific edaphic and climatic conditions that do not necessarily prevail in other regions of the world. Therefore, before the model can be adopted or used in other locality, evaluation or validation study must be undertaken to establish its credibility (Balderama & Bareng, 2009).

The accuracy of the procedure, used to estimate the genetic coefficients, was determined by comparing the simulated values for the development and growth characteristics with their corresponding observed values and by calculating the values for coefficient of determination (R^2), root mean square error (RMSE)

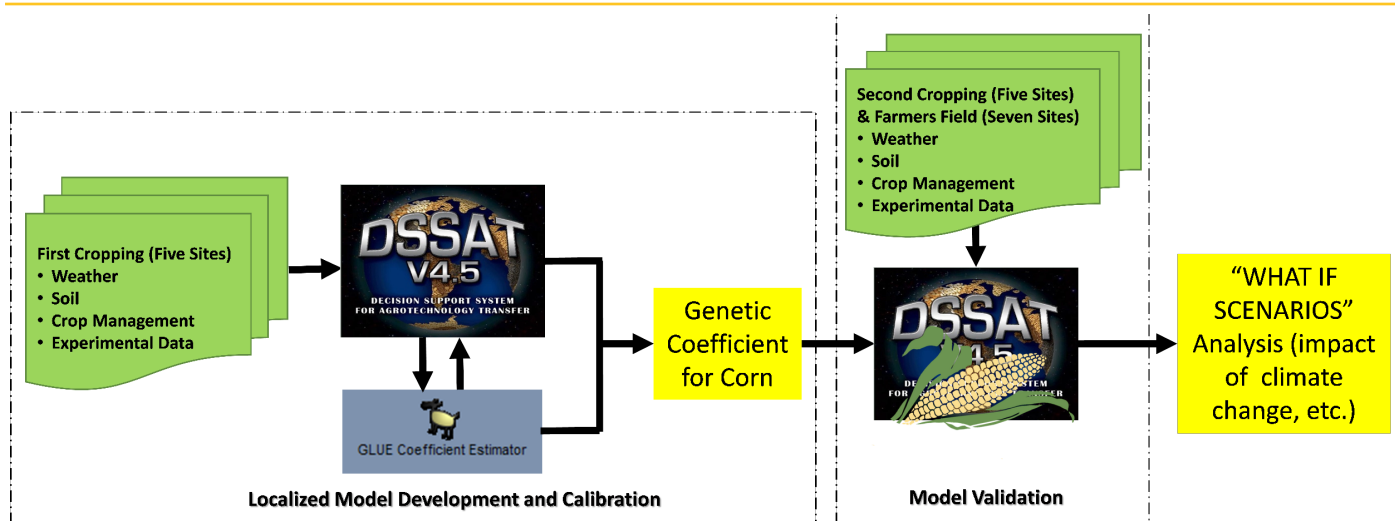


Figure 3. Localized model development, calibration and validation flow chart

as well as the index of agreement (d value). In the results and discussion, the term d-stat will be used instead of d value to follow the term used in DSSAT. The values of R², RMSE and d value indicate the degree of agreement between the predicted values with their corresponding observed values. A low RMSE value and a d value approaching unity are desirable. The R² describes the proportion of the variance in measured data explained by the model. R² ranges from 0 to 1, with higher values indicating less error variance, and typically values greater than 0.5 are considered acceptable (Santhi et al., 2001; Van Liew et al., 2003). The d value was developed by Willmott (1981) as a standardized measure of the degree of model prediction error and varies between 0 and 1. A computed value of 1 indicates a perfect agreement between the measured and predicted values, and 0 indicates no agreement at all (Willmott, 1981). RMSE is one of the commonly used error index statistics (Chu & Shirmohammadi, 2004; Singh et al., 2004; Vasquez-Amabile & Engel, 2005). It is commonly accepted that the lower the RMSE, the better the model performance.

The derived genetic coefficient for corn, actual data from the second cropping season for all the five sites, and the actual data from the farmers were used to validate the model. Model validation for phenological events, biomass and yield was undertaken on same five field sites and twenty four farmer's field sites.

Assessment of Climate Change

Projections are important as basis for adaptation interventions. Table 2 shows the 2020 and 2050 projected weather data from PAGASA which was also used to capture the effect of rise in temperature and change in rainfall amounts in rainfed corn yield. These were produced through downscaling of relatively coarse resolution information from Global Climate Model (GCM) to regional scale. The data are given in percent change of the normal for a three-month period. Normal years identified by PAGASA (2011) were from 1991 to 2000. The normal years climate data used in the simulations were taken from the Agrometeorology station in CVRC, Ilagan City, Isabela. The 2020 climate projection is centered from 2006-2035 and the 2050 from 2036-2065. The emissions considered in this study for the climate data both for 2020 and 2050 were medium range emissions scenario for the province of Isabela. The DSSAT program has a utility for environmental modifications where the projections were inputted as percent change of the normal.

Table 2. Projected temperature and rainfall changes in 2020 and 2050 (PAGASA, 2011)

Simulated year	% change in Rainfall				Increase in Temperature			
	Dec-Feb	Mar-May	Jun-Aug	Sep-Nov	Dec-Feb	Mar-May	Jun-Aug	Sep-Nov
2020 Projections	3.90	-8.60	5.10	13.5	0.80	0.90	0.90	0.80
2050 Projections	25.10	-29.20	8.70	1.70	2.00	2.10	2.10	1.90

Results and Discussion

Calibration of Genetic Coefficients

Calibration was undertaken in the five sites during the first cropping season. Table 3 shows the genetic coefficients of Dekalb 9132 as result of model calibration.

Table 3. Estimated genetic coefficient of Dekalb 9132

Definition	Variable	Unit	Coefficient
1 Thermal time from seedling emergence to the end of the juvenile phase	P1	degree days above TBASE during which the plant is not responsive to changes in photoperiod	287
2 Extent to which development is delayed for each hour increase in photoperiod above the longest photoperiod at which development proceeds at a maximum rate (which is considered to be 12.5 hours)	P2	expressed as days	1.32
3 Thermal time from silking to physiological maturity	P5	expressed in degree days above a base temperature of 8°C	986.70
4 Maximum possible number of kernels per plant	G2	number	528.90
5 Kernel filling rate during the linear grain filling stage and under optimum conditions	G3	mg/day	16.43
6 Phylochron interval; the interval in thermal time between successive leaf tip appearances	PHINT	degree days	45

There are six coefficients derived using local conditions and actual data. Results showed high goodness of fit between simulated and actual above ground biomass. Maize growth reflected through the biomass accumulations was accurately predicted with R² ranging from 0.91 to 0.99 with a d-stat ranging from 0.70 to 0.97 for the five sites.

Also, RMSE values are low which ranged from 1,201 to 2,950 kg/ha of biomass (Table 4).

Table 4. Statistical analysis result between observed and simulated dry aboveground biomass

Site	Standard Deviation		R ²	RMSE	d-Stat.
	Observed	Simulated			
Cabisera 10	3,543.86	3,419.42	0.93	1,201.07	0.97
CVRC (Irrigated)	3,899.12	5,159.72	0.93	2,950.31	0.90
CVRC (Rainfed)	2,537.70	1,937.85	0.99	2,223.02	0.69
Villa Imelda	3,033.28	1,627.94	0.94	1,846.86	0.85
Sindon Bayabo	3,981.63	2,592.47	0.99	2,386.39	0.88

Furthermore, Table 5 shows the close agreement of observed and simulated phenological events.

Table 5. Observed and predicted phenological events

Site	Emergence		Silking		Beginning of Grain Filling		Physiological Maturity	
	Obs.	Sim.	Obs.	Sim.	Obs.	Sim.	Obs.	Sim.
Cabisera 10	3	5	61	63	72	74	115	122
CVRC (Irrigated)	5	6	66	68	74	78	110	111
CVRC (Rainfed)	5	6	66	68	74	78	110	111
Villa Imelda	3	5	61	66	80	80	115	111
Sindon Bayabo	3	5	61	65	74	79	115	91

Note: Obs. = Observed; Sim. = Simulated

Model Validation during the Second Cropping

The calibrated genetic coefficients were evaluated using actual data taken from the five sites during the wet cropping season of 2015. The validation process was successful as manifested by the goodness of fit between actual and simulated biomass from the five validation sites. The R² ranged from 0.86 to 0.97 with d-stat ranging from 0.71 to 0.98. Also, RMSEs were low which ranged from 1,718 to 5,725 kg/ha of biomass (Table 6).

Table 6. Statistical analysis result between observed and simulated dry aboveground biomass in the five sites for the model validation

Site	Standard Deviation		R ²	RMSE	d-Stat.
	Observed	Simulated			
Cabisera 10	3,543.86	3,419.42	0.93	1,201.07	0.97
CVRC (Irrigated)	3,899.12	5,159.72	0.93	2,950.31	0.90
CVRC (Rainfed)	2,537.70	1,937.85	0.99	2,223.02	0.68
Villa Imelda	3,033.28	1,627.94	0.91	1,846.86	0.85
Sindon Bayabo	3,981.63	2,592.47	0.99	2,386.39	0.88

The differences between observed and predicted phenological dates in these three sites were not significant. Table 7 shows the observed and predicted phenological dates from Cabisera 10, CVRC Irrigated, CVRC Rainfed, Villa Imelda and Sindon Bayabo.

Table 7. Observed and predicted phenological events from the five plots in days

Site	Emergence		Silking		Beginning of Grain Filling		Physiological Maturity	
	Obs.	Sim.	Obs.	Sim.	Obs.	Sim.	Obs.	Sim.
Cabisera 10	3	4	57	52	66	66	115	106
CVRC (Irrigated)	5	6	66	68	74	78	110	111
CVRC (Rainfed)	5	6	66	68	74	78	110	111
Villa Imelda	3	4	58	58	69	66	115	109
Sindon Bayabo	3	4	58	56	65	69	114	106

Note: Obs. = Observed; Sim. = Simulated

Harvest Yield

Table 8 shows the actual and simulated grain yield from the five plots. Actual and simulated yield showed high goodness of fit with R², RMSE and d-stat of 0.82, 1,118.40 kg/ha, and 0.89, respectively.

Table 8. Simulated and observed grain yield during the first and second cropping

Site	Planting Date	Observed	Simulated
First Cropping			
CVRC (Irrigated)	January 7	5,687	6,096
CVRC (Rainfed)	January 7	2,431	1,915
Cabisera10	October 23	5,500	4,784
Villa Imelda	November 13	2,520	1,423
Sindon Bayabo	November 11	4,620	2,594
Second Cropping			
CVRC (Irrigated)	June 12	8,800	9,163
CVRC (Rainfed)	June 12	8,213	8,777
Cabisera10	June 2	9,867	10,202
Villa Imelda	July 3	5,190	5,024
Sindon Bayabo	June 27	7,167	7,566

Cabisera 10 yielded the highest due to the right timing of rainfall. Also, CVRC irrigated plots yielded high due to the supplemental irrigation applied. Villa Imelda yielded very low due to waterlogging. The grain yield from the Sindon Bayabo site was a rough estimate given by the farmer. The actual yield during the first cropping considered the harvest reported by the farmer cooperators in Sindon Bayabo and Villa Imelda instead of the final harvest data gathered from the 3 m by 15 m due to inconsistencies brought about by the terrain in the area. The variability in the two sites was corrected in the second cropping through representative sampling at the top, middle and bottom of the slopes.

