Potato yield gap analysis in SSA through participatory modeling: Optimizing the value of historical breeding trial data

CIP Working Paper

Authors: R. Quiroz, D. Harahagazwe, B. Condori, C. Barreda, F. de Mendiburu, A. Amele, D. Anthony, E. Atieno, A. Bararyenya, A. A. Byarugaba, P. Demo, J. Guerrero, B. Kowalski, D. Anthony Kude, C. Lung'aho, V. Mares, D. Mbiri, G. Mulugeta, B. Nasona, A. Ngugi, J. Njeru, B. Ochieng, J. Onditi, M. Parker, J. M. Randrianaivoarivony, E. Schulte-Geldermann, C. M. Tankou, G. Woldegiorgis and A. Worku

Corresponding Author: Roberto Quiroz, International Potato Center (CIP), P.O. Box 1558, Lima, Peru, e-mail: r.quiroz@cgiar.org, Tel. +511 3175304/3175312

February 2014

RESEARCH PROGRAMS ON

Climate Change, Agriculture and Food Security

Roots, Tubers and Bananas

Integrated Systems for the Humid Tropics

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Abstract

The yield gap analysis is an important tool to estimate to what extent the production could be increased if all factors are controlled. This information is well documented for cereals but a lot still to be done on other commodities like potato. The second challenge in this endeavor is the scalability of the analysis as data are in most cases scare in developing countries like in Sub Sahara Africa. To this end, scientists recommended using simulation models but again their parameterization is at times a nightmare.

It's in this context that a regional study has been conducted in Sub Sahara Africa in order to estimate the potato yield gaps. Participated to the study scientists from West Africa (Nigeria), Eastern and Central Africa (Cameroon, Burundi, Rwanda, Kenya, Uganda, Tanzania, Democratic Republic of Congo and Ethiopia), and Southern Africa (Angola, Malawi, Madagascar and Mozambique). The first task was to get the scientists acquainted with the approach and tools prior to use. This was achieved in two workshops respectively held in Nairobi, Kenya and then Addis Ababa, Ethiopia. The big challenge was to estimate the parameters to be fed to the Solanum model developed by CIP. To this end, a Parameter Estimator routine was developed but the expert opinion was tremendous to achieve reliable values prior to simulations.

In this paper we show how potato yield gaps are higher than expected. They even exceed the yields normally obtained by scientists in the on-station trials. The current average farmers' yields are too low, less than 10 t/ha for materials with a potential to achieve 50 t/ha. As the information contained in the paper is site-specific, the community of practice initiated during the workshops agreed to extend the study to special analysis. This will be achieved through an initiative called "Climate-Smart Potato in SSA" conceived by the same community of practice.

Acronyms

- INERA: Institut National pour l'Etude et la Recherche Agronomiques
- KARI: Kenya Agricultural Research Institute
- FIFAMANOR: Fiompiana Fambolena Malagasy Norvéziana
- CIP: Centro Internacional de la Papa
- KAZARDI: Kachwekano Zonal Agricultural Research and Development Institute
- DARTS: Department of Agricultural Research and Technical Services
- EIAR: Ethiopian Agricultural Research Institute
- ISABU: Institut des Sciences Agronomiques du Burundi
- RAB: Rwanda Agriculture Board
- SSA: Sub-Sahara Africa
- ECA: Eastern and Central Africa
- PSE: Production System and the Environment
- FAO: Food and Agriculture Organization of the United Nations

About the Authors

1. Asrat Amele, Regional Potato Breeder, International Potato Center, **Kenya**
2. Danbaba Anthony, Senior Research Officer, Potato Programme at the National Root Crops Research Institute (UMUDIKE), **Nigeria**
3. Elly Atieno, Research Associate in Potato Agronomy, International Potato Center, **Kenya**
4. Astère Bararyenya, National Potato Research Program (NPRP) Leader, National Agricultural Research Institute, **Burundi**
5. Carolina Barreda, Agronomist-PSE Sub-Program , International Potato Center (CIP), **Peru**
6. Arinaitwe Abel Byarugaba, Research Officer/Plant Pathologist at KAZARDI, **Uganda**
7. Bruno Condori, Crop Ecophysiology and Modeling, International Potato Center (CIP), **Peru**
8. Paul Demo, Agronomist - Potato Specialist and Country Liaison Scientist, International Potato Center, **Malawi**
9. Jose Guerrero, System Engineer-PSE Sub-Program, International Potato Center (CIP), **Peru** International Potato Center (CIP), **Peru**
10. Dieudonné Harahagazwe, Crop Ecophysiology and Modeling Scientist, International Potato Center, **Kenya**
11. Britta Kowalski, Senior Country Liaison Scientist, International Potato Center, Angola
12. Danbaba Anthony Kude, Senior Research Officer in the Potato Breeding Unit, Potato Program at the National Root Crops Research Institute (UMUDIKE), **Nigeria**
13. Charles Lung'aho, Country Manager Potato Projects, International Potato Center, **Mozambique**
14. Victor Mares, Agronomist-PSE Sub-Program, International Potato Center (CIP), **Peru**
15. Daniel Mbiri, Research Associate in Seed Potato Production, International Potato Center, **Kenya**
16. Felipe de Mendiburu, Statistician-PSE Sub-Program , International Potato Center (CIP), **Peru**
17. Gedif Mulugeta, Research Officer at the National Potato Research Coordinator at EIAR, **Ethiopia**
18. Bouwe Nasona, Head of Tuber Crops Program at INERA-Mulungu, **Democratic Republic of Congo**
19. Abigail Ngugi, Research Associate in Potato Breeding, International Potato Center, **Kenya**
20. James Njeru, Research Associate in Potato Agronomy, International Potato Center, **Kenya**
21. Bruce Ochieng, Research Associate in Plant Pathology, International Potato Center, **Kenya**
22. John Onditi, Potato Breeder at KARI Tigoni, **Kenya**
23. Monica Parker, Deputy Potato Science Program-SSA Leader, International Potato Center, **Kenya**

24. Roberto Quiroz, Interim Integrated Crop and Systems Research Program Leader, and Production Systems and the Environment Sub-Program Leader, International Potato Center, **Peru**
25. Jean Marc Randrianaivoarivony, Head of Research Department, FIFAMANOR, **Madagascar**
26. Elmar Schulte-Geldermann, Potato Science Program-SSA Leader, International Potato Center, **Kenya**
27. Christopher Mubeteneh Tankou, Professor at the Faculty of Agronomy and Agricultural Sciences, University of Dschang, **Cameroon**
28. Gebremedhin Woldegiorgis, Senior Potato Researcher at EIAR, **Ethiopia**
29. Alemu Worku, National Potato Research Coordinator at EIAR, **Ethiopia**

1. Introduction

As per today the potato (*Solanum tuberosum* L.) is the third most important food crop after rice and wheat for human consumption and over a million people on earth eat potatoes (CIP, 2014). In 2007 the potato production reached a record of 325 million metric tons becoming the first non-grain commodity for the humanity (FAO, 2009). However demand for both food and energy is rising and it is expected to keep the same trend with increases in global population and average income (Lobell *et al*., 2009). The impact of increasing population on food demand will be accentuated in developing countries in general and Sub-Sahara Africa (SSA) in particular as the latter is expected to account for one half of the world population increment by 2050 compared to one fifth in 1999 (Alexandratos, 1999). On the supply side, experts consider that maximum possible yields for major cereals achieved in farmers' fields might level off or even decline in many regions over the few decades to come (Lobell *et al*., 2009). That's means potatoes still have a high potential to solve the food shortage especially in countries where farmers' yields are still far from the potential ones – existence of huge yield gaps - since it's known that food supply is a mathematical product of crop area by yield.

