Sustainable Agriculture Research; Vol. 4, No. 4; 2015
ISSN 1927-050X E-ISSN 1927-0518
Published by Canadian Center of Science and Education

What Can Be Learned about the Adaptation Process of Farming Systems to Climate Dynamics Using Crop Models?

Sandro L. Schlindwein[1], Frank Eulenstein[2], Marcos Lana[2], Stefan Sieber[3], Jean-Philippe Boulanger[4], Edgardo Guevara[5], Santiago Meira[5], Elvira Gentile[6] & Michelle Bonatti[3]

[1] Federal University of Santa Catarina, Florianópolis, Brazil

[2] The Leibniz Centre for Agricultural Landscape Research, Institute of Land Use Systems, Müncheberg, Germany

[3] The Leibniz Centre for Agricultural Landscape Research, Institute of Socio-Economics, Müncheberg, Germany

[4] ECOCLIMASOL Climate Risk Management Solutions, Buenos Aires, Argentina

[5] INTA – National Institute of Agricultural Technology, Pergamino, Argentina

[6] Department of Geography, University of Buenos Aires, Buenos Aires, Argentina

Correspondence: Sandro L. Schlindwein, Federal University of Santa Catarina, CCA – ENR, CP. 476, 88040-900 Florianópolis (SC), Brazil. Tel: 55-48-3721-5434. E-mail: sandro.schlindwein@ufsc.br

Received: June 23, 2015 Accepted: July 19, 2015 Online Published: October 12, 2015

doi:10.5539/ URL: http://dx.doi.org/10.5539/

Abstract

The objective of this paper is to reflect and discuss how the use of crop models by aware practitioners might trigger learning of how to think and act differently about the adaptation process of farming systems to climate dynamics. The development of adaptation strategies is discussed from the perspective of contrasting metaphors, since the metaphors in use have distinctive practical implications regarding how crop models might be used for adaptation purposes. Further, in this paper it is pointed out that adaptation should be understood as the result of a learning process and therefore the use of crop models for adaptation purposes must be transformed. Instead of seeing them only as tools to secure yield of cropping systems under a changing climate they must be conceived as components of learning systems for adaptation of whole farming systems.

Keywords: adaptation, climate change, crop models, learning

1. Introduction

The scientific evidence of human induced global warming and climate change is very strong. Increasing is also society´s awareness about these phenomena and their projected impacts. Less agreement is found however, on the extension of these impacts on ecosystems and society, and how to tackle them properly. As has been discussed by Ison (2010), this is because climate change is among those situations that should be considered as "wicked problems", or "wicked situations", since it is a 'pressing and highly complex policy issue involving multiple causal factors and high levels of disagreement about the nature of the problem and the best way to tackle it'.

Two main general approaches have been adopted so far to tackle global warming and climate change and its impacts: mitigation and adaptation. Simply stated, mitigation measures involve the control and reduction of the emission of greenhouse gases like CO_2, or enhancing the sinks of these gases to keep future warming as low as possible. Mitigation will not be discussed in further detail in this paper, and the interested reader is referred to the vast literature already existing on this issue (as in Fischer, Shah, Tubiello, & van Velhuizen, 2005; Tubiello & Fischer, 2007; Ortiz et al., 2008). Adaptation, on the other hand, is related to changes carried out in socio-ecological systems (as in farming systems) in response to current and expected impacts of climate change aiming to moderate harm or exploit beneficial opportunities (based on Moser & Ekstrom, 2010).

Agriculture is the most climate dependent human activity, and the extent to which farming systems will be affected by climate dynamics (climate change and variability) might vary across crops and regions and adaptation scenarios, as the IPCC projections have shown (Intergovernmental Panel on Climate Change [IPCC], 2014). Accordingly, also the adaptation measures will be different from site to site, and as outlined by Howden et al. (2007) the immense diversity of farming systems and practices will offer a large array of possible adaptation options. Nevertheless, all these site specific adaptation options share some common assumptions, as for example that adaptation should be based on the reduction of the vulnerability of the considered farming systems to climate threats, keeping the risks of negative impacts as low as possible. Therefore, adaptation refers to an ongoing, never ending local decision making process rather than to a final state or condition of a system of interest resulting from the adoption of some global policies or initiatives. This 'local' perspective on adaptation has also been claimed by Smit, Burton, Klein and Wandel (2000), for whom "adaptation depends fundamentally on the characteristics of the system of interest, including its sensitivities and vulnerabilities".