Similarly, the model predicted the second cropping season harvest yield very close from the actual yield with 3.20 to 6.87% difference. It showed better agreement between actual and simulated yield compared to the calibration experimental set ups. The validation experiment yielded a low RMSE of 387 kg/ha while it had high R2 and d-stat with both value of 0.99.

Model Validation from Farmers' Field

Twenty-four farmers in the watershed participated in the validation of the model in the wet season period of 2015. Table 9 shows the profile of farms, date of planting, variety actual yield and simulated yield.

Table 9. Profile of farmer participants

Name	Agro Ecozone	Date of Planting	Variety	Yield	
				Observed	Simulated
Anthony Bernabe	Flood-plain	12-May-15	DEKALB 6819	6,533	7,101
Arman Bolda	Hilly	08-May-15	NK 8850	5,560	5,411
Arsenio Caeliong	Rolling	14-May-15	NK 8840	1,000	1,775
Bong Pangalina	Rolling	28-Apr-15	NK 8840	3,248	3,669
Charlie Servilla	Flood-plain	09-May-15	DEKALB 9132	3,689	3,900
Clarita Magudang	Flood-plain	15-May-15	DEKALB 6819	3,919	6,119
Clemente Lorenzo	Flood-plain	13-May-15	NK 8850	5,795	5,517
Elidior Morales	Flood-plain	12-May-15	DEKALB 9132	4,000	4,511
Franklin Cortez	Flood-plain	18-May-15	DEKALB 9132	3,600	4,419
Freddie Crispin	Hilly	03-Jun-15	DEKALB 9132, PIO-NEER 3774	2,800	3,096
Isagani Bueno	Flood-plain	23-May-15	DEKALB 6919	4,960	5,363
Jessa Pascua	Hilly	13-May-15	PIONEER 3774	2,987	3,218
Jessie Ramiscal	Flood-plain	11-May-15	NK 8840	7,760	7,412
Juan Bajo	Hilly	26-May-15	DEKALB 9132, PIO-NEER 30T80	4,800	4,975
Lolita Quitola	Flood-plain	12-May-15	DEKALB 9132	4,060	3,794
Luz Dumalag	Rolling	23-May-15	DEKALB 9132	2,005	2,725
Maxvel Benzal	Hilly	12-May-15	PIONEER 9047	4,640	3,796
Me-anne Gamiao	Hilly	12-May-15	Not Specified	3,093	3,213
Myrna Lung Ayan	Flood-plain	27-May-15	NK 8840	6,480	6,322
Regie Turqueza	Hilly	28-May-15	NK 8840	2,700	2,817

Table 9. Continued...

Relina Torres	Rolling	23-May-15	DEKALB 9132, NK 8850, NK 8840	1,456	3,857
Vilma Paredes	Rolling	13-May-15	DEKALB 9132	1,880	1,685
Violeta Briones	Flood-plain	14-May-15	DEKALB 9132	4,410	4,978

Seven farmers planted DEKALB 9132 and seventeen farmers planted other hybrid varieties. Simulated and actual yield showed high goodness of fit for DEKALB 9132 farmers actual and simulated yield with high R2 of 0.86, low RMSE of 524 kg/ha and high d-stat value 0.87 (Figure 4).

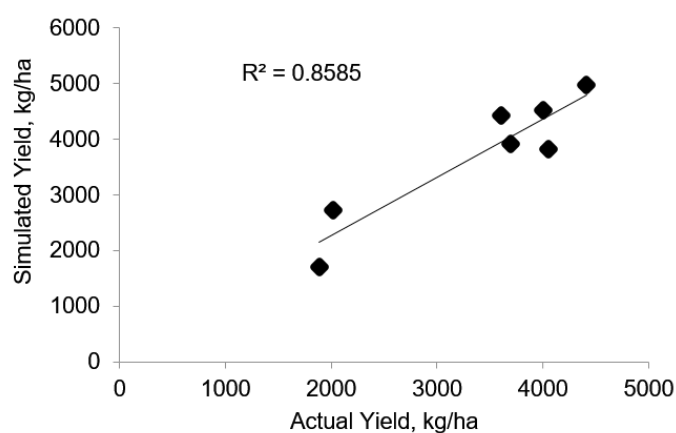


Figure 4. Simulated vs actual yield of the participants who planted DEKALB 9132 in Abuan

Moreover, outputs showed the possibility of the model to be used for other hybrid varieties. Actual farmers yield for other hybrid varieties had high R2 of 0.81, low RMSE of 875 kg/ha and high d-stat of 0.93 (Figure 5).

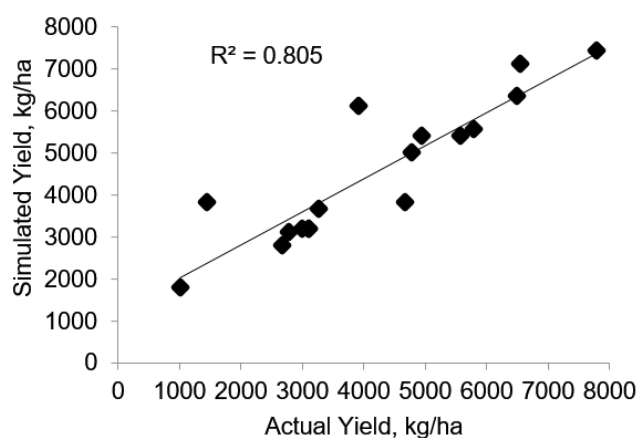


Figure 4. Simulated vs actual yield of the participants who planted other hybrid varieties in Abuan

Impact of Climate Change

Assumed planting date is January 1 which is a dry season. Yield reduction is highest during this season. Recommended fertilizer application rate and a CO₂ emission level of 380 volumes per million (vpm) were used in the crop simulations. Results showed that corn yield would sharply reduce by 44% in 2020 and by 35% in 2050 (Figure 6).

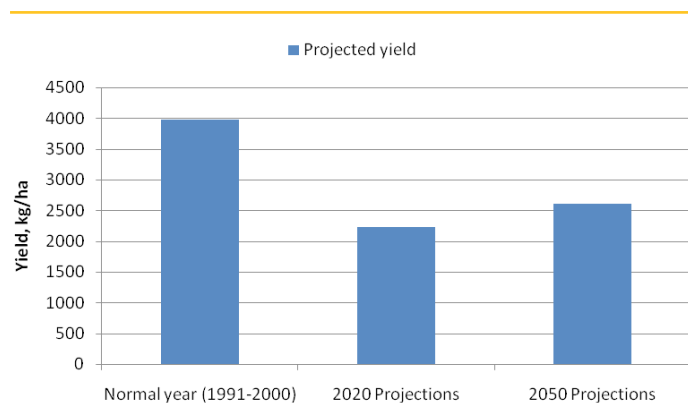


Figure 6. Yield projections for the year 2020 and 2050

These predictions are helpful in formulating strategies to alleviate the effects of extreme drought brought about by climate change. Introduction of drought-resistant corn varieties; provision of irrigation projects; selection of the best date to plant, best date and amount of irrigation, best date and amount of fertilizer application; and crop diversification are among the intervention options to build resilience in corn farms. Moreover, the localized DSSAT-CERES Maize Model can be used to create farmers' decision support system which is a platform for crop forecasting

The policy management is one very useful application of crop simulation models. The issues range from global (impacts of climate change on crops) to field level (effect of crop rotation on soil quality) issues. Thornton et al. (1997) showed that in Burkina Faso, crop simulation modeling using satellite and ground-based data could be used to estimate millet production for famine early warning which can allow policy makers the time they need to take appropriate steps to ameliorate the effects of global food shortages on vulnerable urban and rural populations.

Conclusion

This study was conducted to estimate the genetic coefficient of hybrid corn cultivar in 2013-2015 using Ceres-Maize Model of DSSAT software. Calibration was done to estimate the six genetic coefficients for corn with input data taken from the dry season cropping. The estimated genetic coefficients are the following: (1) thermal time from seedling emergence to end of the juvenile phase is 287 degree days; (2) 1.315 days of which development is delayed for each hour increase in photoperiod; (3) 986.7 degree days from silking to physiological maturity; (4) maximum possible number of kernels per plant is 528.9; (5) kernel filling rate during the linear grain filling stage and under optimum conditions is 16.43 mg/day; and (6) Phylchron

interval—the interval in thermal time between successive leaf tip appearances—is 45 degree days. Calibration of these coefficients was successful as manifested by close agreement between actual and simulated biomass, yield and occurrence of phenological events.

Using the genetic coefficient estimated from the data observed during the first cropping, validation was conducted using the data set observed from the same five plots during the second cropping. Results showed that these genetic coefficients accurately predicted the actual corn yield, biomass production and phenological stages. Yield data was also gathered from 22 farmers for further validation. The model yields high efficiency of 0.81 in predicting the yield of participating farmers in the watershed. The model also showed possibility of simulating corn production for other hybrid varieties.

Application of the Maize Model was also used to assess the impact of climate change in corn production. Results indicated that corn yield would be reduced by up to 44% in 2020 and 35% in 2050 due to changes in rainfall amount and rise in temperature.

The model can be used as primary input in developing farmers decision support system in response to the need for more effective extension program of the Department of Agriculture and local government units.

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Adaptability of the mental models approach to the development of risk communication messages on climate change for rice farmers in Pangasinan Province, Philippines

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Abstract

The mental models approach has been put forward as a method for investigating laypeople's knowledge, beliefs, and perception as precursor to the development of risk communication messages and strategies. Using means-ends analysis, the paper assessed the adaptability of the mental models approach to the development of risk communication messages on climate change for rice farmers in a village in the province of Pangasinan. Overall, the mental models approach was adaptable as it made possible the systematic and in-depth elicitation of relevant knowledge and beliefs on climate change of both the experts and rice farmers, as argued by its proponents. Likewise, the mental models interviews provided an opportunity for a candid discussion with rice farmer-respondents. It also facilitated the identification of knowledge gaps and misconceptions, paving the way for a focused climate change risk communications. Insights on how the adaptability of the approach may be enhanced were discussed. Among these are the need to ensure that the richness and complexity of interviews with experts and laypeople would still guide climate change communication; the importance of an interdisciplinary team in crafting climate change risk communications; and the possibilities opened up by *Sikolohiyang Pilipino* (Filipino Psychology) or SP methods for more culturally appropriate and sensitive elicitation methods in the mental models approach.

Keywords: Mental models approach · *Sikolohiyang Pilipino* (Filipino Psychology) · climate change · rice farmers

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Introduction

Rice or *palay* is an important major crop in the Philippines, known as the 8th biggest producer and 8th largest consumer of rice in the world (Department of Agriculture [DA], 2012). As a staple food, rice provides 30-50% of Filipinos' total calorie intake (Dawane et al., 2010). Accordingly, rice is grown on 44.60% of agricultural farms in the Philippines in 2002 (Philippine Statistics Authority [PSA], 2014). Over two million households in the Philippines depend on rice farming as a source of livelihood (DA, 2012).

