CIP POSITION PAPER

Shaping Climate Smart Agri-Food Systems through Roots and Tubers

- **Potatoes and sweetpotatoes can play a significant role in climate smart agriculture approaches to climate change**
- **Drought, desertification, flooding and rising temperatures associated with climate change will compromise the expanding area of potato and sweetpotato crops**
- **The geographical displacement of agricultural systems is already underway because of changes in weather patterns.**
- **Projected climate variation in Sub Saharan areas could inhibit the delivery of biofortified varieties of orange-fleshed sweetpotato (vitamin A) and potato (iron and zinc).**
- **Climate change is projected to impair the quality of life of smallholder farmers and their families likely resulting in further migration to already overwhelmed urban centers.**
- **To overcome the agronomic, social, and political challenges brought about by climate change the following areas must be strengthened: the development of climate-smart crops, the ongoing improvement of agricultural systems and the biophysical and social sciences.**

Purpose

Resilient root and tuber-based agri-food systems are central to International Potato Center's (CIP for its acronym in Spanish) efforts on climate change. There is an escalating need CIP's development focused high-quality research that positively benefits the smallholder farming families faced with a changing world environment. The paper articulates how CIP's ongoing work will help to **adapt to and mitigate the effects of climate change** in the areas of the world most affected by extreme weather conditions and weather–related shocks.

Role of potato and sweetpotato in resilient agriculture

Potato and sweetpotato are critical providers of food and nutrition security for millions of people globally particularly in the context of developing countries. Potato is the third most important crop, after rice and wheat, in the global food supply. Potato is currently eaten more in developing than in developed countries. More than one and a half billion people worldwide eat potato as a staple food.

Potato's global importance cannot be overstated. More than one-third of total potato production is associated with smallholder farming in developing countries. It is an excellent, low fat source of carbohydrates and when boiled potatoes have more protein than maize and nearly twice the calcium.

The Andean region offers a classic example of the substantial importance of potato as the pillar of food systems that successfully provided food and nutrition to highly populated ancient civilizations. Potato has a long history of resilience and productivity as a pivotal component of food systems in the high Andes, an area of high climate variability with a frequent occurrence of extreme weather such as frost, hail, flooding, and drought. Potato's resilience in the Andean region is based on its relatively short vegetative period, high potential productivity, relatively low water demand, high genetic diversity and its adaptability to different environmental conditions. High genetic diversity alone, included in several *Solanum* species, varieties and landraces within species, is already effectively utilized in the breeding of new varieties adapted to changing environmental conditions. CIP's genebank holds a still untapped pool of genes with climate resilient properties, which should be mobilized to improve breeding products.

Sweetpotato – a multipurpose crop- is also highly relevant in the design of resilient farming systems in subtropical and tropical environments. Compared to cereals, sweetpotato produces higher quantities of energy per day [1]. It is characterized by its water use effectiveness and is a hearty crop that requires few inputs. Its ability to thrive in a diverse range of marginal environments raises the overall productivity of different agricultural systems and landscapes in a sustainable way. As a vine, it grows horizontally rather than vertically, giving it the ability to tolerate severe weather conditions much better than most staple crops. Recent cyclones and typhoons that decimated eastern India and the central Philippines demonstrated sweetpotato resilience when it was one of the few crops able to continue supplying food to the local population. Sweetpotato is thus ideally adapted for climate proofing agricultural systems through resilience to extreme weather. For lowland tropical and sub-tropical areas, sweetpotato is a robust crop that grows under marginal conditions, poor soils, limited water availability and is not demanding of agricultural inputs.

Clearly, sweetpotato is a climate resilient and nutritious crop that can become a solution to both direct and indirect stresses driven by extreme climatic events and climate change. Dual purpose types of sweetpotato (foliage and tubers) have a potential role in the development of production technologies that aim at integrating crops and livestock commodity factors into an integral production system. It is an important crop for developing a micronutrient supply that is accessible to vulnerable populations. Such is the case of vitamin-A rich orange-fleshed sweetpotato in Africa and for disaster relief and recovery in areas affected by natural disasters as was demonstrated in Haiti. Strengthening the resilience of sweetpotato and its adaptation to climate change will ensure that the benefits of this crop are not affected.

[1] Srinivas, T. 2009. Economics of sweetpotato production and marketing. In Loebenstein, G., Thottappilly, G. (Eds.) The Sweetpotato. Springer, pp. 235-267.

Challenges of climate change to potato and sweetpotato agri-food systems

Current evidence indicates that agriculture worldwide is already severely affected by climate change. Rising global temperatures, changing rainfall patterns and more frequent extreme weather events are having disastrous effects on environmental and food production systems.