The importance of yield gap analysis is well documented in the literature as it provides a measure of untapped food production capacity (van Wart *et al*., 2013). However, most studies and initiatives carried out so far on yield gaps were focused on cereal crops with limited information on other crops like potatoes. The Global Yield Gap Atlas is one of those initiatives that are dealing with grain crops (GYGA, 2013). This study is thus an attempt to respond to this gap in developing a methodology that could be used to determine what potato growers in developing countries are losing and/or could achieve. From literature, three techniques are used to estimate the potential yields and yield gaps (Lobell *et al*., 2009): (i) model simulations, (ii) field experiments and yield contests and (iii) maximum farmer yields. Among all simulation modeling is considered to be the most reliable way to estimate the yield gap (Ittersum *et al*., 2013). Nevertheless the task is not that easy in the context of most developing countries especially when dealing with historical field data. This requires innovative approaches to implement this type of analyses in order to overcome the problem of missing information. In addition to the simulation interface itself, the present study explored the development of technological tools and the creation of a community of practice.

This study is being conducted stepwise. In the first phase estimates of yield gaps are based on site-specific simulations. In a second phase this kind of analysis will take a spatial dimension building on the previous lessons.

2. Methodology

2.1. The Participative Approach Used

The analysis of potato yield gap in selected SSA countries was conducted through two workshops organized in Africa. As shown on **Table 1**, the participants to the workshops were scientists who are very knowledgeable of the potato growth and development. Some of them have more than 30 years of experience on the crop. Having a wide knowledge to the crop was one of the pre-requisites to attend the workshops as the study is based on historical field data in most cases with missing parameters that had to be estimated using technological tools but with validation by experts' opinion. This was the main driver of the workshops as field data for modeling purposes are seldom complete in most developing countries in general and SSA in particular.

Table 1. Profile of Participants to the Potato Yield Gap Analysis Workshops

No.	First name	Surname	Workshop		Institution	Field	Years	Country
			Nairobi	Addis Ababa				
1	Asrat	Amele			CIP	Breeding	1	Kenya
2	Danbaba	Anthony			National Root Crops Research Institute	Breeding and Genetics	10	Nigeria
3	Elly	Atieno			CIP	Integrated Crop Management	3	Kenya
4	Astère	Bararyenya			ISABU	Crop Protection and Seed Systems	11	Burundi
5	Carolina	Barreda			CIP	Agronomy	10	Peru
6	Dinah	Borus			University of Tasmania (UTAS)	Crop Modeling	N/A	Australia
7	Arinaitwe	Byarugaba			KAZARDI	Plant Pathology	5	Uganda
8	Felistus	Chipungu			DARTS	Breeding	21	Malawi
9	Bruno	Condori			CIP	Crop Ecophysiology and Modeling	20	Bolivia
10	Felipe	de Mendiburu			CIP	Biometrics	30	Peru
11	Paul	Demo			CIP	Agronomy	23	Malawi
12	Dieudonné	Harahagazwe			CIP	Crop Ecophysiology and Modeling	18	Kenya
13	Rogers	Kakuhenzire			CIP	Plant Pathology	18	Tanzania
14	Britta	Kowalski			CIP	Biotechnology/Agronomy	25	Angola
15	Charles	Lung'aho			CIP	Agronomy	25	Mozambique
16	Carolino	Martinho			IIAM	Agronomy	9	Mozambique

17	Daniel	Mbiri			CIP	Agronomy/Seed Systems	8	Kenya
18	Jane	Mbugua			KARI	Agronomy	4	Kenya
19	Gedif	Mulugeta			EIAR	Breding	6	Ethiopia
20	Bouwe	Nasona			INERA	Agronomy	26	DRC
21	Theophile	Ndacayisenga			RAB	N/A	N/A	Rwanda
22	Abigail	Ngugi			CIP	Breeding	2	Kenya
23	James	Njeru			CIP	Research Methods	1	Kenya
24	Bruce	Ochieng			CIP	Plant Pathology	3	Kenya
25	John	Onditi			KARI	Plant Pathology	6	Kenya
26	Kwigizile	Owekisha			Uyole Agricultural Research Institute	N/A	N/A	Tanzania
27	Monica	Parker			CIP	Crop Protection	1	Kenya
28	Roberto	Quiroz			CIP	Biophysics	31	Peru
29	Jean Marc	Randrianai-voarivony			FIFAMANOR	Breeding	20	Madagascar
30	Elmar	Schulte Geldermann			CIP	Agronomy and Seed Systems	15	Kenya
31	Christopher	Tankou			University of Dschang	Crop Physiology	23	Cameroon
32	Gebremedhin	Woldegiorgis			EIAR	Breeding/Agronomy	25	Ethiopia
33	Alemu	Worku			EIAR	Breeding/Agronomy	8	Ethiopia

N/A: Not available

The first workshop took place at Masai Lodge in Nairobi, Kenya on 24 – 26 June 2013. This workshop was a first introduction of the topic to 26 potato scientists (**Fig. 1**) coming from West Africa (Nigeria), Eastern and Central Africa (Burundi, Rwanda, Kenya, Uganda, Tanzania, Democratic Republic of Congo and Ethiopia) and Southern Africa (Angola, Malawi, Madagascar and Mozambique). During the 2.5 days of interactive training, participants got acquainted with the following subjects: (i) definition of key concept like Yield Gap Analysis and Systems Analysis (see PointPoint presentation on Slideshare at http://www.slideshare.net/CIP-PSE/1-introduction-to-yield-gap-analysis), (ii) weather data management, (iii) parameter estimation using Excel and R, and (iv) introduction to crop modeling using the SOLANUM model downloadable at http://inrm.cip.cgiar.org/home/downmod.htm. The course comprised at the same time theory and hands-on exercises at times in break-out groups. The training was interactive in the sense that communications were both ways. Consequently, participants suggested how improve the tools exposed during the workshop. For example, it was recommended to embed the parameter estimator into the simulation model due to make friendlier the simulation process for non-experts in mathematics and computing.

Figure 1. Group Photo of Participants to the First Yield Gap Workshop.

The second workshop but building the previous one took place at Desalegn Hotel in Addis Ababa on 14-18 October 2013. Twenty-one participants attended the workshop (**Fig. 2**) and all of them except one had attended the introductory one. Three main topics were on agenda for this workshop: (i) introduction to the new version of Solanum Model, (ii) conduct up to the end the potato yield gap analysis, and (iii) discuss the way forward. Facilitators presented the user friendly simulation model which contains a routine of estimating parameters as a response to a request raised during the first workshop. Under the second objective which constitutes the core business of this paper, participants conducted yield gaps from their respective experimental sites. At the end of the workshop, participants discussed the way forward. To this end, they agreed to continue the collaboration through two great ideas. The first idea is to develop a research program on climate-smart potato in SSA. This idea was presented by one of the facilitators in plenary and strategies for implementation were discussed. Last but not least participants agreed to launch a community of practice which could be the vehicle for implementation of the climate-smart potato initiative.

Figure 2. Overview of Participants to the Second Yield Gap Workshop.

It is worth mentioning that a small survey was conducted at the end of the second workshop in order to assess the perception of participants with regard to the work carried that far. To this end, a structured questioned was designed and filled in by all participants. Data are being processed and a report will be released as soon as the analysis is finished.