Rice production is facing a grave threat from the impacts of a changing climate. The United Nations Development Program (2006) identified agriculture, where rice production is an important sub-sector, as one of the sectors that will bear the brunt of dangerous climate change risks. Particularly, rice is sensitive to high temperature, floods, drought spells, and salinity—conditions that are aggravated under climate change (Mohanty et al., 2013). Climate change is expected to increase temperature and frequency of droughts and flooding, which will have negative impacts on yields (Mohanty et al., 2013).

Moreover, the Water for Food, Water for Life Issue Brief No. 5 recognized that the “challenge for rice cultivation in the next 50 years is to feed more people, while keeping prices low to benefit poor rice consumers and reducing production costs to benefit poor growers”. It was furthered that this move is vital for poverty reduction in areas where rice is the staple food such as in the Philippines. To meet this challenge, rice cultivation will have to adapt to water scarcity, drought, flooding, salinity and climate change (Carriger, 2007).

The effectiveness of government policies and programs to climate change adaptation and risk management depends in part on stakeholders' values, beliefs, and perceptions on climate change issues. Public perception on climate change largely influences their support or opposition to government policy and/or action (Leiserowitz, 2005; McCright et al., 2013; Stermann, 2011). Further, Lorenzoni & Pidgeon (2006) underscored the importance of taking into consideration the public's views and beliefs, as they are the ones who will be affected by climate policies and programs. As such, the public's risk perception plays a crucial role to climate change adaptation and risk management.

As part of risk management, one method of analyzing risk perception as a precursor to the development of risk communication messages and strategies is the mental models approach. Rooted in cognitive science and cognitive psychology, mental models are “psychological representations of real or hypothetical situations” (Zaksek, 2004, p.1504). Various mental models approaches have been put forward (Bostrom et al., 1992; Lazo et al., 2000; Morgan et al., 2002; Stermann & Sweeney, 2007). Essentially, these approaches involve the elicitation of both expert and layperson mental models; comparison of these models; integration of findings about these models in the planning and development of communication interventions; and evaluation of interventions.

The mental models approach to risk communication has been applied in drugs, vaccines, breast implants, sexually transmitted diseases, human immunodeficiency virus /acquired immunodeficiency syndrome (HIV/AIDS), injury prevention, hazardous chemicals,

radon in homes, power-frequency electric and magnetic fields, nuclear energy sources on spacecraft, wildfires, flashfloods, landslides, and climate change, among others, with more studies on health risks in the context of the environment (Austin & Fischhoff, 2012; Vogt & Shaefer, 2012; Wagner, 2007).

Past studies point to the usefulness of the mental models approach to risk communication; however, studies also point to areas that need further consideration (Bostrom et al., 1992; Cox et al., 2003; Fischhoff, 1995; Morgan et al., 2002; Niewöhner et al., 2004; Skarlatidou et al., 2012; Vogt & Shaefer, 2012; Zaksek & Arvai, 2004). For instance, according to Cox et al. (2003), the method used in developing the expert influence diagrams unavoidably leads to the loss of the complexity of expert accounts. Niewöhner et al. (2004) stated the importance of validating the expert models through logical soundness and inter-subjective (expert) agreement. Bostrom et al. (1992) also raised the labor intensiveness of open-ended interviews but noted that they were effective in identifying misconceptions. There are also differing perspectives as to which mental models, that of the experts or laypeople, would be used as basis for analysis (Cox et al., 2003; Morgan et al., 2002).

Likewise, most studies dealt with eliciting and creating expert and laypeople's mental models; developing risk communications; and evaluating these communication interventions (Skarlatidou et al., 2012; Wood et al., 2011).

As the mental models approach offers a systematic and evidence-based method for determining what people know and need to know about risks, there is a need to explore its adaptability, especially since few studies solely focus on an assessment of the approach and studies on the mental models approach have been predominantly oriented in the context of Western countries.

As such, this paper aims to assess the adaptability of the mental models approach to the development of risk communication messages on climate change for rice farmers in a village in Pangasinan Province, Philippines. Specifically, the paper explores the prospects and constraints of the mental models approach and recommends ways on how the mental models approach to risk communication may be taken forward.

Theoretical Considerations

Through the years, risk communication practice has developed from pre-risk communication stage wherein the public is largely ignored to a stage wherein the public is treated as partners. According to Strydom (2002), “from restricted and exclusive expert ethos of risk calculation and assessment, risk discourse shifted to a more open ethos of wide-ranging participation in the discursive construction of risk through public communication” (p.34). A corollary of these developments is intensified efforts to communicate to the public about risks as a part of risk management.

Understanding how people perceive risks is a necessary step towards the public becoming partners in risk communication, and ultimately, in risk management. Efforts to understand the dynamics of risk perception are vital to effective risk communication about hazards (Löfstedt & Frewer, 1998) as results of risk perception studies are fed into risk communication programs. However, failure

of various risk communication initiatives has prompted the need to take a closer look at the nature and dynamics of risk perception, with stakeholders' mental models as one of the conceptual angles identified (Löfstedt & Frewer, 1998).

Mental models are cognitive representations that people use as a basis for making decisions. Similarly, Stermann and Sweeney (2007) stated that mental models have been defined as "domain knowledge, typologies for categorizing experience, and heuristics for judgment and decision-making, among others" (p.215). Proponents of the theory of mental models argue that people understand a phenomenon using a 'working model' of that phenomenon in their minds (Johnson-Laird, 1983, 2004, 2006). People use these "working models" or mental models as frameworks for decision-making and action.

Bostrom et al. (1992) developed a mental models approach composed of the following steps: a) creation of an expert influence diagram; b) elicitation of laypeople's relevant beliefs; c) mapping of these beliefs into the diagram; and d) identification of gaps and misconceptions. Meanwhile, Morgan et al. (2002) went further by developing a five-step method for creating and testing risk messages based on the mental models approach: a) creation of the expert model using an influence diagram; b) elicitation of laypeople's mental models; c) creation of confirmatory questionnaire; d) development of communication intervention; and e) evaluation of communication intervention. Essentially, the mental models approach to risk communication entails eliciting expert's models and laypeople's mental models; comparing these models to identify gaps and misconceptions; determining the prevalence of these to the population; and developing and evaluating communication interventions (Austin & Fischhoff, 2012).

Methodology

The mental models approach to risk communication was evaluated using the means-ends analysis. Dale (2004) espouses the means-ends analysis in evaluation under the context of development work and identified the following components of the means-ends structure: 1) inputs or the planned resource allocation; 2) implementation tasks or the planned work tasks; 3) outputs or the direct outcome of the work; and 4) benefits.

This paper focused the assessment on the inputs and implementation tasks of the means-ends structure of the mental models approach as applied in the development of risk messages on climate change for rice farmers in a village in Pangasinan Province, Philippines (Figure 1). The inputs included experts' and rice farmers' knowledge and beliefs on climate change and logistics such as orientation of interviewers in mental models interviews. The implementation tasks included: 1) creation of the experts' model of climate change; 2) elicitation of rice farmers' mental models of climate change; 3) comparison of the rice farmers' mental models and experts' model of climate change; and 4) identification of points of convergence and divergence between the rice farmers' mental models and experts' model.

Adaptability was explored by analyzing the prospects and constraints in the inputs and implementation tasks, excluding the outputs, of the means-ends structure of the mental models approach. Prospects and constraints referred to potentials and limitations, respectively,

of the mental models approach used in generating risk messages on climate change for rice farmers.

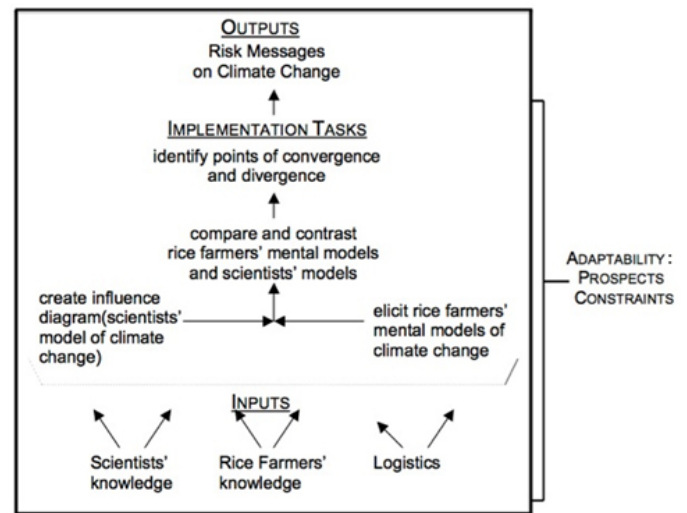


Figure 1. Means-ends structure of the mental models approach to risk communication

Moreover, the case study research design was employed, focusing on the evaluation of the mental models approach as it was applied in the development of climate change risk messages for farmers in a village in Pangasinan Province, Philippines. Corollary to this, in terms of scope, this paper did not dwell on a discussion of the experts' model, laypeople's mental models, and risk messages on climate change, although a general description was provided (See Francisco & Tirol, 2010 for a more detailed discussion of these models and the risk messages).

Results and Discussion

Communicating about risks is unique in the sense that one should be mindful that risk has two components, namely, hazard and outrage, as conceptualized by Sandman (2003). The mental models approach to development of risk communication messages and strategies has incorporated both of these components, with the creation of the experts' model to represent the hazard component; and elicitation of laypeople's mental models of a particular risk to represent the outrage component.

Creating the Experts' Model of Climate Change

As it was applied to the development of risk messages on climate change for rice farmers in a village in Pangasinan Province, the mental models approach generated experts' model of climate change that was composed of concepts such as human-induced activities that contribute to greenhouse gas emissions (GHG); various impacts of climate change (e.g., higher temperature, more intense rainfall and flooding, more intense typhoon, and intensified drought); impacts of these on rice crop growth; and various adaptation strategies that rice farmers could employ (Francisco & Tirol, 2010). The experts' model of climate change captured general and specific concepts that

rice farmers need to know to make informed decisions concerning climate change and rainfed lowland rice production system. Through the creation of the experts' model of climate change, "a composite of expert knowledge and beliefs" (Austin & Fischhoff, 2012, p.126), the mental models approach took into consideration the technical component of climate change risks. Sandman (2003) explained that hazard, the technical component of risk, is the "product of probability and magnitude" and more commonly based on experts' point of view.

The experts' model of climate change was created using the assembly method wherein the key concepts on climate change vis-à-vis rainfed lowland rice production system were listed, and relationships between and among them were determined. These key general and specific concepts and their relationships were determined by reviewing relevant primary and secondary sources at IRRI Library, one of the world's most comprehensive repositories of rice literature. The review of literature phase took two weeks to complete and involved examining highly technical literature. This seems to indicate that creating the experts' model could become a time-consuming process. As such, this entails that a risk communicator, tasked to develop risk communication messages on climate change, must have a good background in this technical field as it is applied in a specific context, in this case, rice production. The researcher who developed the initial experts' model of climate change had a technical background in environmental science, thereby facilitating the review and analysis of related literature.