A critical effect of climate change on agriculture is the impact that the seasonal and annual rainfall variability is having on timely water availability. Without the introduction of new technology into farming systems, the Intergovernmental Panel on Climate Change (IPCC) indicates that rainfall variability and more frequent droughts could reduce crop yields in some areas by up to 50% by 2020. A recent meta-analysis of crop yield under climate change and adaptation shows the association of yield losses with even moderate changes in climate.[2]

The projected impact on global potato yield reduction associated to global warming, for the period (2040-2059), is estimated to be 18% to 32% (without technologies for adaptation)[3]. Most recently, nine potato modeling groups conducted a multi-model assessment using models calibrated with reference data sets in developed and developing countries where changes in CO2, temperature and rainfall were included. Median model ensemble values showed that potato yield increased on average 6% per 100-ppm CO2, declined 4.6% per °C, and declined 2% for every 10% decrease in rainfall (for non-irrigated sites)[4]. The positive CO2 fertilization effect was offset by increments in temperature. Changes in water regimes affected rain fed areas.

Farmers in the Andean highlands have for years been seeking to reduce the pressure of pest and diseases such as late blight, determined by temperatures, rainfall, and humidity, by moving potato cultivation to higher altitudes. Farmers at lower altitudes are seeing a dramatic increase in the use of pesticides. This situation is particularly critical for potato landraces. The cold weather in the high Andes has protected their cultivation for thousands of years. When temperature increases and insect and disease presence intensifies, the rich biodiversity of this crop that is still conserved in farmer fields may be put at risk.

The effects of climate change on sweetpotato have not been determined in the same way as potato. However, extreme weather, such as drought and mega-flooding will increase in some areas of the world, like Africa and Asia, where this crop is an essential component of the agri-food system. A yield reduction can be expected if no adaptation technologies are developed for drought, salinity, and heat tolerant cultivars.

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[2] Challinor, A.J.; Watson, J.; Lobell, D.B.; Howden, S.M.; Smith, D.R.; Chhetri, N. 2014. A meta-analysis of crop yield under climate change and adaptation. Nature Climate Change 4:287–291. http://dx.doi.org/10.1038/nclimate2153.

[3] Hijmans, R.J. 2003. The effect of climate change on global potato production. American Journal of Potato Research. ISSN 1099-209X. 80(4):271-279. http://dx.doi.org/10.1007/BF02855363.

[4] Fleisher, D.H., Condori, B., Quiroz, R. et al., 2016. A potato model intercomparison across varying climates and productivity levels. Global Change Biology (2016), doi: 10.1111/gcb.13411

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Climate change is exacerbating the prospects for future productivity growth in the developing world. It is also exacerbating food insecurity and migration and is raising international humanitarian and political concerns. The Food and Agricultural Organization (FAO) predicts many climate change related challenges for world agriculture in the coming decades. The growing world population will require 70 percent more food to nourish an additional 2.3 billion people by 2050. Organizations will need to address the increased demand for food while simultaneously combating poverty and hunger. The efficient use of scarce natural resources and climate change adaptation are the main challenges world agriculture will face in the coming decades. Meeting these challenges requires a climate smart agri-food system that improves agricultural productivity with a greater resilience to increasing temperatures and extreme weather.

Research and development on how to boost the adaptation, resilience, and sustainability of food systems is essential under current climate change scenarios. Since agriculture itself generates some 12–14% of total greenhouse gas emissions and a high proportion of the more active greenhouse gases, particularly methane (47% of total CH4) and nitrous oxide (58% of total N2O), such research should also seek to reduce the impact of agriculture on climate change. Agricultural research on climate change must include the identification of mitigation strategies that will reduce emissions of greenhouse gasses, better integration of crop production and livestock raising and lead to policy measures on land use change. In this sense, it is important to produce science-based evidence to help policy makers and stakeholders assess opportunities, balance trade-offs and identify entry points for smart, targeted interventions and more efficient investments to make potato and sweetpotato climate-smarter crops.

CIP's response to the climate change challenges

Potato and sweetpotato, like all crops, are sensitive to variations in temperature, water availability and relative humidity. For more than 45 years CIP has actively worked to maintain and enhance the quality and resilience of these crops under climate change conditions. The likely reduction in potato and sweetpotato production under climate change will affect mainly the poor population. If the needed counteractive measures such as the adoption of tolerant varieties and management strategies are not implemented in time, food security, malnutrition, human health, political instability and increased poverty will grow in developing countries.

The interaction among multiple factors involved in climate change and effect on crops add to its complexity. Further research on resilience breeding, crop growth modeling, and climate change scenarios related to root and tuber production is required. New technologies such as remote sensing, assisted phenotyping of germplasm, ideotyping of varieties adapted to new environments, modeling of pest and vector dynamics as affected by climate change scenarios, carbon sequestration and emissions related to land use changes driven by climate change, and market and value chain assessments for their response to climate variation all could be utilized in future research.