2.2. The Concept of Yield Gap

The concept of yield gap (Yg) can be qualified to be both simple and complex. Yield gap is very simple in its definition: the mathematical difference between the potential yield (Yp) and the average farmers' yield over some specified spatial and temporal scale (Lobell *et al*., 2009; Ittersum *et al*., 2013). What is complex in yield gap is the conceptual framework for its calculation. The most difficult task in this exercise is the determination of the potential yield. Van Ittersum and Rabbinge (1997) define the Yp as the yield of a crop cultivar when grown water and nutrients non-limiting and biotic stress effectively controlled. Hence measuring the Yp is thought to be an impossible mission as it is more a concept rather than a quantity whose assessment would request an integration of remote sensing, geospatial analysis, simulation models, field experiments and on-farm validation (Lobell *et al*., 2009).

According to the literature, estimated yield gaps are function of the crop, geospatial and temporal dimensions, and the methods used. Just to give some examples, the global Yg for wheat and rice is estimated at 36% against 50 % for maize (Neumann *et al*., 2010). In Africa the Yg for maize rises at over 80% due biophysical and management conditions (Lobell *et al*., 2009). The same trend applies for other crops in SSA including potato as the conditions are far from controlling the limiting (water and nutrients mainly) and reducing (biotic stresses) factors. This is worsened by the fact that in general farmers don't grow the right varieties and/or seed at the right time.

2.3. Site description and varieties used

The first work conducted was to map the different experimental sites. The georeferencing was carried out using a participatory approach. First we collected the coordinates given by the participating researchers, and then everyone had to validate its exact position in Google earth. Some coordinates were changed and situated in a correct position. The different waypoints used in simulations are situated between 11° of latitude N and 19°S (**Figure 3)**.

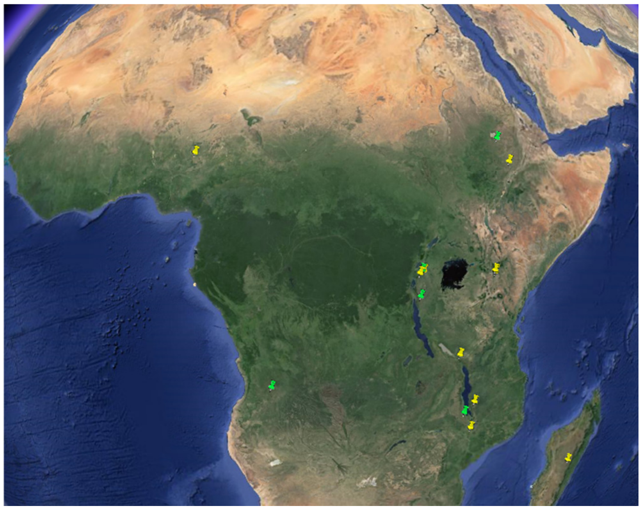


Figure 3. Experimental Sites on a Google Map for Africa.

During the second workshop, a quick analysis of temperatures and solar radiation of the different sites was conducted (**Fig. 4**). These data were retrieved from NASA Website (NASA, 2013). The following figure shows some highlights of the outputs.

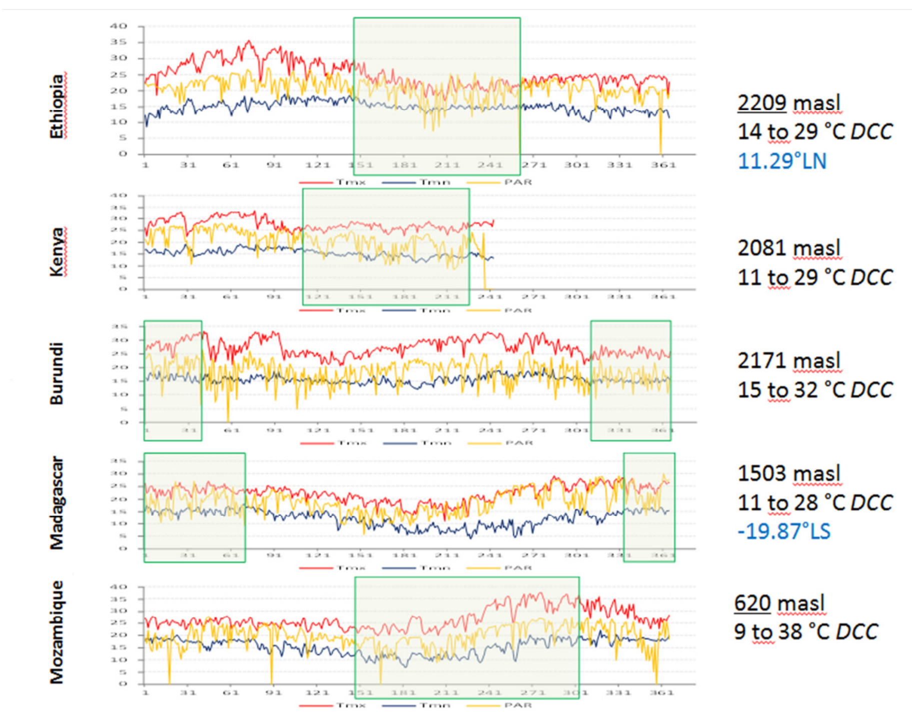


Figure 4. Graphical representation of Minimum Temperature Tmin), Maximum Temperature (Tmax), Solar Radiation (SR) and Main Potato Growing Season in Selected SSA countries: The red line represents Tmax, blue line for Tmin, the yellow line stands for SR; the green frame represents the crop growth period commonly practiced in the region by the growers. The altitude gives a special criterion for defining an environment (from 620 to 2209 masl).

This study was conducted on 12 genotypes that have been evaluated in the different breeding Programs. Those genotypes are as follows: Victoria (Asante), Dosa, CIP395112.9, Guassa (CIP384321.9), Gudene (CIP386423.13), Kenya Mpya (CIP393371.58), Unica (CIP392797.22), Meva (CIP377957.5), Lulimile (Tigoni), Diamant, CIP396038.107 and CIP396036.201. All these materials come from CIP except two, Dosa grown in Cameroon and Diamant found in Nigeria.

2.4. Estimating Potential Yield through Modeling in selected SSA countries

2.4.1. Parameter Calculator

In order to simulate the potential yields, there was need to develop a tool to estimate parameters using allometric and heuristic methods. Embedded into the Solanum Model also developed by CIP and accessible at the URL (http://inrm.cip.cgiar.org/home/t-app/solanum.rar), the Parameter Estimator was a response to a huge gap normally found in developing countries. In most cases historical breeding data are seldom enough to be used for modeling purpose. Nevertheless the knowledge accumulated over decades by potato experts who participated in the workshops was tremendous to come up with a reliable tool which could fill the gap of model parameters.

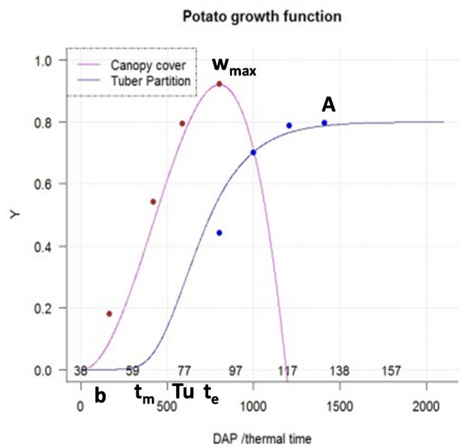
To this end, scientists were requested to provide data related to potato growth and development from their historical breeding trials using a template generated by facilitators (see Template in **Annex 3**). Based on this information, two graphs were developed. The first graph describes the canopy cover over time using the Beta function as expressed in **Equation 1** (Yin *et al*., 2003). In the second graph data were plotted in order to determine tuber partition over time using Gompertz function mathematically written in **Equation 2** (Winsor, 1932).