After the review of related literature phase, the initial experts' model of climate change was presented for discussion to four scientists who had specialized knowledge in rice production and/or climate change. Using semi-structured interviews, the scientists were asked to comment on, improve on, and assess its accuracy and relevance to the risk decisions of farmers concerning climate change and rainfed rice production systems. Lasting for an average of one hour, the semi-structured interviews allowed for in-depth probing of the initial experts' model and paved the way for two-way communication between the experts and the risk communicator such that "those being interviewed can ask questions to the interviewer" and "confirm what is already known but also provides the opportunity for learning" (Case, 1990), especially needed if a risk communicator lacks the relevant technical knowledge. In addition, this step in the mental models approach ensured that the experts' model systematically captured all information deemed relevant by experts on climate change to the risk decision-making of the rice farmers as an audience of climate change risk communications, as suggested by Morgan et al. (2002). Flick (2002, p.89) noted that the expert "is integrated into the study not as a single case but as representing a group (of specific experts...)".

Alternatively, the experts' model of climate change could be created through a focus group discussion (FGD), especially if experts are readily and easily accessible to the risk communicator. Further, the experts' model could be developed based on review of literature alone and supplemented only by experts when possible (Cox et al., 2003).

Meanwhile, the experts' model of climate change was visually represented using an influence diagram (Francisco & Tirol, 2010),

"a form of directed network in which each node represents a factor and each connecting arrow represents a predictive (possibly causal) relationship between factors" (Austin & Fischhoff, 2012, p.125).

As part of a method in designing risk communications, representing the experts' model of climate change using an influence diagram ensures that the technical component of risk was carefully taken into consideration. According to the scientist-respondents, the influence diagram prompted them to examine what they knew about climate change and rice production. They also found the influence diagram easy to understand and captured the important factors about climate change in relation to rice production. They realized that other risk communicators could use the final influence diagram on climate change concerning rainfed lowland rice production to inform similar domains/contexts. As one scientist-respondent pointed out, the influence diagram could be used in other ecosystems aside from rainfed, for instance irrigated lowland.

However, similar to findings in other studies, in an attempt to capture all concepts in one influence diagram, the richness of the interviews with scientists was lost in the final consolidated experts' model of climate change, affirming the findings of Cox et al. (2003).

Meanwhile, with the scientist-respondents oriented towards the hard sciences, the experts' model of climate change as represented in the influence diagram did not include adequate concepts and issues from the social sciences vis-à-vis climate change and rice production. The specializations of the scientists were on hydrology, applied meteorology, crop physiology, and agricultural sciences.

Eliciting the Rice Farmers' Mental Models of Climate Change

The rice farmers' mental models of climate change was composed of their knowledge and beliefs about climate change in relation to a rainfed lowland rice production system, specifically, on the causes of climate change, effects of climate change on the rice plant, and adaptation strategies. Compared to the experts' model of climate change, their mental models were incomplete and not well defined (Francisco & Tirol, 2010). Most of the rice farmers observed changes in rainfall patterns; however, most were unaware of any causes of observed changes in climate. In general, the rice farmers related their observed climate changes to decreases in grain yield. On the average, each rice farmer mentioned two adaptation strategies, with use of fertilizers, use of machines for watering crops, and construction of small dikes as the three most common cited adaptation strategies.

Through the elicitation of the rice farmers' mental models of climate change, the mental models approach integrated the public or laypeople's perception of risk. Sandman (2003) explains that the public's perception of a risk gives rise to the non-technical component of risk, that is, outrage, defined as an "amalgam of voluntariness, control, responsiveness, trust, dread, among others". Unraveling outrage as a component of risk is important as it is the "principal determinant of perceived hazard" (Sandman, 2003).

The rice farmers' mental models of climate change were elicited through open-ended interviews, also called mental model interviews, with 18 rice farmers.

Lasting for about 20-30 minutes, the open-ended interviews were divided into non-directive and directive stages. Based on a think-a-loud strategy, the non-directive part asked the rice farmers to share everything they knew about climate change. The general prompt question was “Tell me about climate change” and translated in Pangalatoc, the local dialect in the area. The respondents’ knowledge and beliefs about climate change and rice production were elicited with minimum input from the researcher and other interviewers. The open-ended interviews proved to be suitable for a candid discussion of the issue at hand.

The main points brought up by the rice farmers during the non-directive part of the mental models interviews were probed further using neutral prompts (e.g., What can you say about...? Could you elaborate what you mean by...?) The open-ended interviews proceeded with the directive stage when the rice farmer-respondent had no more to say. In the directive stage, rice farmers’ knowledge and beliefs on climate change and rice production not mentioned in the non-directive stage were probed.

Morgan et al. (2002) justified their choice of open-ended interviews over the questionnaire. They explained that the use of questionnaire presumes that one knows beforehand the whole gamut of relevant lay beliefs and misconceptions and “in terms which they are intuitively phrased” (p.23). In relation to this, the proponents of the mental models approach recognized that experts and laypeople perceive a risk differently. According to Morgan et al. (2002) technical and laypeople bound a system differently. Hence, although the structure of the open-ended interviews was based on the experts’ model of climate change, the rice farmers were encouraged to talk freely. In this way, how laypeople intuitively think about an issue, in this case rice farmers vis-à-vis their knowledge and beliefs on climate change, was considered and which aspects of the scientific literature actually matter to them were determined, as explained by Morgan et al., 2002. The various gaps elicited in this study could not have emerged in the unique way by which the respondents phrased them if structured tests were used. In relation to this, according to Wagner (2007), “The danger that messages will be dismissed, misinterpreted, or allowed to coexist with misconceptions is remarkably smaller with this approach” [mental models approach] (p.671).

In light of the above-mentioned premises of the mental models interview, the interviewer must possess certain skills. As part of the logistics involved in following the mental models approach, an orientation on conducting a mental models interview was done. Despite this, review of transcriptions revealed that there were a few instances when the interviewers gave more information to the rice farmer-respondents than what was necessary. These instances were encountered especially when rice farmer-respondents had difficulty answering. The danger here lies in leading the laypeople’s answers to conform to that of the experts’ model and as such, could put into question the accuracy of the mental models elicited from laypeople.

On the part of the rice farmer-respondents, it was observed that compared to those who reached secondary level of education, those who reached only up to elementary level took a longer time in answering the questions, had a hard time answering most of the questions, and entailed more probing. This could be because of the nature of open-ended questions wherein interviewees are more

likely to misunderstand a question and give incomplete or vague answers. This is why probing is very important in mental models interviews.

Meanwhile, all the rice-farmer respondents had a favorable attitude towards participating in the mental models interviews. They saw the interviews as opportunities for learning and expressing themselves, reflecting what the proponents of the mental models approach have envisioned as an outcome—moving towards the public becoming partners in risk communication.

Identifying Points of Convergence and Divergence between the Experts’ Model and the Rice Farmers’ Mental Models of Climate Change

In this step of the mental models approach, the rice farmers’ mental models of climate change were examined with the experts’ model of climate change as a reference point. The extent by which they were similar referred to their points of convergence while gaps between rice farmers’ mental models and the experts’ model referred to points of divergence.

Based on the comparison of the experts’ model of climate change and the rice farmers’ mental models of climate change, most of the gaps were on the human activities that drive climate changes. The concept of GHG, which is important in relating human activities with climate change, was not in the rice farmers’ mental models. Further, rice farmers’ mental models of climate change lacked concepts on the specific effects of climate change on their rice crop, except for drought. Instead, the rice farmer-respondents knew in general terms that climate change has an effect on the growth of their rice crop. Lastly, the rice farmers’ mental models of climate change lacked other viable options for adaptation to climate change, except for those they had traditionally applied (Francisco & Tirol, 2010).

Once the experts’ model of climate change and the rice farmers’ mental models of climate change had been determined, identifying the gaps between their models of climate change was straightforward. The influence diagrams, which visually represented the scientists’ model of climate change and the rice farmer-respondents’ mental models of climate change, were keys in the identification of these gaps. Indeed, comparison of the experts’ and laypeople’s models to identify risk messages that need to be focused on in risk communications has been regarded as one of the strengths of the mental models approach (Damman & Timmermans, 2012; Zaksek & Arvai, 2004). However, in cases when the knowledge gaps are not well defined between the laypeople’s mental models and the experts’ model, it would be more challenging to identify gaps from which risk messages could be crafted.

Identification of gaps was facilitated as well by the qualitative approach in eliciting experts’ and laypeople’s knowledge and beliefs. The qualitative approach generated detailed and context-specific explanations, which has been recognized as one of the strengths of the mental models approach (Damman & Timmermans, 2012).

Based on the foregoing discussion, the creation of the experts’ model of climate change, which could be taken to represent the hazard component of climate change risk on rice farming, offers

opportunities such as in-depth probing of the experts' model of climate change and systematized inclusion of all information deemed relevant by experts to the risk decision-making of rice farmers with regard to climate change. In addition, the experts found the influence diagram easy to understand and adaptable to other ecosystems aside from rainfed, for instance irrigated lowland. Meanwhile, the creation of the experts' model of climate change could become time-consuming and entails that the risk communicator has a good background in the technical field. The richness of the interviews with scientists was also lost in the final consolidated experts' model of climate change, affirming the findings of Cox et al. (2003). Moreover, the experts' model did not include adequate concepts and issues from the social sciences vis-à-vis climate change and rice production, with the scientist-respondents oriented towards the hard sciences.

In terms of the elicitation of the rice farmers' mental models of climate change, which could be taken to represent the outrage component of climate change risk on rice farming, opportunities included enabling the rice farmers to talk freely given the open-ended nature of the interviews. Relatedly, information gaps emerged in a unique way by which the rice farmers phrased them. All the rice-farmer respondents had a favorable attitude towards participating in the mental models interviews. On the other hand, with the questions being open-ended in nature, misunderstanding questions and giving vague or incomplete answers were more likely. Lastly, findings point towards the need to train interviewees on carrying out mental models interviews.

Given these opportunities and constraints, the mental models approach, therefore, is deemed adaptable to the development of risk communication messages on climate change for rice farmers in Pangasinan Province, Philippines. The following section provides some directions on enhancing the adaptability of the approach.

Ways of Taking the Mental Models Approach to Risk Communication Forward

Logistics. Given that an important aspect of the mental models interviews is to elicit "natural and spontaneous" responses from laypeople (Austin & Fischhoff, 2012), an adequate training on carrying out mental models interviews is necessary. The training could even include role-playing of the interview and should encompass coding the interview transcriptions wherein the coders need to understand and be familiarized with the concepts in the experts' model so as to ensure intercoder reliability.

Creating the experts' model. Conscious effort must be made to represent various disciplines, including aspects on power relations (Mathevet et al., 2011), related to the domain or context when choosing experts to be consulted in drawing up the experts' model. In creating influence diagrams to represent experts' model, FGD with the experts is recommended when possible. An FGD is a practicable way of eliciting the experts' model using influence diagrams as it saves time and facilitates more brainstorming and learning among the experts and the risk communicator.

In connection with this, climate change communicators using the mental models approach as one of their tools will benefit

from an organizational set-up that brings together experts from various disciplines. Communicating about climate change entails interdisciplinary teams within an institutional framework to facilitate collaboration (Pidgeon & Fischhoff, 2011).