To develop adaptation measures for cropping systems, some of the impacts of climate dynamics on them have been evaluated with the use of crop models (Ewert, 2004; Challinor, Wheeler, Craufurd, Slingo, & Grimes, 2004; Challinor, Ewert, Arnold, Simleton, & Fraser, 2009), which are models that reproduce the growth and development of a certain crop (more details on item 3). With the aid of such models, it is possible, for example, to project and evaluate the effects of increasing temperatures and radiation on crop biophysical responses, development and yield. Crop models have been originally developed for application at the field (local) level, but their application at larger scales as for climate change assessments has become a common practice (Adam, van Bussel, Leffelaar, van Keulen, & Ewert, 2011). Therefore, crop models have been seen as a tool to support the process of developing adaptation strategies of cropping systems to climate dynamics because they allow to evaluate its effects on crop development and yield. To put it in other terms, crop models have been adopted to improve the understanding of the impacts of climate dynamics on crop development and yield, and therefore adopted to assist the development of cropping systems adapted to a changing and variable climate.

However, accepting the claim presented at the beginning of this paper that climate change characterizes a "wicked problem situation", an approach to develop adaptation measures based on the adoption of single tools as crop models raises a number of key issues, particularly if they can deal effectively with such a situation considering its complexity. Therefore, for the purpose of this paper, a very important issue is how crop models could be integrated into learning systems for adaptation, and what can be learned about the adaptation process with their use.

The objective of this paper is to reflect and discuss how the use of crop models by aware practitioners might not only enact the design and implementation of cropping systems adapted to a changing climate, but whether they might also trigger learning of how to think and act differently about the adaptation process of whole farming systems to improve the wicked situations within which these systems are embedded.

2. How Should We Understand Adaptation to Climate Change?

For the IPCC in its Fifth Assessment Report (AR5) "adaptation [to climate change] is the process of adjustment to actual or expected climate and its effects, seeking in human systems to moderate harm or exploit beneficial opportunities" (IPCC, 2014). In the IPCC's Fourth Assessment Report, Easterling et al. (2007) have discussed this issue considering its implications for food, fiber and forest products. They assumed that adaptation means both the actions of adjusting practices, processes and capital in response to the actuality or threat of climate change as well as changes in the decision environment, such as social and institutional structures, and altered technical options that can affect the potential or capacity for these actions to be realized. It follows that adaptation might be understood as a vulnerability reducing process relying not only on the adoption of "hard" measures based on the engineering of existing biophysical systems of interest (as cropping systems), but also as a process relying on "soft" measures related to social, political and historical factors of the context within which these systems are embedded. At the end, adaptation certainly relies on a combination of "hard" and "soft" measures aiming to reduce the vulnerability of the considered systems of interest.

Although in recent years there have been notable developments regarding knowledge and practice on adaptation to climate change and variability, what we can notice so far, as in Adger et al. (2007), is that despite its complexity most of these adaptation developments still consist on the proposition of a set of practices to be potentially adopted everywhere, following the same path adopted in case of mitigation (as almost always has been the case of global mitigation initiatives).

According to Collins and Ison (2009), etymologically adaptation means 'fitted or suited' and to adapt is 'to fit' or 'make suitable'. To discuss the notion of adaptation, these authors explore two metaphors that for the design of adaptation strategies have far reaching practical implications, in science as well as in policy and in intervention. For them, one of the metaphors is that of 'adaptation as fitting into', that corresponds to the most widespread understanding of the process of adapting to a given situation. Interpreted according to this metaphor, adaptation unfolds based on the assumption that both the situation and what is to be adapted are known in advance. They are predetermined. It seems reasonable to assume that most of the already proposed practices on adaptation of agriculture to climate dynamics are based on this understanding, and a significant implication of it is that the same set of adaptation practices recommended for a given situation could be transferred to different contexts. A good example here of this type of adaptation practice in farming systems is the introduction of crops cultivars more tolerant to droughts, or the adoption of agronomic practices to minimize droughts effects.

The other organizing metaphor discussed by Collins and Ison (2009) is that of 'adaptation as co-evolution'. This metaphor is based on the understanding that adaptation results from a process of mutual interaction between the system of interest (a farming system) and its environment. So, in human systems of interest adaptation can be seen as a process of learning and development. For Collins and Ison (2009) the 'adaptation as co-evolution' metaphor draws attention to the systemic concept of 'emergence', because 'adaptation' might be seen as an emergent property of a co-evolutionary process. From this perspective on adaptation follows that current farming systems are adapted to their biophysical environments as a result of co-evolutionary processes in which humans have learned how to manage them under circumstances of high (also climatic) complexity and uncertainty. Landraces might be considered the typical result of this kind of adaptation process. The persistence of Agriculture in human history and its ubiquity might be seen therefore as an emergent property of this relational dynamics between humans and their changing biosphere.