Beta function:

$$w = w_{\max}\left(1 + \frac{t_e - t}{t_e - t_m}\right)\left(\frac{t}{t_e}\right)^{\frac{t_e}{t_e - t_m}} \quad \text{with } 0 \le t_m < t_e \qquad (1)$$

Gompertz function:

$$y = A * (e^{(-e^{(-\frac{t-Tu}{b})}} \qquad (2)$$



<u>Canopy Cover Curve</u>

w_{max}, the maximum value of canopy cover
t_m, the thermal time at maximum canopy cover rate
t_e, the thermal time at the end of the growth period

<u>Tuber Partition Curve</u>

A, the maximum value of tuber partition
Tu, the thermal time at maximum tuber partition rate
b, the thermal time just before the tuber initiation process

Figure 5. Canopy Cover and Tuber Partition Curves and Description of Growth Parameters for the cv. Ndinamagara tested in Gisozi (data from Harahagazwe, 2009).

The Parameter Calculator as described above use numerical solutions in order to generate the different parameters. For Beta function we used bisection numerical method for analysis of nonlinear functions. For tuber partition curve (**Fig. 5**), algebraic analysis was used to clear the unknown function. The process described above was written in R Program and then included as a routine in the Solanum Model. This tool was validated using conventional methods on a potato variety called Cancan even if results are not presented in this paper.

During the workshop participants used the Parameter Estimator to generate parameters related to their respective trials and values obtained are presented in this paper. The results were then compared and discussed in groups until a consensus is reached. The following figure shows one of the outcomes depicting similarities between the Ethiopian case and results generated in Democratic Republic of Congo (**Fig. 6**).

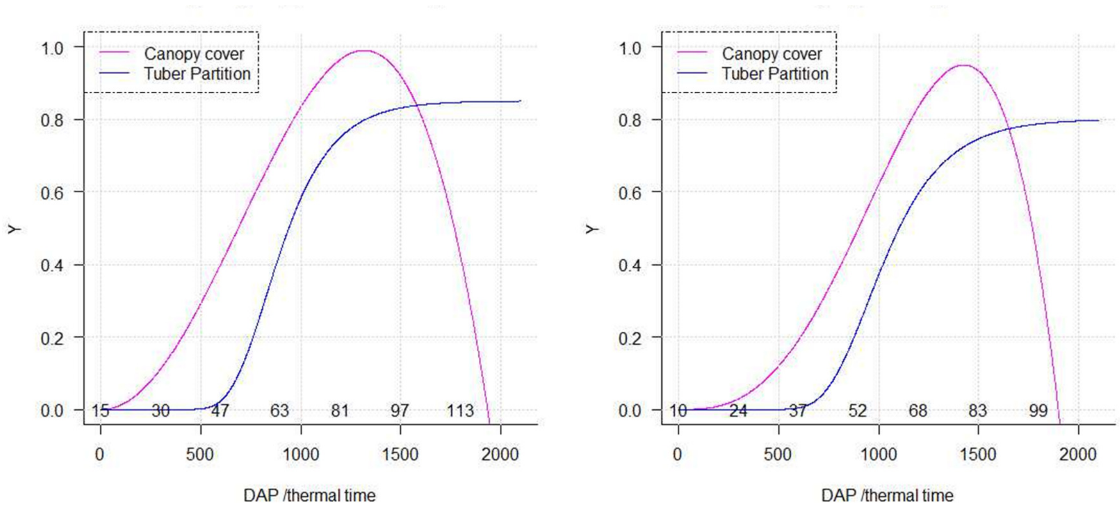


Figure 6. Example of Canopy Cover and Tuber Partition Curses for clone CIP395112.19 in Mulungu, DR Congo (left) and Cultivar Guasa in Adet, Ethiopia (right).

2.4.2. Weather Data

As previously indicated for field data, getting complete weather data is SSA is a big challenge. Only few participants came with gauged weather data like temperatures and rainfall. Therefore, we decided to download Web-based datasets from NASA for the sake of the exercise. By doing so we were aware that these data generated from Internet cannot depict exactly the real situation on ground. Therefore, we conducted a small comparison of minimum temperature and maximum temperature using NASA data and observed data from four case studies: Tigoni (Kenya), Kalengyere (Uganda), Kabuku (Kenya) and Antsirabe (Madagascar).

2.4.3. Solanum Model

SOLANUM is a user-friendly crop growth model that simulates tuber dry mass assimilation in different potato species (*Solanum* sp.), varieties and hybrids. The model estimates the tuber yield under potential, water limited, nitrogen limited and frost limited growing conditions (downloadable at http://inrm.cip.cgiar.org/home/downmod.htm). The Solanum Model is based on LINTUL potato model framework widely described in the literature (Kooman and Haverkort, 1995; Condori *et al.*, 2010; Harahagazwe *et al*., 2012; Condori *et al*., 2014).

The final values of parameters generated by the Parameter Estimator routine were used to run the Solanum model for each researcher. In the second workshop held in Addis Ababa, the potential production routine was used to estimate de maximal production under no limiting and reducing factors.

The potential production considers the genetic expression as influenced by the weather (temperatures and radiation).

At the same time, scientists brought the maximum tuber yields obtained in their respective trials for comparison with the yields generated by simulations. They had also brought average farmers' yields from the neighborhood of the experimental sites/stations. Sources for actual yields varied amongst the scientists but the major sources cited were the Ministries of Agriculture, FAO, surveys, scientific papers and related reports. Again scientists recognized the challenge to access this information related to actual yield. The figures normally released were qualified of inaccurate, mainly underestimating the real situation.

2.5. Potato production statistics in SSA

In order to have an idea on the potato production and productivity in SSA, we downloaded data from FAOST for the last six decades. In Eastern and Central Africa (ECA) we were interested in Burundi, DR Congo, Ethiopia, Kenya, Rwanda, Tanzania and Uganda. In Southern Africa we downloaded data for Angola, Madagascar, Malawi and Mozambique. The countries were selected based on the origin of participants to the workshops. It is worth mentioning that six of the studied countries were part of the top 10 list of potato producers in Africa in 2007 (FAO, 2009). Furthermore, we processed datasets from Monfreda *et al*. (2008) using GIS tools to map the average potato yield in Africa. The key findings of this study are summarized the following paragraphs.

By cumulating the annual potato productions, we found that the total potato supply has been increasing in SSA for the last six decades (**Fig. 7**). The total production in the seven selected countries of ECA has passed the 7 million metric tons – around 10% of the best global producer (China) - compared to 2 million achieved two decades before. As expected, the countries show disparities among them. Kenya, Rwanda and Tanzania turn to be the major potato producers (**Fig. 7** and **8** ***left***). Other countries like Burundi and DR Congo contribute little to the regional production. Also we find that Ethiopia and Uganda seem to have stabilized their potato production despite their relatively significant contribution to the regional production.