Eliciting the laypeople's mental models. In the course of the mental models interviews, the laypeople-respondents increasingly open up their minds, feelings, and concerns related to the subject matter at hand. In this regard, orienting the elicitation of mental models to *Sikolohiyang Pilipino* (Filipino Psychology) might prove more fruitful in the context of Filipinos. *Sikolohiyang Pilipino* (Filipino Psychology) is based on perspectives and methods that fit the local history and culture of Filipinos (Clemente, 2011; San Juan, 2006). In this regard, the mental models interviews could explore Filipino laypeople's experienced knowledge (*kamalayan*), awareness of their surroundings (*ulirat*), and information and understanding (*isip*), among others (Enriquez, 1989 as cited in San Juan, 2006). Among the methods that may be employed to explore these are *pakikisalamuha* (level of mixing), *pakikilahok* (level of joining/participating), and *pakikipagpalagayang-loob* (level of mutual trust/rapport) (San Juan, 2006), including data gathering techniques such as *pagtatanung-tanong* (improvised informal unstructured interviews) and *pakikipagkwentuhan* (storytelling or informal conversations) (Clemente, 2011). In this way, the mental models generated are culturally valid (Clemente, 2011). As such SP methods open up opportunities for elicitation methods that are appropriate and sensitive to the Filipino culture.

Furthermore, in line with the values emanating from treating the public as partners in risk communication, the rice farmers' mental models or laypeople's mental models may be presented back to the community for validation and discussion with a larger group.

Comparing the Experts' Model and the Laypeople's Mental Models. Risk communicators should also be conscious of the importance given to the models elicited. Because the approach starts with eliciting the models of experts, the risk communicator might be predisposed to put more importance in the models of experts. Laypeople's mental models should be allowed to emerge on their own. After which, the models can be structurally compared. Ensuring that the laypeople's mental models have a strong contextual element was also raised by Cox et al. (2003), especially in instances when the expert model is used as a structural template from which analysis of data from users will be based (Morgan et al., 2002).

Conclusions

The paper assessed the utility of the mental models approach to risk communication in the development of risk messages on climate change for rice farmers and provided insights on how the approach may be taken forward.

Overall, the mental models approach was adaptable for it made possible the systematic and in-depth elicitation of relevant knowledge and beliefs on climate change of both experts and rice farmers, as argued by its proponents (Morgan et al., 2002).

Likewise, the mental models interviews provided an opportunity for a candid discussion with rice farmer-respondents, affirming Cox et al. (2003); and facilitated the identification of knowledge gaps and misconceptions, paving the way for a focused climate change risk communications. Findings also revealed the constraints of the mental models approach. The creation of the experts' model of climate change could become time-consuming and would entail that the risk communicator has a good background in the concerned technical field. The experts' model of climate change was limited in reflecting the richness of the interviews with scientists and did not include adequate concepts and issues from the social sciences. Further, in the elicitation of the rice farmers' mental models of climate change, the open-ended nature of the questions could likely lead to misunderstanding of questions and giving of vague or incomplete answers. These constraints point to how the adaptability of the approach may be enhanced. A risk communicator should ensure that the richness and complexity of interviews with experts and laypeople, although could not be entirely captured in the influence diagrams, would still guide climate change communication. Likewise, an interdisciplinary team meets the needs of climate change risk communications, particularly in the use of the mental models approach. Further, *Sikolohiyang Pilipino* (Filipino Psychology) or SP methods open up possibilities for more culturally appropriate and sensitive elicitation methods in the mental models approach.

The future of risk communication, as an integral part of risk management, is towards building partnerships with stakeholders. The mental models approach is a step towards this direction. As such, risk communicators should include the mental models approach among their tools.

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Simulating impacts of El Niño and climate change on corn yield in Isabela, Philippines

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Abstract

Advancing climate change and increasing frequency of El Niño events will impact corn growth and development in Isabela Province. This study assessed the potential impact of El Niño and climate change on yellow corn (*Zea mays* L.). The Aquacrop model was calibrated and validated with acceptable accuracy using destructive sampling in four farms in Isabela Province. Yields from past El Niño events were simulated and analyzed. Future yields were simulated using MarkSim daily weather generator. The MarkSim-generated weather files showed good agreement with observed temperatures in our study site but poor agreement with rainfall. The projected increases in temperatures were within the ranges predicted by the Intergovernmental Panel on Climate Change. Projected rainfall patterns showed wet months becoming wetter and dry months becoming drier. Crop simulations showed 7% to 13% reductions in growing cycles and 17% to 41% reductions in mean yields. Reductions in mean yields were due to the larger influence of water stress on dry yields. The 11% to 13% reductions in wet yields were due to effects of rising temperatures than CO₂ fertilization impacts. The expansion of dry months will reduce length of growing seasons and shorten available growing windows for rainfed farms. Changing planting dates and improving irrigation access can help mitigate heat and water stress from climate change.

Keywords: AquaCrop · yellow corn · Isabela · El Niño · climate change · crop model

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Introduction

El Niño and La Niña represent opposite extremes in a complex naturally occurring climate cycle known as the El Niño Southern Oscillation (ENSO)—when the surface air and water temperature in the equatorial Pacific varies from the norm. In the Philippines, El Niño is associated with high temperatures and severe dry spells. It is normally followed by La Niña, which is characterized by heavy rains, severe typhoons, and flooding.

The impact of climate change and variability to food supplies has taken center stage in world food policy and research (Lobell et al., 2008; Ray et al., 2015; Wheeler & Braun, 2013; Osborne & Wheeler, 2013; Porter & Semenov, 2005). Climate model studies are beginning to understand linkages between sea surface warming associated with climate change and increasing frequency of ENSO events (Cai et al., 2014; Li et al., 2013; Cai et al., 2015). The rising frequency of ENSO events in the Philippines will have devastating effects, especially in agriculture (Lizumi et al., 2014; Battisti & Naylor, 2009) where the poorer sectors of society depend.

The severity of these impacts will depend on emission pathways taken in the future. The Intergovernmental Panel on Climate Change (IPCC) introduced Regional Concentration Pathways (RCPs) to standardize projections by modelers of future emissions. RCP2.6 is an emission pathway that leads to very low greenhouse concentration levels that peaks to 490 ppm by 2050 and declines by 2100. RCP8.5 uses a very high baseline emission scenario with greenhouse concentration rising to 1,370 ppm by 2100. Assumptions about driving forces vary with respect to population, economy, land use, primary energy sources, energy intensity, climate policy, and the role of technologies (Van Vuuren, 2011).

Crop models are inexpensive tools that help us understand climate effects on plant growth and development. Crop models developed so far rely on physical concepts of soil, plant water, and climate interactions (Challinor et al., 2009). When coupled with weather generators that are downscalable to represent local weather, crop models can simulate responses of locally grown crops to a range of environmental conditions including climate change scenarios.

Modeling the impacts of climate change on food-producing regions in the Philippines provides better understanding of the range of threats as well as adaptation options available to farmers. As the country's top yellow corn (*Zea mays* L.) and second rice producer, Isabela Province is an important grain producer that supplies the requirements of other provinces including Metro Manila (Reyes et al., 2009; Isabela Provincial Profile, 2016). In 2015, the province produced 1.12 M metric tons contributing 15% to national corn production of 7.5 M metric tons (Bureau of Agricultural Statistics, 2016). While Isabela province is a major grain producer, it is also vulnerable to flooding and dry spells. During the 2010 ENSO event, drought and flooding accounted for PhP2.26 B and

PhP70 M, respectively in damages to the agricultural sector in a single year, according to records from the Provincial Agriculture Office.

Using crop models, we hypothesized reductions in corn growth and development and changes to growing seasons in Isabela. The objectives of this study were to: 1) calibrate and validate the AquaCrop Model for rainfed hybrid corn in selected field sites in Isabela, 2) evaluate the Global Circulation Models (GCMs) and MarkSim weather generator and compare modeled weather with observed data from a local weather station, and 3) assess the potential impact of El Niño and climate change on the growth, development, and yield of rainfed hybrid corn in Isabela.

Materials and Methods

Study Areas

The study areas comprised three rainfed farms located in Barangays (Brgy.) Cabisera 10, Villa Imelda, and Sindon Bayabo, located in the Abuan watershed east of Ilagan City at the foothills of the Northern Sierra Madre Natural Park of Isabela Province. A fourth plot was located in the floodplain inside the experimental station of the Cagayan Valley Research Center (CVRC) of the Department of Agriculture in Brgy. San Felipe, Ilagan City (Figure 1). The farmers in this province rely on small-scale rainfed farming, which is mostly non-mechanized and involves little use of external inputs. Corn farms in this province are located in three agro-ecological zones: flood plain, rolling, and hilly (Reyes et al., 2009). Crop yields differ across agro-ecological zones in Isabela reflecting variations in soil, topography, irrigation, drainage, rainfall, and other climatic factors (Gerpacio & Pingali, 2007).

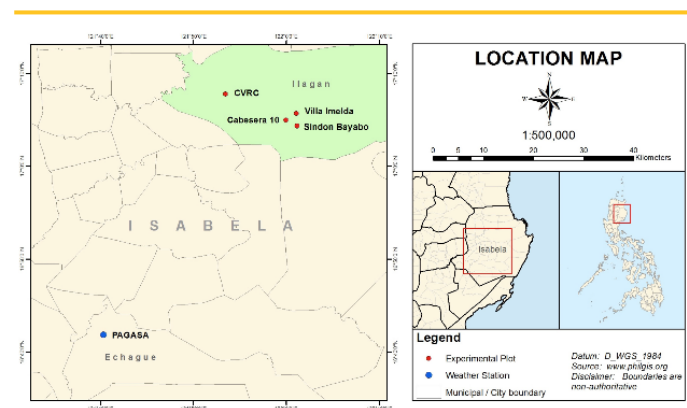


Figure 1. Location map of Villa Imelda, Sindon Bayabo, Cabisera 10 and CVRC farm plots; and PAGASA agrometeorological station in Echague, Isabela.

Agro-meteorological weather stations are located in Villa Imelda and CVRC (Figure 1). Historical weather data were observed at Philippine Atmospheric Geophysical and Astronomical Services Administration (PAGASA) Echague Station.

AquaCrop Model

AquaCrop is a low-input crop water productivity model developed by the Food and Agriculture Organization (FAO) (downloadable at <http://www.fao.org/nr/water/AquaCrop.htm>). It is designed to balance simplicity, accuracy, and robustness, and is suited to address conditions where water is a limiting factor in crop production. It also includes features for carrying out future climate scenario analyses (Steduto et al., 2009; Raes et al., 2009). The AquaCrop model has been parameterized and validated for simulating yield response to water (Hsiao et al., 2009; Heng et al., 2009), therefore making it suitable for rainfed farms. It uses a relatively small number of input variables requiring simple methods for their collection (Vanuytrecht et al., 2011; Abedinpour et al., 2012). Todorovic et al. (2009) recommended AquaCrop under limited input information and water supply conditions.

AquaCrop was used in simulating impacts of climate change on crops in different locations (Hunink & Droogers, 2010; Deb et al., 2014; Masanganise et al., 2012). The model was updated following empirical studies on crop responses to elevated CO₂ conditions (Vanuytrecht & Raes, 2011).

Creating Input Files

AquaCrop requires input files for daily maximum and minimum temperature, rainfall, and evapotranspiration (ET_o). Daily weather data was collected from an automated agro-meteorological weather station located next to the plot in Brgy. Villa Imelda. Solar radiation was recorded from a sunshine recorder and a pyranometer sensor installed at a multi-parameter agro-meteorology station located next to the field plot in CVRC, Brgy. San Felipe, Ilagan City, about 13 km west from the Villa Imelda station. Daily solar radiation was converted to reference ET_o based on FAO Penman–Monteith method as described in Allen et al. (1996).