A further practical implication of adaptation conceptualized as co-evolution, is that adaptation practices must be seen as context or site-specific, and they need to be designed taking into consideration local site features. From this perspective, adaptation would be the result of recursive interactions between the system of interest and its environment over time. For Ison (2010) to understand adaptation as co-evolution seems to be the only way forward for managing in a climate changing world, and he makes the point that this requires an effective form of praxis – a systems practice.

However, conceptualizing a process like adaptation to climate dynamics in terms of metaphors may not only reveal some important features about the nature of this process, but also conceal or hide others. As has been warned by Collins and Ison (2009), climate change adaptation seen as the result of a co-evolutionary process cannot be restricted to studies of climate change *sensu stricto*, but as a systemic praxis it will have to consider all domains of human concern.

Furthermore, there are certainly other possible metaphors underlying the expression 'adaptation to climate change' as even Collins and Ison (2009) discuss. In his book Ison (2010) discusses briefly another metaphor for adaptation which is 'adaptation for'. This metaphor relies on the perspective that in a climate changing world it is necessary to build a discourse and praxis of hope to allow the construction of new horizons of knowing and doing. Therefore, conceptualizing the adaptation process of farming systems in these terms might implicate a radical change of perspective. To give a concrete example, in a study published by Assad et al. (2008) the impacts of climate change on the geography of Brazilian agriculture are discussed, showing that it could be profoundly modified, displacing crops from one region to another, with significant (negative) socio-economic impacts, demanding major adaptations efforts in order to keep it as it is currently. Although this could well be the case, this perspective (typically based on the "adaptation as fitting into" metaphor) simply ignores all the new opportunities and possibilities that this change in the geography of agricultural production bears up, triggering structural changes and new forms of practice in whole regions, opening up new spaces for learning. This is also a good example of how it is important to develop awareness of the metaphor in use, because it is framing the features of the adaptation process in place.

2.1 Adaptation to Climate Change as a Learning Process

The conceptualization of adaptation as 'co-evolution', as a learning and development process, has some distinct practical implications. Accepting this conceptualization of adaptation, implies to accept and to consider that since it is not possible to completely know the situation in the long-term, it is also not possible to know in advance what is to be adapted. As has been briefly described, adaptation will result from the process of mutual, recursive interactions between the changing climate situation and the considered systems of interest (as for example, a farming system). This recurrent process of adapting to changing climate situations, based on the transformation of the systems of interest as well as of their environments, might be thus understood as the result of a learning process.

Learning itself is a very complex process, and for the purpose of this paper it is enough to assume that learning emerges in the process of engaging with a situation with the purpose of improving it. It means that learning implies change of some form and in some degree. So, learning might emerge when in the process of engaging with a climate change situation a change of understandings leads to changes on practices. But here it must be stressed that this understanding on learning is much different than that of O'Neill (2008) since based on a different epistemology. In his discussion about learning in a climate change context this author assumed an instrumental objectivist epistemology and defined learning as the acquisition of new information that leads to changes (to reductions?) in uncertainty. However, considering what has been discussed so far regarding the metaphors of adaptation in use, it might be expected that learning will also happen when moving from the understanding of adaptation based on the fitting into metaphor to the co-evolution metaphor, because this move from one understanding to another will enact new forms of practice, and not because it has any noticeable impact on the existent level of uncertainty. Therefore, according to the perspective espoused in this paper, the aim is not to change the level of uncertainty, but to change the way we engage with it.

Ultimately, the key issue regarding adaptation to climate change goes much beyond than identifying a set of practices or measures fitted to a given situation, although this could be necessary in some moment along the adaptation process. Rather, the key issue is how to set up an adaptation process based on learning and development in a situation characterized by uncertainty, exploring the opportunities that the conceptualization of adaptation as ‘co-evolution’ provides for the design of learning systems for concerted social action towards adaptation to a dynamic climate.

Therefore, this learning perspective on adaptation to climate dynamics has important implications considering how crop models have been and could be used for adaptation purposes. The challenge is how to use them as part of an integrated approach for effectively engaging stakeholders in the adaptation process, creating awareness of the multitude of aspects involved in this process, and in the whole situation.

3. Crop Models

In crop modeling, a large variety of models have been developed since the 1960s. Crop models have many current and potential uses for answering questions in research, crop management, and policy (Boote, Jones, & Pickering, 1996), as for example in many of the questions related to the impacts of climate change and variability on cropping systems. Briefly defined, crop models, or crop simulators, are computer programs that mimic the growth and development of crops. Data of weather, soil, and crop management are processed to predict crop ontogenesis, phenology, maturity date, yield, fertilizer´s efficiency and other important elements of crop production. The calculations performed in crop models are based on the existing knowledge of the physics, physiology and ecology of crop responses to the environment (United States Department of Agriculture [USDA], 2007). There exists a large literature on crop models (Sirotenko, 2001; Batchelor, Basso, & Paz, 2002; Lobell & Burke, 2010), and details about their features will not be discussed here. A good overview on them, particularly on the DSSAT (Decision Support System for Agrotechnology Transfer) package, that incorporates models of different crops with software that facilitates the evaluation and application of crop models for different purposes, can be read in Jones et al. (2003).