CIP's science-driven innovation approach to the challenges of climate change focuses on evaluating pro-poor climate resilient agricultural practices for potato and sweetpotato food systems. CIP's highly qualified and mission oriented scientists are actively developing technologies that enhance production and increase resilience to climate change. We strive to be emission-sensitive and develop decision support systems designed to meet the needs of different stakeholders.

CIP along with our collaborators breed varieties tolerant to heat stress, pests, and diseases. Integrated pest management (IPM) strategies are under development and testing. In its research CIP relies on its large germplasm collections to breed new tolerant varieties that outperform existing ones when exposed to heat or water deficit. Our ongoing innovation process requires new insights and approaches to increase precision and accelerate the development, testing and delivery of varieties and practices that contribute to coping strategies.

Strategies to improve water use efficiency by the potato and sweetpotato crops are also being tested. For instance, including and intensifying potato in cereal-based systems in dry areas in Asia will make the systems more diverse and thus more resilient to potential climate extremes. Moreover, novel techniques based on airborne remote sensing for monitoring crop condition, assisting phenotyping and building decision support systems for different stakeholders, including smallholder farmers, are under development.

One of the main challenges with extreme climate events is that a possible reduction in the availability of planting material will affect the continuation of farming activities. Therefore, seed system improvements are needed to disseminate climate resilient potato and sweetpotato varieties to farmers in a more rapid way.

Close interaction with policy makers who benefit from the use of scientific evidence about soil carbon stocks under different land use systems to inform their policy decisions will help CIP to contribute to the reduction of emissions from agriculture.

CIP will actively promote partnerships and innovation processes with the development community, scientists in the developed and developing world, NGOs, food processors using potato and/or sweetpotato as raw materials, investors, and civil society. CIP will collaborate with governments and farmers to support integrated approaches and overcome barriers to adoption of more sustainable and climate smart agriculture practices. Testing the acceptability, adoption, and impact of technologies, and taking into account the different approaches that genders take to agriculture is embedded in CIP's research, science, delivery, and innovation. CIP's research aims at providing sound guidance on climate resilient food systems in developing countries.

Highlight of CIP's research response to address climate change challenges

Climate resilient research topics	Contributions to the understanding of climate-agriculture interactions and options for coping and adapting to challenges
Climate resilient breeding	Potato is a crop with climate resilient characteristics, such as relatively shorter production cycle, high potential productivity, relatively low water demand, high genetic diversity and its adaptability to different environmental conditions. It is often the crop that is cultivated and harvested in the hunger months. There is an urgent need to develop cultivars that can produce reliable yields and maintain their quality with less water and higher temperatures that are already being experienced with climate change. CIP's breeding research for new variety development uses the genetic diversity of potato and sweetpotato to combine and elevate characteristics that are needed for a high and stable yield of nutritious crops with limited external inputs. CIP's germplasm evaluation and breeding programs are incorporating remote sensing tools into the selection of parents and promising varieties that suffer less from heat and drought. We use these for precise observations of underground (roots) growth and development in genetic and genomic analysis to unravel the potato and sweetpotato's inter-related responses to these key abiotic stresses. For potato, we have suggested two ways of selecting on genetic diversity using stable isotope analysis: a screen for high water use efficiency and high yield, and a screen for low negative response to soil water deficit. Rapid, inexpensive tools that can assist breeders with the measurement of complex plant traits and the individual quantitative parameters that form their basis are needed to accelerate genetic gains. Precision phenotyping combined with genotyping remain to be integrated with crop modeling for target populations of environments for predicting performance across locations and under climate change scenarios. Crop ideotyping based on crop growth models, remote sensing and simulated climate scenarios is another avenue to improve the adaptation of R&T to climate change.