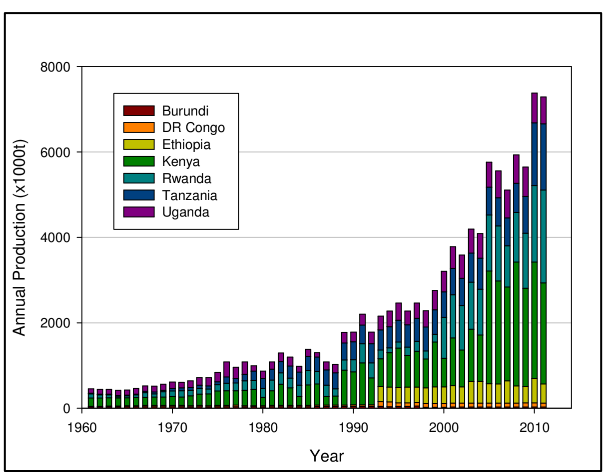
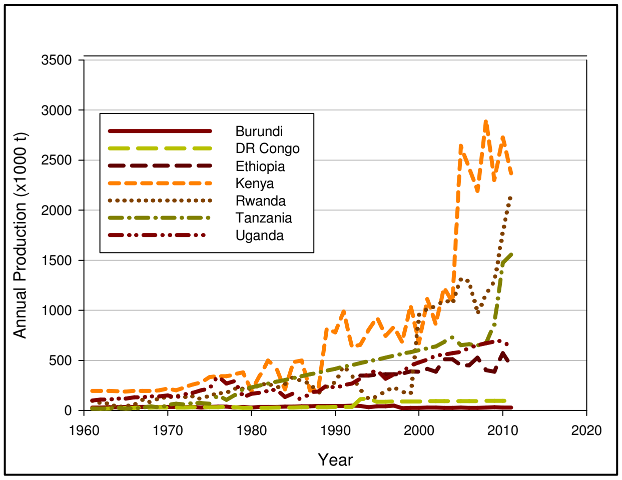


Figure 7. Cumulative Annual Potato Production in Eastern and Central Africa (data from FAO, 2013).

In the four countries studies in Southern Africa, Malawi showed very high difference with the rest of the country (**Fig. 8, *right***). Furthermore, Malawi ranked second in 2007 for potato production across Africa (FAO, 2009). Since 2000 the potato crop started to be an important crop. Mozambique and Madagascar still need to invest in this crop as the graphs show that they might be relying on imports.



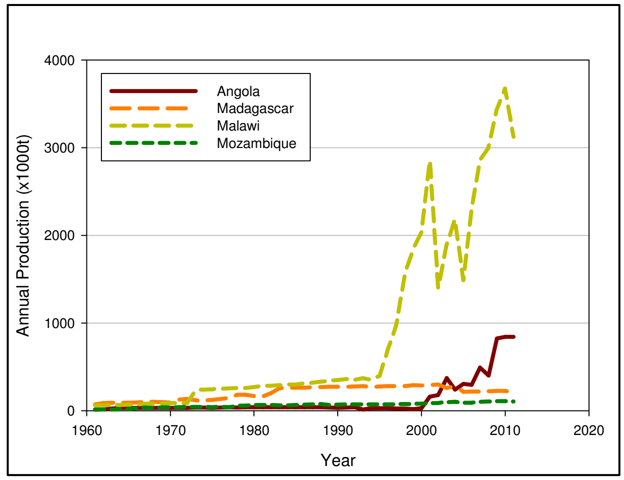
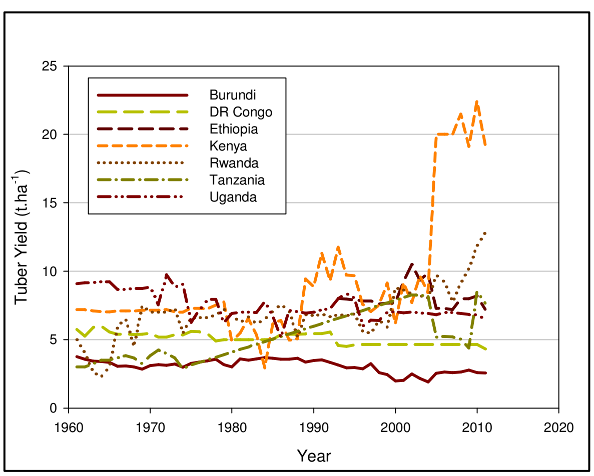


Figure 8. Annual Potato Production in Selected Countries of Eastern and Central Africa (*left*) and Southern Africa (*right*) (data from FAO, 2013)

With regard to tuber yields, they are in general low in most of the countries. In our study area the average yield is less than 10 t/ha except in some countries like Kenya, Mozambique and Malawi (**Fig. 9 and 10**). An analysis of figures **8** (*left*) and **9** (*left*) shows that the sharp and sudden increase of potato production in Kenya could be explained by the increase of tuber yield which occurred in 2005. There is a need to deepen the investigation in order to understand what could be the cause(s) but one of the hypotheses to explore is the release of new varieties with high yielding abilities and/or tolerance to pests and diseases.



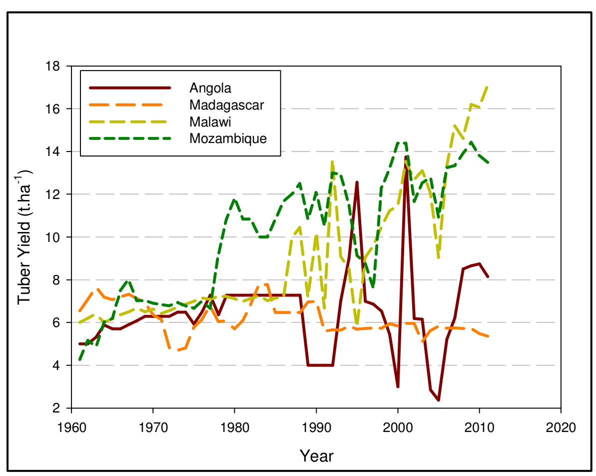


Figure 9. Average Potato Tuber Yield in Selected Countries of Eastern and Central Africa (*left*) and Southern Africa (*right*) (data from FAO, 2013)

The following map shows that in general yields seem to increase from the Equator southward with the highest yields in South Africa. Four major factors could explain these high yields found in South Africa: (i) favorable temperatures during the winter season, (2) appropriate irrigation systems, (2) commercial varieties with high yielding ability and (4) control of pests, diseases and nutrient-related stresses.