Soil File

Soil sampling was carried out and brought to Bureau of Soils and Water Management (BSWM) laboratory for analysis. The soils were described as loam, clay, silty clay loam, and sandy clay loam for plots located in Brgys. Cabisera 10, Villa Imelda, Sindon Bayabo, and San Felipe (CVRC), respectively. Soil analyses showed low natural fertility for all farms and high soil acidity with pH values ranging from 4.5 to 5.6. For modeling purposes, field capacity values were set at 16% based on soil moisture sensor readings. Pedo-transfer values for clay loam were set to 8% for permanent wilting point (θ_{WP}), 800 mm/day for saturated hydraulic conductivity (K_{sat}), and 38% (θ_{SAT}) for volumetric water content at saturation.

Irrigation and Field Management

The plots were planted to Dekalb 9132 which is the dominant cultivar planted by farmers. Plant spacing was 6.6 plants/m² based on recommended plant spacing for all sites. Nitrogen

applications adhered to the 120 kg-N/hectare requirement for all plots. All the farms except for CVRC plot were rainfed. Irrigation was applied thrice on the CVRC plot at 32, 47, and 68 days after planting (DAP) at field capacity, during the 2014 dry season. Phenological events (days to emergence, days to flowering, days to senescence, and days to physical maturity) were recorded when 50% of the plants have reached the development stage.

Field Data

Destructive sampling consisted of collecting ten plant samples every ten days from date of sowing until date of harvest in all plots. A 5 m x 8 m sampling area was delineated in the middle of each plot. Farm data consisted of weighed fresh and dry above-ground biomass, and leaf area index (LAI) collected every ten days. Fresh weights of plant specimens were taken using a digital scale balancer. Plant specimens were oven-dried for 48 hours at 70°C and again weighed for above ground dry biomass (i.e., without the roots). The kernels were dried and weighed separately at harvest. The Harvest Index (HI) was computed as dry weight ratio of kernel to above ground biomass.

LAI was converted into Canopy Cover (CC) using the conversion formula in Hsiao et al. (2009).

$$CC = 1.005[1 - \exp(-0.60 LAI)]^{1.2} \quad (1)$$

The average dry weight per plant is multiplied by plant density to arrive at dry biomass per hectare (kg/ha). The user enters dry biomass in kg/ha, canopy cover, and days after sowing.

Model Calibration and Validation

The model was calibrated to generate a set of parameters that can be applied to all three agro-zones as represented by the four plots. The model was calibrated using observed values from the field sampling of the 2014 dry season as input. The crops were grown under optimal conditions, i.e., non-limiting water and nutrients, no pests and diseases. The same conditions are assumed when validating the model and in simulating crop responses to future scenarios. Controlling these variables as well as other sources of yield variability (e.g., soil, slope) was necessary to isolate climate effects on yields.

The number of days to emergence, flowering, start of senescence, and physical maturity were recorded based on farmers' observation and shape of graph depicting percent canopy cover. After entering the DAP for each phenological event, the model was run for each plot to predict biomass, canopy cover and yields through the HI. The default HI value of 0.48 was used.

Validation was done using weather values during the 2014 wet season and by employing the same sampling methods used in the calibration. For model calibration and validation, the predicted versus the observed values for canopy cover, biomass, and phenology were compared and model performance was evaluated using Normalized Root Mean Square Error (nRMSE) (Loague & Green, 1991). Values of nRMSE close to zero

indicate small differences between simulated and observed mean; thus indicating little systematic deviation or bias in the entire data set and expressing precision and reliability of the simulation for observed estimation points. The performance of the model is excellent when nRMSE is less than 10%, good if it is greater than 10% and less than 20%, fair if it is greater than 20% and less than 30%, and poor if it is greater than 30% (Nyang'au et al., 2014). The equation is expressed as:

$$nRMSE = \sqrt{\frac{\sum_{i=1}^n (Si - Oi)^2}{n}} \cdot \frac{100}{\bar{O}} \quad (2)$$

where S_i and O_i are the simulated and observed (measured) values of samples taken along the season (e.g., biomass and CC), n is the number of observations, and $\bar{O}$ is the mean value of O_i .

Simulating Impacts of El Niño

The validated model was used in simulating El Niño effects on yields. Historical daily records from 1987 to 2014 were obtained from the PAGASA station based in Echague, Isabela, which is 58 km southwest to the study area. The dataset was not continuous and daily weather values were available for 19 years, i.e., 1986 to 1989, 1996 to 2001 and 2006 to 2014. AquaCrop was ran over available years assuming planting dates of May 15 and November 15 representing wet and dry seasons, respectively. The El Niño events with corresponding categories set by the Climate Prediction Center (CPC, 2015) included the following: 1987 to 1988 (strong), 1997 to 1998 (very strong), and 2009 to 2010 (strong). The percentage yield anomalies were derived and plotted by planting date. Years with significant yield reductions were analyzed with respect to the timing and distribution of rainfall.

Simulating Potential Impacts of Climate Change

A feature of AquaCrop is the ability to simulate yields normalized to higher temperatures and CO_2 concentrations. MarkSim was used to produce downscaled daily weather values for the study site. The 16 GCMs of MarkSim were evaluated to see how close they predict weather in Villa Imelda station in 2014 using nRMSE scores. The monthly values for temperature and rainfall generated for each GCM were compared with observed monthly values obtained from the Villa Imelda Station for the year 2014. Model skill was evaluated using nRMSE scores.

CSIRO-Mk3.6 (Commonwealth Scientific and Industrial Research Organization) model (Gordon et al., 2002) was selected to generate daily weather files for RCP 2.6 (best case) and RCP 8.5 (worst case) scenarios for both medium-term (2030 to 2055) and long-term (2075 to 2095). The number of hot days (daily maximum temperature $\geq 35^\circ C$), extremely hot days (daily maximum temperature $\geq 40^\circ C$), days with heavy rains (daily rainfall ≥ 100 mm) and annual maximum consecutive days without rains (daily precipitation (P) < 0.1 mm) were counted for both scenarios.

Inter-annual and monthly rainfall variability was measured using coefficient of variation (cv). The equation is expressed as:

$$cv = \sigma / \mu \quad (3)$$

where σ is the standard deviation and μ is the mean.

Time series crop simulations were performed over the medium-term (2030-2055) and long-term (2075-2095) assuming planting dates of May 15 and November 15, representing wet and dry season yields, respectively. Changes in growing periods, plant water demand, wet yields, and dry yields under climate change were noted. Impacts of mitigation measures on yields were simulated.

Results and Discussion

The Climatological Normals for PAGASA Echague Station over the period of 1987 to 2003 is presented in Figure 2. The temperature ranges are $23.7^\circ C$ to $33.9^\circ C$ and $20.1^\circ C$ to $27.3^\circ C$ for the wet and dry seasons, respectively. The corn growing season in Isabela is characterized by warm wet season with temperatures averaging $28.8^\circ C$ from May to September followed by dry cooler season with temperatures dropping to $23.7^\circ C$ from October to March. The average minimum and maximum temperatures for the wet season are $23.7^\circ C$ and $33.9^\circ C$, respectively. During the dry season, the average minimum and maximum temperatures are $20.1^\circ C$ and $27.3^\circ C$, respectively. Cumulative rainfall for the wet season is 891.0 mm and 614.8 mm for the dry season.

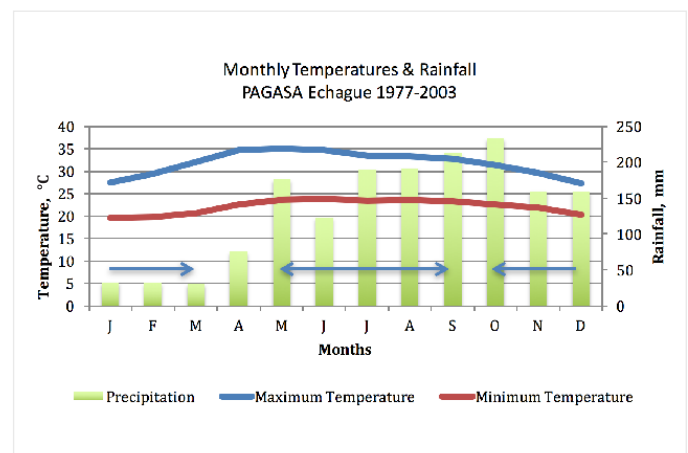


Figure 2. Cropping calendar showing dry cropping season (October to March) and wet cropping season (May to September).

The weather profile during the dry and wet cropping season of 2013 to 2014, as read from the Villa Imelda Station, is shown in Figure 3. The average maximum and minimum temperatures for the dry season (Figure 3a) were $28.1^\circ C$ and $21.5^\circ C$, respectively, with mean of $24.8^\circ C$. The cumulative rainfall was 967 mm, most of which fell in November and December. The average maximum and minimum temperatures for the wet

season (Figure 3b) were 32.6 °C and 23.2 °C, respectively, with mean of 27.9 °C. The cumulative rainfall was 1,040 mm, which was evenly spread from July to November. The dry season was cooler and relatively drier with more sunshine hours. The wet season was warmer, wetter and cloudy.

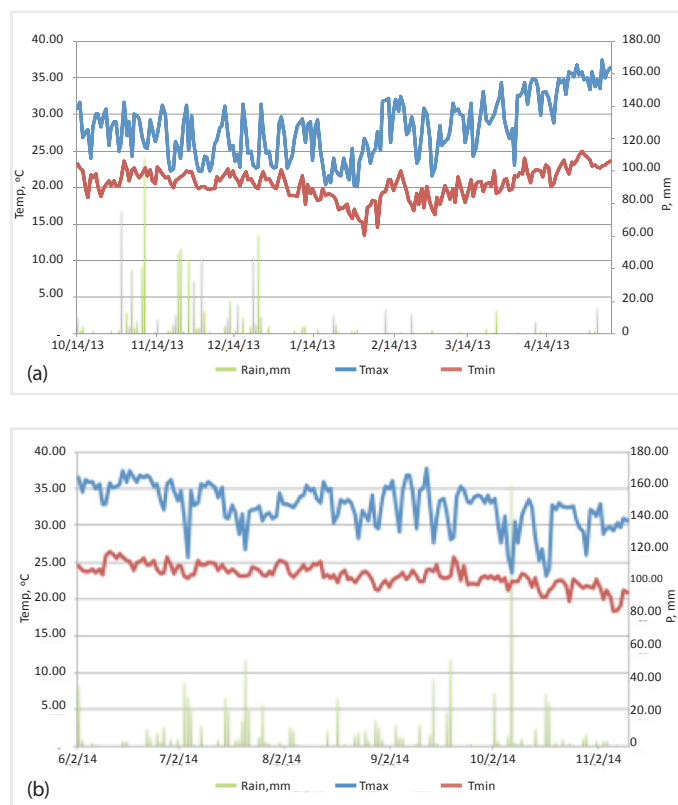


Figure 3. (a) Dry season weather file used in crop model calibration (14 Oct 2013 to 15 May 2014) and (b) Wet season weather file used in model validation (2 Jun to 10 Nov 2014). (Weather file source: Villa Imelda Station).