Improving knowledge of the social dimension of climate change for more effective interventions	One of the main challenges of climate research is to assess the impacts of climate change on global food security, agricultural income and resource use, especially given the uncertainty of the socio-economic environment (GDP, population growth, changing gender relations, consumer preferences). To address these challenges, CIP is conducting research in several areas. CIP is using and contributing to the improvement of the set of global bio-economic foresight modeling tools which are based on the economic multi-market equilibrium model IMPACT (International Model for Policy Analysis of Agricultural Commodities and Trade), developed by the International Food Policy Research Institute (IFPRI), and the crop growth model Decision Support System for Agrotechnology Transfer (DSSAT). This framework allows the ex-ante impact assessment of promising climate-adapted technologies which can mitigate abiotic stresses on agricultural production. An extension of this framework for also integrating the impact of pests and diseases is currently under development. A vulnerability analysis framework was validated in the Andes to provide an overarching picture of food vulnerability in a specific region, with the ability to drill down and isolate the specific variables that exacerbate or drive vulnerability including climate change. The approach allows users to simultaneously review multiple vulnerability factors, at high and low levels of aggregation, and provides a richer understanding of the mechanisms that govern vulnerability. This framework should contribute to aid CIP program and project managers in finding correlations between socio-economic and biophysical variables and identify trends that may not be readily apparent through traditional approaches. Another area of social science focus concerns the way climate change affects women and men differently, leading to different roles in and benefits from, adaptation. The research assesses how women and men respond to climate-induced changes in their farming systems and how we can best contribute to safeguarding food security and livelihoods. High levels of migration by male farmers globally affect gender roles in potato based farming systems. Through reducing labor availability, it can limit the testing and implementation of more climate resilient farming practices. Male bias in technology dissemination networks may mean that women farmers have limited access to climate-smart technologies such as stress-tolerant varieties. Men's absence also interrupts the traditional climate forecasting system that is important for farming decisions. CIP's social and health research in Asia analyzes the contribution of root crop agriculture to food and nutrition security in the context of climate change and other drivers of change, and the gender dimensions of vulnerability and of enhancing climate resilience. Like most countries in Africa and Asia, in Bangladesh, women are the main target for introduction of orange sweetpotato and climate-smart varieties of sweetpotato because of their role in food security through homestead gardening in environments under threat from climate change.

	The intersection between market penetration and climate change can have severe environmental and social effects. In the high altitude Andes of Peru, grazing livestock is part of women's domain and is an important component of their livelihoods and economic autonomy. Therefore, responses to climate change in agriculture must be gender responsive and linked to people's cultural practices and indigenous farming systems. This includes prevention of post-harvest losses to raise the overall food system productivity and improve the efficiency of the value chains even under extreme weather events.
Climate modeling and remote sensing for improving decision making on climate resilient agriculture	Developing countries lack historical climate data to calibrate climate change models; this is critical to ascertaining the impact of climate change. CIP has developed a number of innovative tools to make use of coarse satellite data to generate reliable long-term climate series. The tools include state-of-the-art downscaling algorithms to generate rainfall and temperature data at high temporal and spatial resolution, needed to model the impact of climate change on agriculture. This data is used for crop modeling, yield forecasts, phenotyping and decision support systems. As an example, estimation of yield at regional scales improved greatly when these tools and methods were used. These estimations are useful for policy-making, priority setting and guiding the development and deployment of mitigation strategies including stress-resistant varieties and other components of sustainable crop and natural resource management practices. Field phenotyping is demanded by breeders to accelerate the pace for selecting climate resilient varieties for different environmental conditions. CIP has developed a series of sensors, protocols and software for both proximal (ground-based) and remote sensing based on unmanned aerial vehicles. Imageries taken at regular intervals in experimental stations and farmer fields are used for precision management and as input to process-based crop models to accurately forecast yields.
Crop and pests /diseases modeling tools	Models based on the processes underlying soil-water-plant atmosphere interactions as well as the dynamic of main pest are needed to ascertain both the direct and indirect impact of climate change on agriculture. CIP co-leads with the US Department of Agriculture a global effort to enhance the capacity of simulation models to assess climate change impact. We are also leaders in the development and use of sweetpotato modeling techniques to evaluate the likely impact of climate change on the crop. CIP is renowned for its expertise in Insect Life Cycle Modeling (ILCYM) that facilitates the development of pest insect phenology models and provides analytical tools for studying pest population ecology and changes due to temperature increase. A potato late blight (LB) management and ecology model to assess disease management scenarios is part of the suite of mathematical models developed at CIP. An expert system to convert the results from pest models into valid input for the crop growth models for potato and sweetpotato and assess the indirect impact of climate extreme

	on yield is under development. This is a pioneering effort addressing this gap in climate change-agriculture research.
Game changing solutions to increase potato and sweetpotato resilience to climate change	Game changing solutions are required to generate potato and sweetpotato based resilient food systems. Two major aims for potato are to achieve durable resistance to late blight and increased resistance to drought and heat that will result in climate smarter materials in the future. Also important is the combination of different approaches from the biophysical and socioeconomic angles for ensuring that systems are more resilient to climate change. To meet higher pressures and new strains of pests and pathogens, CIP has redoubled its historically strong efforts in breeding for resistance to biotic stresses. We have used the science of biotechnology to introduce a three genes mediated late blight resistance into virtually any variety, enabling more rapid development of cultivars with the many traits needed to combat multiple, escalating stress problems. Meanwhile, genomics has led to efficient means for marker-assisted selection to incorporate new high levels of resistance to potato leaf roll virus into populations that also resist potato virus Y and warm temperatures under which the vectors of these diseases proliferate.