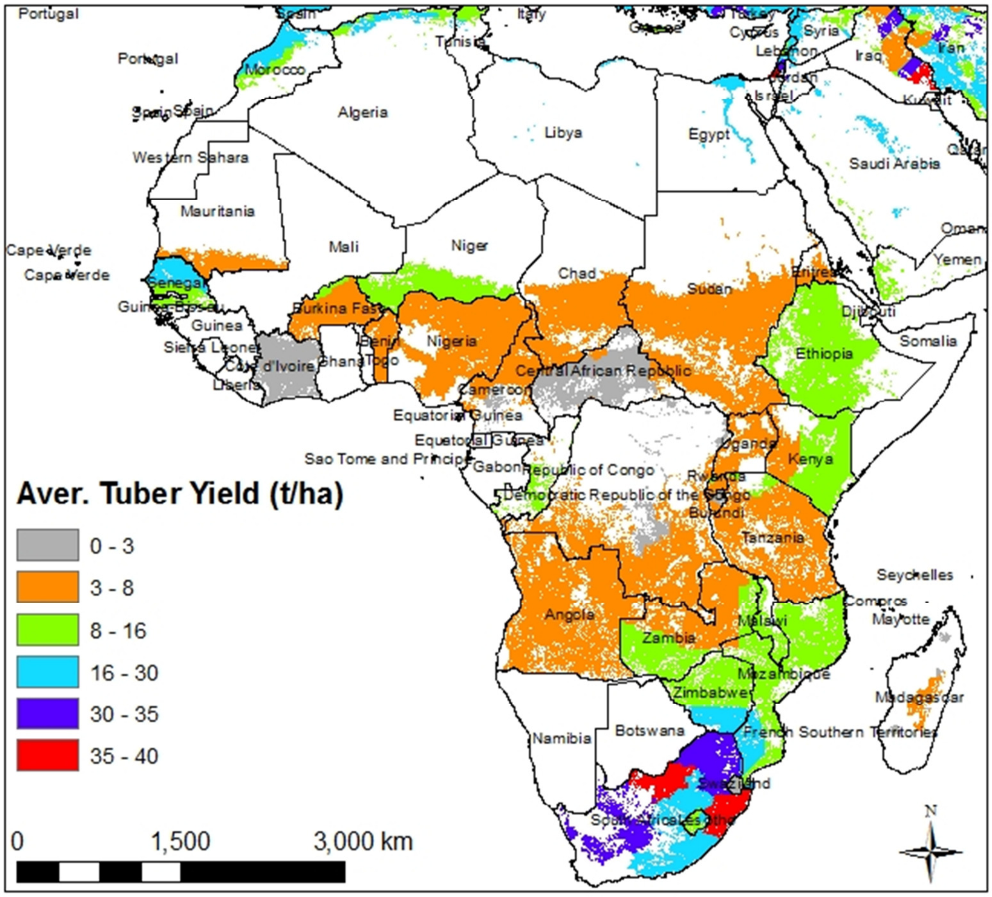
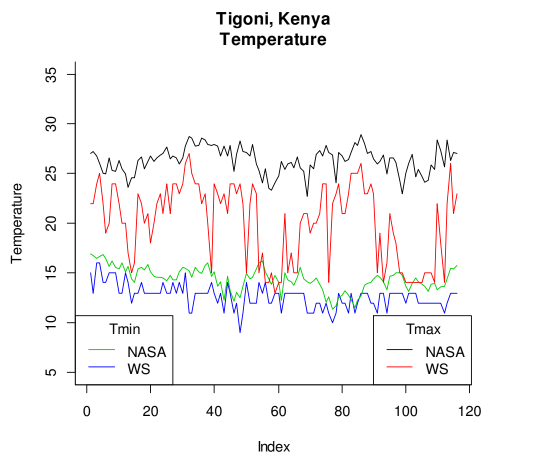


Figure 10. Average Actual Potato Tuber Yield Map for Africa (data from Monfreda *et al*., 2008).

3. Results and discussion

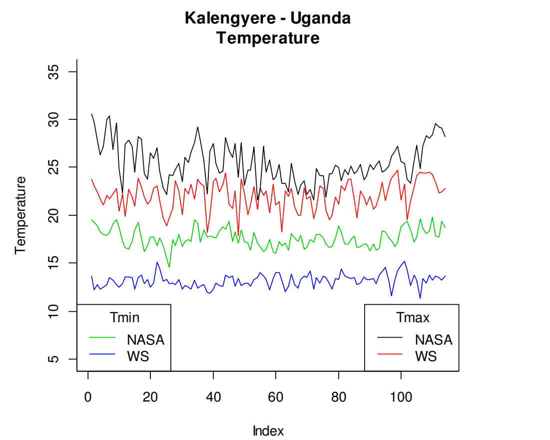
3.1. Weather Data: NASA data versus gauged data

An analysis of the data using R program generated the following graphs showing that NASA data overestimated the minimum and maximum temperatures even if statistics revealed some correlations (**Fig. 11**).



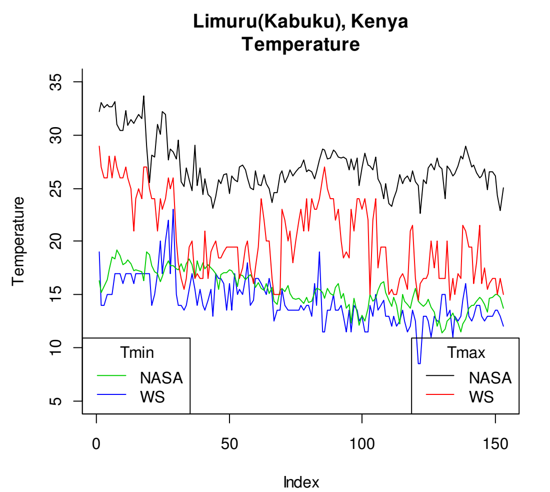
Tmax: Bias = 6.2 (p.value=0) overestimates
Error: 34.9% > 30% (wrong)

Tmin: Bias = 1.7 (p.value=0) overestimates
Error: 15.5% < 30% (Good)



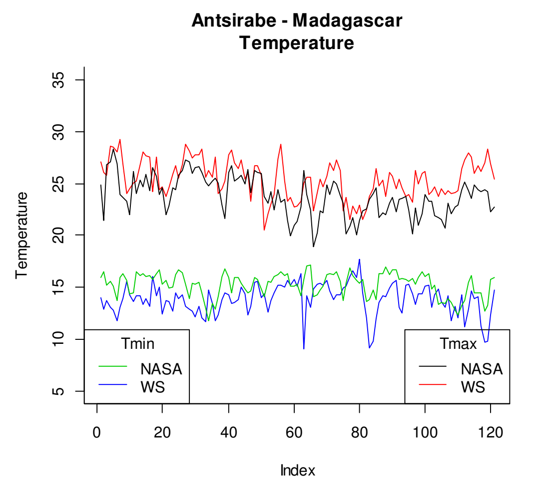
Tmax: Bias = 3.5(p.value=0) overestimates
Error: 17.9% < 30% (Good)

Tmin: Bias = 4.45 (p.value=0) overestimates
Error: 35% > 30% (wrong)



Tmax: Bias = 6.8 (p.value=0) overestimates
Error: 36.5% > 30% (wrong)

Tmin: Bias = 1.1 (p.value=0) overestimates
Error: 14.5% < 30% (Good)



Tmax: Bias = -1.6(p.value=0) underestimates
Error: 8.6% < 30% (Good)

Tmin: Bias = 1.4(p.value=0) overestimates
Error: 14.8% < 30% (Good)

Figure 11. Comparison of NASA data and Gauged data in relation to Tmin and Tmax in Tigoni (*top left*), Kalengyere (*top right*), Kabuku (*bottom left*) and Antsirabe (*bottom right*).

3.2. Parameters generated

As indicated earlier, simulation models do make sense when you have parameters that characterize your germplasm. As part of the workshop held in Addis Ababa, each participant ran the Program routine and generated his/her own parameters (**Table 2**).