The adoption of crop models in many different agricultural situations and for many different purposes is not new. For Boote, Jones and Pickering (1996), a number of crop growth models have been adopted to evaluate the consequences of global climate change, as increasing temperatures and altered rainfall patterns on crop yields. However, for these authors, the efforts to evaluate the effects of a changing climate on yields adopting crop models should be placed with more emphasis on year-to-year fluctuations caused by weather variability. As has been claimed by Hansen and Jones (2000) dynamic, process-level crop models are playing an increasing role in translating information about climate variability into prediction and recommendations at a range of scales, tailored to the needs of agricultural decision makers. Crop models have been also adopted to evaluate agricultural production risks across a wide range of climatic conditions. Despite the high uncertainty of this sort of analysis, particularly for large time scales, they have been adopted as a tool to support strategic decision making in crop production and agricultural land use planning.

For Jones et al. (2003) in the development of DSSAT the systems approach provided “a framework to conduct research and to understand how the system and its components function”. Although the “systemic” nature of crop models have been mentioned by these authors, it is necessary to address briefly what is commonly understood, in conceptual terms, as “the systems approach” in the context of crop modeling, as well as its implications for practice. It is clear from the statement of Jones et al. (2003) that they assume the existence of well-defined “cropping systems”, existing as discrete entities with distinguishable boundaries over which crop models can be developed and the resulting models will be run. This stance is typical of a first-order systems approach. For Russell and Ison (2000), the first-order tradition, on which this systems approach is based, is characterized by concerned intervention, the definition of clear goals, the ‘naming’ of the problem, and the proposal of a rational solution. Accordingly, this systems approach should allow the understanding not only of the functioning of the system, but also allow the prediction of its behavior under given conditions, as well as how to manage or to control it (Jones et al., 2003). Furthermore, DSSAT, which is currently the most used package for running crop models for different purposes, is based on the assumption that knowledge (in form of production technology) can be transferred, an epistemological stance also typically linked to first-order traditions.

The epistemological assumptions behind crop model building is an important aspect that must be considered when using crop models for managing or intervening in "messy" situations or "wicked problems" like climate change. "Messy" or "wicked" situations are highly complex, characterized by uncertainty, interdependencies and which can be observed and interpreted from multiple perspectives. As a consequence, if systemic failures are to be avoided, any intended intervention on such situations can no longer be undertaken by means of prediction and control. These situations simply don't follow deterministic rules. Rather, human intervention on such situations must be based on the acceptance that they are intrinsically unpredictable. It means that for effectively managing such situations of complexity it is necessary to espouse an epistemological stance different than first-order traditions making possible the enactment of new forms of practice. This must also include the way crop models have been used in the development of adaptation strategies. But how to transform crop models into learning devices for raising systemic awareness about the situation?

4. Transforming the Use of Crop Models: From Tools to Optimize Crop Yields to Components of Learning Systems for Adaptation

For Mingers and Brocklesby (1999) a tool is an artifact, often a computer software, that can be used in performing a particular technique, or a specific activity. The particular technique or specific activity that crop models can perform is, for example, to identify the growth factors that contribute most to the achievement of a desired yield level of a cropping system, optimizing it. Thinking in terms of the metaphors discussed so far, this use of crop models as a tool for optimizing purposes can be characterized according to the 'fitting into' metaphor, since it is based on the assumption that the situation (in this case restricted to the climate itself or to some of its variables) as well as what is to be adapted (a cropping system) are known in advance. Then, crop models are used to fit a cropping system into the given environment, setting the practices to be adopted to achieve the desired goal: a certain optimized yield level.

The issue of concern here, however, is not if this "fitting process" is effective or not for the design of cropping systems eventually adapted to a changing climate, but if from this modality of use of crop models learning (of what type? to what extent?) about the adaptation process of a whole farming system to a dynamic climate can emerge. It must be clear at this point that although learning about adaptation to climate dynamics has not been an explicit objective of crop models, their use also does not preclude it at all. However, the point being made here is that depending on the perspective driving the use of crop models for adaptive practices learning can be constrained instead of being enabled. Consequently, to adopt crop models only as a tool to perform simulations to maximize crop yield seems not to be very helpful to improve or to transform the wicked situations in which these cropping systems are embedded, despite their value in assisting decision making in agricultural land use at local levels (Note 1).