Model Calibration and Validation

Calibration was done to fit the model to actual conditions over the 2013 to 2014 dry season. The growing period or days to physical maturity was set to 125 days, equivalent to 1,883 growing degree-days. The thermal time from sowing date to emergence, flowering, start of senescence, and maturity were set at 39, 907, 1,503, and 1,883 growing degree-days, respectively. The observed dry biomass clustered at 16 tons/ha at 125 DAP for the four farms. The water productivity (WP*) normalized for ETo and CO₂ was 33.7 gm/m². The temperature above which pollination starts to fail was set at 40 °C. The minimum temperature required for optimal biomass production was 12 °C-day. The reference HI was set at 0.48. The difference between predicted and observed values for biomass and canopy cover was minimized by adjusting soil fertility loss to 38%.

The calibration data set consists of field samples for phenological events, canopy cover, dry biomass, and HI collected over the 2013 to 2014 dry season. The model performance in predicting phenological events (i.e., days to

emergence, flowering, senescence, and physical maturity) was excellent to good based on nRMSE scores. Model performance in simulating canopy cover was good to fair. The model performance in simulating corn biomass production was excellent to good. The observed HI was 0.46, 0.48, 0.52, and 0.51 for Sindon Bayabo, Cabisera 10, Villa Imelda, and CVRC, respectively, with mean HI = 0.49.

Validation results showed acceptable accuracy for AquaCrop. The validation data set consisted of field samples for phenology, canopy cover, dry biomass, and HI collected over the 2014 wet season. The model performance in predicting phenological events was excellent to good. The model performance in simulating canopy cover had a mix of good, fair, and poor nRMSE scores. The model performance in predicting biomass was good for all sites. The observed HI values were 0.48, 0.53, 0.54, and 0.42 for Sindon Bayabo, Cabisera 10, Villa Imelda, and CVRC, respectively, with mean HI = 0.49.

Simulating Impacts from El Niño

Figure 4 shows the time series AquaCrop simulations for years 1986 to 1989, 1996 to 2001, and 2006 to 2014 assuming May 15 (wet) and November 15 (dry) planting dates. High yield reductions of 70% and 68% were simulated for the dry cropping seasons of 2010 and 1998, respectively. Smaller reductions of 19% and 18% were simulated for the dry season of 1987 and 2014. Yield reductions of 19% were simulated for the 2007 wet season.

Figure 5 shows rainfall anomaly for years 1987, 1998, 2010, and 2014. The onset of below normal rains from December to March coincided with El Niño episodes for 1987, 1988 and 2010. Yield losses of 68% to 70% were simulated for 1988 and 2010 when December rainfall fell by more than 100 mm. The onset of drought in December inhibited canopy growth and yield production affecting final yield.

Validating MarkSim

MarkSim-generated weather values from 16 GCMs were evaluated with those from Villa Imelda station for the year 2014 using nRMSE scores. The model performance in predicting average monthly maximum and minimum temperatures was excellent with nRMSE scores ranging from 7% to 8% and 5% to 8%, respectively. However, MarkSim performance in predicting monthly precipitation was poor with nRMSE ranging from 93% to 140%. The good fit for temperature indicates higher confidence that long-term projected temperatures are reliable and can be applied to the study area. However, the poor fit for rainfall indicates low confidence in the projections by MarkSim. Of the 16 GCMs, the CSIRO-Mk3-6 GCM was selected in projecting temperatures and rainfall by 2050s and 2090s.

Change in Temperature

The projected change in monthly temperatures is presented in Figure 6. By 2050, projected increases in average annual

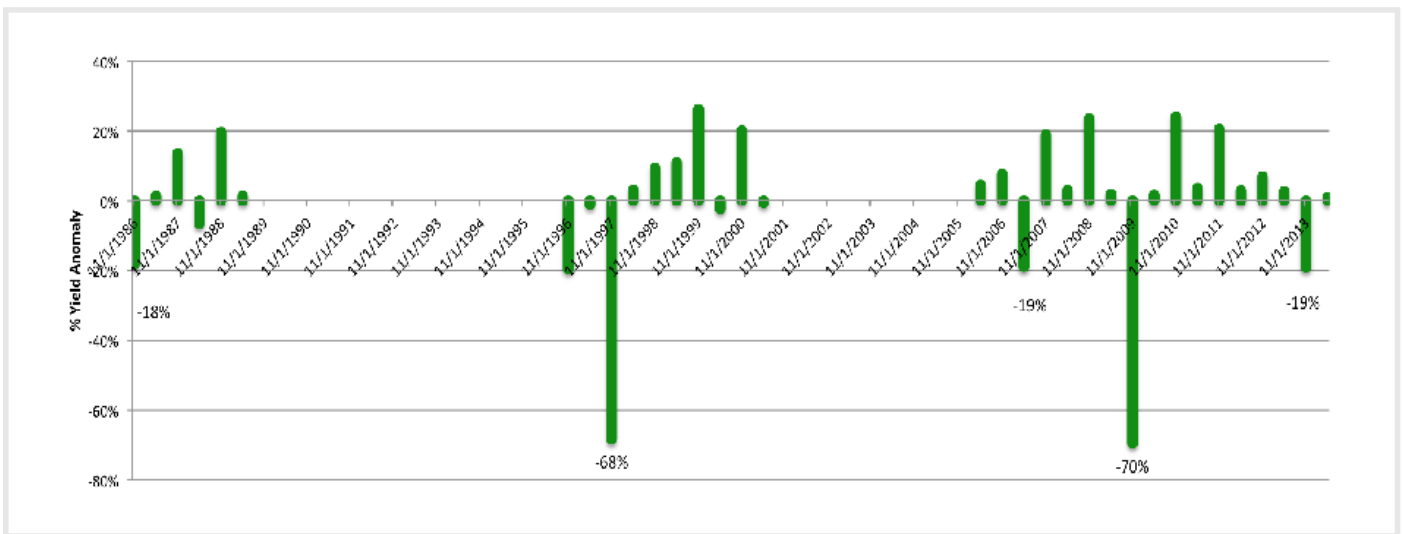


Figure 4. Simulated % yield anomalies by planting dates assuming May 15 (wet season) and November 15 (dry season) planting dates for the period 1987-2014 (selected years). (Daily weather source: PAGASA Echague Station)

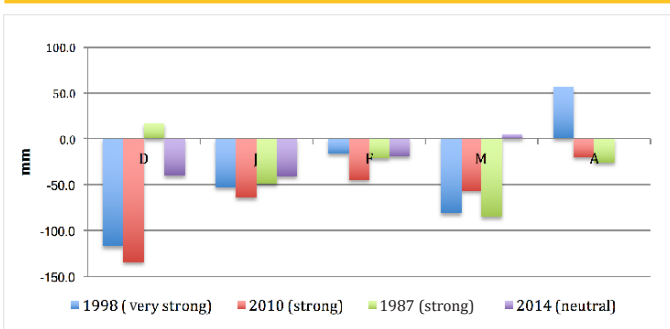


Figure 5. Dry season rainfall anomaly for various El Niño years (1987, 1998, 2010) and 2014 (normal year). (Source: PAGASA Echague Station)

temperature were $+1.38^{\circ}\text{C}$ and $+1.74^{\circ}\text{C}$ for best case and worst case, respectively. Beyond mid-century, the projections start to diverge dramatically. By 2090, the best case scenario shows temperature stabilizing at $+1.96^{\circ}\text{C}$, while the worst case scenario showed an increase of $+4.08^{\circ}\text{C}$.

Table 1 presents the change in temperatures under climate change. The baseline showed CO_2 concentrations of 369 ppm and mean temperatures of 26.9°C for Isabela. The climate scenarios showed increase in CO_2 concentrations ranging from 450 ppm (best case) to 630 ppm (worst case) by 2050 and from 450 ppm (best case) to 1,100 ppm (worst case) by 2090.

By 2050, mean temperatures will increase by $+1.38^{\circ}\text{C}$ from 26.9°C to 28.3°C and by $+1.74^{\circ}\text{C}$ to 28.6°C under best case and worst case scenarios, respectively. By 2090, their tracks will diverge dramatically. The best case scenario showed CO_2 concentrations stabilizing at 440 ppm with lower mean temperature increase of $+1.96^{\circ}\text{C}$, whereas the worst scenario showed mean temperature increase of $+4.08^{\circ}\text{C}$. These projected

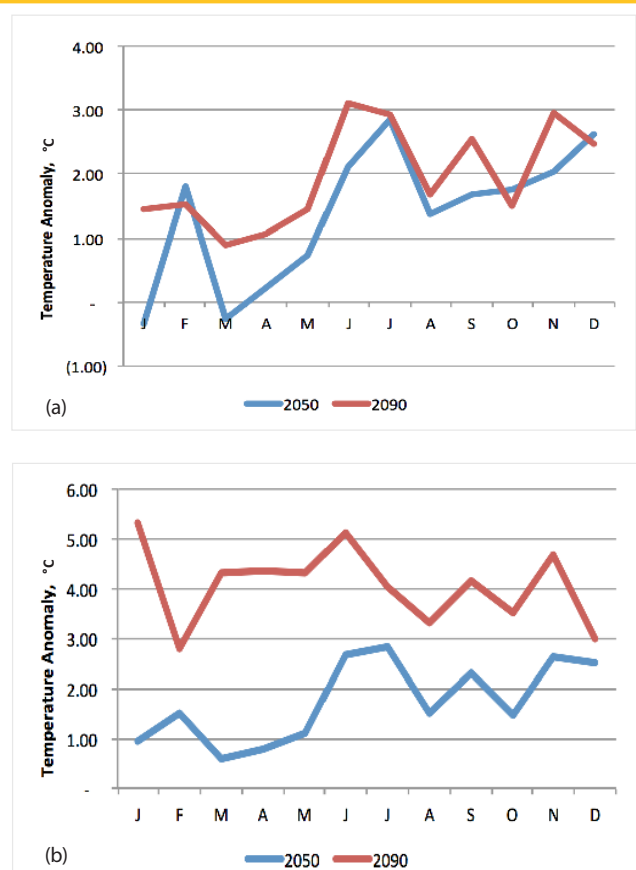


Figure 6. Monthly temperature anomalies under (a) best case RCP2.6 and (b) worse case RCP8.5 scenarios.

increases were well within the range of CO_2 and temperature increases predicted in the 5th Assessment Report of the Intergovernmental Panel on Climate Change (IPCC, 2014).