Table 2. Parameters Generated for Use in Simulation Model for the Different Experimental Sites. Note that Dry Matter Concentrations (DMC) and Radiation Use Efficiency (RUE) were not generated by the Estimator but provided by scientists

Variety name	Country	Site	Parameter for SOLANUM model							
			Wmax	Tm	Te	A	Tu	b	DMC	RUE
Victoria	Burundi	Rwegura	0.99	699	1317	0.85	876	127	0.18	2.7
Dosa	Cameroon	Fongo-Tongo	0.98	643	1523	0.87	972	223	0.23	2.5
CIP395112.9	DRC	Mulungu	0.95	399	1158	0.80	601	140	0.22	2.7
Guassa (384321.9)	Ethiopia	Adet	0.95	411	1092	0.80	684	194	0.23	2.5
Gudene (386423.13)	Ethiopia	Adet	0.95	523	1209	0.80	822	208	0.24	2.5
Tigoni	Kenya	Tigoni	0.90	421	1249	0.87	686	182	0.21	2.5
CIP393371.58	Kenya	Kabuku	0.95	271	1151	0.80	593	219	0.23	2.5
Unica (CIP392797.22)	Kenya	Kabete	0.90	503	1095	0.87	639	99	0.21	2.5
Victoria (Asante)	Kenya	Kabete	0.90	564	1027	0.87	669	78	0.18	2.5
Meva (377957.5)	Madagascar	Antsirabe	0.95	268	1091	0.80	534	187	0.23	2.5
Lulimile	Mozambique	Sussundenga	0.95	555	1175	0.85	829	185	0.21	2.5
Diamant	Nigeria	Kuru	0.91	540	1211	0.82	794	160	0.20	2.5
CIP 396038.107	Uganda	Kalengyere	0.95	597	1361	0.86	846	174	0.23	2.5
Unica	Kenya	Suyian	0.90	468	995	0.87	659	126	0.21	2.5
Unica	Kenya	Marigat	0.95	450	958	0.80	632	124	0.21	2.5
CIP 396036.201	Malawi	Bembeke	0.95	451	1082	0.85	793	232	0.22	2.5

Looking at the different values one could quickly comment they are not so different meaning that the genotypes utilized were not too much different each other. However there is a need to deepen the analysis.

3.3. Different Types of Yield generated in the Addis Ababa Workshop

By the end of the second workshop, all the participants who had brought their data completed the simulations prior to receiving certificates of attendance (**Annex 4**). All results were summarized in a table containing potential yields generated by simulations, the best ever obtained yields in experiments, the farmers' yields and of course the yield gaps as shown in F**ig. 12** and **13**. Regardless of the genotypes, seasons and sites, those yields turned to be 50.6 t/ha for potential yield, 28.6 t/ha on-station yield, 8.2 t/ha as average farmers' yield and 42 t/ha for the overall yield gap.

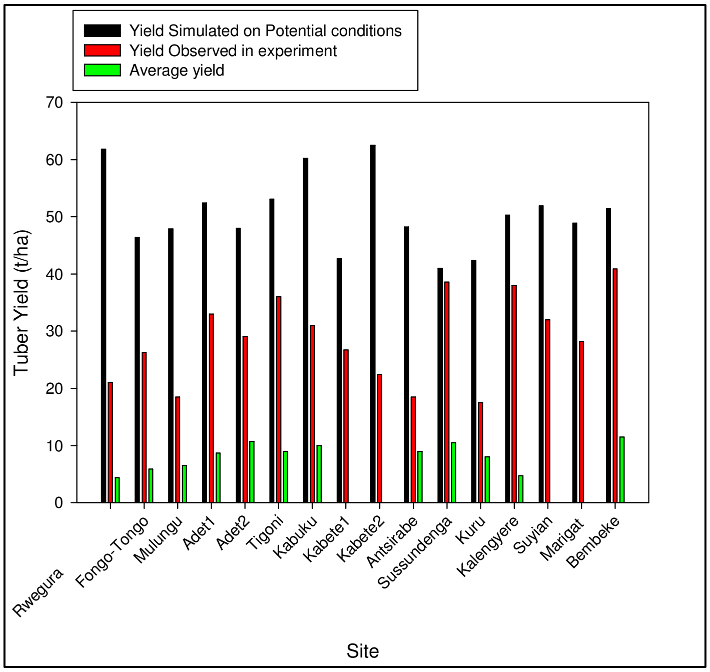


Figure 12. Histograms of Yields Simulated on Potential Conditions, Yields Observed in Experiments and Average Farmers' Yields in Selected Sites.

Boxplots generated using these result show clearly that yield gaps in SSA are superior to yields normally obtained on-station (**Fig. 13**). Indeed with less than 10 t/ha as average farmers' yield, there is a high potential in SSA to increase production if investments are made to optimize the defining production factors and manage properly limiting and reducing factors.

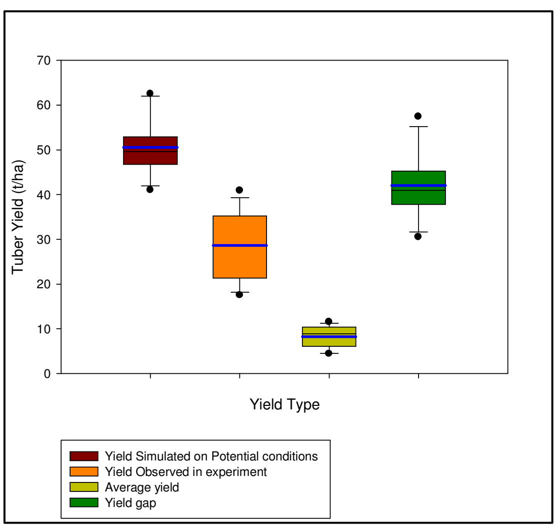


Figure 13. Boxplots of Different Yield Types Generated in Addis Ababa Workshop: in these biplots expressing quartile distributions, the black line in the box is the median, the blue line is the mean and the dots are the outliers.

4. Conclusion and the way forward

The work conducted so far showed the enthusiasm of potato scientists in SSA to share their knowledge and experience for modeling purposes. Results generated showed huge yield potato yield gaps in the region far superior to the yields normally obtained in on-station trials. This is evidence that there is a high potential to increase the volume of potatoes produced in SSA by just working on the different constraints faced by potato growers. Another lesson from the study is the scarcity of data in SSA for modeling purposing – mainly reliable weather data and agrophysiological traits of germplasm used - and agricultural statistics as well.

In this first phase of study, the focus was site-specific. The way forward is to scale up/out the tools and give a geospatial dimension to this analysis. To this end, all participating scientists committed to launch an initiative called "Climate-Smart Potato in SSA" whose objectives are as follows:

i. Characterize potato environments in different target countries using geospatial analysis tools;
ii. Understand and document the agrophysiological traits of most potato varieties grown and consumed in the region;
iii. Predict the behavior of most potato varieties grown in SSA in a changing environment (yield gap, suitable areas and climate change) through modeling in responding to questions like "what if…" ;
iv. Develop and promote a community of practice for a climate-smart potato in SSA.

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Acknowledgements

This study was co-funded by three CGIAR Research Programs: “Climate Change, Agriculture and Food Security” (CCFAS), “Roots, Tubers and Bananas” (RTB) and “Humidtropics”. Authors are grateful to NASA for their open-access Web-based weather data.