To move forward "beyond the dominance of empiricist prediction" it is necessary to depart from the view of crop models only as tools to fix cropping systems under a changing climate. Just to give an example of how to avoid a recipe-like use of crop models, they could be regarded as part of a set of guidelines to design adaptation strategies, becoming part of a methodology in the sense suggested by Ison (2010). As claimed by this author, a methodology involves the conscious braiding together of theory and practice in a given situation, characterizing a context specific enactment. Therefore, instead of using crop models under a changing climate to deterministically and systematically intervene in a cropping system, changing sowing dates, varieties, level of fertilizer input, or anything else to optimize crop yields avoiding a decrease in economic return, based on a non-deterministic and systemic approach crop models are seen as just one among many other tools mobilized to explore novel possibilities of maintaining viable farming systems. This implies a move from the relative certainty of a model prediction (the empiricist tradition) to the uncertain possibilities of an ongoing adaptation process, or the move from the cropping system to the situation of concern. It is from this way of putting crop models into practice in a changing climate situation that practitioners may take responsibility for learning from the process. In this case it is expected that aware practitioners (any stakeholder involved in the process) would be "able to judge what is appropriate for a given context in terms of managing a process" (Ison, 2010) – the adaptation – instead of managing simply an output – the crop yield, since not always optimizing crop yields might be the best option if the purpose is to improve the whole situation and to avoid undesirable unintended consequences.

Furthermore, the uncertainty of future climate constrains the possibility of developing or securing in advance a set of practices to be adopted in an unknown situation. Instead of being informed by the "adaptation as fitting into" metaphor, adaptation to climate change must be informed by the "co-evolution metaphor", as has been discussed previously. It means that the tool-like use of crop models for adaptation purposes must be transformed: they need to be integrated into learning systems for adaptation.

But what is a learning system? From a first-order perspective, the design of a learning system comprises the combination of elements and processes interconnected as subsystems as well as the specification of some boundary conditions – to define what is part of the system, what is not – for the purpose of learning (Blackmore, 2005; Ison, 2010). However if we move to a second-order understanding, adopting a systemic design practice perspective, instead of speaking about the design or the modelling of a 'learning system', it is the situation of concern that will be considered "as if it were a learning system". As discussed by Ison (2010), the implication of this perspective is that a 'learning system' can only ever be said to exist after its enactment, that is, on reflection (Note 2). But if learning as suggested by Kolb (1984) is the creation of knowledge through the transformation of experience, then it is the experience of using crop models that needs to be transformed in order to create knowledge (taken to be a set of practices) about adaptation. Transforming the way crop models have been used is an important step to create the circumstances for effectively engaging stakeholders into the adaptation process, making the improvement of wicked situations like climate change possible. In this way crop models will also contribute to build capacity for social collectives and individuals to respond to a dynamic climate, and stakeholders will move "from a goal-oriented thinking towards thinking in terms of learning".

The key issue regarding the use of crop models to design adaptation strategies to climate dynamics of farming systems can now be re-formulated in the following terms: what can be learned about the situation in case crop models were used as if they were part of a learning system to design adaptation strategies? Based on this learning perspective crop models will be understood not only as a set of rules or a computer program to simulate the development of crops to optimize yields, but as devices taking part in a process of designing systems of interest (farming systems) to tackle a variable and changing climate; they might become part of an epistemological device that opens up new learning possibilities about human-induced climate change, its far reaching implications on ecosystems and society and how to tackle them.

5. Final Remarks

The process of adapting agricultural land use to a dynamic climate and the farmer's adaptation capacity should not be reduced to the capacity to adopt or adjust certain practices assumed to be more suitable in future climatic conditions. In fact, as has been discussed in this article, the adaptation process should be understood as resulting from the permanent capacity to learn with a changing climate transforming wicked situations for the better. To achieve this, the process of developing adaptation strategies should be conceptualized in terms of the 'adaptation as co-evolution' metaphor with learning itself being its emergent property.

This demands however that practitioners be aware of their epistemological choices when designing adaptation strategies to climate dynamics in agricultural systems, for which they might mobilize different resources, among them crop models. So, for example, to frame human-induced climate change as a "wicked situation" is a matter of choice or preference that, however, calls for special forms of practices in the adaptation process. This epistemological awareness might transform the "hard" perspective on using crop models to a "soft", learning based intervention on a situation. Crop models will be seen now as devices to facilitate learning about the whole situation rather than to optimize yields. In analogy to what has been discussed so far, it might be expected that learning will also happen when moving from the tool-like adoption of crop models to the view of crop models as components of learning systems for adaptation, because this move from one understanding to another will enact new forms of practice.