Table 1. Change in temperature under climate change

Baseline, 1987-2014, n=19	369 ppm CO ₂ , 26.9 °C	
Tmax, °C	31.8	
Tmin, °C	22.0	
No. days with Tmax≥35 per year	60	
No days with Tmax≥40 per year	0.25	
Months with days Tmax≥40	Apr, May, Jun	
Annual ETo, mm	1,368	
	Best Case, RCP2.6	Worst Case, RCP8.5
Medium-term, 2030-55, n = 25	450 ppm CO ₂ , 28.3 °C	630 ppm CO ₂ , 28.6 °C
Tmax, °C	32.9	33.3
Tmin, °C	23.7	24.0
No. days with Tmax≥35 per year	108	123
No days with Tmax≥40 per year	6	8
Months with days Tmax≥40	Apr–Oct	Mar–Oct
Annual ETo, mm	1,583	1,593
Long-term, 2075-94, n=20	450 ppm CO ₂ , 28.9 °C	1100 ppm CO ₂ , 31.0 °C
Tmax, °C	33.5	35.7
Tmin, °C	24.2	26.3
No. days with Tmax≥35 per year	134	218
No. days with Tmax≥40 per year	12	41
Months with days Tmax≥40	Apr–Oct	Jan, Mar–Sep
Annual ETo, mm	1,621	1,740

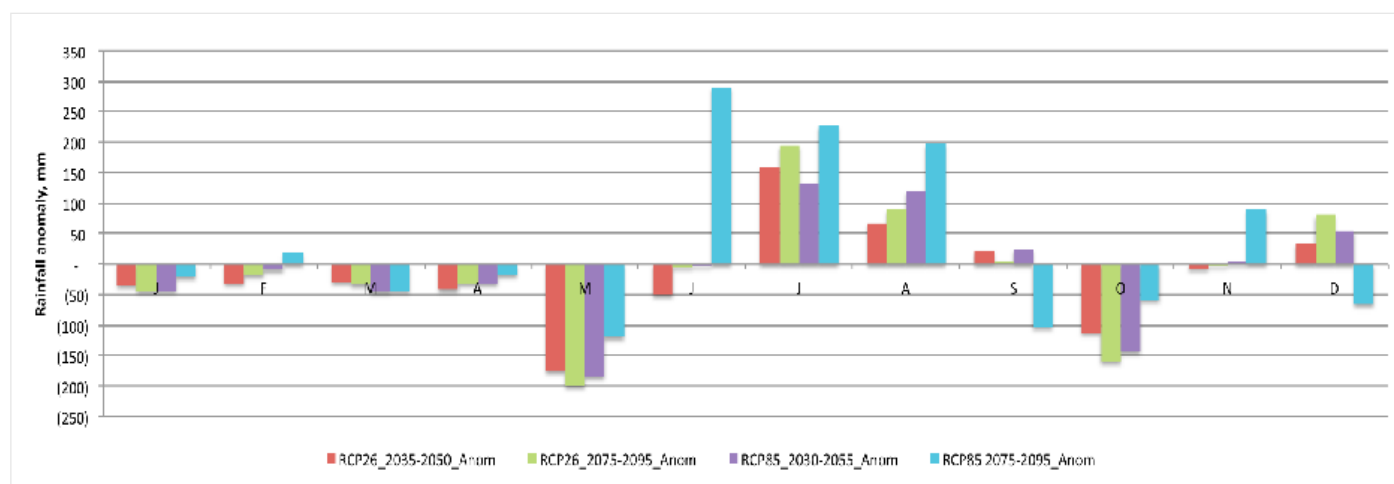
Annual ETo will increase from 1,368 mm to 1,621 mm to 1,740 mm in the long term. The number of extremely hot days will increase from 0.25 days a year to 6 to 8 days a year by 2050 and to 12 to 41 days a year by 2090. Months with extremely hot days will expand from April-June to March-October.

Change in Rainfall

The rainfall distribution under climate change showed a pattern of wet months getting wetter and dry months getting

drier (Figure 7). This indicates higher risk of dry spells during summer and flooding during rainy season. A decrease in rainfall in May will delay the start of the growing season to June, while decreases in January to April rainfall may advance the end of the growing season to December.

Table 2 shows the change in mean and variability in rainfall for the medium-term and long-term. The baseline conditions showed mean rainfall of 2,097 mm, with an inter-annual variability of $cv = 0.19$ over 19 years for the baseline period 1987 to 2014. The inter-annual variation in projected rainfall

**Figure 7.** Projected monthly rainfall anomalies for medium-term (2050s) and long-term (2090s) under climate change

is low with *cv* of 0.04 in the medium-term and 0.02 to 0.05 for the long-term. The variability of projected December rainfall is also low dropping from 0.74 to 0.04 to 0.49 in the long-term.

The annual average maximum consecutive number of dry days was 18 days for the baseline period, mostly occurring in the summer months from January to March. The highest number of days without rain was 34, 30, and 28 days in the months of February 2010, January 1998, and March 1987, respectively, coinciding with El Niño.

The annual average maximum consecutive number of dry days will jump from 18 days to 27 days by 2050, mostly projected in November or October. This contradicted current experience where maximum dry days usually occurred during January to April.

The low variability of projected intra-annual and inter-annual rainfall and the occurrences of extreme events in months outside the current experience in Isabela Province suggests possible failure of the MarkSim weather generator to incorporate the effects of past El Niño and other extreme weather events. This confirms the observation by Jones and Thornton (2000) where MarkSim failed to simulate ENSO effects in Peru and Ecuador, and findings of Mavromatis

and Hansen (2001) where MarkSim showed tendency to overpredict mean monthly rainfall totals, while under representing inter-annual variability of monthly precipitation totals when compared to historical datasets.

Simulating Potential Impacts on Corn

Table 3 presents the results of crop simulations for time slices 2030 to 2055 and 2075 to 2095 for both RCP 2.6 and RCP 8.5 scenarios with reference to the baseline (1987 to 2014). Comparisons were made with respect to growing days, plant transpiration demand (Tx), wet yields, and dry yields.

Simulations show growing days (days to maturity) will be reduced by 7 to 9 days (7% to 8%) by 2050 and by 8 to 15 days (7% to 13%) by 2090. These reductions correspond to 3% to 5% decrease in growing periods per degree rise for all scenarios. By 2050, mean yields will decline from 34% to 41%. By 2090, yields under best case scenario will drop 41% to 4.31 tons/ha, while yields will drop by only 17% under the worst case scenario. Yield reductions ranged from 21% to 25% per °C rise, larger than results from earlier studies (Makadho, 1996; Lobell & Field, 2007; Bassu et al., 2014) and from local studies (Lansigan & Salvacion, 2007). The better yield performance under the long-term worst case scenario was attributed to

Table 2. Change in rainfall under climate change

Baseline, 1987-2014		
Mean Annual P, mm		2,097
cv (across years)		0.19
cv (across months)		0.41 - 0.86
December rainfall, cv		0.74
Ave. no. of maximum consecutive days (P<0.1mm)		18
No. of days with P>100 mm		1-3 times/yr, May, Oct, Nov
	Best Case, RCP2.6	Worst Case, RCP8.5
2050s		
Mean Annual P, mm	1,897	1,974
cv (across years)	0.04	0.04
cv (across months)	0.08-0.62	0.10-0.85
December rainfall, cv	0.18	0.13
Ave. maximum no. of consecutive dry days (P<0.1mm)	27	27
No of days with P>100 mm	1-2 times/yr, Nov-Dec	1-2 times/yr, Nov-Dec
2090s		
Mean Annual P, mm	1,972	2,493
cv (across years)	0.02	0.05
cv (across months)	0.08 - 0.47	3.93-0.02
December rainfall, cv	0.08	0.49
Ave. no. of maximum consecutive dry days (P<0.1mm)	27	24
No. of days with P>100 mm	1-2 times/yr, Nov-Dec	1-2 times/yr, Nov

Table 3. Impacts of climate change on maize yields and adaptation options.

Baseline (1987-2014)				
Growing days, d				110
Tx, mm				125
Wet yield, tons/ha				6.78
Dry yield, tons/ha				7.711
Mean yield, tons/ha				7.25
	Best Case, RCP2.6		Worst Case, RCP8.5	
2050s	% change		% change	
Growing days, d	103	-7%	101	-8%
Tx, mm	183	46%	175	40%
Wet yield, tons/ha	6.06	-11%	5.96	-12%
Dry yield, tons/ha	3.47	-55%	2.64	-66%
Mean yield, tons/ha	4.77	-34%	4.30	-41%
% mean yield loss/deg		-25%		-23%
Oct 15 planting date, yield	6.94	-10%	6.24	-19%
With irrigation, yield	7.60	-1%	7.27	-6%
2090s	% change		% change	
Growing days, d	102	-7%	95	-13%
Tx, mm	181	45%	177	42%
Wet yield, tons/ha	6.05	-11%	5.89	-13%
Dry yield, tons/ha	2.57	-67%	6.18	-20%
Mean yield, tons/ha	4.31	-41%	6.04	-17%
% mean yield loss/deg		-21%		-4%
Oct 15 planting date, yield	6.94	-10%	6.23	-19%
With irrigation, yield	7.44	-4%	6.89	-11%

favorable rainfall that supplied 94% of plant water requirements during the dry season.

Findings showed that the larger reductions in mean yields were influenced more by dry yields where the impacts of water scarcity were larger compared to counterbalancing impacts of rising temperatures and CO₂ levels. By 2050, mean dry yields of 7.7 tons/ha were predicted to drop between 55% to 66% for both scenarios. By 2090, yields dropped to 67% and 20% under best case and worst case, respectively.

Plant demand for water will increase 40% to 46% in all scenarios. Decreasing rainfall during dry months showed only 76% to 81% of the plant water requirement will be met by rainfall. Advancing planting dates to mid-October may reduce yield losses of 55% to 66% to only 10% to 19% by 2050. Vulnerability to water stresses from advancing dry seasons can also be mitigated by access to irrigation.

Wet yields showed losses ranging from 11% to 13% for all scenarios, smaller than those of the dry season. The counterbalancing effects of elevated CO₂ concentrations and temperatures can be inferred from reductions in wet

yields, where rainy weather control for the effects from water stress. The effects of reduced life cycles on final yield nullified the effects from CO₂ fertilization in both medium and long-term scenarios. The limited response of C4 crops to CO₂ fertilization is due to their lower carbon sink potential. Findings agreed with earlier studies that showed zero or negligible net effects, and validated the limited carbon sink potential of C4 crops (Ainsworth & Rogers, 2007; Long et al., 2006; Zvereva & Koslov, 2006; Hatfield et al., 2011).

Simulating Impacts on Length of Growing Seasons

The length of the growing season (LGS) or growing period as defined by FAO is the period in days during the year when soil moisture is sufficient for plant growth or when rainfall exceeds half the potential ETo rates (FAO, 1978). The calculation of the growing period is based on a simple water balance model, comparing water availability with crop water demand (precipitation with ETo), using monthly values.

The baseline LGS is 11 months, which lasts from April to February the following year. This can accommodate two croppings of 120-day hybrid corn a year. By 2050, the LGS is

reduced from 11 months to 9 months (May to January) under best case scenario and further reduced to 8 months (May to December) under the worst case scenario. By 2090, the LGS will be 9 months (May to January) under both scenarios.

Conclusion

The scenarios projected a future of shorter growing seasons, advancing dry months, hotter days and higher rainfall under climate change. Simulations showed reduced corn yields for all scenarios.

Advancing planting dates is a low-cost strategy to addressing El Niño. Low cost small-scale impounding systems can help farmers cope with advancing dry weather and supply increasing plant water requirements. Research on short-duration, drought, and heat-tolerant crops is imperative.

Simulation for other crops in other crop growing provinces will also help build knowledge on spatial impacts of climate change. Because it uses fewer and readily observable input variables, models like AquaCrop are better suited to practitioners and novice users. Its widespread use will accelerate the research growth in the country.

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