Annexes

Annex 1: Program of the Nairobi Workshop

Time	Topic	Facilitator/Responsible
Monday, 24 June 2013		
08:00 – 08:15	Registration of participants	Carolina Barreda
08:15 – 08:30	Welcome remarks, introductions and workshop objectives	Elmar Schulte-Geldermann
08:30 – 09:30	Introduction to yield gap analysis	Dieudonné Harahagazwe
09:30 – 10:30	Introduction to systems analysis and crop modeling	Roberto Quiroz
10:30 – 11:00	*Health break and Group photo*	
11:00 – 13:00	Introduction to systems analysis and crop modeling (Continued)	R. Quiroz
13:00 – 14:00	*Lunch*	
14:00 – 15:30	Introduction to crop modeling (Excel): break-out groups	Bruno Condori, C. Barreda, D. Harahagazwe, F. Mendiburu and R. Quiroz
15:30 – 15:45	*Health break*	
15:45 – 17:00	Introduction to crop modeling (Excel): break-out groups (Continued)	B. Condori, C. Barreda, D. Harahagazwe, F. Mendiburu and R. Quiroz
17:00 – 18:30	*Cocktail*	
Tuesday, 25 June 2013		
08:00 – 09:00	Presentation and assessment of weather, soil and trials data brought by participants	Participants
09:00 – 10:30	Parameter calculator rationale and demonstration	R. Quiroz and Felipe Mendiburu
10:30 – 10:45	*Health break*	
10:45 – 13:00	Parameter estimation: break-out groups	F. Mendiburu, B. Condori, C. Barreda, D. Harahagazwe and R. Quiroz
13:00 – 14:00	*Lunch*	
14:00 – 15:30	Plenary session: Parameter estimation results	Participants
15:30 – 15:45	*Health break*	
15:45 – 18:00	Introduction to SOLANUM for yield gap analysis and installation of the programme	B. Condori

18:00	End of day 2	
Wednesday, 26 June 2013		
08:00 – 10:30	SOLANUM scenarios: break-out groups	B. Condori, C. Barreda, D. Harahagazwe, F. Mendiburu and R. Quiroz
10:30 – 10:45	*Health break*	
10:45 – 11:30	Plenary session: Presentation of results	Participants
11:30 - 12:00	Wrap-up, Way forward and Workshop 1 evaluation	R. Quiroz and Susan Corning
12:00	End of workshop 1	
12:00 – 13:00	*Lunch*	

Annex 2: Program of the Addis workshop

Day/Date	Time	Activity	Methodology/Approach	Product of the day
Sunday, October 13, 2013		Arrival of participants		
Monday, October 14, 2013	AM	Streamline weather data (downloaded and gauge data where existing)	Participants install first the new version of Solanum updated on the basis of recommendations from the first WS held in Kenya	Parameters for every variety and site compiled in Solanum
	PM	Finalize the estimation of model parameters for each particular condition and variety	Based on what we learned in the previous WS, we are bringing the parameters calculator built in the Solanum model, so it its very user friendly	
Tuesday, October 15, 2013	AM	Parameters calibration	Each participant will run Solanum under potential conditions. Based on their potential conditions trials judge whether the simulated yield and their potential harvest match. If not, they need to reiterate the process until each expert is satisfied with the parameters	Verified model parameters for commercial varieties and CIP promising clones
	PM	Group assessment of growth parameters	We need to make groups, based on the varieties each participant is modeling. This is a crucial step since we plan to decrease bias in the estimation with this discussion among professionals experienced with the same variety although working under different environments. The role of CIP scientists here is very important to guide the discussion and hopefully end up with	

			robust parameters. We want to emphasize the behavior of commercial varieties and CIP materials.	
Wednesday, October 16, 2013	AM	Multi–annual simulation with commercial varieties	We will need to download around 20 years of Tmax, Tmin and rainfall for each site. We want to assess potential productivity during the last 20 years for each site.	Estimated yield gap with the commercial varieties grown in the areas
	PM	Yield gap analysis	**Each participant must bring the statistics for the district/province/political unit where his/her research site is located (**+ source, if possible: paper, report, etc..). The difference between the multi-annual simulated yield and the multi-annual statistics is the yield gap.	
Thursday, October 17, 2013	AM	Multi–annual simulation with CIP clones	The idea is to assess the potential benefit of introducing CIP material into the systems	First assessment of water contribution to yield gap per site and the potential contribution of CIP promising clones.
	PM	Introduction to the water limited routine and assessing the contribution of water to explain yield gap in each site	We will use 20 years of rainfall for each site and assess potato productivity under water limited conditions. We prefer gauge rainfall data since we all know that interpolated data can be far off the reality. Nonetheless, we will assess the contribution of rainfall the best we can with the data available to us.	
Friday, October 18, 2013	AM	PPT presentations summarizing all the results		A clear plan on the next step and responsibilities defined
	PM	Wrap-up and discussions on the way forward		
Saturday, October 19, 2013		Departure of participants		

Annex 3. A Sample of Survey templates used to register Metadata and Model Inputs

Complete the following table about potato growth and development, for each environment and genotype, according to experience and /or experimental data.
(Complete la siguiente tabla sobre el crecimiento y desarrollo de variedades de papa, para cada ambiente y genotipo, de acuerdo a sus datos experimentales y/o experiencia)

Type of trial (Tipo de experimento)	EXAMPLE: Potencial crop growth
Leader (Lider)	EXAMPLE: rquiroz
Colaborators (Colaboradores)	EXAMPLE: cbarreda
CIP regional location (Oficina Regional CIP)	OPTIONS: LAC (Latin America and the Caribbean), SSA (Sub-Saharan Africa), SWCA (South West Central Asia), ESEAP (East, Southeast Asia and the Pacific)
Agroecological zone (Zona agroecológica)	OPTIONS: Temperate, Tropical and subtropical higlands, Tropical and sub-tropical lowlands.
Country (Pais)	EXAMPLE: Peru
Administrative unit 1 (Division administrativa 1)	EXAMPLE: Department - Lima
Administrative unit 2 (Division administrativa 2)	EXAMPLE: Province - Lima
Administrative unit 3 (Division administrativa 3)	EXAMPLE: District - La Molina
Clone or variety name (Nombre de la variedad o clon)	EXAMPLE: Canchan
Site of trial (Ubicacion del ensayo experimental)	EXAMPLE: La Molina
Latitude (Latitud)	EXAMPLE: 12º 04’ 39’’ LS
Longitude (Longitud)	EXAMPLE: 76º 56’ 53’’ LO
Elevation (Altitud)	EXAMPLE: 280 msnm
Nearest city or town (Centro poblado mas cercano)	EXAMPLE: Lima
Nearest weather station (Estacion meteorológica más cercana)	EXAMPLE: Alexander Von Humboldt (UNALM)
VARIABLE	VALUE
Photoperiod sensitivity (Respuesta al fotoperiodo)	OPTIONS: Short day (less than 13 hours of sun light), Neutral day (from 13 to 15 hours of sun light), Long day (more than 15 hours of sun light)
Earliness (Precocidad)	OPTIONS: Early (120 days), intermediate (150 days), late (180 days)
Planting date (Fecha de siembra)	EXAMPLE: 23 June 2006
Planting density – Number of plants per m2 (Densidad de siembra)	EXAMPLE: 3.7
Emergence day – days after planting (Días a la emergencia, días después de la siembra)	EXAMPLE: 21
Tuber initiation onset – days after planting (Días al inicio de tuberización, días después de la siembra)	EXAMPLE: 40
Maximum canopy cover – 0-100% (Máxima cobertura vegetal, 0-100%)	EXAMPLE: 98%
Maximum canopy cover day – days after planting (Días a la máxima cobertura vegetal-días después de la siembra)	EXAMPLE: 104
Senescence initiation onset – days after planting (Días al inicio de senescencia-días después de la siembra)	EXAMPLE: 136
Harvest date (Fecha de cosecha)	EXAMPLE: 20 November 2006

Annex 4: Certificate Template

• INTERNACIONAL • CENTRO DE LA PAPA • CIP

A member of the CGIAR Consortium

Certificate of Attendance

Presented to:

Astère Bararyenya

For attendance to the

Yield Gap Analysis and Crop Modeling Workshop

held in Addis Ababa on October 14 – 18, 2013

Dr. Roberto Quiroz
a.i. Integrated Crop and Systems Research Program Leader

October, 2013