It is certainly possible to learn something about climate change adopting crop models as if they were tools to design adaptation strategies in agricultural land use systems. But this adaptation approach is no longer enough. Agricultural land use is a complex human activity system immersed in an environment of extremely high uncertainty about future climate. Under such circumstances crop models alone can't cope with all the complexity; they can't absorb all the variety present in such situations. Therefore, crop models must be part of an integrated approach to adaptation, enabling new forms of practice for managing the complexity of the decision making process driving adaptation of agricultural land use. By accepting this shift in perspective regarding the use of crop models for adaptation purposes, it is up to the crop modelers to engage in processes leading to the integration of crop models into learning systems for adaptation, enabling the emergence of learning and awareness about the whole situation.

In terms of adaptation to climate dynamics in agricultural land use, it only can make sense to use crop models in case they do not close options for future adaptability to change. In the “messy”, “wicked” situation we find ourselves, any designed adaptation strategy must avoid ‘a narrowing of possibilities on pathways towards effective action’. If we assume that there is no right or wrong answer in using crop models to design adaptation strategies, we must agree that it is necessary to evaluate the context where crop models can be used for effective action.

Regarding effective action, it must also be considered that although decision support systems as DSSAT have been used to facilitate the formulation of adaptation strategies to climate dynamics, the resulting model based farming systems not necessarily are transformed into farming practices, even in conditions of high climatic risk. So, for example, McCown (2012) reports about a program of research that has been conducted to see if, and under what conditions, computer simulations of farming scenarios can be valued by farmers. This research program was a response to the researcher´s growing awareness of persistent low interest in software of decision support systems among farmers, at least in Australian dryland cropping. Under these climatic conditions decision makers ‘rely heavily on intuitive judgment underpinned by experience’ and not necessarily on results of decision support systems, which might remain an enigma for them (McCown, 2012).

Furthermore, it is important to emphasize that the “problem” of climatic change of anthropogenic causes can’t be reduced to technological or economic aspects, as remembered by Orr (2009), and that for managing this situation it is necessary to learn to think and act differently, as has been claimed by Ison (2010). It is based on this process of learning to think and act differently that should emerge the capacity to adapt to climate change, and not as the result of identifying or adopting practices better fitted to a given climatic situation. This clearly points to the need of adopting a different research approach if learning is to be fostered, a research approach which is also oriented towards practice facilitating action which is systemically desirable and/or culturally feasible. A good example of such a research approach is ‘systemic inquiry’ understood as an institutional form and process designed for engaging with uncertainty and complexity (http://www.open.ac.uk/blogs/govan/?page_id=23 accessed 30 september 2015) like situations of climate change adaptation. As systemic inquiry progresses it involves the enactment of a process of learning amongst those who already have, or through participation build, a stake in an issue of concern (Ison, 2002; SLIM, 2004), as might be the case of farmers and researchers committed to improve whole farming systems under a dynamic climate. Therefore, paraphrasing Bawden (2010), to the challenge of climate change it is necessary to give a learning response.

Acknowledgments

The first author wishes to express his gratitude to FAPESC of the state government of Santa Catarina, Brazil, and to the German Academic Exchange Service (DAAD) for financial support during his permanence at ZALF in January/February 2011, when this work has been initiated. He also expresses his gratitude to the Leibniz-Centre for Agricultural Landscape Research (ZALF) and to its Institute of Land Use Systems for providing the necessary resources and for hospitality during his stay on several occasions. The research leading to these results also has received funding from the European Community's Seventh Framework Programme (FP7/2007-2013) under Grant Agreement Nº 212492: CLARIS LPB. A Europe-South America Network for Climate Change Assessment and Impact Studies in La Plata Basin.

References

Adam, M., van Bussel, L. G. J., Leffelaar, P. A., van Keulen, H., & Ewert, F. (2011). Effects of modeling detail on simulated potential crop yields under a wide range of climatic conditions. *Ecological Modelling, 222*(1), 131-143. http://dx.doi.org/10.1016/j.ecolmodel.2010.09.001

Adger, W. N., Agrawala, S., Mirza, M. M. Q., Conde, C., O’Brien, K., Pulhin, J., … Takahashi, K. (2007). Assessment of adaptation practices, options, constraints and capacity. In M. L. Parry, O. F. Canziani, J. P. Palutikof, P. J. van der Linden, & C. E. Hanson (Eds.), *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* (pp. 717-743). Cambridge, UK: Cambridge University Press.

Assad, E. D., Pinto, H. S., Zullo Junior, J., Marin, F. R., Pellegrino, G. Q., Evangelista, S. R., & Otavian, A. F. (2008). *Aquecimento global e a nova geografia da produção agrícola no Brasil*. Brasília, DF: Embaixada Britânica.

Basso, B., Ritchie, J. T., Pierce, F. J., Braga, R. P., & Jones, J. W. (2001). Spatial validation of crop models for precision agriculture. *Agricultural Systems, 68*(2), 97-112. http://dx.doi.org/10.1016/S0308-521X(00)00063-9

Batchelor, W. D., Basso, B., & Paz, J. O. (2002). Examples of strategies to analyze spatial and temporal yield variability using crop models. *European Journal of Agronomy, 18*(1-2), 141-158. http://dx.doi.org/10.1016/S1161-0301(02)00101-6

Bawden, R. (2010). The community challenge: the learning response. In C. Blackmore (Ed.), *Social Learning Systems and Communities of Practice* (pp. 39-56). London: Springer

Blackmore, C. (2005). Learning to appreciate learning systems for environmental decision making – a "work in progress" perspective. *Systems Research & Behavioral Science, 22*(4), 329-341. http://dx.doi.org/10.1002/sres.697

Boote, K. J., Jones, J. W., & Pickering, N. B. (1996). Potential uses and limitations of crop models. *Agronomy Journal, 88*(5), 704-716. http://dx.doi.org/10.2134/agronj1996.00021962008800050005x

Challinor, A. J., Wheeler, T. R., Craufurd, P. Q., Slingo, J. M., & Grimes, D. I. F. (2004). Design and optimisation of a large area process-based model for annual crops. *Agricultural and Forest Meteorology, 124*(1-2), 99-120. http://dx.doi.org/10.1016/j.agrformet.2004.01.002

Challinor, A. J., Ewert, F., Arnold, S., Simelton, E., & Fraser, E. (2009). Crops and climate change: progress, trends, and challenges in simulating impacts and informing adaptation. *Journal of Experimental Botany, 60*(10), 2775-2789. http://dx.doi.org/10.1093/jxb/erp062

Collins, K., & Ison, R. (2009). Editorial: living with environmental change: adaptation as social learning. *Environmental Policy and Governance, 19*(6), 351-357. http://dx.doi.org/10.1002/eet.520

Easterling, W. E., Aggarwal, P. K., Batima, P., Brander, K. M., Erda, L., Howden, S. M., … Tubiello, F. N. (2007). Food, fibre and forest products. In M. L. Parry, O. F. Canziani, J. P. Palutikof, P. J. van der Linden, & C. E. Hanson (Eds.), *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* (pp. 273-313). Cambridge, UK: Cambridge University Press.

Ewert, F. (2004). *Modelling Changes in Global Regionalized Food Production Systems Under Changing Climate and Consequences for Food Security and Environment – Development of an Approach for Improved Crop Modelling within IMAGE*. Wageningen/Bilthoven: Plant Production Systems Group, Department of Plant Sciences, Wageningen University & Netherlands Environmental Assessment Agency (MNP), National Institute for Public Health and Environment (RIVM).

Fischer, G., Shah, M., Tubiello, F. N., & van Velhuizen, H. (2005). Socio-economic and climate change impacts on agriculture: An integrated assessment, 1990-2080. *Philosophical Transactions of the Royal Society B: Biological Sciences, 360*(1463), 2067-2083. http://dx.doi.org/10.1098/rstb.2005.1744

Hansen, J. W., & Jones, J. W. (2000). Scaling-up crop models for climate variability applications. *Agricultural Systems, 65*(1), 43-72. http://dx.doi.org/10.1016/S0308-521X(00)00025-1

Howden, S. M., Soussana, J. F., Tubiello, F. N., Chhetri, N., Dunlop, M., & Meinke, H. (2007). Adapting agriculture to climate change. *Proceedings of the National Academy of Sciences, 104*(50), 19691-19696. http://dx.doi.org/10.1073/pnas.0701890104

Intergovernmental Panel on Climate Change. (2014). Summary for policymakers. In C. B. Field, V. R. Barros, D. J. Dokken, K. J. Mach, M. D. Mastrandrea, T. E. Bilir, M. Chatterjee, K. L. Ebi, Y. O. Estrada, R. C. Genova, B. Girma, E. S. Kissel, A. N. Levy, S. MacCracken, P. R. Mastrandrea, and L. L. White (Eds.), *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* (pp. 1-32). Cambridge, UK and New York, NY, USA: Cambridge University Press.

Ison, R. (2002). Some reflections on a knowledge transfer strategy: a systemic inquiry. In A. Cristovão and L. O. Zorini (Eds.), *Farming and rural systems research and extension: Proceedings of the Fifth IFSA European Symposium* (pp. 647-656). Florence, Italy.

Ison, R. (2010). *Systems Practice: How to Act in a Climate-Change World*. London: Springer.

Jones, J. W., Hoogenboom, G., Poster, C. H., Boote, K. J., Batchelor, W. D., Hunt, L. A., … Ritchie, J. T. (2003). The DSSAT cropping system model. *European Journal of Agronomy, 18*(3-4), 235-265. http://dx.doi.org/10.1016/S1161-0301(02)00107-7

Kolb, D. A. (1984). *Experiential Learning: Experience as the Source of Learning and Development*. New Jersey: Prentice Hall.

Lobell, D. B., & Burke, M. B. (2010). On the use of statistical models to predict crop yield responses to climate change. *Agricultural and Forest Meteorology, 150*(11), 1443-1452. http://dx.doi.org/10.1016/j.agrformet.2010.07.008

McCown, R. L. (2012). A cognitive systems framework to inform delivery of analytic support for farmer´s intuitive management under seasonal climatic variability. *Agricultural Systems, 105*(1), 7-20. http://dx.doi.org/10.1016/j.agsy.2011.08.005

Mingers, J., & Brocklesby, J. (1997). Multimethodology: towards a framework for mixing methodologies. *Omega – The International Journal of Management Science, 25*(5), 489-509. http://dx.doi.org/10.1016/S0305-0483(97)00018-2

Moser, S., & Ekstrom, J. (2010). A framework to diagnose barriers to climate change adaptation. *Proceedings of the National Academy of Sciences, 107*(51), 22026-33031. http://dx.doi.org/10.1073/pnas.1007887107

Oliver, Y. M., Robertson, M. J., & Wong, M. T. F. (2010). Integrating farmer knowledge, precision agriculture tools, and crop simulation modelling to evaluate management options for poor-performing patches in cropping fields. *European Journal of Agronomy, 32*(1), 40-50. http://dx.doi.org/10.1016/j.eja.2009.05.002

O'Neill, B. (2008). Learning and climate change: an introduction and overview. *Climatic Change, 89*, 1-6. http://dx.doi.org/10.1007/s10584-008-9443-8

Orr, D. S. (2009). *Down to the Wire. Confronting Climate Collapse*. New York: Oxford University Press.

Ortiz, R., Sayre, K. D., Govaerts, B., Gupta R., Subbarao, G.V., Ban, T., … Reynolds, M. (2008). Climate change: Can wheat beat the heat? *Agriculture, Ecosystems and Environment, 126*(1-2), 46-58. http://dx.doi.org/10.1016/j.agee.2008.01.019

Russell, D. B., & Ison, R. L. (2000). The research-development relationship in rural communities: an opportunity for contextual science. In R. Ison & D. Russell. *Agricultural Extension and Rural Development: Breaking Out of Traditions. A Second-Order Systems Perspective* (pp. 10-31). Cambridge, UK: Cambridge University Press.

Sirotenko, O. D. (2001). Crop modeling: Advances and problems. *Agronomy Journal, 93*(3), 650-653. http://dx.doi.org/ 10.2134/agronj2001.933650-ax

SLIM. (2004). *SLIM framework: social learning as a policy approach for sustainable use of water.* Retrieved September 29, 2015, from https://sites.google.com/site/slimsociallearningforiwm/system/app/pages/search?scope=search-site&q=slim+framework

Smit, B., Burton, I., Klein, R. J. T., & Wandel, J. (2000). An anatomy of adaptation to climate change and variability. *Climatic Change, 45*, 223-251. http://dx.doi.org/10.1023/A:1005661622966

Tubiello, F. N., & Fischer, G. (2007). Reducing climate change impacts on agriculture: Global and regional effects of mitigation, 2000-2080. *Technological Forecasting and Social Change, 74*(7), 1030-1056. http://dx.doi.org/10.1016/j.techfore.2006.05.027

United States Department of Agriculture. (2007). *What are crop simulation models?* Retrieved February 1, 2011, from http://www.ars.usda.gov/main/docs.htm?docid=2890

Notes

Note 1. This might be the case, for instance, in the context of precision farming. In such circumstances, crop models have been used in combination with other tools for yield map prediction, increasing the availability of information on spatial variation to allow zone-specific management prescriptions (Basso, Ritchie, Pierce, Braga & Jones, 2001; Oliver, Robertson & Wong, 2010). However, also this kind of adoption of crop models to improve decision making doesn´t break out of optimizing traditions since the ultimate objective is to maximize yields.

Note 2. Since it is not the purpose of this paper to discuss in more detail these different perspectives on learning systems and its implications, the interested reader is referred to Ison (2010) for further details.